Evaluation of cold water immersion and contrast water therapy for recovery with well-trained team sport athletes: Rugby Union

A PhD thesis by Trevor R Higgins

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Date: __6th November 2015

Peer reviewed publications and conference presentations

Higgins, T. R., Heazlewood, I. T., & Climstein, M. (2011). A random control trial of contrast baths and ice baths for recovery during competition in U/20 Rugby Union. *Journal of Strength & Conditioning Research*, 25(4), 1046-1051.

Higgins, T R, Climstein, M, and Cameron, M. (2013) Evaluation of hydrotherapy, using passive tests and power tests, for recovery across a cyclic week of competitive Rugby Union. *Journal of Strength & Conditioning Research*, 27(4), 954–965.

Higgins, T. R., Climstein, M., & Cameron, M. (2013). Acute response to hydrotherapy for recovery after a simulated game of Rugby Union. *Journal of Strength & Conditioning Research*, 27(10), 2851-60.

Higgins, T. R., Cameron, M., & Climstein, M. (*In Press*). Evaluation of passive recovery, cold water immersion, and contrast baths for recovery, as measured by game performances markers, between two simulated games of Rugby Union. *Journal of Strength & Conditioning Research*, Jun 11. [Epub ahead of print]

Higgins, T. R., Greene, D. A., & Baker, M. K. (Under Review). The effects of cold water immersion and contrast water therapy for recovery from team sport: A systematic review and meta-analysis. *Journal of Strength & Conditioning Research*, xx(x), xx

Higgins, T. R., & Heazlewood, I. T. (2008). Evaluation of Contrast Baths and Ice Baths for Recovery in U/20 Rugby Union - A Random Control Trial. *Journal of Science and Medicine in Sport*, 11 (Supplement), S23.

Higgins, T. R., Heazlewood, I. T., & Climstein, M. (2009). Contrast water immersion combined with electrical muscle stimulation is beneficial for recovery from rugby league in comparison to contrast water immersion alone. *Journal of Science and Medicine in Sport*, 12 (Supplement 2), e52.

Higgins, T. R., Climstein, M., & Cameron, M. (July, 2012). Evaluation of hydrotherapy, using passive tests and power tests, for recovery across a cyclic week of competitive Rugby Union. Paper presented at the Sport Science in the Heart of Europe: 17th Annual Congress of the European College of Sport Science, Bruges, Belgium. July 4-7, 2012

Abstract

In most team sports, a cycle of training, competition, and recovery repeatedly occurs over each week of a competitive season. For athletic performance to be maintained through a season, an optimal balance between training and recovery is required. To facilitate the recovery process after competition games and training, hydrotherapy has been adopted by a number of sporting teams.

Methods: In the present thesis a review of literature was undertaken to identify the most commonly investigated methods of recovery in professional sport. Pilot studies were then conducted across periods of four weeks. The review of literature highlighted the need for research into recovery to examine beyond the acute phase. To address the need to examine recovery beyond the acute phase the major study evaluated three related questions: Firstly, the effectiveness of hydrotherapy for recovery in the first 48h after a simulated game: Secondly, the effectiveness of hydrotherapy for recovery across a cyclic week, including a simulated game and three training sessions: Thirdly; the effectiveness of hydrotherapy for recovery as measured across performance in two simulated Rugby Union games. A simulated game of Rugby Union previously used in evaluating factors affecting performance in Rugby Union was adopted as the key physiological stressor: Finally, to accommodate and compare the studies within this thesis with the increasing volume of published literature evaluating hydrotherapy for recovery in team sport, a systematic review with meta-analysis was carried out.

Male Rugby Union players (n=24) were recruited to participate in this research. Participants were randomly assigned to one of three groups. A cold water immersion (CWI) group underwent two cycles of 5 minutes at 10^{o}C, a contrast water therapy (CWT) group underwent 5 cycles (1 minute alternating immersions at 10^{o}C/40^{o}C) and a control group underwent passive recovery, which involved being seated for 15 minutes. Within group and between group analyses were conducted using an ANOVA model with baseline scores as covariates for each of the three research questions. Post hoc analysis was conducted manually, with each time point as the covariate and analysed individually against each time point. Effect sizes were calculated as partial eta^2 (η_p^2) (omnibus) and Cohen's *d* (univariate).

Study 1 evaluated the benefit of hydrotherapy (CWI and CWT) towards recovery in the first 48 hours (acute response) following a simulated game of Rugby Union. Data collection points were 1 hour pre-game, then 1 hour, 24 hours and 48 hours following the simulated game of Rugby Union.

Study 1, a significant difference was identified at 1 hour following the simulated game for muscle soreness (p=0.05) between control and CWT, and 48 hours following the simulated game for muscle soreness (p=0.02) between CWI and CWT. Group association accounted for a large effect 1hour (η_p^2 = 0.18), 24 hours (η_p^2 =

0.18) and 48 hours (η_p^2 = 0.26) following the simulated game for muscle soreness. In addition, group association also accounted for large effects 1 hour (η_p^2 = 0.14), and medium to large effects at 24hours (η_p^2 = 0.12) and 48 hours (η_p^2 = 0.10) following the simulated game, for circumferences.

Study 2 evaluated the benefits of hydrotherapy for recovery from Rugby Union across the weekly cycle of a game (represented by a simulated game of Rugby Union) and three training sessions. Data collection points were 1 hour pre-game and then 48 hours, 72 hours, 96 hours and 144 hours following the simulated game of Rugby Union.

In study 2 only three time points reported significant differences. Between group comparisons identified a significant difference for muscle soreness 72 hours (p=0.03) and 96 hours (p=0.04) following the simulated game, between control and CWT and 48 hours (p=0.02) following the simulated game, between CWI and CWT. A significant difference for perceptions of exertion during training sessions (Session RPE scores) was identified between time points 72 hours and 96 hours (p=0.015) following the simulated game, between CWI and CWT. Although all participants underwent the same squad training the contrast bath group consistently indicated a greater perception of exertion during training. There were no significant differences across any other dependent variables.

Study 3, evaluated hydrotherapy for recovery between two simulated games of Rugby Union scheduled one week apart. Dependent variables were consistent across these three studies. They included hamstring flexibility (sit and reach; measured in centimetres), delayed onset muscle soreness (DOMS; self-reported on a 100mm visual analogue scale), circumference of the upper thigh (measured in centimetres), power output (counter movement jump, units normalised to bodyweight and 10 metre and 40 metre sprint times in seconds), and session rating of perceived exertion (measured in arbitrary units). Between-game comparisons evaluated the changes in participants' performance between each station comprising the simulated games. In addition total performance in both first simulated halves, both second simulated halves and both total simulated games were also compared.

In study 3 no significant differences was identified between performances in the game to game comparison. A significant difference was identified for one station, station 6, a defensive sprint drill, during the first half (p=0.02), between control group and CWI. However no significant differences were identified at any other station or between total work (in seconds) performed in either the first half, second half, or across the full game.

The systematic review with meta-analysis was carried out following the recommendations outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement. A computerised literature search was undertaken using a Boolean logic [AND] keyword search of databases:

SPORTDiscus; AMED; CINAHL; MEDLINE. Data was extracted and the standardised mean differences were calculated with 95% CI. The analysis of pooled data was conducted using a random-effect model, with Heterogeneity assessed using I^2.

The systematic review with meta-analysis identified 23 peer reviewed papers (n=606) which met the criteria. Meta-analyses results indicated CWI was beneficial for recovery at 24h (CMJ: p= 0.05, CI -0.004 to 0.578; All-out sprint: p=0.02, -0.056 to 0.801) following team sport. CWI was beneficial for recovery at 72h (fatigue: p=0.03, CI 0.061 to 1.418) and CWT was beneficial for recovery at 48h (fatigue: p=0.04, CI 0.013 to 0.942) following team sport. No significant differences were reported from the meta-analysis.

Results of the three research questions evaluated in this thesis are in line with findings from the systematic review with meta-analysis concluding this thesis. From the results we can surmise that across the acute phase, throughout a cyclic week of activity and when assessing performances between games, CWI was superior to either CWT or passive recovery in attenuating the effects of muscle pain, and in reducing players' perceptions of exertion during high intensity squad training and in maintaining performances between the two simulated games. In addition, across all three studies and the systematic review, there appears little evidence supporting CWT in enhancing players' perceptions of recovery from either team sport competition or team training. Finally, there was little evidence suggesting that either CWI or CWT enhanced recovery or attenuated fatigue of neuromuscular performances in well-trained team sport athletes.

Acknowledgements

I would like to express my most sincere thank you to the six supervisors I have been assigned at different times of my candidature. Firstly, I would like to thank Dr I Tim Heazlewood; you guided me through the initial stages of the development and implementation of my research. The many discussions on statistics, your knowledge and passion are truly unparalleled. I look forward to our discussions in the future. Dr Mike Climstein, it is a difficult task to join a research program when it is already half way through. The guidance and support you provided and the time you afforded to me in your already full schedule was truly appreciated. The additional encouragement and guidance you provided assisted me through to the completion of my thesis, thank you. Dr Lainie Cameron, to throw yourself into a PhD at the very end, with your knowledge and passion for statistics, your eye for detail, and your desire to ensure my work was of the highest standard, all this was truly appreciated, thank you. Dr John Saunders, my fourth supervisor. Your command of the English language had me reaching for the dictionary on many occasions, merely to decipher your emails. However, it was done with much admiration, your ability to add a word or phrase to a sentence, providing it with clarity and punch, time and time again, is truly remarkable. I enjoyed our campfire discussions about the woes of Australian Rugby, perhaps the answer can be found in those discussions, thank you once again. To Dr David Greene and Dr Michael Baker, my 5th and 6th supervisors, that entered the arduous journey that became my doctorate. As you stated, at our initial meeting, there was not much for either of you to enter this process. All the research had been conducted and all the publications published. Despite having little personal benefit in seeing my thesis through to the end, both of you provided me with much assistance. I especially appreciate, that my views were considered, my points taken on board and both of you were open to the input I offered. Irrespective of the outcomes of this examination, my opinions have been added to the thesis.

I extend my gratitude to the players and coaching staff at the Eastwood District Rugby Union Club. The time and commitment required to assist with research is considerable and without immediate benefits to the participants. Thank you to the players and coaches for their commitment and support, for without your support this research would never had been possible.

I wish also to thank the lecturers and students at ACU, to all who have been available to me to help with ideas and suggestions. To the students at ACU who assisted me with my data collection by manning the various stations in the simulated game of Rugby Union and testing programs, again, many hands make a difficult task manageable so thank you.

To my wife, I have no words that can adequately apologise for what became of my doctorate. If I had known in advance, what would occur throughout my candidature, I would not have proceeded. A four year process that was to enhance the quality of our lives together became the opposite. I cannot justify what you were put through, by a system that was in place to promote scholarly investigation, yet failed completely. Why you continued to support me I do not know. But support me you did. When supervisors refused my points you listened to my frustration, always providing a calming word and calming direction. When supervisors directed me first one way and then the other, again you listened to my frustration, calmed me and re-centred me. When first one supervisor left followed by another you stayed your support. When I was left without a supervisor, adrift without support or direction, you listened. When the assurances from ACU that the matter would be addressed, but was not, you calmed me down. When the Trevor of yesterday began to rise, when my semblance of rational thought was lost, you were the only one who saw what was happening and where it was heading. You bought me back from a place I would not have been able to return from. Your love and support are the only reason, that once again I am submitting a thesis. All I may achieve has only been possible because I had you by my side. With you and Patrick, the two of you are the most precious things in my life. So to you, Jane, thank you, and my love for you grows stronger with each passing day.

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1.1 Introduction

Throughout history the attention to the recovery process following sporting activities has been a constant part of the sporting environment. With the era of professional sport, particularly in the various codes of football, recovery has evolved into the specific recovery session, including pool sessions, massage, active recovery, stretching, “ice baths”, nutrition and rest (Barnett, 2006; Halson, 2011).

An amateur based sport until 1995, recovery protocols and sessions were of low priority in Rugby Union. Until the advent of professionalism in 1995, players held jobs during the week, trained of an evening and played on weekends. With several days between games and training sessions, the demand on players was minimal. The old adage of “train every other day”, still common with general populations in the health and fitness industry today, allowed for days off between games and training for players to recover. This however changed with the professionalization of Rugby Union.

Without the time or flexibility, amateur players were unable to invest heavily in training loads. However, with professionalism came expected increases in physical robustness, strength and pace through training of full time athletes (Garraway, Lee, Hutton, Russell, & Macleod, 2000). Professional players were able to spend the working week dedicated to preparation for competition (Garraway, et al., 2000). They now had the time to invest in their sport and an increase in training volume followed (Garraway, et al., 2000).

In addition to increases in training volume, there also came an increased expectation of success (Christie, Wulforst, Krause, Crawford, & Docheff, 1997). Revenues generated through corporate sponsorship and commercial television broadcasting rights funded the new professional Rugby Union. This investment by business can increase pressures on players and coaches to deliver on the field (Christie, et al., 1997; Soebbing & Mason, 2009). To gain an edge over competitors and meet corporate expectations, coaching staff looked to evidence-based research to aid in the development of enhanced training methods and periodised programs to develop the fitness requirements of players (Reilly & Ekblom, 2005).

This research along with the increase in training time available, led to increases in the athletic fitness of players, higher work rates in games and a higher tempo in match play (Reilly & Ekblom, 2005). Furthermore, professionalism in Rugby Union led to the abandonment of the traditional training week of two nights per week. Players now cycled through habitual activity across the competitive season (Dadebo, White, & George, 2004). This habitual activity consisted of a cycle of multiple training sessions, competition and recovery over a week for each week of the season (Reilly & Ekblom, 2005). Multiple training sessions across the training week consisted of dedicated conditioning sessions incorporating skills and unit practices, resistance training sessions, functional training and team runs involving strategy and game patterns. Each individual element of the various training session would elicit various degrees of exercise-induced muscle damage (EIMD). Whether undertaking resistance training or field conditioning and team runs, EIMD would result from increasing exposure to eccentric muscle actions associated with lowering phases/braking actions in locomotion. At the same time, the former 48 hours between sessions to recover was lost. The introduction of multiple training sessions in a single day became the norm, along with a reduction in days resting between training and games. This cycle extracted an ever increasing physical toll from athletes, leading to the development of accumulated fatigue (Reilly & Ekblom, 2005).

To accommodate such changing approaches to game play and training, coaching staff began the implementation of a variety of recovery strategies (Barnett, 2006; Halson, 2011). Recovery sessions included dedicated stretching, active recovery, massage, attention to nutritional strategies and hydration requirements, all of which were believed to enhance the recovery process (Barnett, 2006; Halson, 2011). The rationale was that by accelerating the recovery process, players could be in better functional state at training and as such undertake enhanced training sessions, which would then lead to enhanced game performances (Barnett, 2006; Halson, 2011). In search of the competitive edge, coaching staff then began exploring additional methods to further enhance the recovery process.

1.2 Literature Review

Muscles, which consist of a number of motor units, are arranged in bundles of various grade and strength that allow for variable muscle force in response to varying levels of muscle contractions (Baird, Graham, Baker, & Bickerstaff, 2012). A motor unit consists of nerve fibres and their associated groups of muscle fibres, and are recruited as required through nerve stimulation (Baird, et al., 2012). If a greater force is required then motor unit recruitment is increased (Baird, et al., 2012). However, if the motor units available for recruitment are unable to meet the demands of force required, then mechanical and/or metabolic stress occurs compromising force production through an impairment of contractile function (Baird, et al., 2012; Brancaccio, Maffulli, & Limongelli, 2007; Saraslanidis, Manetzis, Tsalis et al., 2009). The capacity to generate force through muscle contractions is linked to the activity of the myonuclei, mitochondria, and the system of Transverse tubules (T-tubule) and sarcoplasmic reticulum (SR) (Magaudda, Di Mauro, Trimarchi, & Anastasi, 2004). Two primary factors associated with the impairment of this muscle contraction are mechanical overload (Falvo & Bloomer, 2006; Tee, Bosch, & Lambert, 2007) and metabolic overload (Tee, et al., 2007).

1.2.1 Mechanical overload

Mechanical overload may be attributed to disruption of the sarcolemma or fragmentation of the SR and T-tubule impairment (Eston & Peters, 1999; Symons, Clasey, Gater, & Yates, 2004; Falvo & Bloomer, 2006), negatively impacting contractile function leading to muscular fatigue (Dahlstedt, Katz, Wieringa, & Westerblad, 2000). The damage can also include myofibril protein degradation, lesions of the plasma membrane, swollen mitochondria, increases in capillary permeability and extracellular protein concentration, leading to inflammation of the muscle tissue (Eston & Peters, 1999; Symons, et al., 2004).

Although damage associated with mechanical overload is considered, by coaches and athletes, to affect the entire activated muscle, lengthening of active muscle does not occur by uniform lengthening of all sarcomeres within the muscle (Philippou, Halapas, Maridaki, & Koutsilieris, 2007). Muscle activation is focal and confined to individual sarcomeric units (Warhol, Siegel, Evans, & Silverman, 1985), with lengthening contractions occurring via a non-uniform distribution of sarcomere length change. This causes some weak sarcomeres to overextend, leading to damage (Philippou, et al., 2007). Muscular adaptation then can occur through repair of the damaged sarcomeres. Therefore, damage to the weak sarcomeres must first progress in the post-exercise period allowing for adaptation processes to occur through the repair process (Ebbeling & Clarkson, 1989).

The repair process or myofibril regeneration following local muscle damage involves a dynamic restructuring of the muscle's intermediate filament system (Philippou, et al., 2007). It can take up to seven days following damage for the repair process to be completed (Ciciliot & Schiaffino, 2010; Philippou, et al., 2007). This includes the formation of new multinucleated myotubes and expression of embryonic myosin heavy chains, leading to the replacement of the damaged muscle fibres (Philippou, et al., 2007).

From previous investigations (Baird, et al., 2012; Ciciliot & Schiaffino, 2010; Ebbeling & Clarkson, 1989), it would appear that the muscular system at the point of fatigue suffers from a number of system overloads. Initially, this overload impacts muscle contractibility due to metabolic disturbances followed by structural disruptions within the muscle fibres (Baird, et al., 2012; Saraslanidis, et al., 2009; Tee, et al., 2007). In the context of team sports, during general preparation and specific preparation phases of a periodised program, these components are essential (Issurin, 2010). They are required for the development of adaptation to a given workload and consequently enhancement of athletic performance during these periods of the training program (Issurin, 2010). However, during the competition phase of a season the focus is on the maintenance of a player's physiological condition as opposed to its development (Issurin, 2010). Maintenance becomes problematic during the competition phases of Rugby Union as structural disruptions have a recovery period of between 3–7 days (Issurin, 2010). With time periods of less than 72 hours between games/training sessions, players are exposed to additional training stimuli before they are fully recovered. Therefore the management of structural disruptions becomes important.

In summary, it is recognised that both biochemical disturbances and mechanical overload have an impact on muscle contractions (Adhihetty, et al., 2003; Ciciliot & Schiaffino, 2010; Magaudda, et al., 2004; Philippou, et al., 2007) resulting in muscular fatigue (Dahlstedt, et al., 2000). However, with regard to how biochemical disturbances and mechanical overload impacts muscular fatigue, timeframes vary. T-tubule and SR disruption, plasma membrane disruption, mitochondria and influx/efflux of biochemical compounds undergo a rapid response post-exercise (Adhihetty, et al., 2003; Ciciliot & Schiaffino, 2010; Magaudda, et al., 2004; Philippou, et al., 2007). In contrast, damage to muscle fibre takes 3–7 days for the repair of damaged sarcomeres (Ciciliot & Schiaffino, 2010; Philippou, et al., 2007).

1.2.2 Metabolic overload

The impairment of muscle contraction, as a result of metabolic overload, is associated with changes to levels of biochemical markers (Tee, et al., 2007). The appearance of creatine kinase (CK) in blood has generally been considered to be an indirect marker of muscle damage (Baird, et al., 2012; Saraslanidis, et al., 2009) and continues to be the most commonly used biochemical marker of skeletal muscle damage (Kon, Tanabe, Akimoto, Kimura, & Tanimura, 2008). Most studies have focused primarily on investigating changes to levels of CK during the acute response, post-exercise and a relationship with fatigue and/or recovery.

However, when considering the acute damage to plasma membrane, associated with mechanical/metabolic overload, the damage may not be relevant in regards to recovery (Idone, Tam, & Andrews, 2008; Reddy, Caler, & Andrews, 2001). Firstly, repair of plasma membrane has been reported to be a very rapid process, triggered almost immediately post-exercise (Idone, et al., 2008; Reddy, et al., 2001). This occurs because damage to the plasma membrane allows for Ca2+ influx from the extracellular milieu into the cytosol of a damaged cell, thus triggering the repair process within seconds after damage (Idone, et al., 2008). In addition, the efficiency of this process is further enhanced with well-trained athletes, in cells that have previously been exposed to mechanical stressors (Idone, et al., 2008). Furthermore, damage to the plasma membrane is a reported requirement necessary for adaptation to sport and/or exercise (Idone, et al., 2008; Reddy, et al., 2001) through Ca2+-regulated exocytosis (Reddy, et al., 2001).

T-tubule networks in skeletal muscle fibres allow propagation of electrical signals across the fibres (Shorten & Soboleva, 2007). These signals are generated by the transport of ions across the T-tubule membranes, resulting in significant changes in ion concentrations within the T-tubules' during muscle excitation (Shorten & Soboleva, 2007). This initiation of electrical activity in the T-tubules membrane followed by a release of calcium from the sarcoplasmic reticulum is responsible for the activation of skeletal muscle contractions (Franzini-Armstrong, 1999). Therefore, with activities leading to EIMD, the propagation of electrical signals and release of Ca2+ may be impaired as a result of damage or disruption to either the T-tubules and/or the sarcoplasmic reticulum. This impairment will then have a negative impact on future muscle contractions and the ability to produce force, thus leading to a state often referred to as muscular fatigue (Dahlstedt, et al., 2000).

When examining recovery, it is suggested that repetitive skeletal muscle tissue trauma caused by heavy training and competition could result in an accumulation of fatigue. This accumulation of fatigue may be demonstrated as a persistent systemic cytokine response (Neubauer, König, & Wagner, 2008) demonstrated with chronic levels of biochemical markers. This response is associated with a chronic inflammatory state, immune dysfunction and the less clearly understood condition of overreaching/overtraining (Neubauer, et al., 2008). It is this persistent cytokine response that has led to biochemical markers being used to assess recovery.

The most common biochemical markers include CK, myoglobin (Kon, et al., 2008), C-reactive protein (CRP), testosterone, cortisol, and the Testosterone: Cortisol ratio (T:C). The rationale for the examination of these biomarkers is the associated changes occurring at fatigue. In addition, faster clearance rates of biochemical markers have assumed to be an indication of enhanced recovery. This review examines published research into these markers in an attempt to identify relationships between changes in levels of CK, myoglobin, CRP and T:C and fatigue and a return to pre-fatigue functional capacity.

1.2.2.1 Creatine Kinase

CK is a diametric protein, which can be found as either one of three iso-enzymes including muscle (MM), heart (MB) and brain (BB) (Su, Tian, Zhang, & Zhang, 2008). It therefore is released into the circulation during muscular lesions (Totsuka, Nakaji, Suzuki, Sugawara, & Sato, 2002), and used as an indicator of skeletal muscle injury (Neubauer, et al., 2008; Yamamoto, Judelson, Farrell, et al., 2008). As elevated serum CK has been proposed to be an indicator of skeletal muscle breakdown, it has become the most frequently used marker of muscle damage (Su, et al., 2008). The reported relationship between CK and EIMD initially was used as a way of identifying the level of fatigue athletes had sustained and the requirement for additional recovery, post athletic performance.

To evaluate CK as an indicator of recovery from EIMD, information from the available literature needs to be examined carefully. The examination will need to include the variability of CK response post-exercise, the time course (the time post-exercise that CK takes to enter circulation) over which changes in CK levels post-exercise occur. Finally, to evaluate the suitability of CK levels to identify recovery, the correlation between changes in performance and changes in CK levels needs to be examined.

The initial area of concern in assessing the suitability of CK levels as an indicator of damage and repair, is their reported variability post-exercise (Lazarim, Antunes-Neto, da Silva, et al., 2009). Variability in CK levels post-exercise has been reported with studies indicating large ranges between low and high scores for peak CK levels of 96–34500 IU/L (Chen, 2006) and 602–18823 IU/L (Ehlers, Ball, & Liston, 2002). Ehlers et al. (2002) reported that CK levels can increase from anywhere between 5–10 times above baseline values when associated with EIMD. Additional research, where only mean scores and standard deviations were provided, has indicated standard deviations of greater than 80% of mean scores (Skurvydas, Brazaitis, & Kamandulis, 2010). Such findings indicate that CK levels show a large variability of responses between individuals across studies. Such large inter-individual variability between participants undergoing similar training, suggests the unreliability of CK levels as an indirect marker of muscle damage.

To further complicate the issue, the cause of the variability is unknown. One answer proposed suggests the cause is found in the adaptation and repair processes that the muscle undergoes after damaging exercise. This adaptation process results in muscle cells being able to over time, withstand similar training loads subsequently reducing EIMD. This would explain the ‘buffering’ of CK levels across a competitive season in football (Kraemer, Spiering, Volek, et al., 2009; Lazarim, et al., 2009). In Kraemer et al. (2009) and Lazarim et al. (2009), CK levels were shown to stabilise as a football season progressed. Higher CK levels were reported during pre-season and the initial stages of the competition. By the end of the competition season, CK levels were constant, indicating the level of EIMD had plateaued (Kraemer, et al., 2009; Lazarim, et al., 2009).

The use of periodised programs throughout the competitive season adds to the changes in CK levels. The amount of EIMD, as assessed through CK levels, can be expected to be greater during the initial period of any new training modalities. As programs change between cycles of strength, power and/or endurance, the levels of CK are likely to be higher when new cycles of training are first introduced, followed by reductions in levels of CK as the cycle continues, and adaptation within the muscular system has occurred.

CK levels have generally been assessed in recovery interventions with lower levels reflecting enhanced recovery (Gill, 2006). The greatest concern with regard to the use of CK as a marker in measuring recovery includes the identified large variability between participants and the times course for peak CK levels (Neubauer, et al., 2008; Newton, Morgan, Sacco, et al., 2008; Totsuka, et al., 2002). The variability reported in the time course responses of CK was considerable. Peak CK levels have been reported 24–48 hours after isometric exercises (Totsuka, et al., 2002), 3–7 days after maximal voluntary eccentric exercise of the elbow flexors (Newton, et al., 2008), and 3–6 days after 70 eccentric contractions of the elbow flexors (Chen, 2006).

To date, the vast majority of research into recovery has examined the acute response (48 hours post) with several studies also examining periods beyond the acute response (Dawson, Gow, Modra, Bishop, & Stewart, 2005; Gill, Beaven, & Cook, 2006; Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; Montgomery, Pyne, Cox, et al., 2008; Rowsell, Coutts, Reaburn, & Hill-Haas, 2009). However, as the time course of peak CK levels varies over 1–7 days, making informed decisions based on CK levels after recovery interventions can be problematic, as changes in CK levels at various time points may merely reflect the variability in CK response.

When used in the assessment of various recovery interventions, particularly with reference to hydrotherapy, do changes in CK levels accurately reflect recovery? A number of papers examining cryotherapy have reported changes/no changes in CK levels as reflecting/not reflecting recovery (Gill, et al., 2006; Ingram, et al., 2009; Montgomery, Pyne, Cox, et al., 2008; Rowsell, et al., 2009). However, the intracellular CK may be more reflective of the rate of clearance versus the rate of appearance than of a state of recovery (Bleakley & Davison, 2010; Pournot, Bieuzen, DuYeld, et al., 2011). As CWI may impact membrane permeability, suppression of intracellular CK levels suggests either slower appearance or faster clearance of CK rather than reduced skeletal muscle damage (Pournot, et al., 2011).

Fatigue has been previously defined as a reduction in physical and or functional performance and recovery from athletic performance as the return to baseline levels of physical and/or functional performance (Dahlstedt, et al., 2000; Williams, 1997). When evaluating recovery from athletic performance in relation to CK levels, a correlation between recovery of athletic performance and CK is required to be established to support changes in CK levels as evidence of recovery. Reviewing the sport science literature, Neubauer et al. (2008) found no link between CK levels and athletic performance (Neubauer, et al., 2008). In addition, Ingram et al. (2009) stated that plasma concentrations of CK were not significantly correlated with either muscle soreness or performance capabilities in their participants. With both Neubauer et al. (2008) and Ingram et al. (2009) examining athletic performance, in both cases there was no effect on muscle performance despite significant increases in CK levels. If high CK levels do not adversely affect subsequent muscle performance, then it would be erroneous to claim that a reduction in, or faster clearance of CK, indicates recovery from athletic performance.

Furthermore, similar levels of CK did not predict similar muscle performance (Paschalis, Koutedakis, Jamurtas, Mougios, & Baltzopoulos, 2005). Paschalis et al. (2005) found that despite similar CK level responses between untrained young healthy men, subsequent muscle performance was significantly different ($p = 0.05$). Additional support for Paschalis et al. (2005) comes from Beck, Housh, Johnson, et al. (2007) whose study also found that despite having no difference in CK levels between untrained male participants, significant differences were found between them in the recovery of strength (Beck et al., 2007). Both these studies have shown that levels of CK do not accurately reflect muscle performance. If CK levels were to be considered a valid marker of recovery, then high levels would need to consistently reflect poor muscle performances, and a return of CK levels to pre-exercise levels should correlate with recovery of muscular performance.

The rationale for the use of changes in CK levels as a marker of recovery originated from the suggestion that it is an indirect marker of muscle damage. Previously it was assumed that CK levels indicated damage to the muscle in its entirety. However Sakomoto et al. (2009) insist that damage to muscle fibres as a result of training is restricted to weaker myofibrils and sarcomeres only (Sakamoto, Maruyama, Naito, & Sinclair, 2009). With highly trained participants, the number of susceptible fibres may be expected to vary depending on training cycles. As such the number of muscles fibres susceptible to damage may be lower, later in training cycle phases. This may suggest that CK levels would be reflective of damage to a relatively small number of weaker fibres. Allowing the relatively large number of intact muscle fibres to maintain muscle performance. Therefore, in the case of well-trained participants CK levels may be less relevant as a marker of recovery.

A lack of evidence in the sport science literature exists supporting CK as a marker of recovery (Bishop, Jones, & Woods, 2008; Bleakley & Davison, 2010; French, Thompson, Garland, et al., 2008; Gill, et al., 2006; Takarada, 2003; Totsuka, et al., 2002). A number of studies have concluded that neither faster clearance rates nor lower levels of CK accurately reflect recovery (Bishop, et al., 2008; Bleakley & Davison, 2010; French, et al., 2008; Takarada, 2003; Totsuka, et al., 2002). Furthermore, it has been reported that subsequent athletic performance has not been shown to be affected by changes in CK levels (Bishop, et al., 2008; Bleakley & Davison, 2010; French, et al., 2008; Takarada, 2003; Totsuka, et al., 2002). Without evidence of a strong correlation between CK levels and future muscle performance, the use of CK as a marker of recovery is questionable.

1.2.2.2 Myoglobin

Myoglobin, which is a small, skeletal muscle specific, cytoplasmatic protein (Margaritis, Tessier, Verdera, Bermon, & Marconnet, 1999; Weber, Kinscherf, Krakowski-Roosenal, et al., 2007), has become one of the most common biochemical markers evaluated in the research field of muscle fatigue and recovery (Tee, et al., 2007). As Myoglobin is the highest circulating protein immediately after EIMD generating physical activity (Margaritis, et al., 1999; Tee, et al., 2007) it is considered to be the earliest blood protein responder to muscle damage (Margaritis, et al., 1999; Neubauer, et al., 2008). Therefore, as both muscle fibre damage and muscle breakdown have been identified as primary factors associated with muscle fatigue (Coso, Gonza´lez-Milla´n, Salinero, et al., 2012), the evaluation of Myoglobin continues in fatigue and recovery research.

Notwithstanding, when evaluating recovery of muscle fatigue currently there is substantial evidence against the effectiveness of myoglobin. Initially, although a significant positive correlation identified between plasma levels of myoglobin and the total cross sectional area formed by type I and by type IIa fibres (Weber, et al., 2007), no significant correlation was found between Myoglobin and the total cross sectional area of type IIx fibres (Weber, et al., 2007). This may suggest that the functionally important aerobic slow-twitch type 1 fibres are the primary source of plasma Myoglobin (Weber, et al., 2007). This may explain why, that although blood markers of muscle damage have shown a strong correlation with acute jump height loss, including myoglobin concentration (23%), a high proportion of muscle fatigue variability remains unexplained by blood markers, specifically with type IIx fibres (Margaritis, et al., 1999).

A further confounding impact on Myoglobin measuring recovery is its reported clearance rate and additional causes of prolonged Myoglobin levels. Firstly, it has been shown that Myoglobin has a fast return to baseline levels during recovery (Margaritis, et al., 1999), evidence reports it has a relative short half-life of five and a half hours (Weber, et al., 2007). In addition, a prolonged appearance of myofibre proteins in plasma, up to 5 days following an event, is most likely related to subsequent muscle repair processes and probable local inflammatory responses, rather than previous muscle damage that impaired performance (Neubauer, et al., 2008).

In addition, an individual’s Myoglobin responses will vary over periods of training. As vigorous training and competition, resulting in oxidative stress, are known to decrease the exercise-induced myocellular release of proteins (Margaritis, et al., 1999). Athletes are subsequently protected from excessive oxidative damage during subsequent training sessions (Silva, Ascensa˜o, Marques, et al., 2013). In support, Silva et al. (2013) reported that higher training levels led to professional players showing lower physiological disturbances (Silva, et al., 2013). As such, these variations in enzyme activity negatively impact on their reliability to evaluate recovery over extended periods of training and competition.

Finally, when evaluating recovery it has been suggested that muscle enzyme release cannot be used to predict the magnitude of muscle function impairment after muscle damage (Margaritis, et al., 1999). That a lack of a quantitative relationship between muscle enzyme release and muscle function impairment exists (Margaritis, et al., 1999). It has been suggested Myoglobin enzyme activity is more a reflection of current enzyme release or the after-effects of previous release as opposed to reflecting levels of recovery (Margaritis, et al., 1999).

1.2.2.3 Testosterone and Cortisol

Testosterone and cortisol are two of the most common hormonal markers used to monitor training and adaptations (Abdelkrim, Castagna, El Fazaa, Tabka, & El Ati, 2009) in exercise and sport. Together, both testosterone and cortisol characterise the anabolic (testosterone) and catabolic (cortisol) environment, and are reported via the Testosterone: Cortisol Ratio (T:C). The ratio is calculated by dividing the concentration of testosterone by the concentration of cortisol and reflects the balance between anabolic and catabolic states (Argus, Gill, Keogh, Hopkins, & Beaven, 2009). T:C ratio plays a vital role in adaptive responses to exercise, modifying the rate of recovery through regulation of the anabolic and catabolic environment (Shkurnikov, Donnikov, Akimov, Sakharov, & Tonevitsky, 2008). Kraemer et al. (2009) stated that exercise leads to an anabolic hormonal response, leading to an increase in the T:C ratio. While an elevation in the T:C ratio expresses an increase in testosterone, creating an anabolic environment, its reduction expresses an increase in cortisol, creating a catabolic environment (Kraemer, et al., 2009).

Cautions in the use of T:C as a marker of recovery initially centre on the large variability of testosterone and cortisol between individuals (Beaven, Gill, & Cook, 2008). In addition, careful consideration of a number of parameters, including type of exercise, time course, and the training status of the athletes, is required when evaluating hormonal responses in research (Beaven, et al., 2008).

Significant increases in testosterone have initially been reported in association with high volume training including aerobic training (Anttila, Mänttäri, & Järvilehto, 2008) and resistance training (Eliakim, et al., 2009). However, it has also been reported that only resistance training with a high intensity (>70% 1RM) would increase testosterone significantly (Crewther, Cronin, Keogh, & Cook, 2008; Linnamo, Pakarinen, Kraemer, & Häkkinen, 2005; Ramson, Jurimae, Jurimae, & Maestu, 2009). Additional studies questioning the significance of the response of T:C to exercise include that of Shkurnikov et al. (2008) who failed to find significant differences in testosterone levels between groups over a four-week period of anaerobic training (Shkurnikov, et al., 2008) and Kraemer et al. (2009) who reported no significant changes in hormonal responses over a 44-hour period immediately before, during and after an American football game (Kraemer, et al., 2009).

While examining the acute response of cortisol to exercise, cortisol remains elevated for up to 40 minutes post-exercise (Cinar, Cakmakci, Mogulkoc, & Baltaci, 2009) and returns to baseline levels between 1.5 to 4 hours post-activity (Kraemer, et al., 2009). After sport performances, T:C initially declines, but then normalises within the first day of recovery (Neubauer, et al., 2008). In contrast, cortisol concentrations were reported to be elevated for up to 24 hours (Filaire, Filaire, & Le Scanff, 2007). These contrasting results may stem from the differing stressors that generated the rise in cortisol levels. Kraemer et al. (2009) evaluated college football which involves high impact and as such participants may have developed a blunted cortisol response due to adaptation that may develop across the season (Kraemer, et al., 2009). Whereas Filaire et al. (2007) examined motor cycle racing, which although having physiological stressors may also have included a greater component of psychological stressors which may not have been subject to a blunted response.

Additionally, if T:C is to be associated with recovery, a link between changes in T:C and performance would need to be established. However, Coutts et al. (2007) evaluated the benefit of tapering after six weeks of induced overtraining (Coutts, Reaburn, Piva, & Rowsell, 2007). The changes to both T:C and performance markers (strength and power) were analysed, after six weeks of deliberate over-training (Coutts, et al., 2007). Although all variables were significantly lower from base tests, after a one week taper, all strength and power performance indicators had returned to or above base test levels, whilst T:C was still significantly lower (Coutts, et al., 2007), indicating that in the acute response, a return of strength and power performances after fatigue are not correlated with a return to pre-fatigue T:C ratios.

1.2.2.4 Summary

Professionalism in sport has resulted in an increase in the physiological demands placed on athletes (Reilly & Ekblom, 2005). These increases have come about through higher training volumes, increases in the number of competitive games and training sessions, and greater intensities during competitions (Reilly & Ekblom, 2005). Moreover, these factors have led to a reduction in the turnaround time between training and competition (Reilly & Ekblom, 2005). Therefore, it is important to identify the areas associated with muscular fatigue and performance that are most likely to have the greatest impact on the athlete. Although disruption to muscle fibres at the cellular level, whether biochemical or mechanical, impacts muscular contraction, it is the time taken to repair damaged muscles fibres that is likely to have the greatest impact, especially in field sports such as Rugby Union.

1.2.3 Physiological strain in Rugby Union

Both hormonal responses and phagocytic activity after competitive Rugby Union indicate Rugby Union is an intense form of exercise with a high physiological strain on players (Cunniffe, et al., 2010; Gill, et al., 2006). Cunniffe et al. (2009) reported that at the completion of an international game of Rugby Union, the stress hormone cortisol showed significantly increased concentrations (~40%) along with a corresponding decrease in testosterone concentrations (~43%). These hormonal changes resulted in a large decrease in the T:C ratio (Cunniffe, et al., 2010). Furthermore, post-match levels of neutrophil count showed significant increases from pre-match levels (Suzuki, et al., 2004). The reported high level of physiological strain on players, support the notion that Rugby Union players require appropriate and beneficial recovery.

To evaluate recovery interventions and their effect on recovery from fatigue generated in Rugby Union, the specific physical demands of the game have to be considered. In addition to hormonal responses and phagocytic activity, Rugby Union elicits considerable muscle tissue damage in players as evidenced by increased CK levels post-games (Cunniffe, et al., 2010; Smart, Gill, Beaven, Cook, & Blazevich, 2008). Although EIMD has been associated with acceleration and deceleration events, which are considerable in Rugby Union (Takarada, 2003), the level of muscle damage evident in the game (Smart, et al., 2008; Takarada, 2003) exceeds that which might be expected to be generated from running activities alone.

It is feasible that in addition to eccentric damage from locomotion, high-impact collisions received by players during contact events elicit an additional degree of muscle damage, previously associated only with EIMD (Cunniffe, et al., 2010). The increased level of muscle damage generated in Rugby Union has been suggested by both Takarada, (2003) and Smart et al. (2008) to be a result of the forceful body contact/collisions in the game with specific actions which include tackles, rucks, mauls, and scrums.

Both Takarada, (2003) and Smart et al. (2008) reported that changes in CK levels (pre-game to post-game) were related to the number of high impact related game events, classified as tackles made, tackle involvement, and attacking ruck involvement. Although CK values were different between the two studies as were contact event descriptors, both reported high correlation between high impact related game events and changes in CK levels (Takarada, $r = 0.922$; Smart et al., $r = 0.69$–0.74). These findings suggest the use of competitive games of Rugby Union, with contact events, is required to evaluate fatigue and recovery in Rugby Union.

1.2.4 Cryotherapy in athletic recovery

To enhance and/or accelerate athletic recovery, a number of hydrotherapy protocols have been adopted in the field of professional sport (Bishop, et al., 2008; Bleakley & Davison, 2010; Halson, 2011; Leeder, Gissane, van Somerson, Gregson, & Howatson, 2012; Poppendieck, Faude, Wegmann, & Meyer, 2013). Hydrotherapy is a broad-based term in sport science and includes immersion in hot or cold water, ice massage, hot and/or cold showers, exercise in water or various combinations of these interventions (Bishop, et al., 2008; Bleakley & Davison, 2010; Halson, 2011; Leeder, et al., 2012; Poppendieck, et al., 2013). The professional sporting community in general believes that hydrotherapy accelerates the recovery process of athletes, bringing about a faster return to an optimal functioning state.

Cold water hydrotherapy (cryotherapy) was originally defined in 1993 as a form of electromagnetic energy that involves the removal of heat from tissue by conduction (Arnheim & Prentice, 1993). The length of exposure to cold, the medium being used, and the conductivity of the tissue influence the extent to which the tissue is cooled (Wilcock, Cronin, & Hing, 2006). Fat acts as an insulator, and thus limits heat loss. Muscle, which has relatively high water content, will draw the heat out of the core body by increasing the energy gradient between the core body and peripheral temperatures (Wilcock, et al., 2006). Therefore, sporting populations, with higher levels of lean muscle mass and low levels of subcutaneous fat may respond more rapidly to cold treatment when compared to populations which have higher fat levels.

The mechanisms believed to support the use of hydrotherapy to accelerate recovery include reduction in blood flow through vasoconstriction of the arterioles and venules (Arnheim & Prentice, 1993) and a reduction in the inflammation response after EIMD (Burke, Holt, Rasmussen,et al., 2001; Ingram, et al., 2009). Vasoconstriction of blood vessels occurs within the first 15 minutes of cold application, at a temperature of 10 °C (Arnheim & Prentice, 1993). After cold application for 15–30 minutes, an intermittent period of vasodilatation will occur for four to six minutes, which generates the return of oxygen to the area via increased blood flow thus aiding in recovery.

Moreover, cryotherapy (cold water application) reduces tissue temperature which leads to slower rates of chemical reactions (Hubbard, Aronson, & Denegar, 2004; Peiffer et al., 2009). The reduction in the rate of chemical reactions leads to a reduction in the demand for ATP, which reduces the requirement for oxygen (Hubbard, et al., 2004). Following trauma, the majority of damage occurring to the cells is a result of hypoxia, a result of compromised circulation resulting from excessive oedema (Arnheim & Prentice, 1993; Wilcock, et al., 2006). Cryotherapy acts to decrease the extent of hypoxia, by first restricting the excessive oedema, which restricts the flow of oxygen by compressing capillaries (Yanagisawa, et al., 2003). Secondly, cryotherapy reduces cell metabolism leading to a decrease in oxygen demand, subsequently reducing secondary tissue injury peripheral to the primary injury, resulting in decreased damage of tissue (Arnheim & Prentice, 1993; Hubbard et al., 2004; Wilcock et al., 2006; Yanagisawa et al., 2003).

Cryotherapy also reduces the permeability of capillary vessel walls leading to a decrease in metabolic disturbances, which may limit performance or reduce recovery. One such metabolic by-product attributed to decreased performance and delayed recovery is changes in pH levels (Yanagisawa, et al., 2003; Belfry, et al., 2012). In reducing hydrogen ion accumulation after exercise, positive effects within intracellular buffering systems including hydrogen ion extrusion mechanisms have been claimed for cryotherapy (Yanagisawa, et al., 2003; Belfry, et al., 2012). In addition, CK, a circulating protein that is released into circulation during muscular lesions (Totsuka, et al., 2002; Yamamoto, et al., 2008), has been shown to respond to cryotherapy. Cryotherapy has been demonstrated to reduce overall CK levels (Eston & Peters, 1999; Yanagisawa, et al., 2003) by decreasing CK efflux from damaged muscles (Eston & Peters, 1999). However, as discussed previously the significance of CK and recovery remains unclear.

Further mechanisms through which cryotherapy aids recovery from fatiguing exercises are claimed to include a significant reduction in core temperature and an associated anticipatory regulatory response to exercise in the heat (Peiffer, et al., 2009; Vaile, Halson, Gill, & Dawson, 2008b). Furthermore, cold water temperatures may decrease peripheral blood flow, leading to an increase in blood supply to working muscles via enhanced central blood flow (Vaile, et al., 2008b). Further increases to blood flow by aiding the muscle pump may also be provided with cold and hot water contrast treatment (Vaile, et al., 2008b).

1.2.5 Performance

Despite the increasing amount of published research in hydrotherapy, a paucity of scientific research into hydrotherapy with team sport athletes is evident. A search through a number of databases identified less than 30 papers from several different sports, each with their own specific mechanical/metabolic overload factors, evaluating hydrotherapy for recovery with team sport athletes. Furthermore, although Dawson et al. (2005) reported the need to extend the period of research in recovery, to beyond 48 hours (Dawson, et al., 2005), few studies evaluated periods beyond 48 hours. As team sport predominately involves a cyclic week of competition and multiple training sessions, the effect of common recovery interventions, specifically hydrotherapy, needs to be evaluated beyond 48 hours.

The majority of studies evaluated the effect of hydrotherapy 24 hours following a physiological stressor, only three studies extended the research beyond 72 hours and only three studies extended research to 90 hours or beyond. Rowsell et al. (2009) and Montgomery et al. (2008) examined the effectiveness of hydrotherapy in recovery during four and three day tournaments (Montgomery, Pyne, Cox, et al., 2008; Montgomery, et al., 2008; Rowsell, et al., 2009; Rowsell, Coutts, Reaburn, & Hill-Haas, 2011), respectively. In addition, Bahnert et al. (2013) evaluated a number of interventions over an AFL season (Bahnert, Norton, & Lock, 2013), whereas Higgins et al. (2011) examined a four week period of a Rugby Union competition (Higgins, Heazlewood, & Climstein, 2011) and a weekly cycle of simulated Rugby Union inclusive of training (Higgins, Climstein, & Cameron, 2013). Finally, Webb et al. (2013) evaluated recovery across several weeks of an NRL competition (Webb, Harris, Cronin, & Walker, 2013).

1.2.6 Recovery of power

Beneficial effects of hydrotherapy for recovery have been assessed with the CMJ, one all out sprint running performance and cycling as indices of power performance (Takeda, et al., 2014; Vaile, Halson, Gill, & Dawson, 2007). It has been suggested, that after exercise-induced muscle damage, a decline in CMJ and sprinting performance is a result of compromised neuromuscular function and neuromuscular efficiency (Takeda, et al., 2014). Compromised neuromuscular function has been associated with a number of factors including recruitment patterns, muscle activation and muscle coordination, as the nervous system may facilitate changes in recruitment patterns (Bieuzen, et al., 2014; Pruscino, Halson, & Hargreaves, 2013).

Although a number of studies indicated that CWI was beneficial for recovery of power, it should be noted that at 1 hour and 24 hours following team sport activity, irrespective of recovery intervention, the power of athletes as measured by a CMJ was still compromised (Kinugasa & Kilding, 2009; Montgomery, et al., 2008; Rowsell, et al., 2009). However, by 48 hours following team sport activity, irrespective of recovery intervention, all groups had returned to within two percent of baseline scores for CMJ (Kinugasa & Kilding, 2009; Montgomery, et al., 2008; Rowsell, et al., 2009).

Beyond 48 hours, only two studies (Higgins, Climstein, et al., 2013; Rowsell, et al., 2009) evaluated the effectiveness of CWI and CWT in CMJ performance. In both studies results were unclear as to whether CWI or CWT provided any beneficial effect in restoring CMJ performance.

As was found with the CMJ, CWI was beneficial in the recovery of all-out maximal sprinting performances within 24 hours following team sport (Montgomery, et al., 2008). As with the CMJ, all participants recorded decrements in scores for sprinting performances irrespective of recovery intervention. The reported benefits of CWI, 24 hours following team sport, were in attenuating the decrements in all-out maximal sprinting performances (Montgomery, et al., 2008).

Additional power performance measures included running sprint performance and cycling performance across five studies (four in running and one in cycling) to evaluate recovery of power. Ingram et al. (2009), Rowsell et al. (2009), Montgomery et al. (2008) and French et al. (2008) included sprint running tasks to evaluate recovery. Despite all four using sprinting tasks, three differing protocols were used, namely 20 metre sprint times (Montgomery, et al., 2008), 10 metre and 30 metre sprint time (French, et al., 2008) and 12 x 20 metre repeat sprint performance (Ingram, et al., 2009; Rowsell, et al., 2009).

Montgomery et al. (2008) reported that cold water immersion was substantially better (~ 0.09 sec) in attenuating performance decrements in acceleration over 20 metres in comparison to the use of compression garments. In contrast, French et al. (2008) reported no significant difference between groups across 10 metre or 30 metre sprint times. Whereas, Rowsell et al. (2009) and Ingram et al. (2009) both reported no significant difference between groups in sprint repeat results. However, without the individual workloads of participants along with differing interventions across studies, definitive conclusions in regards to cold water immersion and its effects on sprint performances cannot be determined.

Although Montgomery et al. (2008) reported cold water immersion to be substantially better than compression garments. Results indicated a difference in 20 metre sprints performance decrements of only 0.2 seconds between the two recovery methods. Furthermore, with small statistical power and the use of different sprint protocols, definitive conclusions as to the relative benefits of any of the recovery protocols and subsequent sprint performance are difficult to make.

Montgomery et al. (2008) reported that additional game time resulted in decrements in performance in line drills (0.5 to 1.5%), 20 metre acceleration (~3%), CMJ (2.6 to 6.7%) and agility (1.2 to 1.4%) for both the compression garments and the control condition. In contrast, cold water immersion resulted in no change across performances in line drills, 20 metre acceleration, CMJ and agility with increased game time.

Three studies evaluating cycling performance reported varying findings when using differing time periods and testing protocols. Vaile, Halson, Gill, & Dawson, (2008b) reported a greater maintenance of performance across two 15 minute time trials, assessed by total work completed when using cold water immersion (15^{o}C) of varying durations from 10 minutes to 20 minutes compared to a control group. However, Peiffer et al. (2009) reported cold water immersion (14^{o}C) led to reduced neuromuscular function by as much as 13%, in comparison to a control group, when measuring maximum voluntary isometric contractions of the leg extensors on a Biodex Isokinetic dynometer. They concluded that cold water immersion had a detrimental effect on neuromuscular function through muscle function impairment (Peiffer, et al., 2009).

Examining the influence of recovery interventions on high intensity cycling on repetitive days, Vaile et al. (2008a) evaluated both cold water immersion and contrast water therapy in attenuating performance decrements. They reported sprint performance (~2.2%) and time trial performance (~1.7%) in cycling were maintained or showed a slight improvement in times with cold water immersion (15^{o}C) and contrast water therapy (15^{o}C and 38^{o}C) compared to hot water immersion (38^{o}C) and a control (passive rest). Overall, Vaile et al. (2008a) reported a significant difference in changes in sprint performance and time trial performance ($p<0.05$) after five days of high intensity cycling. Cold water immersion and contrast water therapy showed improvements of 1.7% to 2.2% whereas hot water immersion showed performance decrements in sprint performance and time trial performance of ~3.5%.

Again, a scarcity of research into recovery of sprinting performance beyond 24 hours was noted. In evaluating hydrotherapy and sprinting performance, there was data from only two studies to evaluate the effect at 48h following team sport with unclear results identified. Three studies evaluated the effect of hydrotherapy on sprinting beyond 48 hours following team sport (Higgins, Climstein, et al., 2013; Higgins, et al., 2011; Rowsell, et al., 2009).

Although indications are that CWI is beneficial in attenuating the detrimental effects of fatigue on neuromuscular function with the first 24 hours, beyond 24 hours the beneficial effect of CWI in recovery was unclear when evaluated with either a CMJ or one all-out sprint.

The inconsistency between findings across studies may be attributed to a number of factors. During periods of muscle fatigue, either as a result of mechanical overload or metabolic overload, the ability of the nervous system to facilitate changes in motor unit recruitment patterns and muscle coordination may impact on performance (Bieuzen, et al., 2014; Pruscino, Halson, & Hargreaves, 2013). It is feasible that the changes facilitated by the nervous system allowed for similar performances in maximal tests of power, irrespective of the state of recovery. In addition the different sports evaluated may impact findings (Halson, 2011). As sports may have different physiological stresses (Halson, 2011; Leeder, et al., 2012), inconsistency of findings may be a reflection of the different physiological strain associated with individual sports (Halson, 2011; Leeder, et al., 2012). Sports with a high volume of explosive actions may be more susceptible to mechanical overload as opposed to endurance based sports (Halson, 2011; Leeder, et al., 2012). Therefore, the inconsistency of findings between sports may reflect the different fatigue and recovery profiles across sport. Finally the training status of participants may also impact findings. Both Halson (2011) and Leeder, et al., (2012) highlighted the impact training status had on fatigue and recovery. Highly trained participants may be less susceptible to mechanical overload associated with fatigue than recreational/untrained participants, having undergone greater levels of adaptation to training/competition (Halson, 2011; Leeder, et al., 2012).

Several studies did evaluate neuromuscular function via myoglobin measurements (Pointon & Duffield, 2012; Pointon, Duffield, Cannon, & Marino, 2012). Each reported CWI offering greater benefits in recovery of neuromuscular function of the knee extensors (Pointon, et al., 2012). However, these results need to be viewed with some level of caution. It has been suggested that functional tests, best reflect recovery of performance in team sport, whereas the studies using myoglobin used a seated knee extension testing protocol. Furthermore, hip extensors and knee flexors have been previously identified as the primary movers in team sport activities (Gabbett, 2005, 2008). Therefore, clarification is required of reported recovery of the knee extensors (Pointon, et al., 2012) being duplicated with a similar recovery response of the hip extensors and/or knee flexors.

Finally, results from across the review indicated that irrespective of the recovery intervention, neuromuscular function returned to near baseline levels within 48 hours of team sport activity. This may suggest that the effectiveness of such intervention strategies in enhancing recovery before the next competition is limited.

1.2.7 Perception of muscle soreness and fatigue

Perceptual measures of muscle soreness and fatigue are widely accepted tools in monitoring of athletes recovery. It has been proposed that athletes will instinctively regulate intensity (Delextrat, Calleja-González, Hippocrate, & Clarke, 2013) and govern physical workloads (Morgans, Adams, Mullen, McLellan, & Williams, 2014) according to their perceptions (Delextrat, et al., 2013; Morgans, et al., 2014). A number of studies have report CWI and/or CWT to be more beneficial in alleviating perceptions of muscle soreness during the acute response (Getto & Golden, 2013; Higgins, Cameron, & Climstein, 2013; Higgins, Climstein, et al., 2013; Ingram, et al., 2009; Montgomery, Pyne, Hopkins, et al., 2008; Pournot, et al., 2011; Rupp, Selkow, Parente, et al., 2012). The reported beneficial effects of CWI and CWT with muscle soreness, can be linked with an acute analgesic affect (García-Manso, et al., 2011). The mechanisms associated with the acute analgesic effect of CWI and CWT centres primarily on the reduction of muscle soreness through pain inhibition and lower pain sensation (García-Manso, et al., 2011; Jakeman, Byrne, & Eston, 2010b; Pournot, et al., 2011; Rupp, et al., 2012). The effect of cold water immersion reduces nerve conduction velocity (García-Manso, et al., 2011; Jakeman, et al., 2010b; Rupp, et al., 2012) which in turn reduces muscle spindle activity allowing the muscle to relax, and alleviating the perception of pain (García-Manso, et al., 2011; Rupp, et al., 2012).

Although it is believed that hydrostatic pressure generated during water immersion will impact on recovery mechanisms (Halson, 2011), it was not evident when CWI and thermoneutral water immersion (TWI) were evaluated jointly (Rowsell, et al., 2009). As CWI was identified to be more beneficial than TWI in enhancing perceptions of recovery (Rowsell, et al., 2009), this would suggest that the underlying mechanisms enhancing perceptions of recovery are associated with the cold temperature rather than hydrostatic pressure.

Authors also postulated that CWI and CWT benefitted perceptions of muscle soreness through the reduction of inflammation after exercise-induced muscle damage (Bahnert, et al., 2013). The reduction in inflammation has been attributed to a number of mechanisms. Cold therapy has been reported to reduce oedema through vasoconstriction altering lymph evacuation and lymph flow as well as blood flow (Montgomery, Pyne, Cox, et al., 2008; Rupp, et al., 2012). Reducing oedema would result in a reduction in pressure on pain receptors (Delextrat, et al., 2013; Montgomery, Pyne, Cox, et al., 2008; Rupp, et al., 2012) and reduced cell necrosis alleviating muscle soreness (Ingram, et al., 2009). Furthermore, reduced cellular permeability and cellular diffusion has been associated with vasoconstriction (Pournot, et al., 2011) reducing both neutrophil migration (Ingram, et al., 2009) and inflammation, subsequently inducing inhibitory influences on pain (Pournot, et al., 2011).

In addition, the previously discussed link between perceptions of pain and fatigue and intensity regulation was not evident. Individually, a number of papers did report greater beneficial effects of CWI and/or CWT with perceptual measures of recovery; however, no beneficial effects in performance measures were reported (Bahnert, et al., 2013; Dawson, et al., 2005; Delextrat, et al., 2013; Higgins, Climstein, et al., 2013; Jones, Lander, & Brubaker, 2013; Juliff, Halson, Bonetti, et al., 2014; King & Duffield, 2009; Kinugasa & Kilding, 2009; Rowsell, et al., 2009).

1.2.8 Repeat effort testing

Although it was previously suggested repeat effort testing may be more appropriate in assessing recovery (Dawson, et al., 2005), a lack of research evaluating such is evident. In all, seven studies were identified in this systematic review that evaluated repeat effort performances, which included actual game performance (Buchheit, Horobeanu, Mendez-Villanueva, Simpson, & Bourdon, 2011; Rowsell, et al., 2011), simulated game performance (Higgins, Cameron, & Climstein, In Press) and sprint repeat performance (Delextrat, et al., 2013; Ingram, et al., 2009; Montgomery, Pyne, Hopkins, et al., 2008). Importantly, as with neuromuscular performance and subjective measures, only two studies evaluated beyond 48 hours (Higgins, et al., In Press; Rowsell, et al., 2009).

Two of the studies did report some notable findings. Firstly, Buchheit et al. (2011) did report there were differences in overall running distances between groups in the second game (Buchheit, et al., 2011), without reporting differences in high intensity running. This may provide an example of players regulating intensity when fatigued, as previously discussed. In attempting to conserve energy for high intensity activities associated with soccer, players reduced their levels of incidental movement throughout the second game. This led the authors to postulate that hydrotherapy was beneficial for recovery when consecutive games of football were played.

The second notable finding was identified by Higgins et al. (in Press), when evaluating performances between two simulated games of Rugby Union. It was found that throughout the second simulated game, athletes performed all out maximal sprints in times, equal to or improved above baseline scores (Higgins, et al., In Press). However, when athletes performed multi-task rugby specific actions, performances in the second simulated game were (although not significant) below baseline measures (Higgins, et al., In Press). This may in itself reflect the complexity of measuring fatigue and recovery with well-trained athletes. The level of exercise-induced muscle damage may not be severe enough, due to adaptations bought about through training. As such, well-trained athletes may have sufficient motor units functioning to record near maximal efforts in one all out tests (Higgins, et al., In Press). As has been previously recommended, repeat effort testing, which reflects actual game requirements, may be better suited to assess recovery for well-trained team sport athletes (Dawson, et al., 2005).

1.2.9 Biochemical measures

The studies evaluating biochemical markers of muscle damage and inflammation in this review indicated that team sports elicit a high level of muscle damage and inflammation, as evident with significant increases in biochemical markers. Although evaluating recovery biochemical markers of both muscle damage and inflammation are routinely assessed, as with other measures of fatigue and recovery discussed above, this review highlights the paucity of research evaluating biochemical responses to hydrotherapy and recovery from team field sport. The review identified that CK was the most commonly used biochemical marker evaluated.

Despite a large overall effect in reducing CK levels, individually research papers offered conflicting results. The beneficial effect of CWI and/or CWT in reducing CK levels was reported by several papers (French, et al., 2008; Hamlin, et al., 2012; Pournot, et al., 2011), whilst no beneficial effect of CWI and/or CWT in reducing CK levels was reported in other studies (Bieuzen, et al., 2014; Pointon, et al., 2012; Rowsell, et al., 2009). The conflicting results may be related to the time course of peak CK levels. The majority of time course responses evaluated were less than 48 hours, and although one study reported peak CK levels at 24 hours post (Gill, et al., 2006) peak CK levels have been reported to generally occur up to 96 hours post physiological stressor (Kraemer, et al., 2009). The conflicting results may reflect the time frames of studies missing peak CK levels. Extended time periods of research would be required to truly evaluate the effect CWI or CWT has on CK levels.

In addition to the conflicting results into the efficacy of CWI and/or CWT in enhancing clearance of biochemical markers discussed, conflicting positions have been raised by a number of authors. Gill et al. (2006) concluded that enhanced clearance of CK after Rugby Union reflected enhanced recovery (Gill, et al., 2006) whereas Pournot et al. (2011), professed that changes in intracellular proteins in venous blood was merely a reflection of increased clearance and or appearance of proteins such as CK

(Pournot, et al., 2011), without reference to recovery. Importantly, opposing positions were identified in relation to biochemical markers and performance. Ingram et al. (2009) reported that there was no significant correlation between either muscle soreness or performance capabilities and plasma concentrations of either CK or CRP (Ingram, et al., 2009), whereas Gill et al. (2006) reported reduced CK levels indicating recovery (Gill, et al., 2006), although Gill et al. (2006) did not report performance measures. Additionally, Montgomery et al. postulated that the acute elevations of myoglobin and FABP compared with the sustained elevation of CK made them a more effective marker (Montgomery, Pyne, Cox, et al., 2008).

Team sport does elicit high levels of muscle damage and inflammation, whether in a contact or non-contact sport. In addition, when multiple days of team sport competition and/or training are conducted, levels of muscle damage and inflammation will be compounded (Montgomery, Pyne, Cox, et al., 2008; Rowsell, et al., 2009). Therefore, the importance of recovery after competition and training cannot be underestimated. However, there is still a scarcity of research evaluating CWI and CWT and biochemical markers, specifically beyond 48 hours, and utility of such measures remains unclear. The conflicting results discussed above fail to provide a definitive answer in relation to the beneficial effects of either CWI and/or CWT on the subsequent clearance of biochemical markers and enhanced recovery.

1.2.10 Mid-thigh circumferences

Montgomery et al. (2008) along with French et al. (2008) were the only studies to assess changes in thigh circumferences as a measure of muscle oedema. Montgomery et al. (2008) reported only trivial differences in changes in thigh girths (0.5 to 1.2%). French et al. (2008) reported only compression garments attenuated oedema from significant inflammatory actions. French et al. (2008) found that CWT was ineffective in reducing oedema which was in conflict with the findings of Eston & Peters, (1999) and Wilcock et al. (2006). Although the latter two studies were not in the systematic review, they had provided the initial support for CWT aiding osmotic fluid shifts. French et al. (2008) concluded that CWT were ineffective in achieving a reduction in the inflammatory response or oedema after exercise-induced muscle damage.

1.2.11 Flexibility/range of motion

Dawson et al. (2005) and French et al. (2008) were the only two studies in this systematic review which evaluated either flexibility or range of motion. However, comparisons between these studies were not possible as different protocols were used. Dawson et al. (2005) used a sit and reach test and French et al. (2008) a range of motion test. Dawson et al. (2005) reported no significant difference in flexibility between the control group, active recovery group, pool/stretching group, and CWT group during the 48 hours following an AFL game. Whereas, French et al. (2008) reported large variability and conflicting data between participants within the CWT group, compression garment group and the control group, in relation to changes in range of motion and concluded that no consistent trends were identified offering little insight into beneficial effects. It appears further investigation is warranted into flexibility and the beneficial effect hydrotherapy may have in recovery of flexibility following team sport.

Although the popularity of hydrotherapy for recovery has increased, a number of questions have been raised in regards to its suitability (Elias, et al., 2012; Versey, Halson, and Dawson, 2013). Initial concerns have included heat applied in contrast therapy increasing inflammation and oedema (Elias, et al., 2012). The initial impact of heat may have a detrimental effect on recovery with increased inflammation and oedema (Elias, et al., 2012). However, the authors speculated the initial heat would be off-set by the subsequent application of cold, although the benefits of a single continuous immersion would exceed those of intermittent immersions (Elias, et al., 2012).

In addition, Versey, Halson, and Dawson (2013) speculated that although hydrotherapy benefitted acute recovery performance, raised concerns in regards to hydrotherapy blunting the chronic adaptation processes. It was theorized that hydrotherapy could disrupt mechanisms of fatigue which may be a prerequisite for adaptation, sought by athletes and training staff, in the development of fitness parameters (Versey, Halson, and Dawson, 2013). However, benefits associated with recovery in the acute stages, specifically increases in frequency, intensity or duration of training, could offset the potential detrimental effects via a blunted adaptation response (Versey, Halson, and Dawson, 2013).

A number of factors explaining the inconsistencies between results from the studies reviewed have been raised in the literature. Halson (2011) and Leeder et al. (2012) stated that when evaluating recovery from sporting performance a number of factors need to be taken into account (Halson, 2011; Leeder, et al., 2012). Initially, athletes will respond different to different types of physiological stressor. Non-weight bearing activities such as swimming and cycling will generate different physiological disturbances than weight bearing activities such as running (Halson, 2011; Leeder, et al., 2012). Therefore, evaluation of recovery modalities should be conducted using physiological stressors similar to the sporting activities of each specific athletic population (Halson, 2011; Leeder, et al., 2012). Training status of participants also needs consideration. Due to high training status and subsequent adaptation processors, well-trained, professional, elite level athletes may have blunted responses to physiological stressors in comparison to untrained or recreational athletes (Halson, 2011; Leeder, et al., 2012). Results from evaluations of recovery protocols with participants of either high training or untrained cannot be routinely transferred to differing participants (Halson, 2011; Leeder, et al., 2012). Therefore, recovery protocols should be evaluated with participants of an appropriate training status (Halson, 2011; Leeder, et al., 2012).

1.2.12 Conclusion

When applying hydrotherapy, CK, DOMS and tests of power were the most routinely used measures for recovery from exercise-induced muscle damage. Conflicting findings were reported across studies for CK, DOMS and power. In addition, assessments of flexibility and muscle oedema, across studies, were unable to provide clear indications as to any beneficial effect of hydrotherapy towards recovery.

Despite this shortage of scientific support and on the basis of anecdotal support alone, a phone survey conducted by the author found hydrotherapy to be the most common recovery modality utilised following Rugby Union. As such, the need for additional research into hydrotherapy as a recovery modality, specifically for Rugby Union is warranted. Therefore, the research undertaken in this thesis will be designed to evaluate CWI and CWT as recovery modalities with well-trained Rugby Union players undergoing Rugby Union specific activities.

1.3 Aims

In search of the competitive edge, coaching staff have explored additional methods to enhance the recovery process. Despite the wide spread acceptance of a multitude of recovery modalities, the literature reveals little is known of their effectiveness in recovery from team sport. Consequently, this research aims to narrow this research gap and conduct research into the most commonly used recovery modalities currently employed in the team sport of Rugby Union. The results will be used to provide recommendations towards recovery in response to the physical demands of training and competition in Rugby Union.

1.4 Research Objectives

The above aim will be accomplished by fulfilling the following research objectives:

1. Review the literature currently available in relation to recovery in team sport.
2. Identify current recovery practices across collision team sports including rugby league and rugby union, and then incorporate the most common recovery modalities in a research pilot study for rugby union.
3. From the review of literature and pilot study, establish the research protocol to evaluate hydrotherapy in a systematic approach.
4. Identify the beneficial effect of hydrotherapy for recovery during the initial 48 hours after a competitive game of rugby union.

5. Extend the research from point 4 through the evaluation of hydrotherapy for recovery in relation to residual fatigue associated with a competitive game followed by multiple training sessions associated with team sport.
6. Further extend the body of research conducted in points 4 and 5, by evaluating the beneficial effect of hydrotherapy in relation to game performances across a number of competitive games
7. Conclude the research by conducting a systematic review with meta-analysis across the increasing volume of sport science literature into hydrotherapy recovery in team sport. Enabling the clarification of findings from the research conducted in points 4, 5, and 6 in relation to the field of sport science.

1.5 Reference list

Abdelkrim, N. B., Castagna, C., El Fazaa, S., Tabka, Z., & El Ati, J. (2009). Blood metabolites during basketball competitions. *Journal of Strength & Conditioning Research, 23*(3), 765-773.

Adhihetty, P. J., Irrcher, I., Joseph, A., Ljubicic, V., & Hood, D. A. (2003). Plasticity of skeletal muscle mitochondria in response to contractile activity. *Experimental Physiology, 88*(1), 99-107.

Anttila, K., Mänttäri, S., & Järvilehto, M. (2008). Testosterone and Ca2+ regulation in skeletal muscle. *International Journal of Sports Medicine, 29*(10), 795-802.

Argus, C. K., Gill, N. D., Keogh, J. W. L., Hopkins, W. G., & Beaven, C. M. (2009). Changes in strength, power, and steroid hormones during a professional rugby union competition. *Journal of Strength & Conditioning Research, 23*(5), 1583-1592.

Arnheim, D. D., & Prentice, W. E. (Eds.). (1993). *Therapeutic Modalities. In: Principles of Athletic Training.* Baltimore, MD: Mosby

Bahnert, A., Norton, K., & Lock, P. (2013). Association between post-game recovery protocols, physical and perceived recovery, and performance in elite Australian Football League players. *Journal of Science & Medicine in Sport, 16*(2), 151-156.

Baird, M. F., Graham, S. M., Baker, J. S., & Bickerstaff, G. F. (2012). Creatine-Kinase- and exercise-related muscle damage implications for muscle performance and recovery. *Journal of Nutrition and Metabolism, 2012*, Article ID 960363.

Barnett, A. (2006). Using recovery modalities between training sessions in elite athletes. *Sports Medicine, 36*(9), 781-796.

Beaven, M., Gill, N. D., & Cook, C. (2008). Salivary testosterone and cortisol responses in professional rugby players after four resistance exercise protocols *Journal of Strength & Conditioning Research, 22*(2), 426-432.

Beck, T. W., Housh, T. J., Johnson, G., Schmidt, R. J., Housh, D. J., Coburn, J. W., et al. (2007). Effects of a protease supplement on eccentric exercise-induced markers of delayed-onset muscle soreness and muscle damage. *Journal of Strength & Conditioning Research, 21*(3), 661-667.

Belfry G., Raymer G., Marsh G., Paterson D., Thompson R., Thomas S. (2012). Muscle metabolic status and acid-base balance during 10-s work:5-s recovery intermittent and continuous exercise. *J Appl Physiol 113,* 41 –417.

Bieuzen, F., Brisswalter, J., Easthope, C., Vercruyssen, F., Bernard, T., & Hausswirth, C. (2014). Effect of Wearing Compression Stockings on Recovery After Mild Exercise-Induced Muscle Damage. *International Journal of Sports Physiology & Performance, 9*(2), 256-264.

Bishop, P. A., Jones, E., & Woods, A. K. (2008). Recovery from training: A brief review. *Journal of Strength & Conditioning Research, 22*(3), 1015-1024.

Bleakley, C. M., & Davison, G. W. (2010). What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. *British Journal of Sports Medicine, 44*(3), 179-187.

Bo, H., Zhang, Y., & Ji, L. L. (2010). Redefining the role of mitochondria in exercise: a dynamic remodeling. *Annals of the New York Academy of Science, 1201*, 121-128.

Brancaccio, P., Maffulli, N., & Limongelli, F. M. (2007). Creatine kinase monitoring in sport medicine. *British Medical Bulletin, 81 and 82*, 209-230.

Buchheit, M., Horobeanu, C., Mendez-Villanueva, A., Simpson, B. M., & Bourdon, P. C. (2011). Effects of age and spa treatment on match running performance over two consecutive games in highly trained young soccer players. *Journal of Sports Sciences, 29*(6), 591-598.

Burke, D. G., Holt, L. E., Rasmussen, R., Mackinnon, N. C., Vossen, J. F., & Pelhame, T. W. (2001). Effects of hot or cold water immersion and modified proprioceptive neuromuscular facilitation flexibility exer-cise on hamstring length. *Journal of Athletic Training, 36*, 16-19.

Chen, T. C. (2006). Variability in muscle damage after eccentric exercise and the repeated bout effect. *Research Quarterly for Exercise & Sport, 77*(3), 362-371.

Christie, B. A., Wulforst, L., Krause, J., Crawford, S., & Docheff, D. (1997). Will the increase of paid coaches for youth sport travel teams or elite teams increase the pressures to win at all costs for the coach and players? *Journal of Physical Education, Recreation & Dance, 68*(4), 10-11.

Ciciliot, S., & Schiaffino, S. (2010). Regeneration of mammalian skeletal muscle. Basic mechanisms and clinical implications. *Current Pharmaceutical Design 16*(8), 906-914.

Cinar, V., Cakmakci, O., Mogulkoc, R., & Baltaci, A. K. (2009). Effects of exhaustion and calcium supplementation on adrenocorticotropic hormone and cortisol levels in athletes. *Biological Trace Element Research, 127*(1), 1-5.

Coso, J. D., Gonza´lez-Milla´n, C., Salinero, J. J., Abia´n-Vice´n, J., Soriano, L., & al, e. (2012). Muscle Damage and Its Relationship with Muscle Fatigue During a Half-Iron Triathlon. *PLoS ONE [Electronic Resource], 7*(8), e43280.

Coutts, A. E., Reaburn, P., Piva, T. J., & Rowsell, G. J. (2007). Monitoring for overreaching in rugby league players. *European Journal of Applied Physiology, 99*, 313-324.

Crewther, B., Cronin, J. B., Keogh, J., & Cook, C. (2008). The salivary testosterone and cortisol response to three loading schemes. *Journal of Strength & Conditioning Research, 22*(1), 250-255.

Cunniffe, B., Hore, A. J., Whitcombe, D. M., Jones, K. P., Baker, J. S., & Davies, B. (2010). Time course of changes in immuneoendocrine markers following an international rugby game. *European Journal of Applied Physiology, 108*(1), 113-122.

Dadebo, B., White, J., & George, K. P. (2004). A survey of flexibility training protocols and hamstring strains in professional football clubs in England. *British Journal of Sports Medicine, 38*, 388-394.

Dahlstedt, A. J., Katz, A., Wieringa, B., & Westerblad, H. (2000). Is creatine kinase responsible for fatigue? Studies of isolated skeletal muscle deficient in creatine kinase. *FASEB, 14*, 982-990.

Dawson, B., Gow, S., Modra, S., Bishop, D., & Stewart, G. (2005). Effects of immediate post-game recovery procedures on muscle soreness, power and flexiblity [sic flexibility] levels over the next 48 hours. *Journal of Science & Medicine in Sport, 8*(2), 210-221.

Delextrat, A., Calleja-González, J., Hippocrate, A., & Clarke, N. D. (2013). Effects of sports massage and intermittent cold-water immersion on recovery from matches by basketball players. *Journal of Sports Sciences, 31*(1), 11-19.

Ebbeling, C. B., & Clarkson, P. M. (1989). Exercise-induced muscle damage and adaptation. *Sports Medicine, 7*, 207-234.

Ehlers, G. G., Ball, T. E., & Liston, L. (2002). Creatine kinase levels are elevated during 2-a-day practices in collegiate football players. *Journal of Athletic Training, 37*(2), 151-156.

Eliakim, A., Portal, S., Zadik, Z., Rabinowitz, J., Adler-Portal, D., Cooper, D. M., et al. (2009). The effect of a volleyball practice on anabolic hormones and inflammatory markers in elite male and female adolescent players. *Journal of Strength & Conditioning Research, 23*(5), 1553-1559.

Elias, G.P., Varley, M.C., Wyckeisma, V.L., McKenna, M.L., Minahan, C.L., and Aughey, R.J. (2012). Effects of water immersion on post training recovery in Australian footballers. *International Journal of Sports Physiology and Performance, 7,* 357-366.

Eston, R., & Peters, D. (1999). Effects of cold water immersion on the symptons of exercise-induced muscle damage. *Journal of Sports Sciences, 17*, 231-238.

Falvo, M. J., & Bloomer, R. J. (2006). Review of exercise-induced muscle injury: Relevance for athletic populations. *Research in Sports Medicine, 14*, 65-82.

Filaire, E., Filaire, M., & Le Scanff, C. (2007). Salivary cortisol, heart rate and blood lactate during a qualifying trial and an official race in motorcycling competition. *Journal of Sports Medicine & Physical Fitness, 7*, 413-417.

Franzini-Armstrong, C. (1999). The sarcoplasmic reticulum and the control of muscle contraction. *FASEB, 13* (9002), s266-S270.

French, D. N., Thompson, K. G., Garland, S. W., Barnes, C. A., Portas, M. D., Hood, P. E., et al. (2008). The Effects of Contrast Bathing and Compression Therapy on Muscular Performance. *Medicine & Science in Sports & Exercise, 40*(7), 1297-1306.

Gabbett, T. J. (2005). Changes in physiological and anthropometric characteristics of rugby league players during a competitive season. *Journal of Strength and Conditioning Research, 19*(2), 400-408.

Gabbett, T. J. (2008). Influence of fatigue on tackling technique in rugby league players. *Journal of Strength and Conditioning Research, 22*(2), 625-632.

García-Manso, J. M., Rodríguez-Matoso, D., Rodríguez-Ruiz, D., Sarmiento, S., de Saa, Y., & Calderón, J. (2011). Effect of cold-water immersion on skeletal muscle contractile properties in soccer players. *American Journal of Physical Medicine & Rehabilitation, 90*(5), 356-363.

Garraway, W. M., Lee, A. J., Hutton, S. J., Russell, E. B. A. W., & Macleod, D. A. D. (2000). Impact of professionalism on injuries in rugby union. Br J Sports Med 2000; 34:348–351. *British Journal of Sports Medicine, 34*, 348-351.

Getto, C. N., & Golden, G. (2013). Comparison of active recovery in water and cold-water immersion after exhaustive exercise. *Athletic Training & Sports Health Care: The Journal for the Practicing Clinician, 5*(4), 169-176.

Gill, N. D., Beaven, C. M., & Cook, C. (2006). Effectiveness of post-match recovery strategies in rugby players. *British Journal of Sports Medicine, 40*(3), 260-263.

Halson, S. L. (2011). Does the time frame between exercise influence the effectiveness of hydrotherapy for recovery?. [Review]. *International journal of sports physiology & performance, 6*(2), 147-159.

Hamlin, M. J., Mitchell, C. J., Ward, F. D., Draper, N., Shearman, J. P., & Kimber, N. E. (2012). Effect of compression garments on short-term recovery of repeated sprint and 3-km running performance in rugby union players. *Journal of Strength & Conditioning Research, 26*(11), 2975-2982.

Higgins, T. R., Cameron, M., & Climstein, M. (In Press). Evaluation of passive recovery, cold water immersion, and contrast baths for recovery, as measured by game performances markers, between two simulated games of rugby union. *Journal of Strength and Conditioning Research, X*(X), XX.

Higgins, T. R., Cameron, M. L., & Climstein, M. (2013). Acute response to hydrotherapy after a simulated game of rugby. *Journal of Strength & Conditioning Research, 27*(10), 2851-2860.

Higgins, T. R., Climstein, M., & Cameron, M. (2013). Evaluation of hydrotherapy, using passive tests and power tests, for recovery across a cyclic week of competitive rugby union. *Journal of Strength & Conditioning Research, 27*(4), 954-965.

Higgins, T. R., Heazlewood, I. T., & Climstein, M. (2011). A random control trial of contrast baths and ice baths for recovery during competition in u/20 rugby union. *Journal of Strength & Conditioning Research, 25*(4), 1046-1051.

Holloszy, J. O. (2009). Skeletal muscle “mitochondrial deficiency” does not mediate insulin resistance. *American Journal of Clinical Nutrition, 89* (1), 463S-466S.

Hubbard, T. J., Aronson, S. L., & Denegar, C. R. (2004). Does cryotherapy hasten return to participation? A systematic review. *Journal of Athletic Training, 39*, 88-94.

Idone, V., Tam, C., & Andrews, N. W. (2008). Two-way traffic on the road to membrane repair. *Trends in Cell Biology, 18*(11), 552-559.

Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science & Medicine in Sport, 12*(3), 417-421.

Issurin V.B. (2010). New horizons for the methodology and physiology of training periodization. *Sports Medicine, 40*(3), 189-206.

Jakeman, J. R., Byrne, C., & Eston, R. G. (2010). Lower limb compression garment improves recovery from exercise-induced muscle damage in young, active females. *European Journal of Applied Physiology, 109*(6), 1137-1144.

Jones, B., Lander, J., & Brubaker, D. (2013). The effects of different recovery interventions following a repeated rugby union (sevens) game simulated protocol. *Journal of Australian Strength & Conditioning, 21*(4), 5-13.

Juliff, L. E., Halson, S. L., Bonetti, D. L., Versey, N. G., Driller, M. W., & Peiffer, J. J. (2014). Influence of contrast shower and water immersion on recovery in elite netballers. *Journal of Strength & Conditioning Research, 28*(8), 2353-2358.

King, M., & Duffield, R. (2009). The effects of recovery interventions on consecutive days of intermittent sprint exercise. *Journal of Strength and Conditioning Research, 23*(6), 1795-1802.

Kinugasa, T., & Kilding, A. E. (2009). A comparison of post-match recovery strategies in youth soccer players. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins), 23*(5), 1402-1407.

Kon, M., Tanabe, K., Akimoto, T., Kimura, F., & Tanimura, Y. (2008). Reducing exercise-induced muscular injury in kendo athletes with supplementation of coenzyme Q10. *The British Journal of Nutrition 100*(4), 903-909.

Kraemer, W. J., Spiering, B. A., Volek, J. S., Martin, G. J., Howard, R. L., Ratamess, N. A., et al. (2009). Recovery from a National Collegiate Athletic Association Division I football game: muscle damage and hormonal status. *Journal of Strength & Conditioning Research, 23*(1), 2-10.

Lazarim, F. L., Antunes-Neto, J. M. F., da Silva, F. O. C., Nunes, L. A. S., Bassini-Cameron, A., Cameron, L.-C., et al. (2009). The upper values of plasma creatine kinase of professional soccer players during the Brazilian National Championship. *Journal of Science and Medicine in Sport, 12*(1), 85-90.

Leeder, J., Gissane, C., van Somerson, K., Gregson, W., & Howatson, G. (2012). Cold water immersion and recovery from strenuous exercise: a meta-analysis. *British Journal of Sports Medicine, 46*, 233-240.

Linnamo, V., Pakarinen, A., P.V, K., Kraemer, W. J., & Häkkinen, K. (2005). Acute hormonal responses to submaximal and maximal heavy resistance and explosive exercises in men and women. *Journal of Strength & Conditioning Research, 19*(3), 566-571.

Magaudda, L., Di Mauro, D., Trimarchi, F., & Anastasi, G. (2004). Effects of physical exercise on skeletal muscle fiber: ultrastructural and molecular aspects. *Basic Applied Myology, 14*, 17-21.

Margaritis, I., Tessier, F., Verdera, F., Bermon, S., & Marconnet, P. (1999). Muscle enzyme release does not predict muscle function impairment after triathlon. *Journal of Sports Medicine & Physical Fitness, 39*(2), 133-138.

Montgomery, P. G., Pyne, D. B., Cox, A. J., Hopkins, W. G., Minahan, C. L., & Hunt, P. H. (2008). Muscle damage, inflammation, and recovery interventions during a 3-day basketball tournament. *European Journal of Sport Science, 8*(5), 241-250.

Montgomery, P. G., Pyne, D. B., Hopkins, W. G., Dorman, J. C., Cook, K., & Minahan, C. L. (2008). The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *Journal of Sports Sciences, 26*(11), 1135-1145.

Morgans, R., Adams, D., Mullen, R., McLellan, C., & Williams, M. (2014). An English championship league soccer team did not experience impaired physical match performance in a second match after 75 hours of recovery. *Journal of Australian Strength & Conditioning, 22*(4), 16-23.

Neubauer, O., König, D., & Wagner, K. H. (2008). Recovery after an Ironman triathlon: sustained inflammatory responses and muscular stress. *European journal of applied physiology, 104*(3), 417-426.
Newton, M. J., Morgan, G. T., Sacco, P., Nosaka, K., Chapman, P., & Dale, W. (2008). Comparison of responses to strenuous eccentric exercise of the elbow flexors between resistance-trained and untrained men. *Journal of Strength and Conditioning Research, 22*(2), 597-607.
Paschalis, V., Koutedakis, Y., Jamurtas, A. Z., Mougios, V., & Baltzopoulos, V. (2005). Equal volumes of high and low intensity of eccentric exercise in relation to muscle damage and performance. *Journal of Strength & Conditioning Research, 19*(1), 184-188.
Peiffer, J. J., Abbiss, C. R., Watson, G., Nosaka, K., & Laursen, P. B. (2009). Effect of cold-water immersion duration on body temperature and muscle function. *Journal of Sports Sciences, 27*(10), 987-993.
Philippou, A., Halapas, A., Maridaki, M., & Koutsilieris, M. (2007). Type I insulin-like growth factor receptor signaling in skeletal muscle regeneration and hypertrophy. *J Musculoskelet Neuronal Interact, 7*(3), 208-218.
Pointon, M., & Duffield, R. (2012). Cold water immersion recovery after simulated collision sport exercise. *Medicine & Science in Sports & Exercise, 44*(2), 206-216.
Pointon, M., Duffield, R., Cannon, J., & Marino, F. E. (2012). Cold water immersion recovery following intermittent-sprint exercise in the heat. *European Journal of Applied Physiology, 112*, 2483–2494.
Poppendieck, W., Faude, O., Wegmann, M., & Meyer, T. (2013). Cooling and performance recovery of trained athletes: A meta-analytical review. *International journal of sports physiology & performance, 8*, 227-242.
Pournot, P., Bieuzen, F., DuYeld, R., Lepretre, P.-M., Cozzolino, C., & Hausswirth, C. (2011). Short term effects of various water immersions on recovery from exhaustive intermittent exercise. *European Journal of Applied Physiology, 111*, 1287–1295.
Pruscino, C. L., Halson, S., & Hargreaves, M. (2013). Effects of compression garments on recovery following intermittent exercise. *European Journal of Applied Physiology, 113*, 1585–1596.
Ra¨mson, R., Ju¨ rima¨ e, J., Ju¨ rima¨ e, T., & Ma¨ estu, J. (2009). Behavior of testosterone and cortisol during an intensity-controlled high volume training period measured by a training task-specific test in men rowers. *Journal of Strength & Conditioning Research, 23*(2), 645-651.
Reddy, A., Caler, E. V., & Andrews, N. W. (2001). Plasma membrane repair is mediated by Ca2+ - regulated exocytosis of lysosomes. *Cell, 106*(2), 157-169.
Reilly, T., & Ekblom, B. (2005). The use of recovery methods post-exercise. *Journal of sports sciences, 23*(6), 619-627.
Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal of Sports Sciences, 27*(6), 565-573.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2011). Effect of post-match cold-water immersion on subsequent match running performance in junior soccer players during tournament play. *Journal of Sports Sciences, 29*(1), 1-6.

Rupp, K. A., Selkow, N. M., Parente, W. R., Ingersoll, C. D., Weltman, A. L., & Saliba, S. A. (2012). The effect of cold water immersion on 48-hour performance testing in collegiate soccer players. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins), 26*(8), 2043-2050.

Sakamoto, A., Maruyama, T., Naito, H., & Sinclair, P. J. (2009). Effects of exhaustive dumbbell exercise after isokinetic eccentric damage: recovery of static and dynamic muscle performance. *Journal of Strength & Conditioning Research, 23*(9), 2467-2476.

Saraslanidis, P. J., Manetzis, C. G., Tsalis, G. A., Zafeiridis, A. S., Mougios, V. G., & Kellis, S. E. (2009). Biochemical evaluation of running workouts used in training for the 400-m sprint. *Journal of Strength & Conditioning Research, 23*(8), 2266-2271.

Shkurnikov, M. U., Donnikov, A. E., Akimov, E. B., Sakharov, D. A., & Tonevitsky, A. G. (2008). Free testosterone as marker of adaptation to medium-intensive exercise. *Bulletin of Experimental Biology and Medicine, 146*(9), 330-332.

Shorten, P. R., & Soboleva, T. K. (2007). Anomalous ion diffusion within skeletal muscle transverse tubule networks. *Theoretical Biology and Medical Modelling 4*(18).

Silva, J. R., Ascensa˜o, A., Marques, F., Seabra, A., Rebelo, A., & Magalha˜es, J. (2013). Neuromuscular function, hormonal and redox status and muscle damage of professional soccer players after a high-level competitive match. *European Journal of Applied Physiology, 113*, 2193–2201.

Skurvydas, A., Brazaitis, M., & Kamandulis, S. (2010). Muscle-damaging exercise affects isokinetic torque more at short muscle length. *Journal of Strength and Conditioning Research, 25*(5), 1400-1406.

Smart, D., Gill, N., Beaven, C., Cook, C., & Blazevich, A. (2008). The relationship between changes in interstitial creatine kinase and game-related impacts in rugby union. *British Journal of Sports Medicine, 42*(3), 198-201.

Soebbing, B. P., & Mason, D. S. (2009). Managing legitimacy and uncertainty in professional team sport: the NBA's draft lottery *Team Performance Management: An International Journal 15*(3/4), 141-157.

Su, Q., Tian, Y., Zhang, J., & Zhang, H. (2008). Effects of allicin supplementation on plasma markers of exercise-induced muscle damage, IL-6 and antioxidant capacity. *European Journal of Applied Physiology, 103*, 275-283.

Suzuki, M., Umeda, T., Nakaji, S., Shimoyama, T., Mashiko, T., & Sugawara, K. (2004). Effect of incorporating low intensity exercise into the recovery period after a rugby match. *British Journal of Sports Medicine, 38*, 436-440.

Symons, T. B., Clasey, J. L., Gater, D. R., & Yates, J. W. (2004). Effects of deep heat as a preventative mechanism on delayed onset muscle soreness. *Journal of Strength & Conditioning Research, 18*(1), 155-161.

Takarada, Y. (2003). Evaluation of muscle damage after a rugby match with special reference to tackle plays. *British Journal of Sports Medicine, 37*(5), 416-419.

Takeda, M., Sato, T., Hasegawa, T., Shintaku, H., Kato, H., Yamaguchi, Y., et al. (2014). The effects of cold water immersion after rugby training on muscle power and biochemical markers. *Journal of Sport Science and Medicine, 13*, 616-623.

Tee, J. C., Bosch, A. N., & Lambert, M. I. (2007). Metabolic Consequences of Exercise-Induced Muscle Damage. *Sports Medicine, 37*(10), 827-836.

Totsuka, M., Nakaji, S., Suzuki, K., Sugawara, K., & Sato, K. (2002). Break point of serum creatine kinase release after endurance exercise. *Journal of Applied Physiology, 93*, 1280-1286.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2007). Effect of hydrotherapy on recovery from fatigue. *International Journal of Sports Physiology and Performance, 29*, 539-544.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008a). Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. *Journal of Sports Sciences, 26*(5), 431-440.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008b). Effect of hydrotherapy on recovery from fatigue. *International Journal of Sports Physiology and Performance, 29*, 539-544.

Versey, N.G., Halson, S.L., and Dawson, B.T (2013). Water immersion recovery for athletes: effect on exercise performance and practical recommendations. *Sports Med 43*, 1101–1130.

Warhol, M. J., Siegel, A. J., Evans, W. J., & Silverman, L. M. (1985). Skeletal muscle injury and repair in marathon runners after competition. *American Journal Of Pathology, 118*(2), 331-339.

Webb, N. P., Harris, N. K., Cronin, J. B., & Walker, C. (2013). The relative efficacy of three recovery modalities after professional rugby league matches. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins), 27*(9), 2449-2455.

Weber, M., Kinscherf, R., Krakowski-Roosen, H., Aulmann, M., Renk, H., Künkele, A., et al. (2007). Myoglobin plasma level related to muscle mass and fiber composition – a clinical marker of muscle wasting? *Journal of Molecular Medicine, 85*, 887-896.

Wiacek, M., Andrzejewski, M., Chmura, J., & Zubrzycki, I. Z. (2011). The changes of the specific physiological parameters in response to 12-week individualized training of young soccer players. *Journal of Strength & Conditioning Research, 25*(6), 1541-1511.

Wilcock, I. M., Cronin, J. B., & Hing, W. A. (2006). Physiological response to water immersion: A method for sport recovery? . *Sports Medicine, 36*(9), 747-765.

Williams, J. H. (1997). Contractile apparatus and sarcoplasmic reticulum function: effects of fatigue, recovery, and elevated Ca2+. *Journal of Applied Physiology, 83*(2), 440-450.

Yamamoto, L. M., Judelson, D. A., Farrell, M. J., Lee, E. C., Armstrong, L. E., Casa, D. J., et al. (2008). Effects of hydration state and resistance exercise on markers of muscle damage. *Journal of Strength and Conditioning Research, 22*(5), 1387-1393.

Yanagisawa, O., Niitsu, M., Takahashi, H., Goto, K., & Itai, Y. (2003). Evaluations of cooling exercised muscle with MR imaging and PMR spectroscopy. *Medicine and Science in Sports and Exercise, 35*(9), 1517-1523.

Chapter 2

2.1 A random control trial of contrast baths and cold water immersion for recovery during competition in U/20 Rugby Union.

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2.1.1 Abstract

Higgins, T. R., Heazlewood, I. T., & Climstein, M. (2011). A random control trial of contrast baths and ice baths for recovery during competition in U/20 rugby union. *Journal of Strength & Conditioning Research*, 25(4), 1046-1051 - Players in team sports must recover in a relatively short period of time to perform at optimal levels. To enhance recovery, cryotherapy is widely used. To date, there are limited scientific data to support the use of cryotherapy for recovery. Players (n = 26) from a premier rugby club volunteered to participate in a random control trial (RCT) using CWT, ice baths, and no recovery. Statistical analysis, between group and within group, with repeated measures was conducted along with determination of effect sizes in 2 field tests. Pre and post-field tests including a 300m test and a phosphate decrement test and subjective reports were conducted during the RCT. No significant difference was identified between base tests and retests in the phosphate decrement test or the 300m tests. Effect size calculations identified a medium to large effect (d = 0.72) for 300m tests for CWT against control. Trivial effects were identified for ice baths (d = 0.17) in the 300m test against control. Effect size calculations in the phosphate decrement test showed a trivial effect (d = 0.18) CWT and a negative effect (d = 20.62) for ice baths. Treatment–treatment analysis identified a large effect for CWT (d = 0.99) in the phosphate decrement test and a medium effect for CWT (d = 0.53) in the 300m test. Effect scores across CWT, ice baths, and passive recovery along with subjective reports indicate a trend toward CWT benefiting recovery in rugby. The continued use of 5 minute ice baths for recovery should be reconsidered based on this research because trends suggest a detrimental effect.

2.1.2 Introduction

It has been postulated that recovery is an important factor in athletic life and that optimal recovery may prevent underperformance (Kellmann, 2002). Currently, players in elite sport cycle through habitual activity across each week of a season

(Dadebo, et al., 2004). This cycle of habitual activity includes training, game time, and recovery over each competitive week (Reilly & Ekblom, 2005). In addition, the relative short turn around between games and training may lead players to accumulate fatigue as the season progresses (Reilly & Ekblom, 2005).

A number of recovery modalities, including cryotherapy and contrast baths (CWT), have been adopted by sporting teams to assist player recovery. A comprehensive search through sports science and sports medicine databases found limited papers into recovery modalities and their outcomes. Additionally, the majority have used untrained subjects, with only a small number evaluating the benefits of recovery strategies with well-trained athletes.

Published papers on recovery offer conflicting results in the benefit of hydrotherapy for recovery. No significant differences were identified across 4 recovery protocols with elite junior soccer players in 10m sprints or countermovement jumps (Tessitore, Meusen, Demarie, Ugolotti, & Capranica, 2004). Multiple recovery protocols were used in testing Australian Rules footballers (Dawson, et al., 2005), dependent variables were not significantly enhanced by performing immediate postgame recovery protocols. In contrast, cold water immersion was found to promote restoration of physical performance measures over a 3-day basketball tournament (Montgomery, Pyne, Hopkins, et al., 2008).

It was reported that consequences of performance decrements immediately after cold whirlpool immersion needed to be considered before returning athletes to activity post-treatment (Patterson, Udermann, Doberstein, & Reineke, 2008). Additionally, ice water immersion was shown to be ineffectual in minimizing markers of delayed onset of muscle soreness (DOMS) with untrained men (Sellwood, Brukner, Williams, Nicol, & Hinman, 2007). However, ice baths were identified to delay the perception of fatigue and leg soreness in junior elite soccer players over a week of tournament play (Rowsell, et al., 2009), although no clear beneficial effect on physical performance was identified. However, 10 minutes of ice bath identified trends in recovery through effect sizes from simulated team sport (Ingram, et al., 2009).

Cold water immersion was found to be effective in maintaining subsequent performances in high-intensity cycling (Vaile, Halson, Gill, & Dawson, 2008a) and across 5 days of cycling (Vaile, Halson, et al., 2007). In contrast, no effect on isokinetic strength or 1-km time trials in cycling was identified after cold water immersion (Peiffer, Abbiss, Watson, Nosaka, & Laursen, 2010).

Research into recovery for highly or well-trained athletes identified that return in squat-jump peak power in highly trained athletes occurred more quickly with contrast therapy than with passive recovery (Vaile, Gill, & Blazevich, 2007). In contrast, contrast therapy was found to offer no enhancement in recovery from simulated team sport. In addition, neither CWT nor compression garments showed any benefit to recovery from exercise induced muscle damage (French, et al., 2008).

Reported mechanisms of hydrotherapy enhancing recovery include reduction in inflammation and diminishing the stretch–reflex response to elongation (Burke, et al., 2001). Hydrotherapy reduces blood flow through vasoconstriction of the arterioles and venules (Arnheim & Prentice, 1993). In addition, hydrotherapy has been shown to reduce tissue temperature lowering the rate of chemical reactions (Hubbard, et al., 2004). The reduction in the rate of chemical reactions leads to a reduction in the demand for adenosine triphosphate (ATP), reducing the requirement for oxygen and reducing the adverse effects of hypoxia (Hubbard, et al., 2004). Hydrotherapy has also been shown to aide in metabolic waste product removal via increase in circulation through vasodilatation and vasoconstriction assisting the venous pump (Gill, et al., 2006).

The current research problem with team sports which consist of high levels of collisions or impacts such as Rugby Union, is will different recovery strategies including cryotherapy have a positive influence on anaerobic recovery, as measured by performance in anaerobic tasks dependent on anaerobic glycolysis?

In this research, it was hypothesized, based on the review of the literature that CWT would be superior to ice baths and passive modalities in enhancing anaerobic recovery, as measured by a modified phosphate decrement test and 300m test.

2.1.3 Methods

2.1.3.1 Experimental Approach to the Problem

In the present study, a random control trial research design was used. Subjects were required to undertake take four competition games of Rugby Union across four weeks. Subjects were also required to undertake two training sessions per week. After each game and each training session subjects underwent one of three recovery modalities (ice baths, CWT or passive recovery). Pre-tests were conducted in the week preceding the first game. Post-tests were conducted the week after the fourth competition game. All testing was conducted at the teams scheduled training sessions.

2.1.3.2 Subjects

Subjects were members of an under 20 Rugby Union team (Colts) competing in the Sydney Premier Rugby Competition (see Table 2.1). Following the Australian Catholic University’s ethics committee approval, and in accordance with guidelines for the use of human subjects in research, a Premier Rugby Union club was approached to participate in a random control trial (RCT).

Male players from the U/20 competition (Colts) volunteered to participate in the RCT. Before commencing, players were given an information letter explaining the study and an opportunity to ask questions. Players volunteering gave written consent; players under the age of 18 provided a signed consent form from a parent or guardian.

Having previously identified the most common recovery methods in rugby (Higgins & Heazlewood, 2008), ice baths and CWT were selected for this study as the independent variables. A control group was established for comparison purposes. The participants in the control group were instructed to perform passive recovery, which involved passive rest following training sessions.

The RCT was conducted during weeks 5–9 inclusive of the 2008 Rugby Union competition. Players suffering an injury or illness during the period or were part of the National Training Squad were excluded from the study. Players with known allergies to cold or displayed symptoms such as rashes were withdrawn from participation in the study.

A convenient sample of Colt Rugby players (n = 26) met the inclusion criteria to participate in the study. Training was conducted as a squad including warm-up (20 minutes), fitness training (30 minutes), skill session (45 minutes), and opposed team run (20 minutes). Training loads were kept constant across all participants during the study, in line with the teams' periodised training schedule. Training loads and intensities had been previously established for each drill with data trackers (GPSpi 10, Canberra, Australia).

The participants were randomly assigned to 1 of 3 groups: ice baths (Higgins & Heazlewood, 2008), which involved immersion in cold water for 5 minutes, above the waistline, with a temperature range of between 10 and 12^{o}C; and CWT (Higgins & Heazlewood, 2008), which involved alternating from cold water at temperature range between 10 and 12^{o}C and warm water at a temperature range of between 38 and 40^{o}C for 60 seconds in each cycle, through 7 cycles. Finally, those in the control group were to follow a passive recovery strategy.

It has been reported that energy contributions in intermittent team games are primarily anaerobic (Duthie, Pyne, & Hooper, 2003). There is also a requirement for high anaerobic capacity during sustained and repeated intense efforts in Rugby Union (Duthie, et al., 2003). Therefore, tests to be used included a phosphate decrement test, which involved 7 all out sprints for 7 seconds with 21 seconds recovery and a 300m sprint test.

Testing was carried out after the squads' standardized warm-up, which included 2 Honan drills for 15 minutes at training. Baseline phosphate decrement was conducted on Monday of week 1 of the study; the baseline 300m test was conducted on Wednesday of week 1 of the study. Ice baths and contrast bath treatments were applied after all training sessions and each competition game.

The phosphate decrement test was performed on a grass covered rugby oval with participants performing the test in 3 random groups. Standard training cones were placed across the field every 2m for 50m, to measure distance covered in each sprint. The 7 second time for sprints and 21 second time for recovery was monitored by the researcher, using a standard handheld stop watch. Start and end sprints were signalled by the researcher blowing a referee’s whistle. Alongside the first cone and at the sound of a referee's whistle; each participant would sprint for 7 seconds, at which point the referees whistle would be blown again. Participants would then line up alongside the last cone at the opposite end, and after 21 seconds the referee’s whistle would be blown again. The cycle was repeated until the group had completed 7 sprints. Each participant was instructed to use maximal effort. Each participant was assigned a spotter to identify which cone they had last passed; at the sounding of the referee’s whistle. Each cone had previously been identified with an identifying value. After blowing of the whistle, the spotter would identify the last cone their assigned participant had passed the identified cone would then be recorded next to the participant’s name for statistical analysis. A pilot study to test reliability of the modified phosphate decrement test, which included 7 participants from the same pool of subjects, with 4 markers assigned to each, identified a coefficient of variation from between 3.2 and 4.9% across the 7 runs between subjects across markers. A reliability statistic of Cronbach’s Alpha 0.926 was also reported. The 300m time trial was conducted around the training oval, with the distance paced out with the use of a trundle wheel and agility posts placed every 20m to mark the course. Participants performed the time trial in 3 random groups, running in an anticlockwise direction. Each participant assigned an individual keeper who recorded the time with a standard, handheld stop watch.

Subjective self-reports were also received from players. Reports included how rested they felt, how tight they felt, and whether they felt the treatment was beneficial. Retests were conducted on the fifth week of the study. The phosphate decrement test and the 300m sprint test were conducted using the identical protocol as for baseline tests.

2.1.3.3 Statistical Analyses

The statistical analyses were facilitated by SPSS version 15.0, which included between-group and within-group analyses. One-way analysis of variance (ANOVA) evaluated between groups for significant difference on the pre-test scores to confirm equality of groups and group variances before post-test analyses. Initial differences at the pre-test level based on participant scores were identified to adjust for any initial difference, Between-groups analysis of covariance (ANCOVA) tests were conducted on the post-test scores as the dependent variable; the Between-group factor was the treatments and the pre-test scores were defined as the covariate. A mixed ANOVA design was also applied to understand any changes in between-group (treatment) and within-group (pre-test to post-test) simultaneously.

Effect size analyses (Cohen's *d*) were conducted to identify in detail outcomes based on treatment effects (Atkinson, 2007; Batterham & Hopkins, 2006). Effect sizes were assessed in line with Batterham and Hopkins and included the following criteria, 0.2 as trivial, 0.2–0.6 as small, 0.6–1.2 as moderate, 1.2–2.0 as large, and .2.0 as very large (Batterham & Hopkins, 2006). It has been stated that parametric statistical tests based on statistical significant difference fail to address real-world significance of a practical treatment outcome (Atkinson, 2007; Batterham & Hopkins, 2006), the concept in sport that is now referred to as performance significant outcomes. Additionally, inferences based on true effect sizes can be more important than statistical significance (Atkinson, 2007) because a non-significant result does not necessarily rule out a worthwhile effect (Batterham & Hopkins, 2006).

2.1.4 Results

Subject characteristics for age, height, and mass (mean ± SD) for the 3 treatment conditions are included in Table 2.1. Mean training loads and heart rate intensities are included in Figure 2.1.

Table 2.1. Subject characteristics (mean[±SD]) (includes group scores and total scores)

Groups	Age (y)	Height (cm)	Mass (kg)
Ice baths (n=7)	19.3 (±0.6)	185 (±0.1)	84.6 (±11.2)
CWT (n=8)	19.0 (±0.6)	179 (±0.1)	93.1 (±12.5)
Control group (n=11)	19.2 (±1.1)	178 (±0.1)	77.4 (±9.1)
Total (n=26)	19.2 (±0.8)	180 (±0.1)	84.2 (±12.4)

Analysis of covariance test between groups for mean base tests and mean retests did not identify a significant difference vs. treatment for mean scores for the phosphate decrement test or 300m test. The 300m test indicated that there was a change from the pre-test to post-test stage for all groups combined and that there was no interaction effect. The statistical results are displayed in Table 2.2.

Table 2.2. Mixed model ANCOVA solution comparing treatment and pre/post-test interactions*†

Test	Mean square	df	F	Sig
Phosphate Dec				
Pre and post-test	4.26	1	0.78	0.39
Phosphate dec*Treatment	7.34	2	1.34	0.28[T]
300 m				
Pre and post-test	84.79	1	10.05	0.00
300 m*Treatment	6.34	2	0.75	0.48[T]

ANCOVA = analysis of covariance.
†No treatment interactions were identified from pre-tests to post-tests

The pre-test to post-test scores for all treatment conditions are displayed in Table 2.3, which indicates some of the trends in treatment effects.

Table 2.3. Means and SD's for the 3 treatment conditions with pre-test and post-test scores for 300 m and phosphate decrement (Phos Dec) tests

Treatment condition	Pre-test score (±SD)		Post-test score (±SD)	
Ice bath	300m	72.0s (±5.9)	300m	70.3s (±3.1)
	Phos dec	5.7m (±1.8)	Phos dec	7.7m (±2.1)
Contrast bath	300m	74.4s (±64.7)	300m	72.1s (±4.3)
	Phos dec	5.1m (±2.2)	Phos dec	5.7m (±1.9)
Control	300m	71.5s (±7.5)	300m	69.8s (±2.8)
	Phos dec	5.6m (±2.3)	Phos dec	6.2m (±2.7)

No significant difference was identified between scores across treatments

Effect size calculations within the confidence interval of 95% identified a medium to large effect size (d = 0.72) for 300m tests for CWT. A less than small effect size was identified for ice baths (d = 0.17) in the 300m test. Effect size calculations within the confidence interval of 95% identified a small effect size (d = 0.18) for phosphate decrement scores for CWT. A negative medium effect size was identified for ice baths (d = 0.62) for phosphate decrement scores.

Further effect size analysis to compare treatment against treatment identified a greater than large effect size (d = 0.99) of contrast against ice treatment in the phosphate decrement scores. A medium effect size (d = 0.53) for contrast against ice treatment in the 300-m test was also identified.

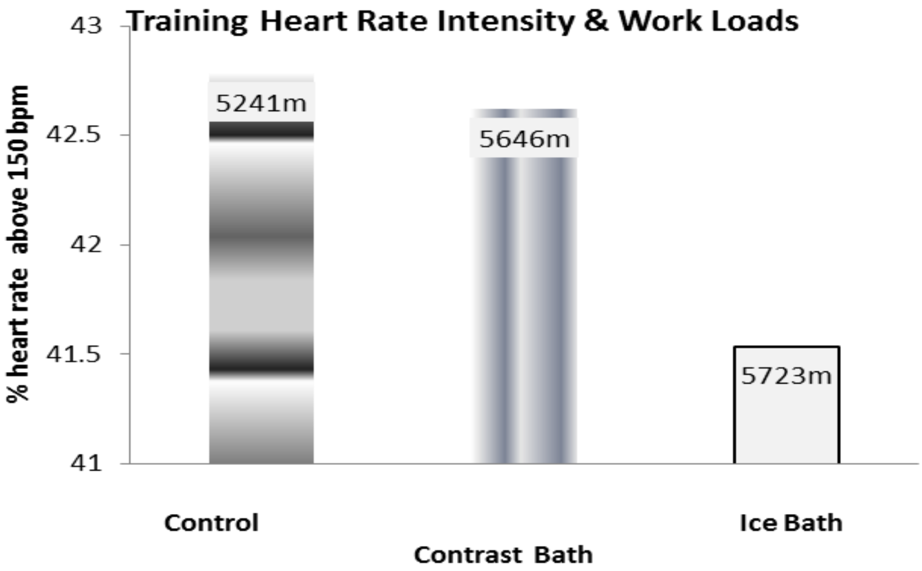

Figure 2.1 Training heart rate intensity and workloads

Columns represent mean scores for percentage of heart rate above 150 bpm during training sessions across the study. Figures in columns represent mean distance covered during training sessions across the study. No significant difference was identified between groups

From subjective reports, 5 of 7 participants from the ice bath group reported feeling more tight 2 days after games than when previously adopting no recovery strategies. All 7 participants in the ice bath group had a negative feeling toward the baths. Participants from the contrast group reported having a more positive feeling after the treatment: a feeling of being more relaxed and finding it easier to rest and sleep, postgame and post-training.

2.1.5 Discussion

Statistical analysis of baseline testing indicated there was no difference between groups, allowing assumptions that groups had similar anaerobic glycolytic fitness levels across tests at the start of the RCT. It is important to emphasize that no significant treatment or interaction effects were identified with mixed ANOVA repeated-measures analysis or with ANCOVA.

Results from effect size calculations identified a trend toward the use of CWT in recovery from team sports, when anaerobic performance is measured. Relating effect sizes through percentile standings (Becker, 2008) may indicate important sporting performance outcomes.

In team sports with well-trained and elite athletes, during a long competitive season, maintaining competitive performance and fitness is critical to success. In an environment where coaches and athletes are looking for every advantage over opponents, percentile ranking may partially support the strategies that are in use.

Medium to large effect sizes in the 300m test for CWT indicate participants undergoing contrast treatment had mean scores at approximately the 76th percentile of mean scores for the control group. The trivial effect size in the 300m test between ice bath and control group indicates little difference in outcomes between ice treatment and passive recovery.

Evaluation of ice baths against both the contrast bath group and the control group brings into question the use of ice baths in recovery. Effect size comparisons between the 2 treatment groups may indicate CWT may be of more benefit when compared to ice baths. Medium effect size indicates the contrast bath group would be at the 69th percentile of the ice bath in the 300m tests. A large effect occurred in the phosphate decrement score for CWT over ice baths, which had participants at the 82nd percentile of ice baths.

A negative medium effect with ice baths compared with control group questions ice baths for recovery, when tests relying on the phosphate and anaerobic glycolysis energy system are measured.

In team sport, recovery from both training and competition is essential for the maintenance of performance across the season (Kellmann, 2002). During competition, turnaround times between training and games can be short. Recovery strategies that are employed need to provide benefits in physiological recovery. Additionally, in professional sport, there is a greater demand on athletes' time, necessitating the requirement of any training and recovery protocol implemented to be a proven benefit to the athlete.

It may be argued that employing protocols without significant support may merely add to athletes' restricted time burdens without providing benefit. Evidence has already established the importance of athletes recovering mentally from sport and its demands (Kellmann, 2002). Coaching staff need to assess whether the differences between CWT and passive recovery will be of a sufficient benefit. If athletes are showing signs of mental fatigue, any physiological advantage supported by effect sizes may be negated by additional time burden presented by scheduled recovery sessions.

With long seasons in professional competitions, players may develop psychological stresses leading to poorer performances (Kellmann, 2002). Extending game days or training sessions with recovery treatments that do not provide a significant difference may add to mental stressors, further diminishing performance.

Although 5 minute ice baths appear to have a wide use in sport, results of this study would indicate that their use is not warranted. Results may indicate that ice baths, of 5 minutes, have a detrimental effect on players' performance recovering from competition and training. The detrimental effect may be found when players are required to perform short, intense activities that rely on anaerobic energy systems.

The reason supporting 5 minutes for ice baths is unclear, because published research on time frames of 5 minute appears scarce. In addition, Arnheim and

Prentice, (1993) state that 15 minutes of immersion is required for vasoconstriction to occur. It may be that 5 minutes is insufficient time to lower tissue temperature enough to deliver benefits associated with cryotherapy as mentioned previously.

Reported purposes of CWT are enhancing circulation via aiding venous return through vasoconstriction and vasodilatation. Mechanisms aiding recovery may be via circulatory responses, including removal of metabolic wastes, reduction in oedema and aiding delivery of oxygen to muscles.

2.1.6 Practical applications

In the sport of rugby, trends toward CWT benefiting recovery have been identified. The continued use of 5-minute ice baths should be reconsidered based on the findings of this research because there may be a detrimental effect, in particular when high intermittent, repeat performance, commonly found in team field sports, is required. In addition, coaches and trainers need to consider the benefit of recovery protocols established and examine if physiological benefits achieved justify the additional time burden placed on players who may have limited free time away from sport and consequences toward mental fatigue.

2.1.7 References

Arnheim, D. D., & Prentice, W. E. (Eds.). (1993). *Therapeutic Modalities. In: Principles of Athletic Training.* Baltimore, MD: Mosby

Atkinson, G. (2007). What's behind the numbers? important decisions in judging practical significance. *Sportscience, 11*, 12-15.

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International journal of sports physiology & performance, 1*(1), 50-57.

Becker, L. (2008). Effect size (ES). Retrieved August 26, 2008, from http://web.uccs.edu/lbecker/Psy590/es.htm.

Burke, D. G., Holt, L. E., Rasmussen, R., Mackinnon, N. C., Vossen, J. F., & Pelhame, T. W. (2001). Effects of hot or cold water immersion and modified proprioceptive neuromuscular facilitation flexibility exer-cise on hamstring length. *Journal of Athletic Training, 36*, 16-19.

Dadebo, B., White, J., & George, K. P. (2004). A survey of flexibility training protocols and hamstring strains in professional football clubs in England. *British Journal of Sports Medicine, 38*, 388-394.

Dawson, B., Gow, S., Modra, S., Bishop, D., & Stewart, G. (2005). Effects of immediate post-game recovery procedures on muscle soreness, power and flexiblity [sic flexibility] levels over the next 48 hours. *Journal of Science & Medicine in Sport, 8*(2), 210-221.

Duthie, G., Pyne, D., & Hooper, S. (2003). Applied physiology and game analysis of rugby union. *Sports Medicine, 33*, 973-989.

French, D. N., Thompson, K. G., Garland, S. W., Barnes, C. A., Portas, M. D., Hood, P. E., et al. (2008). The Effects of Contrast Bathing and Compression Therapy on Muscular Performance. *Medicine & Science in Sports & Exercise, 40*(7), 1297-1306.

Gill, N. D., Beaven, C. M., & Cook, C. (2006). Effectiveness of post-match recovery strategies in rugby players. *British Journal of Sports Medicine, 40*(3), 260-263.

Higgins, T. R., & Heazlewood, T. (2008). *Evaluation of Contrast Baths and Ice Baths for Recovery in U/20 Rugby Union.* Paper presented at the ASICS Conference of Science and Medicine in Sport, Hamilton Island, Australia.

Hubbard, T. J., Aronson, S. L., & Denegar, C. R. (2004). Does cryotherapy hasten return to participation? A systematic review. *Journal of Athletic Training, 39*, 88-94.

Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science & Medicine in Sport, 12*(3), 417-421.

Kellmann, M. (Ed.). (2002). *Current status and directions of recovery research. In enhancing recovery: Preventing underperformance in athletes*. Champaign, IL: Human Kinetics.

Montgomery, P. G., Pyne, D. B., Hopkins, W. G., Dorman, J. C., Cook, K., & Minahan, C. L. (2008). The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *Journal of Sports Sciences, 26*(11), 1135-1145.

Patterson, S. M., Udermann, B. E., Doberstein, S. T., & Reineke, D. M. (2008). The effects of cold whirlpool on power, speed, agility, and range of motion. *Journal of Sports Science and Medicine, 7*, 387-394.

Peiffer, J. J., Abbiss, C. R., Watson, G., Nosaka, K., & Laursen, P. B. (2010). Effect of cold water immersion on repeated 1-km cycling performance in the heat. *Journal of Science & Medicine in Sport, 13*, 112-116.

Reilly, T., & Ekblom, B. (2005). The use of recovery methods post-exercise. *Journal of sports sciences, 23*(6), 619-627.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal of Sports Sciences, 27*(6), 565-573.

Sellwood, K. L., Brukner, P., Williams, D., Nicol, A., & Hinman, R. (2007). Ice-water immersion and delayed-onset muscle soreness: A randomised controlled trial. *British Journal of Sports Medicine, 41*, 392-397.

Tessitore, A., Meusen, R., Demarie, S., Ugolotti, G., & Capranica, L. (2004). Effects of different recovery methods following soccer training. *Journal of Sports Science, 22*, 562-563.

Vaile, J., Gill, N., & Blazevich, A. J. (2007). The effect of contrast water therapy on symptons of delayed onset muscle soreness. *Journal of Strength & Conditioning Research, 21*(3), 697-702.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2007). Effect of hydrotherapy on recovery from fatigue. *International Journal of Sports Physiology and Performance, 29*, 539-544.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008). Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. *Journal of Sports Sciences, 26*(5), 431-440.

Chapter 3

3.1 A Critical review of: A random control trial of contrast baths and ice baths for recovery during competition in U/20 rugby union

3.1.1 Limitations of the study

As previously discussed (Introduction [1.1]; Literature Review [1.2]) modern Rugby Union consist of a number of physiological, psychological and mechanical stressors which are generally of a short duration (less than 10 seconds). These stressors include running activities, consisting of rapid changes of direction, acceleration, deceleration, body contact/collision and ground contact events, as well as high intensity wrestling type activities which include rucks, mauls and scrums. However, although each game of Rugby Union consists of a number of such events, each event, of each game, is independent from all previous events. Furthermore, intensities and workloads across positions and between games will vary due to a number of factors. These factors can include environmental and playing conditions, competitive levels of different teams, varying tactics and styles of play, between teams and the motivational investment players have associated with different games. All of these factors will impact on the level of fatigue and subsequent recovery requirements of players. In an attempt to nullify the impact these factors may have in a study evaluating only one game, the study was held across four weeks. Despite this, individual player workloads and subsequent level of fatigue was not controlled. Therefore, the findings of the study and the practical applications associated with the findings need to be viewed with caution.

As with the variation between games and positions, there were also a number of variations between individual participants, which may have impacted on results. Participants, although recruited from the same club, were recruited from three teams who trained separately from each other. It is possible, that although each team followed the same training program and structure, intensity of training may have varied across the three teams. It is possible that players from each team may have experienced differing levels of fatigue. Additionally, each team only trained twice a week, in comparison, professional teams have multiple sessions across the day and across a training week. With only two training sessions and one game across the weekly cycle, the time between each session may have afforded participants with sufficient time to adequately recover, irrespective of recovery protocol.

As with limitations with variations of participant workload and variations in intensities, limitation exists in the methodology of the study. Although the two tests that were applied have support within the literature, they do not provide sufficient information to allow for identification of mechanisms responsible for fatigue and recovery. The study was unable to identify if peripheral or central fatigue was the underlying mechanism. Furthermore, the increasing use of perceptual measures of fatigue and recovery may have provided an insight into the participants' subjective feelings. Although generalised attitudes were discussed about participants feeling of recovery, neither a supported qualitative or quantitative tools was employed, measuring perceptions of fatigue and muscle soreness and participant's subsequent readiness for the next rugby specific event, either game or training.

Finally, the variation between the lengths of each recovery protocol may have implications towards conclusions from findings. The CWI recovery protocol consisted of only five minutes of immersion, in comparison CWT consisted of a total of 14 mins immersion. As the paper suggested, five minutes of immersion may be insufficient, as such a true evaluation between the beneficial effects of either CWI and CWT for recovery requires similar times of recovery.

3.1.2 Thesis research direction

3.1.2.1 Replicating the demands of the game of Rugby Union

When examining the impact interventions have on athletes, traditionally, standard performing testing protocols (10m and 40m, CMJ, agility, aerobic measures, anaerobic tests) have been applied. Although results from these tests are beneficial, they are limited in their capacity to reflect performance across an entire game in comparison to measuring actual game performance. Within competitive team sport, match demands can vary dramatically depending on a number of differing factors

(Kelly & Coutts, 2007). These include the quality of the opposition, days between games, match locations, and environmental factors including rain, wind, and temperature (Kelly & Coutts, 2007). Due to the variance in match demands, measuring and comparing the performance of players between games can be problematic, particularly when evaluating any treatment and its effect on players' game performance.

Initially, the vast majority of research into recovery modalities had made use of adopted exercise protocols in a laboratory setting. Although, the protocols in laboratory tests elicit either EIMD or biochemical responses associated with fatigue, the relevance of their findings to actual field sport activities has been questioned (Hamlin, Hinckson, Wood, & Hopkins, 2008; Higgins, Naughton, & Burgess, 2009; Stuart, Hopkins, Cook, & Cairns, 2005). More importantly, it has been suggested that exercise stressors should resemble actual sporting activities when evaluating subsequent recovery intervention effects on sporting performances (Halson, 2011; Singh, Guelfi, Landers, Dawson, & Bishop, 2011). Ideally, the use of actual sporting performance in research provides the most valid and precise basis for identifying a cause and effect relationship with an intervention. However, in team field sport, multiple variables are evident. Primarily the work load of individuals can vary greatly from game to game based on competition, environment, game tactics, motivational factors etc. Furthermore, in sports such as Rugby Union, workloads vary greatly between positions. With so many variables at play in a team field sport, applying a sporting simulation, which includes movement patterns associated with the sport and controlling, monitoring and ensuring equal workloads between subjects, offers the most desirable basis for comparison.

Although, a simulation may provide a more accurate, common workload from which to examine recovery than laboratory testing protocols, an understanding of the limitations of a simulated game is still required when relating results to actual sporting environments. The major limitation with the simulated game used in this research is the absence of direct physical impacts/collisions that are common in Rugby Union. As discussed previously, both Takarada (2003) and Smart et al.

(2009) argued that the high impact in tackles and collisions from Rugby Union events was the mechanism responsible for increased muscle trauma. Takarada (2003) suggested that the increase in damage was associated with direct impact events and associated the direct impact with the law of conservation of energy. The law of conservation of energy refers to the total momentum being redistributed between players at impact. Smart et al. (2008) confirmed the position of Takarada (2003) by explaining that initial impact trauma is responsible for the damage. Their conclusions were based on earlier research by Zuliani and Franchini (1985) who found higher levels of CK after boxing in comparison to shadow boxing, which had no contact (Zuliani et al., 1985). It was concluded that blunt force trauma from receiving punches was responsible for increased CK and associated muscle damage. However, in Rugby Union events that involve both impact and eccentric contractions, is the impact the predominant force involved, or do both components need to be considered?

In Rugby Union impact is often followed immediately with a contest as players from both teams compete for the ball and field position. Although, there may be a redistribution of momentum, it is seldom instantaneous. In most cases, one party, either the attacker or defender, has greater momentum. After the initial impact, resistive forces would generally be applied as players with the lesser momentum try to halt the momentum of the opposing players. In such cases, we may hypothesise that the resistive or braking forces would consist of high levels of eccentric muscle contractions that add to the muscle damage. The forces at the initial impact would be large as stated by Smart et al. (2008). However, the time under tension during the resistive force would also add to the physical strain on the muscles, thereby offering an additional mechanism for the higher levels of muscular damage and increased CK levels. Although contact involvement would lead to muscle damage, to assign the increases in CK solely to the impact phase without considering the additional eccentric muscle actions involved, leads to an over-simplification of the forces involved in the contact areas of Rugby Union.

Considering that both impact/collisions and eccentric contractions are associated with resisting forces in Rugby Union contact events, it would be a limiting factor not to include tackle or contact events in a simulated game of Rugby Union. However, including impact events in a simulated game for research is problematic. Initially, an ethical issue may arise from directly causing impact trauma in a research study. To alleviate ethical concerns, applying simulated tackling with the use of tackle bags and bump pads may allow for a closer replication of actual sporting performance (Singh, et al., 2011). However, the control of impact forces in a simulated tackle, as with actual sporting competition, becomes problematic as different impact forces will occur with each tackle. These forces will depend on the momentum of players involved and the number of defenders and attackers involved. It will also vary based on the direction of contact impacts. Did the impact occur head on or side on? Did the contact include either defenders or attackers coming into contact with the ground? Was there a period of extended time after the initial impact where defenders and attackers underwent a contest? Essentially the question is can researchers reliably control the forces involved in each contact event whether in a competitive game of Rugby Union or in a simulated game?

Singh et al. (2011) reported in their study, that they were unable to confirm the true forces involved in the simulated tackles (Singh, et al., 2011). However, in their investigation of contact and non-contact events in simulated sporting performance, Singh et al. (2011) found little difference between simulated contact and non-contact in markers of damage. Although indications were that the simulated contact was not as high as direct body-to-body collisions in actual sporting performance, they concluded that using simulated team sport comprising either non-contact or simulated contact appeared reliable for assessing sport performance.

3.1.2.2 The simulated game of Rugby Union

The simulated game of Rugby Union used in this research has been previously used and accepted as reliable and valid, when evaluating changes in game performance (Hamlin, et al., 2008; Stuart, et al., 2005). As in this research, both studies evaluated the effect interventions had on performances associated with rugby. With Stuart et al. (2005) the intervention was evaluating the effect of caffeine and with Hamlin et al. (2008) it was the effect of altitude training. In both studies, changes between performances across two simulated games of Rugby Union were used to identify if the interventions were beneficial, unclear or not beneficial with regard to Rugby Union performance.

Despite its previous use, questions may still arise from the use of a simulated game to evaluate recovery from Rugby Union. Can a simulated game without direct contact/collisions accurately predict the beneficial effect of any recovery intervention? Predominately, most contact events in Rugby Union will occur from either front on or side on (Takarada, 2003). With this in mind, it is most unlikely that damage to hip extensors, subsequently impairing performance, would be a result of direct impact or collisions. The damage to the hip extensors is more likely to be a result of eccentric muscle actions generated from accelerating and decelerating as reported by Takarada (2003). Therefore, as the hip extensors have been previously identified as the major muscles responsible for game related events in rugby (Bennell, et al., 1998; Gabbett, 2005), a simulation that replicates these game related events, has high face validity when evaluating an intervention and subsequent Rugby Union performance. However, any interpretation will be limited by the absence of impact/collision trauma. Any identified effect, positive or negative, cannot include how damage brought about by impact trauma may influence a player's future performance, irrespective of recovery of the hip extensors. It should be noted that in this research, during the training week, contact and collisions occurred. Exact numbers and forces involved in tackles cannot be controlled, similar to limitations in using actual competition games.

The simulated Rugby Union game was designed based on research into the physiological and kinematic data of elite under-19 Rugby Union players (Deutsch, Maw, Jenkins, & Reaburn, 1998) and consisted of 11 stations set up as a circuit (Stuart et al., 2005). Stations included straight line sprints, defensive sprints, attacking sprints, power output in a rugby specific action (hit and drive), tackling and passing skills. In addition, the circuit included three rest stations. Participants performed the task at each station, then immediately progressed to the next station.

3.1.2.3 Perceptual measures of fatigue and recovery

The perceptions of fatigue and recovery associated with an athletes' readiness to perform has been monitored with session RPE. Fatigue is generally thought of as a physiological phenomenon and defined as the inability of muscle to produce force (Williams, 1997), as a result of either biochemical disturbances (Magaudda, et al., 2004) and or mechanical disturbances (Falvo & Bloomer, 2006). However, it has been proposed that the development of fatigue is not an absolute but a more relative event, with the underlying mechanism behind the sensation of fatigue driven by neural integrative processes (St Clair Gibson & Noakes, 2004). This concept of a neural integrative process linked with a physiological cause of fatigue, has subsequently led to fatigue being classified as either ''peripheral'' or ''central'' in origin (St Clair Gibson & Noakes, 2004).

Peripheral muscle fatigue is generally viewed, as a result of metabolic overload and/or insufficient availability of key metabolites that enable contracting muscles to meet increased energy demand (Baird, et al., 2012). Central fatigue is viewed as a reduction in neural drive to the muscle resulting in a decline in force production or tension development, independent of changes in skeletal muscle contractility (St Clair Gibson & Noakes, 2004). The central fatigue model posits that the reduction in power output during prolonged exercise is caused by altered efferent commands from the brain (St Clair Gibson & Noakes, 2004). St Clair Gibson & Noakes (2004) stated that the sensation of fatigue is simply the sensory representation of the underlying neural integrative processes, rather than merely biochemical or mechanical disturbances leading to reduced skeletal muscle force output. Therefore, while examining the relationship between fatigue and recovery, it is important to assess the sensation of fatigue. If fatigue results in reduced motor unit recruitment caused by alterations in efferent neural commands, then evaluating the sensation of fatigue through a valid and reliable tool becomes a necessary part of a thorough investigation into fatigue and recovery relationship. In this end, a number of psychometric tools evaluating both fatigue and muscle soreness have been developed and used in studies to evaluate participants. Rating of perceived exertion, visual analogue scale, total quality recovery, and category ratio scale have all being routinely used in research (Jones, Howatson, Russell, & French, 2013; Montgomery, Pyne, Hopkins, et al., 2008; Rowsell, et al., 2009; Rupp, et al., 2012).

Although, as stated above, subjective measures of fatigue have widespread use in research on recovery from fatigue, when evaluating perceptions of exertion and/or fatigue it is important to have a valid measure of player's perception of the (internal) training load (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). However the monitoring of players' perceptions of exertion during training in team sport can be difficult. Multiple types of training and exercise are routinely in use in team sport. In particular, loads associated with high-intensity training, have proven to be difficult to quantify (Foster, et al., 2001). With this in mind, the session rating of perceived exertion scale (session RPE) has been shown to be a valid and reliable measure of a player's perception of exertion whilst training in sport settings, correlating well with already established and valid tools including the training impulse method (TRIMP; $r = 0.76$) and the summated-heart-rate-zone (SHRZ; $r = 0.84$) (Borresen & Lambert, 2008; Foster, et al., 2001; Wallace, Slattery, & Coutts, 2008).

The session RPE scale is based on Borg's category ratio (CR-10), which is considered a global indicator of exercise intensity (Borg, Hassmén, & Lagerström, 1987). The CR-10 translates the athlete's perception of exertion into a numerical score between 0 and 10 (Borresen & Lambert, 2008). When using the CR-10 within the session RPE, the athlete's global impression of the intensity of the workout is measured (Borresen & Lambert, 2008). The goal of the session RPE is to encourage the athlete to view the training session globally and to simplify the myriad of exercise intensity cues during an entire session (Sweet, Foster, McGuigan, & Brice, 2004). The session RPE quantifies a player's internal perception of exertion whilst training by multiplying the whole training session RPE using the CR-10 by its duration. The player's perception of exertion whilst training was initially defined as arbitrary units

(AU) = Session RPE × minutes of training session (Foster, Daines, Hector, Snyder, & Welsh, 1996) and has subsequently been supported (Wallace, et al., 2008).

The session RPE is a superior measurement specifically when athletes undergo interval training sessions with varying work period durations. Previously, it has been identified that athletes will adjust their intensity to the extent that both blood lactate and perceived exertion responses are essentially identical (Seiler & Sjursen, 2004). Although interval sessions can be increased (time/duration/workload) to extend the capacity of the athlete, the athlete self-selects his/her intensity that in turn generates similar physiological responses when measured by either the RPE and summated heart rate methods (Seiler & Sjursen, 2004). In contrast to RPE and summated heart rate methods, the session RPE has been shown to more accurately reflect variations within interval training, supporting the use of session RPE as a valid method in very high intensity exercise (Foster, et al., 2001) and across a wide variety of exercises (Day, McGuigan, Brice, & Foster, 2004; Egan, Winchester, Foster, & McGuigan, 2006; Foster, et al., 2001; Impellizzeri, et al., 2004).

3.1.3 References

Baird, M. F., Graham, S. M., Baker, J. S., & Bickerstaff, G. F. (2012). Creatine-Kinase- and exercise-related muscle damage implications for muscle performance and recovery. *Journal of Nutrition and Metabolism, 2012*, Article ID 960363.

Bennell, K., Wajswelner, H., Lew, P., Schall-Riaucour, A., Leslie, S., Plant, D., et al. (1998). Isokinetic strength testing does not predict hamstring injury in Australian Rules footballers. *British Journal of Sports Medicine, 32*, 309-314.

Borg, G., Hassmén, P., & Lagerström, M. (1987). Perceived exertion related to heart rate and blood lactate during arm and leg exercise. *European Journal of Applied Physiology and Occupational Physiology, 56*(6), 679-685.

Borresen, J., & Lambert, M. I. (2008). Quantifying training load: a comparison of subjective and objective methods. *International journal of sports physiology & performance, 3*(1), 16-30.

Day, M. L., McGuigan, M. R., Brice, G., & Foster, C. (2004). Monitoring exercise intensity during resistance training using the session RPE scale. *18*(2), 353-358.

Deutsch, M. U., Maw, G. J., Jenkins, D., & Reaburn, P. (1998). Heart rate, blood lactate and kinematic data of elite colts (under-19) rugby union players during competition *Journal of Sports Science, 16*(6), 561-570.

Egan, A. D., Winchester, J. B., Foster, C., & McGuigan, M. R. (2006). Using session RPE to monitor diff erent methods of resistance exercise *Journal of Sports Science and Medicine & Science in Sports & Exercise, 5*, 289-295.

Falvo, M. J., & Bloomer, R. J. (2006). Review of exercise-induced muscle injury: Relevance for athletic populations. *Research in Sports Medicine, 14*, 65-82.

Foster, C., Daines, E., Hector, L., Snyder, A. C., & Welsh, R. (1996). Athletic performance in relation to training load. *Wis. Med. J, 95*, 370-374.

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., et al. (2001). A new approach to monitoring exercise training. *Journal of Strength & Conditioning Research, 15*(1), 109-115.

Gabbett, T. J. (2005). Changes in physiological and anthropometric characteristics of rugby league players during a competitive season. *Journal of Strength and Conditioning Research, 19*(2), 400-408.

Halson, S. L. (2011). Does the time frame between exercise influence the effectiveness of hydrotherapy for recovery?. [Review]. *International journal of sports physiology & performance, 6*(2), 147-159.

Hamlin, M. J., Hinckson, E. A., Wood, M. R., & Hopkins, W. G. (2008). Simulated rugby performance at 1550-m altitude following adaptation to intermittent normobaric hypoxia. *Journal of Science and Medicine in Sport, 11*, 593-599.

Higgins, T. R., Naughton, G. A., & Burgess, D. (2009). Effects of wearing compression garments on physiological and performance measures in a simulated game-specific circuit for netball. *Journal of Science and Medicine in Sport, 12*(1), 223-226.

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine & Science in Sports & Exercise, 36*(6), 1042-1047.

Jones, T. W., Howatson, G., Russell, M., & French, D. N. (2013). Performance and neuromuscular adaptations following differing ratios of concurrent strength and endurance training. [Randomized Controlled Trial]. *Journal of Strength & Conditioning Research, 27*(12), 3342-3351.

Kelly, V. G., & Coutts, A. J. (2007). Planning and monitoring training loads during the competition phase in team sports. *Strength and Conditioning Journal, 29*(4), 32-37.

Magaudda, L., Di Mauro, D., Trimarchi, F., & Anastasi, G. (2004). Effects of physical exercise on skeletal muscle fiber: ultrastructural and molecular aspects. *Basic Applied Myology, 14*, 17-21.

Montgomery, P. G., Pyne, D. B., Hopkins, W. G., Dorman, J. C., Cook, K., & Minahan, C. L. (2008). The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *Journal of Sports Sciences, 26*(11), 1135-1145.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal of Sports Sciences, 27*(6), 565-573.

Rupp, K. A., Selkow, N. M., Parente, W. R., Ingersoll, C. D., Weltman, A. L., & Saliba, S. A. (2012). The effect of cold water immersion on 48-hour

performance testing in collegiate soccer players. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins), 26*(8), 2043-2050.
Seiler, S., & Sjursen, J. E. (2004). Effect of work duration on physiological and rating scale of perceived exertion responses during self-paced interval training. *Scandinavian Journal of Medicine & Science in Sports, 14*, 318-325.
Singh, T. K. R., Guelfi, K. J., Landers, G., Dawson, B., & Bishop, D. (2011). A comparison of muscle damage, soreness and performance following a simulated contact and non-contact team sport activity. *Journal of Science and Medicine in Sport, 14*(5), 441-446.
Smart, D., Gill, N., Beaven, C., Cook, C., & Blazevich, A. (2008). The relationship between changes in interstitial creatine kinase and game-related impacts in rugby union. *British Journal of Sports Medicine, 42*(3), 198-201.
St Clair Gibson, A., & Noakes, T. D. (2004). Evidence of complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans. *British Journal of Sports Medicine, 38*, 797-806.
Stuart, G. R., Hopkins, W. G., Cook, C., & Cairns, S. P. (2005). Multiple effects of cafeine on simulated high-intensity team-sport performance. *Medicine & Science in Sports & Exercise, 37*(11), 1998-2005.
Sweet, T. W., Foster, C., McGuigan, M. R., & Brice, G. (2004). Quantitation of resistance training using the session rating of perceived exertion method. *Journal of Strength and Conditioning Research, 18*(4), 796-802.
Takarada, Y. (2003). Evaluation of muscle damage after a rugby match with special reference to tackle plays. *British Journal of Sports Medicine, 37*(5), 416-419.
Wallace, L. K., Slattery, K. M., & Coutts, A. J. (2008). The ecological validity and application of the session-RPE method for quantifying training loads in swimming. *Journal of Strength & Conditioning Research, 23*(1), 33-38.
Williams, J. H. (1997). Contractile apparatus and sarcoplasmic reticulum function: effects of fatigue, recovery, and elevated Ca2+. *Journal of Applied Physiology, 83*(2), 440-450.
Zuliani, U., Bonetti, A., Franchini, D., Serventi, G., Ugolotti, G., & Varacca, A. (1985). Effect of boxing on some metabolic indices of muscular contraction. *International Journal of Sports Medicine, 6*(4), 234-236.

Chapter 4

4.1 Acute response to hydrotherapy after a simulated game of Rugby

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4.1.1 Abstract

Higgins, T.R., Cameron, M.L., & Climstein, M. (2013). Acute response to hydrotherapy after a simulated game of rugby. *Journal of Strength and Conditioning Research*, 27(10), 281-2860. Despite lacking clear scientific evidence, hydrotherapies (water treatments) are accepted techniques to help team sport athletes recover from the physical effects of games. The purpose of this study was to assess the comparative effectiveness of cold water immersions (CWIs) and hot-and-cold (CWT) on athletes' recovery after a simulated game of Rugby Union. Twenty-four experienced, well-trained, male Rugby Union players were divided into 3 groups to receive recovery interventions: CWI for 1 group, CWT for a second group, and passive recovery for a third (control) group. Pre-game and post-game measurements included a countermovement jump (normalized as a ratio to body weight), a sit-and-stretch flexibility test (cm), thigh circumference (to detect swelling; cm), and participants' perception of delayed-onset muscular soreness (DOMS, 100mm visual analog scale). Statistical analysis included analysis of variance and the calculation of omnibus effect sizes for each group (partial eta squared) and the magnitudes of change within and between groups (Cohen's *d*). The participants in the contrast bath group reported statistically significantly greater measures of DOMS than participants in the control group did at 1 hour post-intervention ($p = 0.05$, control group: $d = 1.80$; contrast bath: $d = 4.75$), and participants in the CWI group did at 48 hours post-intervention ($p = 0.02$, CWI: $d = 1.17$; contrast bath: $d = 1.97$). These findings provide modest evidence that CWT is a less effective strategy for recovery from Rugby Union than are CWI or passive recovery. Specifically, 2 X 5-minute CWI is superior to both contrasts baths and passive recovery in alleviating DOMS after exercise-induced muscle damage. Our recommendation for Rugby Union players aiming to

attenuate the effects of DOMS post-games is to take 2 x 5-minute CWIs baths immediately after the game.

4.1.2 Introduction

Over the course of an Australian rugby season, rugby union team players are exposed to a cyclic pattern of training, competition, and recovery. The work load and intensity of a competitive rugby game induce high levels of fatigue, muscle damage, and soreness (Dadebo, et al., 2004; Gill, et al., 2006). Rugby Union players must then recover quickly to perform at optimal levels during subsequent training or competitive games (Reilly & Ekblom, 2005). Optimizing recovery is of great importance to rugby players and coaches (Dadebo, et al., 2004). It has been suggested that insufficient periods of recovery may lead to accumulated levels of player fatigue as a season progresses (Dadebo, et al., 2004). Despite widespread use, there is limited research into the benefits of hydrotherapy (water therapies) as a recovery strategy for muscle fatigue from the physical demands of Rugby Union (Bishop, et al., 2008; Reilly, Dowzer, & Cable, 2003; Reilly & Ekblom, 2005).

Muscle fatigue occurs when micro-trauma to muscle tissue compromises the capacity of skeletal muscle to generate force (Williams, 1997). The micro-trauma to muscle tissue associated with athletic performance in Rugby Union is referred to as exercise-induced muscle damage (EIMD) (Duthie, et al., 2003; Gill, et al., 2006; Suzuki, et al., 2004). Exercise-induced muscle damage may be attributed to a number of factors, including the disruption of the sarcolemma, fragmentation of the sarcoplasmic reticulum, lesions of the plasma membrane, cytoskeletal damage, or swollen mitochondria. Tissue inflammation, increases in capillary permeability, and increases in extracellular protein concentration have all been identified as results of micro-trauma to muscle tissue (Eston & Peters, 1999). To attenuate the effect of EIMD and enhance recovery, a number of hydrotherapy protocols have been implemented in Rugby Union.

Cryotherapy (e.g., the application of an ice pack or immersion in cold water) is an accepted strategy for treating acute traumatic injury to muscle tissue (Barnett, 2006) and is the most common method for reducing inflammation (e.g. pain, heat, redness, and swelling) and sports-related musculoskeletal injuries (Hubbard, et al., 2004). Over the past 20 years, strength and conditioning coaches have adopted various cryotherapy protocols to assist athletes recover from muscle damage associated with exercise, training, and competition (Barnett, 2006). Professional Rugby Union teams have universally adopted cryotherapy; it was reported as the most common recovery method used during the Australian Rugby Championship in 2007 (Higgins, et al., 2011).

Research into cryotherapy can be divided into 2 types: its role in recovery after athletic endeavours and its role in the treatment of injury. In the case of the former, the majority of research centres on untrained participants, focusing on their responses to cryotherapy during the acute post-exercise period (Coffey, Leveritt, & Gill, 2004; Dawson, et al., 2005; Eston & Peters, 1999; Howatson & Van Someren, 2008). There has been limited research on the beneficial effects of cryotherapy in the recovery of well-trained, uninjured participants from team sports (Bishop, et al., 2008; Reilly, et al., 2003; Reilly & Ekblom, 2005). This study explores that gap.

Research into the beneficial effects of cryotherapy is equivocal or conflicted (Gill, et al., 2006; Heyman, De Geus, Mertens, & Meeusen, 2009; Hubbard, et al., 2004; Jakeman, Macrae, & Eston, 2009). Previous studies have shown that cold water immersion (CWI) has no beneficial effect on swelling, isometric strength, or functional tests after exercise on eccentric exercise machines (Jakeman, et al., 2009; Sellwood, et al., 2007) or in team sport performance (Dawson, et al., 2005; Rowsell, et al., 2009). Several researchers report that CWI significantly increases the severity of the participants' muscle pain, measured 24 hours after an eccentric exercise protocol (Gill, et al., 2006; Sellwood, et al., 2007; Vaile, Halson, et al., 2007). Ingram et al. (2009), however, report that two 5-minute CWIs were superior to contrast water immersion or no treatment whatsoever (Ingram, et al., 2009). There were significantly lower scores ($p<0.05$) for measures of muscle soreness after participation in team sports (Ingram, et al., 2009).

Vaile et al. (2007) compared contrast water therapy to passive recovery in 2 groups of 20 participants, reporting that contrast therapy was superior to passive recovery in restoring strength and power (Vaile, Gill, et al., 2007). In addition, they report that contrast water therapy attenuated the negative effects of delayed-onset muscle soreness (DOMS) (Vaile, Gill, et al., 2007). However, details on how DOMS was measured were absent. Furthermore, reduced thigh circumferences were significantly different between groups ($p<0.05$; 90–166 cm^3 95% confidence interval), associating a reduction in thigh volume with a reduction in DOMS. This reported link between DOMS and thigh volume, without a measurement for DOMS, is questionable.

In contrast, Ingram et al. (2009) report that contrast therapy was ineffective in enhancing recovery after participating in team sports. Consistent with those findings, French et al. (2008) found there was little evidence to support the benefit of CWT after EIMD, as opposed to passive recovery (French, et al., 2008). However, they report that, based on the large magnitude of the effects, certain physiological patterns after CWT warrant further investigation.

The aim of this study is to evaluate the benefits of CWI vs. CWT in assisting well-trained rugby athletes to recover during the initial 48 hours after playing in a simulated game of Rugby Union. We hypothesized that both CWI and CWT would be beneficial to the rugby athletes’ recoveries as compared with that of the control group (passive).

4.1.3 Methods

4.1.3.1 Experimental approach to the problem

Despite the widespread use of CWI as a post-match protocol in rugby, there is relatively little evidence supporting its use. The null hypothesis for this study states that neither CWI nor CWT will have a significant effect on recovery. After the use of these recovery methods, and passive recovery, the athletes participated in muscle pain measures, hamstring flexibility, swelling, and power performance. The resulting between-group study examined the effectiveness of the 3 different recovery protocols in preventing the larger concept of fatigue.

4.1.3.2 Subjects

The sample for this study consisted of well-trained male participants (n = 24) from an under-20 Rugby Union team. The average age was 19.5±0.8 years, body mass was 82.38±11.1kg, and height was 179±6cm. The study was conducted after 26 weeks of training, which included 10 weeks of preseason training (5.5 hours, 3 sessions weekly), followed by 16 weeks of the scheduled 22-week competition (6.5 hours, 3 sessions weekly).

Preseason training included 2 weekly training sessions, Saturday beach sessions (weeks 1–6), and trial games (weeks 7–9). Training sessions consisted of a 15-minute warm-up followed by 40 minutes (weeks 1–6) and 20 minutes (weeks 7–10) of conditioning. Conditioning focused on speed and acceleration running drills, contact drills, and small-sided games. Work-to-rest ratio ranged from 1: 2–3 (weeks 1–6) to 1:1 and 2:1 (weeks 7–10).

After the conditioning phase, the focus of the workouts shifted to rugby skill sets. Intensity of the conditioning elements ranged from 75% of heart rate maximum (HRmax) to 95% HRmax. Skill set drill intensity ranged from 50% HRmax to 70% HRmax. Beach sessions were structured around conditioning elements only. Each session commenced with a 15-minute warm-up followed by 70 minutes of conditioning. The conditioning included speed and agility drills, wrestling drills, small-sided games, and team-based relay shuttles. Intensity of the beach sessions ranged between 70% HRmax and 90% HRmax with a work-to-rest ratio of 1:3.

After 6 weeks, the beach training sessions were replaced with trial games for 3 weeks. The last Saturday before the competition commenced was a scheduled rest day to mark the end of preseason training. Trial games were played under standard laws of the game. However, the first 2 trials were played with 20 minute periods, not the 30 minute periods of standard rugby games. The players rotated throughout the day, with most players competing in three 20 minute periods. The third trial was played under standard laws with 30 minute periods. The players rotated throughout the day, with the majority of players competing in two 30 minute periods.

During the competition phase, 2 training sessions were conducted during the week. Training sessions included a 10 minute warm-up followed by a conditioning period of between 10 and 20 minutes. The activities of conditioning sessions varied between sprint work and small-sided games. Intensity of conditioning elements ranged between 85% HRmax and 100% HRmax, with a work-to-rest ratio of 1–3:1. The remainder of the training sessions was structured around skills, Rugby Union units, team play, and semi-opposed runs. Intensity ranged from 50% HRmax to 85% HRmax. The distance covered in training throughout the preseason ranged from 6,000 to 7,200m and throughout the competition phase of the season from 6,000 to 6,500m.

The study was conducted over 3 consecutive days during the team's regularly scheduled training sessions at the team's scheduled training time, 18:00 to 20:00 hours. The subjects had no history of recent musculoskeletal injury and were free of illness during the testing period. Each participant signed an informed consent form before taking part in the study, which was approved by The Australian Catholic University's Human Research Ethics Committee, before commencement (N200708-24). We excluded from our participant pool players who were involved in labour-intensive jobs, and those who had either been injured or suffered an illness before or during the study period.

4.1.3.3 Research Design

To familiarize the participants with the evaluation techniques, the players conducted trial runs through the circuit on 4 occasions during the 2 weeks preceding the study. The first trial included a verbal explanation of each station followed by a walk-through. The participants then commenced real-time run-throughs at each station at their own pace. Trained researchers gave verbal directions to each participant as needed (Figure 4.1).

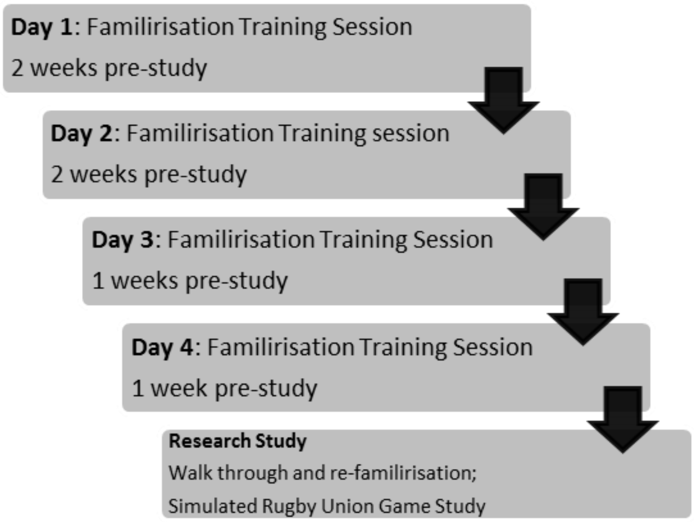

Figure 4.1 Research methodology design

Throughout the study, each station was manned by 2 researchers familiar with each station who assisted with data collection. The researchers were responsible for operating timing gates and the jump mat, and for recording scores on the sprint and passing tasks.

Immediately after a participant completed the simulated game of Rugby Union, the researchers took capillary lactate samples and downloaded HR data using Polar HR software. The participants then undertook 1 of 3 intervention protocols: CWI, CWT, or passive recovery (control). Random assignment had previously been organized through blind allocation, and the participants performed only one of the recovery methods throughout the study.

4.1.3.4 Measures

4.1.3.4.1 Hamstring Flexibility

Physical testing began with the sit-and-reach test (Montgomery, Pyne, Hopkins, et al., 2008). The participants took off their shoes and sat on the floor with their legs straight and feet against the near side of the Sit-n-Reach box. After placing their hands flat together, one on top of the other, the participants bent forward without bending their knees and pushed a marker along the bottom of the Sit-n-Reach box as far as possible. The distance from the marker to the near side of the box was recorded, and the best score of 3 attempts was used in data analysis.

4.1.3.4.2 Thigh Circumference

Circumference of both lower limbs was taken with an anthropometric measuring tape (Vaile, Gill, et al., 2007) to assess changes in thigh volume (Yanagisawa, et al., 2003). To assure consistent measurements from trial to trial, marks were made with a non-permanent felt marker on the skin of each participant’s legs, 5 cm on the superior aspect of the patella and then at a second anatomical point 8 cm superior (Sellwood, et al., 2007) on both the biceps femoris and rectus femoris.

4.1.3.4.3 Muscle Pain Measures

Players’ perceptions of pain were recorded with pressure-to-pain-threshold measurements using a visual analog scale (VAS) (29) and a hand-held pressure algometer using a 1.2-cm diameter head (Chatillon DFX series, FL, USA). Pressure was applied with the algometer at the midpoint between the top of the patella and the superior iliac crest in the rectus femoris and biceps femoris. The participants were instructed to indicate when the pain they felt attained a level 5 on the VAS. The VAS was numbered 1–10, with 1 corresponding to “no pain,” 5 corresponding to “somewhat painful,” and 10 corresponding to “worst pain ever.” The force applied to attain pain level 5 was then recorded in newtons per square meter.

4.1.3.4.4 Force Production

Peak force production was assessed during a countermovement jump (CMJ) using a portable jump mat (Quattro Jump, Kistler, Switzerland). The highest value achieved from 3 jumps was used in data analysis. The participants then performed three 40-m sprint trials (French, et al., 2008) through timing gates (Swift Performance, Sydney, Australia). Once again, the fastest of 3 trials was used in data analysis.

4.1.3.5 Procedures

4.1.3.5.1 Overview

The study was conducted over 3 days. Initially, baseline testing was conducted before commencement of the simulated game of Rugby Union. Upon completion of the simulated game, the participants were randomly assigned (blind allocation) to 1 of 3 recovery protocols. Testing was performed 1, 24, and 48 hours following the simulated game of Rugby Union (Figure 4.2).

4.1.3.5.2 Warm-Up

All the participants performed a group warm-up identical to the team's standardized pre- game warm-up before competition games. The warm-up commenced with the participants performing dynamic walking lunges for 25m, followed by walking sumo squats for 25m. Dynamic flexibility exercises were conducted in a 30m grid by all the participants simultaneously. The warm up protocol is depicted in Table 4.1. The participants then performed dynamic flexibility exercises. These exercises included 10 swings of each leg and 10 swings across each leg, dynamic groin lunges and calf pumps.

Table 4.1. Standardized warm-up protocol sequence

Dynamic flex exercise	Running interval	Interval distances (m)	Repetitions
Heel flicks	Slow pace	5	6
High knees	Slow pace	5	6
Side skips	Nil	30	2
Run-throughs	Medium pace	30	2
Fast feet	Medium pace	5	6
Carioca	Nil	30	2
Run-throughs	Medium fast pace	30	2

Note: Participants complete each dynamic flex exercise completely before performing the next exercise. The participants worked through each exercise from top to bottom in order.

The participants were then allowed a 1-minute hydration break where they consumed water at ambient temperature. The participants then commenced hand passing drills involving transferring the rugby ball across the line while in motion for a total of 5 minutes. In total, the participants spent 25 minutes warming up before moving on to the simulated game of Rugby Union.

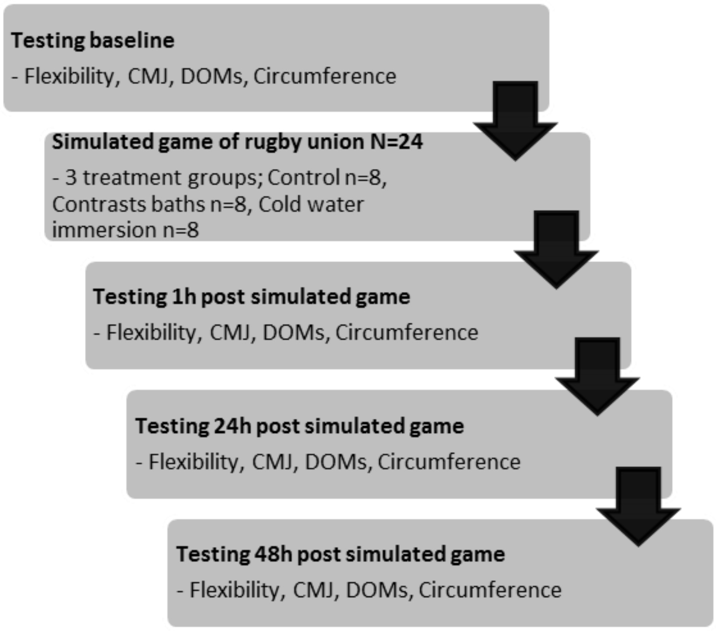

Figure 4.2 Study testing and intervention time line

4.1.3.5.3 Simulated Rugby Union Match

Before commencement of the simulated Rugby Union game, each participant was taken through the circuit to re-familiarize himself with each station. The participants were then instructed to move to their designated stations. Upon hearing a referee's whistle, each participant began the circuit. The participants worked their way through the 11 stations of the simulated game at intervals of 30 seconds. Four complete rotations were completed twice with a 10 minute half-time rest period between each set of 4 rotations. The simulated game of Rugby Union was developed, designed, and verified as representing the demands of a game of Rugby Union (Stuart, et al., 2005). For a full description of the simulated game, see Stuart et al. (2005). A summary of the simulated game of Rugby Union can be seen in Table 4.2.

Table 4.2. Station descriptors for simulated game of Rugby Union

Station identification number	Station task
1	20m straight line sprint
2	22m Swerving sprint with tackle
3	Rest and hydration station
4	Hit and drive 3 2 on scrum machine
5	Rest and hydration station
6	Defensive up, slide and back run, 3 times
7	Rest and hydration station
8	Multiple task defensive station
9	Skill station, passing
10	30m Straight sprint
11	Walking recovery return to station 1

Note: Participants move from station to station, performing the stated task, every 30 seconds.

4.1.3.5.4 Physiological responses to the Rugby Union match simulation

Heart rate was used to monitor exercise intensity during the simulated rugby game (Polar, Inc., Montvale, NJ, USA). Mean and peak HRs for each participant during each half of the simulated game (1 of the 2 periods of play), and the mean and peak HR for the entire simulated game were analysed using proprietary software (Polar Performance 5.0, Polar).

Ear lobe capillary blood samples were taken with a portable analyzer (Lactate Pro, KDK Corporation, Shiga, Japan) to quantify blood lactate responses to the simulated rugby game. The Lactate Pro has previously been shown to provide a valid and reliable measure of blood lactate (Baldari, et al., 2009; McNaughton, et al., 2002).

4.1.3.5.5 Hydrotherapy Protocols

For the CWI protocol, the participants climbed into cold water and assumed a seated, upright position. The water depth was individualized to reach each participant’s superior iliac spines (Sellwood, et al., 2007). The temperature range was 10–12^{o}C (Ingram, et al., 2009; Vaile, Halson, et al., 2007). The participants underwent two 5 minute immersions, with each immersion separated by 2.5 minutes seated out of the bath at room temperature (Ingram, et al., 2009). The contrast bath protocol had the participants alternating between cold water (temperature range 10–12^{o}C) and warm water (temperature range 38–40^{o}C) for 60 seconds in each. The participants performed 5 cycles in each bath, for a total of 10 minute recovery (Vaile, et al., 2008b). The CWI and warm water bath were adjacent to one another. The researchers monitored participants' times in each bath using a standard stop watch (Seiko, Tokyo, Japan) and instructed the participants when to change recovery conditions.

Commercially available 220-L storage tubs were used for the CWI and warm water baths. Temperatures were continually monitored with floating temperature gauges; monitors added ice or hot water, respectively, when cold immersion temperatures rose to 11.5^{0}C or warm water baths fell to 38.5^{0}C. The control group initiated a passive recovery strategy involving maintaining a seated position for 10 minutes in a thermoneutral environment.

Baseline tests, including tests of hamstring flexibility, force output, measures of muscle soreness, and circumferences, were conducted 1 hour, 24 hours, and 48 hours following the simulated game of Rugby Union. Testing was conducted in the same order as was conducted during baseline testing (Cheung, Hume, & Maxwell, 2003; French, et al., 2008; Sellwood, et al., 2007; Vaile, Gill, et al., 2007). The participants were instructed not to perform any physical activity (other than incidental walking), use saunas or hot spas, or take any nonsteroidal anti-inflammatory drugs or analgesics before or during the 48 hour period after the exercise and recovery period. The participants were also instructed to refrain from consuming alcohol during those 48 hours.

4.1.3.6 Statistical Analyses

All statistical analyses were completed using SPSS (ver 17.0). Because of differences between baseline scores, between groups, analyses of covariance were performed for all outcome measures within each group at 3 time points and between the 3 groups (CWT, CWI, control). Baseline scores were treated as covariates to account for inherent differences between groups insufficiently addressed by randomization in a small sample. Omnibus between-group effects sizes are reported as partial eta squared (η_ρ^2) (Table 4.3). Conventions for interpreting η_ρ^2 are small = 0.01, moderate = 0.06, large = 0.14. The value η_ρ^2 can be used to establish the level of group membership that accounts for variation in the mean scores between groups. Standardized scores (Cohen's *d*) were used to identify trends across dependent variables in relation to the effect the simulated game had on each variable (Table 4.4). Cohen's *d* was used to identify the effect that treatments had on each variable across the acute phase. Definitions in previous studies of this sort suggest that a Cohen's *d* value of 0.20 is trivial, *d* = 0.50 is moderate, and *d* = 0.80 is large (Atkinson, 2007; Batterham & Hopkins, 2006; Kirk, 2003). Overall effect sizes were calculated as η_p^2, representing the variance accounted for by group membership.

4.1.4 Results

To verify work intensities between groups throughout the simulated games, mean HRs and blood lactate levels (Buckley, Bourdon, & Woolford, 2003) were recorded. There was no significant difference in mean scores for HRs between groups in either of the simulated games (game 1; p=0.22, game 2; p=0.44). The HR mean score in beats per minute for simulated game 1 with CWI recovery methods was 122±14 $b.min^{-1}$. For CWT, the result was 122±14 $b.min^{-1}$. The control was 135±19 $b.min^{-1}$. Heart rate mean scores for simulated game 2 were CWI 130±12 $b.min^{-1}$, CWT 137±12 $b.min^{-1}$, control 140±18 $b.min^{-1}$. Blood lactate scores (range 3.90–6.10±1.7 mmol) also indicated that there was no significant difference between groups in either of the simulated games. With no significant differences between groups during the simulated games, we assert that any differences identified were results of interventions applied in the study.

Both omnibus and univariate analyses were applied to the data from this repeated measures design. Before analysing the effect that the interventions had on dependent variables, statistical analysis was conducted on baseline data to provide evidence that the simulated game generated sufficient stress to cause fatigue. Significant differences were identified across time points for muscle pain measures (across all time points, $p < 0.001$) and thigh circumference ($p = 0.001$, $p = 0.05$, and $p = 0.02$) at 1 hour, 24 hours, and 48 hours following the simulated game, respectively. A significant difference was also identified across time points for hamstring flexibility ($p = 0.05$ and $p = 0.02$) at 24 hours and 48 hours following the simulated game, respectively. In addition, CMJ reported a significant difference at 1 hour following the simulated game (p = 0.01). Line graphs for 4 key dependent variables (CMJ, ham- string flexibility, DOMS, thigh circumference) are presented below (Figures 4.3–4.6). These graphs demonstrate both within-group differences over time and between-group differences at each time point.

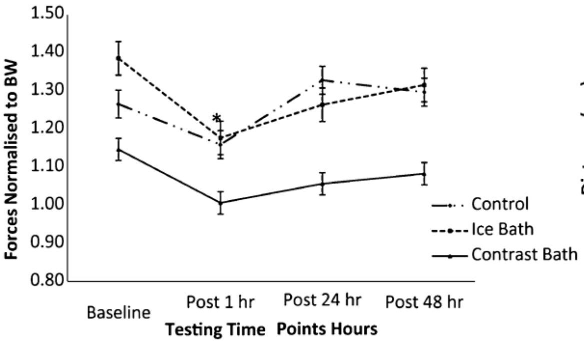

Figure 4.3. Change in peak force during countermovement Jump performance (Nm.kg-1). Data are mean±SD. BW = body weight.

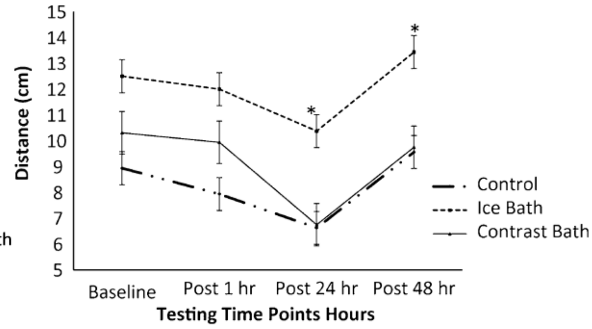

Figure 4.4 Change in sit-and-reach-flexibility (cm). Data are mean±SD.

* Denotes significant difference between baseline scores and all groups at time point scores

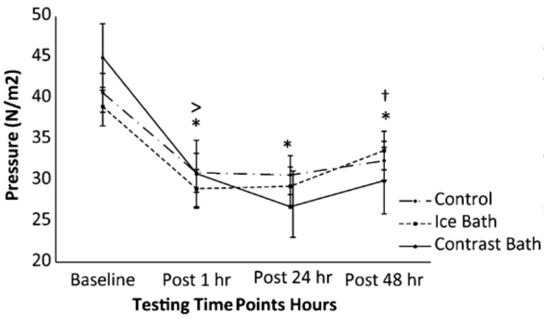

Figure 4.5 Change in muscle pain. Data are mean±SD. † Denotes significant difference between ice baths (CWI) and contrast baths (CWT) >Denotes significant difference between control group and CWT

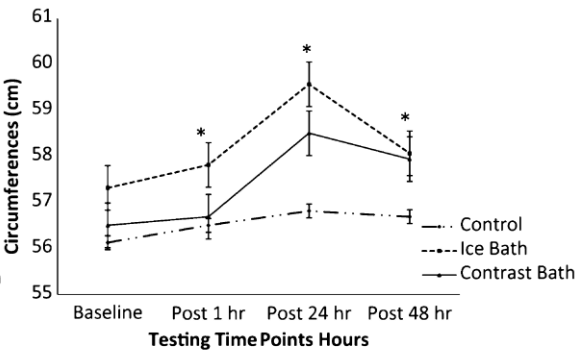

Figure 4.6 Change in peak thigh circumference (cm). Data are mean±SD

* Denotes a significant difference between baseline scores and all groups at time point scores

Table 4.3 shows that treatment interaction terms were small across dependent variables, with the exception of muscle pain measures. At 1 hour after intervention, the contrast bath group reported significantly (p = 0.05) higher perceptions of muscle pain than the control group did. In addition, at 48 hours after intervention, the contrast bath group reported significantly ($p = 0.02$) higher scores for perceptions of pain than the CWI group. Group membership accounted for large effects in this outcome at all-time points (1h, $\eta_p^2 = 0.18$; 24h, $\eta_p^2 = 0.18$; 48h, $\eta_p^2 = 0.26$).

Variances in upper leg circumference scores were largely accounted for by group membership ($\eta_p^2 = 0.1$) in the right leg at all-time points and in the left leg at 24 hours post-game. Although no significant differences were identified between groups for this variable at the same time points (right leg, $p = 0.22$, $p = 0.30$, and $p = 0.37$; left leg, $p = 0.24$), all other dependent variables had small to medium effects for group membership across time points, with no significant differences between groups (Table 4.3).

Further analysis evaluating the magnitude of change was conducted using Cohen's *d* within-group effects between baseline scores for 1 hour, 24 hours, and 48 hours following the simulated game for each variable. Effects termed greater than large were reported for muscle pain measures across all 3 treatments and all 3 times. It should be noted that for measuring muscle pain, lower effect size values (Cohen's *d*) indicate a faster trend in returning to baseline values. Time points indicate that muscle pain measures scores peaked 24 hours following and trended back toward baseline scores at 48 hours following the simulated game. All other dependent variables suggested trivial to moderate effects across all time points (Table 4.4).

Table 4.3 Descriptive statistics for dependent variables for cold water immersion, contrast baths, and control (passive recovery) at baseline (1 hour before simulated game), 1 hour post-simulated game, 24 hours post-simulated game, and 48 hours post-simulated game

Dependent variable time line	Control vs. CWI*	Control vs. contrast	CWI* vs. contrast	Between-group comparison	
	Sig. dif	Sig. dif	Sig. dif	Sig. dif	η_p^2
Countermovement jump					
Base vs. post 1h	0.52	0.66	0.84	0.8	0.02
Base vs. post 24h	0.42	0.26	0.74	0.5	0.07
Base vs. post 48h	0.61	0.43	0.78	0.72	0.03
Post 24 vs. post 48	0.44	0.67	0.73	0.73	0.03
Flexibility					
Base vs. post 1h	0.62	0.59	0.98	0.83	0.02
Base vs. post 24h	0.93	0.65	0.72	0.89	0.01
Base vs. post 48h	0.42	0.46	0.13	0.3	0.11
Post 24 vs. Post 48	0.31	0.95	0.34	0.52	0.06
DOMS right					
Base vs. post 1h	0.53	0.05†	0.2	0.14	0.18^{z}
Base vs. post 24h	0.31	0.99	0.33	0.52	0.06
Base vs. post 48h	0.93	0.45	0.53	0.72	0.03
Post 24 vs. Post 48	0.8	0.54	0.72	0.82	0.02
DOMS left					
Base vs. post 1h	0.6	0.61	0.99	0.83	0.02
Base vs. post 24h	0.73	0.06	0.12	0.14	0.18^{z}
Base vs. post 48h	0.41	0.09	0.02§	0.05§	0.26^{z}
Post 24 vs. post 48	0.45	0.95	0.42	0.65	0.04
Circumference right					
Base vs. post 1h	0.1	0.77	0.17	0.22	0.14^{z}
Base vs. post 24h	0.16	0.2	0.88	0.3	0.12^{z}
Base vs. post 48h	0.31	0.18	0.73	0.37	0.1
Post 24 vs. post 48	0.4	0.93	0.34	0.58	0.05
Circumference left					
Base vs. post 1h	0.86	0.64	0.52	0.8	0.02
Base vs. post 24h	0.11	0.19	0.75	0.24	0.14^{z}
Base vs. post 48h	0.76	0.4	0.58	0.69	0.04
Post 24 vs. post 48	0.09	0.62	0.21	0.22	0.14^{z}

Note *CWI = cold water immersions; DOMS = delayed-onset muscular soreness.
† Significant difference identified between control group and contrast baths.
Z Large effect on group membership
§ Significant difference identified between CWI and contrast baths

Table 4.4. Magnitude of change (Cohen's *d*) across dependent variables between baseline testing and post 1 hour, post 24 hours, and post 48 hours simulated game

Group	CMJ (*d*)	Flexibility (*d*)	DOMS right (*d*)	DOMS left (*d*)	Circumf right (*d*)	Circumf left (*d*)
Control group						
Baseline vs post 1h	0.26	0.14	1.80†	2.13†	0.10	0.11
Baseline vs post 24h	-0.11	0.25	2.82†	1.78†	0.15	0.19
Baseline vs post 48 h	-0.10	-0.10	1.45†	1.45†	0.01	0.13
Contrast baths						
Baseline vs post 1h	0.42	0.04	4.75†	3.41†	0.03	0.03
Baseline vs post 24h	0.31	0.28	4.62†ŧ	6.74†ŧ	0.38	0.32
Baseline vs post 48h	0.26	0.07	1.97†	2.30†	0.29	0.26
Cold Water Immersion						
Baseline vs post 1h	0.40	0.06	1.68†	1.26†	-0.07	0.11
Baseline vs post 24h	0.31	0.19	3.24†	1.41†	0.46	1.13†
Baseline vs post 48h	0.16	-0.14	1.17†	0.96†	0.23	0.17

Note: CMJ = countermovement jump; DOMS = delayed-onset muscular soreness
†Large effect directed from baseline scores
ŧ Moderate to large effect directed from post 48 hours to post 24 hours

4.1.5 Discussion

This study assessed CWI and CWT as recovery methods during the initial 48 hours (the acute phase) after a simulated game of Rugby Union. There were no significant differences between HR and blood lactate, and thus, we were able to draw the following conclusions. First, each group performed the simulated game of Rugby Union with similar workloads and intensities. Second, any differences between groups across tests after the simulated game of Rugby Union were a result of the recovery interventions applied.

Only muscle pain measures demonstrated significant differences between groups, with the passive control group showing less muscle pain compared with the CWT at 1 hour following the simulated game. The CWI group showed less muscle pain than did the contrast bath group at 48 hours post. It is important to note that at 48 hours post, all groups' muscle pain measures were below baseline levels. This suggests that complete recovery had still not occurred at 48 hours after the simulated game. The muscle pain measures were -13%, -20%, and -33% in the CWI, control, and contrast water therapy (CWT) groups, respectively.

These results are similar to previous recovery research findings. In a study of simulated team sports conducted by Ingram et al. (2009), they reported that CWI fostered significantly lower muscle soreness scores ($p = 0.05$) than did the control group and CWT. Furthermore, although measuring the generic term "leg soreness," rather than using muscle pain measures to a standard stimulus, Rowsell et al. (2009) reported that CWI fostered significantly lower levels of leg soreness than a thermoneutral bath, measured across the duration of a soccer tournament. In a similar research, albeit a 2-group comparison, Dawson et al. (2005) fond no significant difference in scores of muscle soreness between control and contrast bath groups 15 hours post and 48 hours post of an Australian Football game.

An emerging trend in athletic research is studying team sports that involve running movement patterns, including sprinting, directional changes, and back-pedalling. The rugby match simulations used in this study feature all those aspects. Collectively, these findings suggest that when treating DOMS, CWT offer little aid in attenuating muscle pain in the legs, up to 48 hours post-activity. Indeed, each study that evaluated CWT no significant difference was identified between CWT and control groups (Dawson, et al., 2005; Ingram, et al., 2009; Rowsell, et al., 2009). Although each group recorded increased muscle soreness from baseline scores, the contrast bath group reported a greater level of muscle soreness across all time points in this research. In fact, at 48 hours following the simulated game, the CWT group had recovered the least of the 3 groups, indicating that CWT offers the least benefit in minimizing the effects of DOMS. Furthermore, the findings indicate that when CWI is evaluated, CWT offer little benefit in comparison with CWI, either in enhancing recovery from muscle pain measures or in attenuating muscle pain effects.

No significant differences were identified (Table 4.3) between groups at any time point for CMJ, hamstring, flexibility, or thigh circumference. Overall, our results indicate that immediately after the simulated game of Rugby Union, each group suffered decreases in CMJ performance, reductions in hamstring flexibility, and an increase in thigh circumference. At 48 hours following the simulated game, all the groups had demonstrated signs of recovery toward baseline values. The return to baseline values occurred irrespective of the levels of muscle soreness still being recorded.

Although $\eta_\rho^2 = 0.07$ for CMJ, there are indications that a moderate group association exists (7%) between groups for variations in scores for CMJ at 24 hours following the simulated game. These trends are not consistent across this study. With only a small effect present at 1 hour following the simulated game (η_ρ^2 = 0:02) and 48 hours following the simulated game ($\eta_\rho^2 = 0.03$), indications are that recovery of power, as measured by a CMJ, will occur irrespective of the intervention, if time is permitted. These observations agree with Dawson et al. (2005) who reported that despite showing elevated muscle soreness 48 hours after an Australian Football match, well-trained athletes are able to reach near-baseline levels in one-off tests of power.

This leaves coaches and athletes with 2 crucial decisions to make concerning recovery protocols. First, what is the time frame between game and the next session, whether game or training? Second, what indicator is the most important factor to consider when evaluating an athlete's readiness for their next athletic performance?

If there is ample time between sessions (48 hours), and power functions are of primary importance, recovery interventions may offer athletes scant benefits in recovery over no treatment whatsoever. However, CWI may be the best option if coaches are concerned about the impact of leg muscle soreness (DOMS). If an athlete's approach to subsequent games and training, while suffering with leg muscle soreness, is compromised then the use of CWI may be the appropriate recovery intervention to apply. Importantly, if there is insufficient time to recover (<48 hours) between games and training, then the recovery intervention of CWI offers more to the athlete in attenuating the effects of DOMS and hastening the return of power in comparison with passive recovery or CWT.

The magnitude of change, from baseline scores to 48 hours following the simulated game, shows only trivial effects within groups across CMJ, circumferences, and flexibility (Table 4.4). Larger effects were reported across all the groups for muscle pain measures, which is consistent with previous research findings (Dawson, et al., 2005; Ingram, et al., 2009; Rowsell, et al., 2009). Furthermore, large group membership values (24 hours post η_ρ^2 = 0.18, 48 hours post η_ρ^2 = 0:26) Indicates that between 18 and 26% of the variation in scores, is a result of the recovery interventions. These indications of trends suggest that CWI is more beneficial than both CWT and no recovery intervention in attenuating the effects of muscle pain measures. This provides further support that CWI is more beneficial in recovery for participants' suffering from muscle pain.

A medium to large effect (η_ρ^2 = 0.11) of the variation of mean scores was reported for hamstring flexibility at 48 hours and a large effects (η_ρ^2 = 0.14) of the variation for circumferences were reported at 1 hour following the simulated game. Furthermore, at 24 hours (η_ρ^2 = 0.12) and 48 hours following (η_ρ^2 = 0.10), medium to large effects identified for group membership accounted for a range of variance between 10% and 14%. Although each group showed decrements followed by recovery over the time period, trends indicate that CWI offers increased recovery of hamstring flexibility and changes in mid-thigh circumference measurements, compared with CWT and no intervention. These findings are similar to those of previous research that has examined recovery from EIMD in simulated team sports (Barnett, 2006). Apart from muscle pain measures, performance measures had returned primarily to near baseline levels after 48 hours, irrespective of the recovery intervention employed.

This study indicates that if athletes are experiencing muscle pain, 2 x 5-minute CWI is superior to 5 x (1 minute hot/1 minute cold) contrasts baths and passive recovery in attenuating the effects of muscle pain. Furthermore, effect sizes indicate that after simulated team sports CWI is superior to both CWT and passive recovery in returning participants hamstring flexibility to pre-simulated game conditions and reducing interstitial fluids associated with EIMD. Furthermore, it is important for coaches to note, when considering recovery of CMJ performance, hamstring flexibility, mid-thigh circumference, and muscle pain measures, CWT offer fewer benefits to participants in recovery during the acute phase than partaking in passive recovery. The mechanisms for CWT to aid recovery have primarily centred on accelerating clearance of waste products by aiding muscle pump function through increased vasodilation and vasoconstriction. Currently, it is believed that immersion times in CWT are insufficient to reduce deep muscle temperature sufficiently to increase vasodilation and vasoconstriction and aid muscle pump. However, this would not explain why CWT where less effective for recovery than passive recovery, specifically in regards to DOMS.

It has been proposed that short durations of immersion in cold water (<3 minutes) may increase free-radical production, leading to oxidative stress (Bleakley & Davison, 2010). Furthermore, in the event of increasing levels of oxidative stress, subsequent increases in muscle stress would occur delaying the recovery process (Bleakley & Davison, 2010).

Bleakley and Davison (2010) reported the increase in free-radical production was associated with immersions of 3 minutes. In our research, contrast bath immersions included 5 x 1 minute immersions, alternating from hot and cold. With the continuing exposure to short durations of CWI, free-radical production and subsequent increases in oxidative stress would have led to greater stress on muscle than the exercise activity alone. This increase in stress on muscle would have a corresponding increase with the inflammatory response and overall recovery time, providing the underlying mechanism responsible for results indicating CWT to be the least effective recovery intervention. Despite its acceptance as a recovery protocol in professional sports including Rugby Union, this research indicates that CWT should be discontinued as a recovery protocol.

4.1.6 Practical applications

The findings in this research support those of previous research indicating that 2 x 5 minute CWI produces results that are superior to both contrasts baths and passive recovery in alleviating muscle pain after EIMD. If coaches and strength and conditioning coaches are concerned that players are adversely affected by muscle pain at their first training session after competition, this study recommends for players in Rugby Union aiming to decrease or reduce the effects of muscle pain post-games should follow this study's protocol for CWIs, consisting of 2 x 5-minute baths immediately after the game. Further, it should be noted that our research demonstrated that CWT were less effective as a recovery modality than either CWI or passive recovery.

4.1.7 Acknowledgments

The authors thank the contributions of Associate Professor Aaron Coutts (UTS, Australia) to the research design and methodology, and thank the coaches and players from the Eastwood District Rugby Union Football Club for their support and participation is this study.

4.1.8 References

Atkinson, G. (2007). What's behind the numbers? important decisions in judging practical significance. *Sportscience, 11*, 12-15.

Baldari, C., Bonavolonta, V., Emerenziani, G. P., Gallotta, M. C., Silva, A. J., & Guidetti, L. (2009). Accuracy, reliability, linearity of Accutrend and Lactate Pro versus EBIO plus analyzer. *European Journal of Applied Physiology, 107*, 105-112.

Barnett, A. (2006). Using recovery modalities between training sessions in elite athletes. *Sports Medicine, 36*(9), 781-796.

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International journal of sports physiology & performance, 1*(1), 50-57.

Bishop, P. A., Jones, E., & Woods, A. K. (2008). Recovery from training: A brief review. *Journal of Strength & Conditioning Research, 22*(3), 1015-1024.

Bleakley, C. M., & Davison, G. W. (2010). What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. *British Journal of Sports Medicine, 44*(3), 179-187.

Buckley, J. D., Bourdon, P. C., & Woolford, S. M. (2003). Effect of measuring blood lactate concentrations using different automated lactate analyzers on blood lactate transition thresholds. *Journal of Science & Medicine in Sport, 6*, 408-421.

Cheung, K., Hume, P., & Maxwell, L. (2003). Delayed onset muscle soreness: Treatment strategies and performance factors. [Review]. *Sports Medicine, 33*, 145-157.

Coffey, V., Leveritt, M., & Gill, N. (2004). Effect of recovery modality on 4- hour repeated treadmill running performance and changes in physiological variables. *Journal of Science & Medicine in Sport, 7*.

Dadebo, B., White, J., & George, K. P. (2004). A survey of flexibility training protocols and hamstring strains in professional football clubs in England. *British Journal of Sports Medicine, 38*, 388-394.

Dawson, B., Gow, S., Modra, S., Bishop, D., & Stewart, G. (2005). Effects of immediate post-game recovery procedures on muscle soreness, power and flexiblity [sic flexibility] levels over the next 48 hours. *Journal of Science & Medicine in Sport, 8*(2), 210-221.

Duthie, G., Pyne, D., & Hooper, S. (2003). Applied physiology and game analysis of Rugby Union. *Sports Medicine, 33*, 973-989.

Eston, R., & Peters, D. (1999). Effects of cold water immersion on the symptons of exercise-induced muscle damage. *Journal of Sports Sciences, 17*, 231-238.

French, D. N., Thompson, K. G., Garland, S. W., Barnes, C. A., Portas, M. D., Hood, P. E., et al. (2008). The Effects of Contrast Bathing and Compression Therapy on Muscular Performance. *Medicine & Science in Sports & Exercise, 40*(7), 1297-1306.

Gill, N. D., Beaven, C. M., & Cook, C. (2006). Effectiveness of post-match recovery strategies in rugby players. *British Journal of Sports Medicine, 40*(3), 260-263.

Heyman, E., De Geus, B., Mertens, I., & Meeusen, R. (2009). Effects of four recovery methods on repeated maximal rock climbing performance. *Medicine & Science in Sports & Exercise, 41*, 1303-1310.

Higgins, T. R., Heazlewood, I. T., & Climstein, M. (2011). A random control trial of contrast baths and ice baths for recovery during competition in u/20 rugby union. *Journal of Strength & Conditioning Research, 25*(4), 1046-1051.

Howatson, G., & Van Someren, K. A. (2008). The prevention and treatment of exercise-induced muscle damage. *Sports Medicine, 38*, 483-503.

Hubbard, T. J., Aronson, S. L., & Denegar, C. R. (2004). Does cryotherapy hasten return to participation? A systematic review. *Journal of Athletic Training, 39*, 88-94.

Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science & Medicine in Sport, 12*(3), 417-421.

Jakeman, J. R., Macrae, R., & Eston, R. (2009). A single bout of cold-water immersion therapy after strenuous plyometric exercise has no beneficial effect on recovery from the symptoms of exercise-induced muscle damage. *Ergonomics, 52*(4), 456-460.

Kirk, R. E. (2003). Research Methods in Experimental Research Psychology. In S. F. Davis (Ed.), *The importance of effect magnitude* (pp. 83-10). Oxford, United Kingdom: Blackwell.

McNaughton, L. R., Thompson, D., Philips, G., Backs, K., & Crickmore, L. (2002). A comparison of the Lactate pro, Accusport, Analox GM7 and Kodak Ektachem analysers in normal, hot and humid conditions. *International Journal of Sports Medicine, 23*, 130-135.

Montgomery, P. G., Pyne, D. B., Hopkins, W. G., Dorman, J. C., Cook, K., & Minahan, C. L. (2008). The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *Journal of Sports Sciences, 26*(11), 1135-1145.

Reilly, T., Dowzer, C. N., & Cable, N. T. (2003). The physiology of deep- water running. *Journal of Sports Science, 21*, 959-972.

Reilly, T., & Ekblom, B. (2005). The use of recovery methods post-exercise. *Journal of sports sciences, 23*(6), 619-627.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal of Sports Sciences, 27*(6), 565-573.

Sellwood, K. L., Brukner, P., Williams, D., Nicol, A., & Hinman, R. (2007). Ice-water immersion and delayed-onset muscle soreness: A randomised controlled trial. *British Journal of Sports Medicine, 41*, 392-397.

Stuart, G. R., Hopkins, W. G., Cook, C., & Cairns, S. P. (2005). Multiple effects of cafeine on simulated high-intensity team-sport performance. *Medicine & Science in Sports & Exercise, 37*(11), 1998-2005.

Suzuki, M., Umeda, T., Nakaji, S., Shimoyama, T., Mashiko, T., & Sugawara, K. (2004). Effect of incorporating low intensity exercise into the recovery period after a rugby match. *British Journal of Sports Medicine, 38*, 436-440.

Vaile, J., Gill, N., & Blazevich, A. J. (2007). The effect of contrast water therapy on symptons of delayed onset muscle soreness. *Journal of Strength & Conditioning Research, 21*(3), 697-702.
Vaile, J., Halson, S., Gill, N., & Dawson, B. (2007). Effect of hydrotherapy on recovery from fatigue. *International Journal of Sports Physiology and Performance, 29*, 539-544.
Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008). Effect of hydrotherapy on recovery from fatigue. *International Journal of Sports Physiology and Performance, 29*, 539-544.
Williams, J. H. (1997). Contractile apparatus and sarcoplasmic reticulum function: effects of fatigue, recovery, and elevated Ca2+. *Journal of Applied Physiology, 83*(2), 440-450.
Yanagisawa, O., Niitsu, M., Takahashi, H., Goto, K., & Itai, Y. (2003). Evaluations of cooling exercised muscle with MR imaging and PMR spectroscopy. *Medicine and Science in Sports and Exercise, 35*(9), 1517-1523.

Chapter 5

5.1 Evaluation of hydrotherapy, using passive tests and power tests, for recovery across a cyclic week of competitive Rugby Union

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1 School of Exercise Science, Australian Catholic University, Australia;
2 Centre of Physical Activity Across the Lifespan (CoPAAL), School of Exercise Science, Australian Catholic University, Australia;
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5.1.1 Abstract

Higgins, T.R, Climstein, M, and Cameron, M. (2013). Evaluation of hydrotherapy, using passive tests and power tests, for recovery across a cyclic week of competitive rugby union. *Journal of Strength and Conditioning Research* 27(4): 954–965. In team sports, a cycle of training, competition, and recovery occurs weekly during the competitive season. In this research, we evaluated hydrotherapy for recovery from a simulated game of Rugby Union tracked over a week of training. Twenty-four experienced male Rugby Union players (mean±SD, age 19.5±0.8 years, weight 82.4±11.1kg, height 178.5±5.8cm) were randomly divided into 3 groups: cold water immersion (n = 8), contrast bath therapy (n = 8), and a control group (n = 8). The 2 forms of hydrotherapy were administered immediately after a simulated rugby game. Testing was conducted 1 hour before the game and at 5 intervals post-game: 1h, 48h, 72h, 96h, and 144h. Dependent variables included countermovement jump, 10m and 40m sprints, session rating of perceived exertion (RPE), flexibility, thigh circumference, and self-reported delayed onset muscle soreness (DOMS). Significant differences in DOMS were found between the cold water immersion and contrast bath groups at 48h intervention ($p = 0.02$), and between the control and contrast bath groups at 72h ($p = 0.03$) and 96h ($p = 0.04$) post intervention. Cold water immersion and contrast bath groups reported significantly different session RPE at 72h ($p = 0.05$) and 96h ($p = 0.05$) intervention. Athletes' perceptions of muscle soreness and session RPE scores for training were greater in the contrast bath group (20%) after the simulated game and throughout the training week. Although results from passive and power tests were inconclusive in determining whether cold water immersion or passive recovery was more effective in attenuating fatigue, results indicated contrast baths had little benefit in enhancing recovery during a cyclic week of Rugby Union.

5.1.2 Introduction

Currently, players of elite sport cycle through habitual activity across the season, usually based on principles of periodization of training (Dadebo, et al., 2004). During a competitive season, in many team sports, a cycle of training, competition and recovery occurs over each week throughout the season (Reilly & Ekblom, 2005). This cyclic activity may result in players accumulating fatigue as the season progresses; the quick turnaround between training and competition may not provide sufficient time for players to fully recover (Reilly & Ekblom, 2005). It is important, therefore, that optimal recovery strategies are identified and implemented to maximize athletic performance through effective recovery.

The weekly activity during Rugby Union competition includes a competition game and then a period of relative rest, generally between 48 and 72 hours, until training for the next competition game is commenced. In professional Rugby Union, the training week usually consists of 4 field sessions including skills, unit work (scrums, line-outs, and backline moves), conditioning, team runs, and 2–3 weight sessions. With the training load and the potential accumulation of fatigue, importance is placed on ensuring that recovery has occurred after the previous game and before commencement of the next competitive game.

Despite the common use of hydrotherapy as a recovery strategy in elite sport there is little research available demonstrating effectiveness (Dawson, et al., 2005; Heyman, et al., 2009; Ingram, et al., 2009; Kinugasa & Kilding, 2009; Rowsell, et al., 2009), and a paucity of evidence supporting hydrotherapy to enhance recovery from the training load associated with a typical week in Rugby Union. Of interest to team coaches, athletes, and strength and conditioning coaches is the actual effectiveness of hydrotherapy relevant to their work, therefore; the purpose of this research was to evaluate 2 forms of hydrotherapy in promoting recovery across the weekly cycle of game and training in Rugby Union.

5.1.3 Methods

5.1.3.1 Experimental approach to the problem

Despite the widespread use of cold water immersion and contrast baths as a post-match recovery strategy in Rugby Union, there is relatively little evidence supporting its use. To address the null hypothesis that neither cold water immersion nor contrast baths protocols would have a significant effect upon muscle pain measures, flexibility, swelling, power performance, and perceptions of load, the between-groups study examined the effectiveness of three different recovery protocols on these markers of fatigue. The aim of this study was to provide information for coaches and highly trained players in Rugby Union on the effectiveness of hydrotherapy as a recovery protocol from Rugby Union.

5.1.3.2 Subjects

This study was performed with highly trained male participants (n = 24) from an under-20 Rugby Union team (mean±SD, age 19.5±0.8 years, body mass 82.4±11.1 kg, height 179±6 cm). The study was conducted after 26 weeks of training, which included 10 weeks of preseason training (5.5 hours/3 sessions weekly), followed by 16 weeks of the scheduled 22-week competition (6.5 hours/3 sessions weekly).

5.1.3.3 Preseason phase demands

Preseason training included 2 weekly training sessions, a Saturday beach sessions (first 6 weeks) and trial games (weeks 7–9). Training sessions were structured to include a 15-minute warm-up followed by 40 minutes (first 6 weeks) and 20 minutes (weeks 7–10) of conditioning. Conditioning focused on speed and acceleration running drills, contact drills and small-sided games. Work-to-rest ratio ranged from 1: 2–3 (first 6 weeks) to 1:1 and 2:1 (weeks 7–10). After the conditioning phase, training of rugby skills became the focus. Intensity of the conditioning elements ranged between 75% HRmax and 95% HRmax. Skill set drills intensity ranged between 50% HRmax and 70% HRmax.

Beach sessions were structured around conditioning elements only. Each session commenced with a 15 minute warm-up followed by 70 minutes of conditioning. The conditioning included speed and agility drills, wrestling drills, small-sided games, and team-based relay shuttles. Intensity of the beach sessions ranged between 70% HRmax and 90% HRmax with a work-to-rest ratio of 1:3. After 6 weeks, the beach training sessions were replaced with trial games of Rugby Union for 3 weeks. The last Saturday before commencement of competition was a scheduled rest day to mark the end of preseason training. Trial games were played with standard rules of the game, but the first 2 trials were played with 20 minute periods. The players would rotate throughout the day, with most players competing in three 20 minute periods. The third trial was played under standard rules with 30 minute periods. The players would rotate throughout the day, with majority of players competing in two 30 minute periods.

5.1.3.4 Competition phase demands.

During the competition phase, 2 training sessions were conducted each week. Training sessions were structured to include a 10 minute warm-up followed by a conditioning period of 10–20 minutes. Conditioning sessions varied between sprint work and small-sided games. From five seasons of Rugby Union training sessions with the use of GPS data trackers, intensity of conditioning elements ranged between 85% HRmax and 100% HRmax, with a work-to-rest ratio ranging from 1–3:1. The remainder of the training sessions was structured around skills, Rugby Union units, team play and semi-opposed runs. Intensity ranged from 50% HRmax to 85% HRmax. Distance covered per session during the preseason phase ranged from 6,000 to 7,200m and throughout the competition phase of the season ranged from 6,000 to 6,500m.

5.1.3.5 Study design.

The study was conducted over 6 consecutive days during the team’s regularly scheduled game time 15:00–16:30 hours and training time 18:00–20:00 hours. Environmental conditions during the week were constant with no rain. Temperatures ranged from 12-15^0 at training and 18–20^{0}C during the simulated game.

All the subjects had no history of recent musculoskeletal injury and were free of illness during the testing period. They were instructed not to perform any physical activity (other than incidental walking), use saunas or hot spas, or take any nonsteroidal anti-inflammatory analgesic drugs during the 48 hour period before or during the testing period. The participants were also instructed to refrain from consuming alcohol 48 hours before and during the testing. Each participant signed an informed consent form before taking part in the study design was approved by The Australian Catholic University's Human Research Ethics Committee (N200708-24). We excluded from our participant pool players who were involved in labour intensive jobs, and those who had either been injured or suffered an illness within 4 weeks before, or during the study period.

5.1.3.6 Measures

Physiological testing began with the sit-n-reach test (Montgomery, Pyne, Hopkins, et al., 2008) with the best of 3 attempts recorded. The participants sat with legs straight with shoes off and feet against the sit-n-reach box. The participants would place hands one on top of the other before bending forward and pushing the marker along the sit-n-reach box. Circumference measurements of both lower limbs were conducted using an anthropometric tape measure (Vaile, Gill, et al., 2007), to indicate any acute changes in thigh volume previously been reported to occur due to osmotic fluid shifts or inflammation (Yanagisawa, et al., 2003). To fix thigh measurement sites, subjects' skin was marked with a permanent felt marker 5 cm above the superior aspect of the patella (Sellwood, et al., 2007) and then a second anatomical point a further 8 cm superior (Sellwood, et al., 2007) on both the biceps femoris and rectus femoris.

Individual participants' perception of pain was recorded as pressure to pain threshold measurements associated with delayed onset muscle soreness (DOMS). Using a visual analog scale (VAS; 0–100mm) (Sellwood, et al., 2007) and a handheld pressure algometer using a 1.2-cm diameter head (Chatillon DFX series, FL, USA), pressure was applied at the midpoint between the top of the patella and the superior iliac crest in the rectus femoris and biceps femoris. The participants were instructed to indicate when the pain reached 5 on the VAS. The force in Newtons per meter squared applied to attain a level of 5 was recorded.

After the passive tests were completed, tests of power were conducted. Power output was initially accessed via a counter-movement jump (CMJ) using a portable jump mat (Quattro Jump, Kistler, Switzerland) measuring peak force output in Newton meters normalized to body weight ($Nm.kg^{-1}$). Three jumps were conducted with the highest value recorded (French, et al., 2008). The participants then performed three 40m sprint trials (French, et al., 2008) through timing gates (Swift Performance, Sydney, Australia). The fastest of the 3 trials was recorded.

5.1.3.7 Procedure

All the participants performed a warm-up, which was identical to the team's standardized pregame warm-up conducted before competition games. The warm-up commenced with participants performing a dynamic walking lunge for 25m followed by a walking sumo squat for 25m. Dynamic flexibility exercises were conducted in a 30m grid by all participants simultaneously. Dynamic flexibility exercises included butt kicks, high knees, lateral steps, fast feet, and finally crossovers. The participants then performed 10 swing throughs and 10 swings across with each leg. In addition, participants performed dynamic groin lunges and calf pumps. Total warm-up duration was 25 minutes.

After the warm-up was completed, the participants commenced the simulated game of Rugby Union. Through the trials and study, each station was staffed by 2 researchers who assisted with data collection. Researchers underwent training and familiarization of each station before the testing.

Immediately after the completion of the circuit, the participants were randomly assigned to 1 of 3 intervention protocols: cold water immersion (n = 8), contrast baths (n = 8), or passive recovery (control, n = 8).

Cold water protocol: Participants were required to climb into the cold water immersion and assume a seated, upright position. Water depth was individualized to each participant's superior iliac spines (Sellwood, et al., 2007). Temperature ranged between 10-12^{0}C (Ingram, et al., 2009; Vaile, et al., 2008a). The participants underwent 2 x 5-minute immersions in the cold water separated by 2.5 minutes seated out of the baths at room temperature (Ingram, et al., 2009).

Contrast bath protocol: The contrast bath protocol involved alternating from cold water baths (10–12^{0}C) to warm water baths (38–40^{0}C), spending 60 seconds in each. The participants performed 5 cycles in each bath for a total of 10 minutes (Vaile, Gill, et al., 2007). Cold water and warm water baths were adjacent to one another. A researcher monitored time using a standard stop watch (Seiko, Japan) and instructed the participants to change recovery conditions, stepping from the cold water immersion bath to the adjacent hot water bath, every minute.

Commercially available 220-L storage tubs were used for the baths (cold water and warm water baths). Temperatures were monitored with floating temperature gauges; ice and hot water respectively, were added when required as temperatures rose to 11.5^{0}C (cold water immersion) or fell to 38.5^{0}C (warm water bath). The control group undertook a passive recovery strategy involving sitting for 10 minutes in thermoneutral environment. Testing was conducted 1 hour before simulated Rugby Union game and again 1h, 48h, 72h, 96h, and 144h post-simulated game.

The participants undertook a weekly training schedule that included the previously mentioned testing protocols at the commencement of each training session. On each of the 3 training session days, testing went for approximately 30 minutes, followed by 90 minute training sessions. Training loads during these training sessions were quantified using session rating of perceived exertion (RPE) scores recorded as arbitrary units (AU) (Alexiou & Coutts, 2008). The testing protocol conducted at base line was repeated identically at each of the subsequent test times.

5.1.3.8 First training session, 48h

The first training session, conducted 48 hours after the simulated game, was structured in 15 minute blocks with participants allowed 2 minute recovery and hydration breaks between blocks. Water was provided at ambient temperature at the end of each drill. During these breaks, participants were given instructions for the next drill.

In the first drill, the participants conducted 3 sets of six 40m sprints followed by 60m jogging (active recovery), with each sprint performed at 30 second intervals and completed in 7 seconds. Participants were granted a 60 second rest period after each set. The participants performed, in total, 18 x 40m sprints, covering a total of 720m sprinting and 1,080m jogging for active recovery.

For the second drill a rectangle, 30m by 15m, was set up using 6 cones. Two other cones were placed in the centre of the rectangle, 1m apart. The participants were split into 2 groups, 1 group held hit shields representing the attacking players; the second group represented the defenders. Players started from the same end of the rectangle from opposite corners. At the same time, the first player from each group ran toward the 2 cones in the centre. The attacking player straightened up as he ran through the gate, the defending player aligned himself on the inside shoulder as he made his tackle, striking both the shield and player. After the tackle, players swapped groups with the attacker handing over the shield to the defender. The 2 groups' cycled through 4 times with the process repeated from each point of the rectangle.

The third drill was a 4-phase fitness drill. A grid 20m long and 10m wide was set up with training cones placed every 5 m, dividing the grid into 4 sections. Three tackle bags were placed in the first section and held by the recovery group, with each participant carrying a hit shield. The players worked in threes against an opposing group of 3. The working group started in the first section, while the opposing group rested at tackle bags, each with a hit shield. On the call of up, the working group hit the tackle bags and then ran backwards around the cone to the second section, while the opposing group mirrored their move to the second section. The working group moved up as a defensive line to make tackles on hit shields. The procedure was repeated through the third and fourth sections. Each group cycled through 3 times before swapping with the opposing group. At the completion of the 3 fitness-based drills, the players broke into forwards and backs for unit training. Forwards conducted line out drills, whilst the backs conducted backline plays. Unit drills ran for 20 minutes; the players then spent the final 20 minutes of the session in semi-contested play. Semi-contested play consists of a competitive game of Rugby Union, however, instead of full tackles, the players performed a 2-handed grab, with the attacking player accepting the tackle and going to ground.

5.1.3.9 Second training session, 72h

The second training session, conducted 72 hours after the simulated game, was structured as per the first training session, in 15 minute blocks with the participants granted a 2 minute recovery and hydration break, and water provided at ambient temperature at the end of each drill. During the break, the participants were given instructions for the next drill.

The first fitness-based drill commenced with a sprint push-up drill, in a grid with training cones placed at 0m, 20m, and 40m. Participants lined up on the cones at 0m, on the call of “go”, they sprinted to the 20m cones then jogged to the 40m cones, stopped, and turned around to prepare for the next sprint. At 10 seconds after the first sprint began, the second one commenced. The series was repeated for 6 sprints. This phase of the drill lasted for 60 seconds, then the sprint/push-up phase commenced. Participants ran to the 20m mark, performed 8 push-ups, and then ran back to the start line. At 20 second intervals, they repeated the format for a total of nine drills over 3 minutes. The participants then perform 6 sprint drills again as above, followed by a 20m run then 7 crunches at 20 second intervals, 9 times, as per push-up drill.

The second fitness-based drill was a pick’n’go drill, set in a grid 10m long and 15m wide. The ruck moved diagonally to the opposite corner. Teams then swapped ball possession. The participants were set in a ruck position, held. One participant was on the ground presenting the ball whilst other participants’ bridged and protected the ball. Defending participants’ position was a tight defensive pattern. Pick’n’go was always to the right. Participants’ Pick’n’go tight to the ruck for 2 paces. Attacking participants rolled right to protect the ball and Pick’n’go again. Defending participants continued to roll left to defend the Pick’n’go.

The third fitness-based drill was a speed endurance drill. A rectangle grid was marked out with training cones 40m by 20m. The participants were grouped at each corner post. At the sound of a whistle, the participants ran to the next post in an anti-clockwise direction. At the next whistle, they ran to the next post. The process was continued for the specified time (15 minutes). Initial interval was 12 seconds, each leg for 4 laps. The next 6 laps were at an interval of 10 seconds then finally the last 6 laps were ran at intervals of 8 seconds. The 40m leg was the working leg with the 20m leg an active recovery leg.

As with the first training session, at the completion of the fitness-based drills, the participants broke into 20 minutes of unit skills followed by 20 minutes of a semi-contested play, consisting of a game of Rugby Union.

5.1.3.10 Third training session, 96h

The third training session, conducted 96 hours after the simulated game was structured in 15 minute blocks with participants granted a 2 minute recovery and hydration break; water was provided at ambient temperature at the end of each drill. During this period, the participants were given instructions for the next drill. The fitness-based drills conducted in the first training session were replicated in the third training session.

5.1.3.11 Statistical Analyses

Statistical power was calculated at 0.60 for a sample size of N = 24, with an alpha level of 0.05 and an effect size of 0.8. To verify internal consistency of the simulated game, analysis was conducted during the familiarization process and reported Cronbach’s alpha (based on standardized scores) of 0.81, suggesting a relatively high internal consistency.

Independent variables for weekly cyclic activity included 2 treatment groups, contrast baths and cold water immersion and a control group performing seated recovery in a thermal neutral room. The dependent variables included mid-thigh circumference measurements (CIRCUMF), sit-and-reach test (FLEX), pressure forces (newton meters) via handheld pressure algometer for DOMS scores via VAS, power measurement (normalized to body weight) in CMJ off a portable force platform (Kistler), 10m and 40m sprint times through timing gates (Swift Performance) and session RPE quantified as AU. Because of initial differences between groups at pre-test scores, analysis of covariance (ANCOVA) tests were conducted on post-test scores as the dependent variable, the between-group factor was the treatments and the pre-test scores were defined as the covariate. Post hoc analysis may inflate significance, as such and with small sample sizes, Univariate analysis was conducted independently across all variables across each time points to identify changes in between group (treatment) and within group (pre-test to post-test). Each time point acted as the covariate against each other time point throughout statistical analysis.

Treatment effects and the level of group association analysis were conducted through effect sizes (Cohen's *d* and η_ρ^2). It has been stated that parametric statistical tests based on statistical significant difference fail to address real-world significance of a practical treatment outcome (Atkinson, 2007; Batterham & Hopkins, 2006). Furthermore, effect sizes enable a researcher to interpret measurements, results and intervention outcomes in terms of what is meaningful to the participants (Stoove & Andersen, 2003). Primarily, after an intervention is the participant able to perform more efficiently or function better as opposed to a non-intervention group (Stoove & Andersen, 2003). With this in mind it has been stated that the primary product of research is the measures of effect sizes (Cohen, 1990).

5.1.4 Results

Results obtained in this study were passive markers, which included flexibility of the hamstrings (Flex) measured with a sit-n-reach test, DOMS measured in the hamstrings using a VAS chart and a Chatillon gauge, circumference of the upper leg (Circumf) to evaluate osmotic fluid shifts brought about through exercise induced muscle damage and power tests including a CMJ on a portable force platform (Kistler) and 10m and 40m sprint times. Time points for collection were baseline (pre-1 hour), post 1h, 48h, 72h, 96h, and 144h post-simulated game of Rugby Union. To analyse and interpret data from this repeated measures design, both omnibus and univariate analyses were applied, and these results are presented consecutively in this section (Table 5.1).

Table 5.1 Mean scores across dependent variables

	Base Line		Post 1h		Post 48h		Post 72h		Post 96h		Post 144h	
	ẋ	SD	ẋ	SD	ẋ	SD	ẋ	SD	ẋ	SD	ẋ	SD
Flex												
Control	8.94	7.19	7.94	7.06	9.56	6.01	9.00	6.16	9.25	4.80	10.88	5.25
CWI	12.50	8.05	12.00	7.91	13.44	6.76	13.50	7.37	13.88	7.08	13.06	6.41
Contrast	10.31	9.50	9.94	9.82	9.75	8.24	11.13	8.10	10.13	8.76	11.38	8.25
DOMS												
Control	40.68	7.92	30.92	4.58	32.38	5.74	38.34	6.63	32.60	7.92	33.27	5.33
CWI	38.98	8.65	28.98	7.91	33.62	5.60	34.07	2.88	33.28	3.97	28.92	3.97
Contrast	45.03	7.60	30.83	4.16	29.97	6.56	32.88	4.04	32.42	4.07	26.88	7.08
Circumf												
Control	56.13	3.10	56.50	3.27	56.69	4.31	56.25	4.33	57.63	4.45	57.06	4.81
CWI	57.31	4.17	57.81	4.57	58.06	4.29	58.88	4.29	60.31	5.21	59.63	5.36
Contrast	56.50	6.52	56.69	6.77	57.94	5.49	58.75	6.32	59.63	6.45	58.94	5.50
CMJ												
Control	1.27	0.38	1.16	0.42	1.30	0.56	1.41	0.85	1.37	0.93	1.10	0.33
CWI	1.39	0.53	1.18	0.53	1.32	0.49	1.29	0.52	1.29	0.39	1.19	0.36
Contrast	1.15	0.40	1.01	0.33	1.08	0.27	1.18	0.30	1.06	0.25	1.04	0.23

Note CWI = cold water immersion; DOMS = delayed onset muscle soreness, measured on a Chatillon gauge with VAS, where higher scores represent greater muscle soreness; Flex = flexibility as measured in a sit-n-reach measured in cm; Circumf = measuring swelling in the upper leg circumference brought about by osmotic fluid shift, where higher scores represent greater swelling; CMJ = countermovement jump measured on a portable force platform reported as a ratio of body weight

Given there were differences in pre-test scores both between individuals and between groups, a univariate ANCOVA analysis was therefore conducted using baseline scores as covariates. Significant differences in muscle soreness (DOMS) between groups were identified at 1h ($p = 0.05$) and 48h ($p = 0.002$), and limb circumference (CIRCUMF) 1h, 48h, 72h, 96h, and 144h post (all comparisons $p = 0.000$). Significant differences were also identified for flexibility (FLEX) between groups at 1h, 48h, 72h, 96h, and 144h post (all comparisons $p = 0.000$) (Table 5.2).

Table 5.2 Analysis of covariance table comparing 144h against 96h post

	Sig. Dif	S.D±	x̄ Dif	η_p^2.
CWI Vs Control				
CMJ	0.42	0.36	0.12	0.04
Flexibility	0.01*	6.41	-2.14	0.33#
Circumference	0.92	5.36	0.07	0.00
DOMS	0.15	3.97	-4.25	0.21#
Control Vs Contrast bath				
CMJ	0.65	0.23	-0.32	0.04
Flexibility	0.65	8.25	-0.32	0.33#
Circumference	0.98	5.50	0.02	0.00
DOMS	0.04*	7.08	-6.42	0.21#
CWI Vs Contrast Bath				
CMJ	0.49	0.36	0.10	0.04
Flexibility	0.02*	6.41	-1.82	0.33#
Circumference	0.95	5.36	0.05	0.00
DOMS	0.46	3.97	2.16	0.21#

Note *Significant difference between 144h post scores and 96h post scores. # Identifies a large effect identifying a strong association between time points and group membership

Dependent variables evaluating muscle function for power were CMJ and 10m and 40m sprint times. Significant differences were identified for CMJ at 1h and 48h ($p = 0.000$), 72h ($p = 0.007$), 96h ($p = 0.005$) and at 144h post ($p = 0.007$). Because of technical malfunctions including high dew levels interfering with sensor beams and connection points on timing gates, sprint times at 48h were not available. With available sprint times, significant differences were identified for 10m sprint times at 72h and 96h post ($p = 0.000$) and 144h post ($p = 0.01$). For 40m sprint times significant differences were identified at 72h, 96h, and 144h post ($p = 0.000$).

Table 5.3: Partial eta square values

	Post 1h	Post 48h	Post 72h	Post 96	Post 144h
CMJ	0.02	0.03	0.04	0.04	0.01
Flexibility	0.02	0.11	0.07	0.12#	0.01
Circumf	0.02	0.04	0.15#	0.09	0.09
DOMS	0.02	0.25#	0.23#	0.04	0.21#

Note # represents an effect size indicating large group association

Treatment interaction terms were small, suggesting that at the global level there was little variation between groups after the interventions. Across all dependent variables only 3 reported a significant difference. Between-group comparisons identified a significant difference for DOMS at 72h post (p = 0.03) and 96h post (p = 0.04) between control and contrast baths. Further significant differences were identified 48h post (p = 0.02) between cold water immersion and contrast baths (Figures 5.1–5.6).

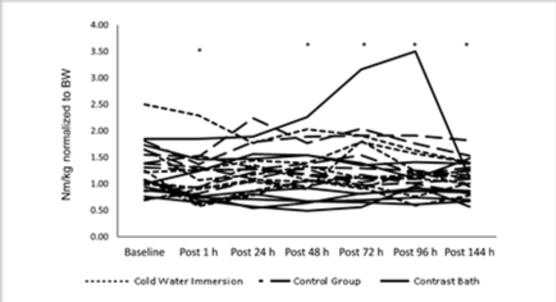

Figure 1. Change in peak force during countermovement jump performance (newton meter per kilogram) during the study. *Significant difference p . 0.005–0.000, no treatment interaction.

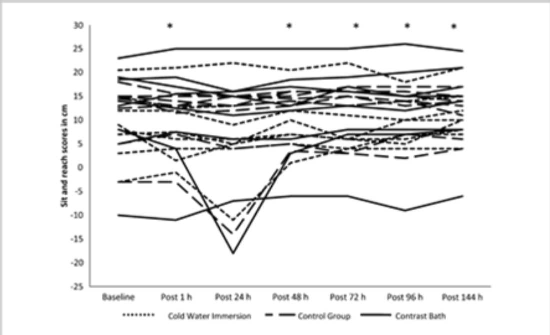

Figure 2. Change in sit-and-reach-flexibility (centimeters) during the study. *Significant difference p . 0.000, no treatment interaction.

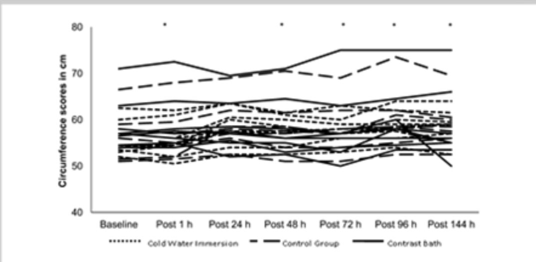

Figure 3. Change in peak thigh circumference (centimeters) during the study. *Significant difference p . 0.000, no treatment interaction.

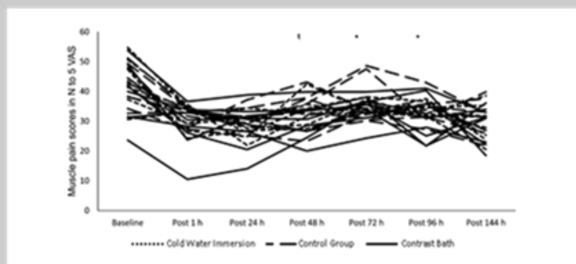

Figure 4. Change in muscle pain during the study. zSignificant difference CWI vs Contrast p = 0.02; *Significant difference Control vs Contrast p = 0.03 and 0.04.

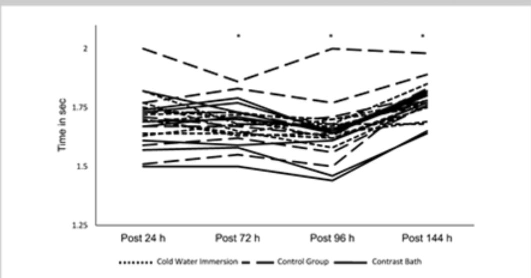

Figure 5. Change in 10-m sprint times during the study. *Significant difference p . 0.01, no treatment interaction.

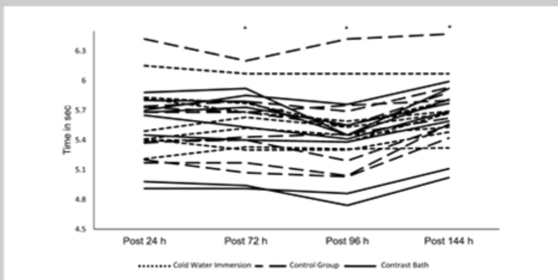

Figure 6. Change in 40-m sprint times during the study. *Significant difference p . 0.000, no treatment interaction.

An additional ANCOVA examining the relationship between each dependent variable with each time point acting as the covariate was conducted. Significant differences were identified leading to further post hoc analysis examining treatment interaction being conducted. A significant difference was reported for flexibility between 96h and 144h post (cold water immersion versus control, p = 0.01 and cold water immersion versus contrast bath, p = 0.02). In addition, DOMS reported a significant difference occurring at 48h and 72h post (cold water immersion versus contrast, p = 0.04 and control vs. contrast bath, p = 0.03). Furthermore, a significant difference was identified at 144h post (control vs. contrast baths, p = 0.04) (Table 5.4).

Table 5.4: Magnitude of change from base line scores (Cohen's *d*)

Treatment	Post 1h	Post 48h	Post 72h	Post 96h	Post 144h
Control					
CMJ	-0.28	0.08	0.39	0.28	-0.44
Flexibility	-0.14	0.09	0.01	0.04	0.27
Circumf	0.12	0.18	0.04	0.48	0.3
DOMS	-1.23	-1.05	-0.30	-1.02	-0.93
CWI					
CMJ	-0.39	-0.13	-0.17	-0.17	-0.36
Flexibility	-0.06	0.12	0.12	0.17	0.07
Circumf	0.12	0.18	0.38	0.72	0.56
DOMS	-1.16	-0.62	-0.57	-0.66	-1.16
Contrast					
CMJ	-0.35	-0.16	0.08	-0.22	-0.28
Flexibility	-0.04	-0.06	0.09	-0.02	0.11
Circumf	0.03	0.22	0.34	0.48	0.37
DOMS	-1.87	-1.98	-1.60	-1.66	-2.39

Note CWI = cold water immersion; DOMS = delayed onset muscle soreness; Flex = flexibility; Circumf = measuring swelling in the upper leg circumference; CMJ = countermovement jump.

To assist in quantifying training loads for statistical analysis, session RPE values were recorded 30 minutes post session and then multiplied with training times in minutes to determine AUs (Alexiou & Coutts, 2008). Univariate analysis did not identify significant differences between groups for the simulated game, or for the training sessions at 48h and 72h post. A significant difference was recorded between training sessions 72h and 96h post (p = 0.05) between cold water immersion and contrast baths (Figure 5.7).

Effect size analysis, through partial eta square (η_p^2), identified a large group association for changes from baseline scores for DOMS at 48h, 72h and 144h post. Furthermore, a large group association was also identified for circumference at 72h post and flexibility at 96h post. In relation to other time points, group association was reported to range from only small to medium (Table 5.3).

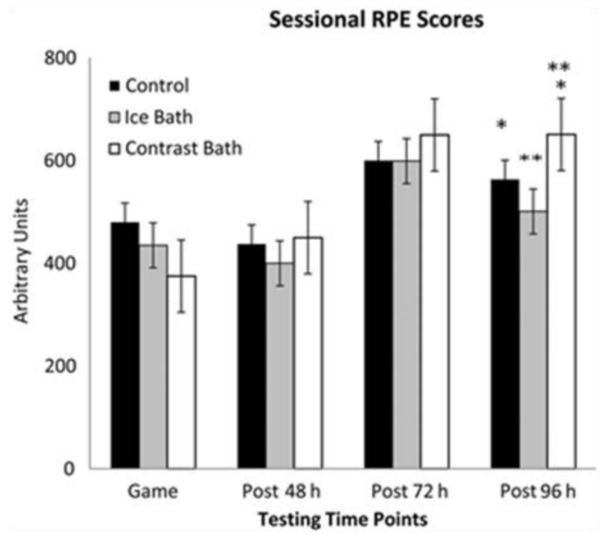

Figure 7. Change in sessional rating of perceived exertion scores during the study. Data are mean 6 SD. Sessional RPE scores recorded in arbitrary units (Arbitrary units = RPE multi Training time in min). *Significant difference between control group and contrast baths (p = 0.04). **Significant difference between cold water immersion and contrast baths (p = 0.05).

Further analysis examining the magnitude of change, via Cohen's *d*, across dependent variables are reported in Table 5.4. Baseline scores were defined as the control with 1h, 48h, 72h, 96h, and 144h defined as the treatment groups. Magnitude of change is indicative of the physical stressor, the simulated game and the three training sessions having on each dependent variable.

5.1.5 Discussion

The purpose of this research was to examine the efficacy of 2 common hydrotherapy protocols in promoting recovery from a simulated game and a traditional week of activity associated with Rugby Union. A search through the literature indicated a lack of conclusive results on the recovery protocols despite their common use in professional sporting competitions. Furthermore, research available to date has predominantly examined the acute response to hydrotherapy. With this research, it was expected to identify the efficacy of hydrotherapy as a recovery protocol in field sport across a traditional week of cyclic activity.

At the completion of the last training session (96h), the participants had a rest period of 48 hours coinciding with traditional schedules during competitive seasons. The final testing was scheduled to occur at normal game time. The results indicated that all 3 groups had showed levels of fatigue occurring after the simulated game and continuing fatigue associated with the intensive training held throughout the week. There was a level of residual fatigue still present at 144h regardless of recovery protocol adopted.

Flexibility was the only variable to report scores above baseline levels across all 3 groups at 144h. Scores across each variable indicated each group suffered an immediate deleterious response to scores after the simulated game. Thus, indicating the work load and intensity in the simulated game was sufficient to induce levels of fatigue. Regardless of recovery protocol adopted, all the groups showed trends toward recovery within 48 hours of the simulated game (Figures 5.1–5.6). However, this trend toward recovery was somewhat confounded during the training week as a result of continual physical stimulants been applied, in this case, squad training.

Results from this research support research into hydrotherapy for recovery (Dawson, et al., 2005; Ingram, et al., 2009). Indications are that neither treatments offer a significant response toward recovery over passive recovery when evaluated with traditional measures. Although significant differences were identified between groups in regard to DOMS at 3 time points and flexibility at 1 time point, these findings are insufficient to indicate one recovery protocol to be superior over another.

The large values for group association through η_p^2 are in-line with time points and variables, that indicated a significant difference. As the remainder of the η_p^2 values were between small and medium, again the indications are inconclusive as to identifying one protocol to be superior to another. Although large group associations were identified at 5 time points, there was no consistent pattern toward these results. As previously reported, these results fail to identify a trend toward one protocol over another as being more beneficial in recovery. When examining the effect of the game simulation upon each variable a detrimental effect was identified for CMJ, Circumf, Flex, and DOMS for each group immediately after the simulated game. All variables reported trivial effects with the exception of DOMS, which reported large effects for each variable. Cohen's *d* values reported were trivial with each group reporting similar trends toward a return to base-line scores across the week, with the exception of DOMS, which continued to report large effects across the week regardless of treatment.

However, in regard to trends reflected by Cohen's *d* for DOMS, both control group and CWI group reported an improvement in DOMS scores across the week indicating trends with the final tests at 144h returning faster toward scores at 1h. Cohen's *d* for the contrast baths group DOMS were indicating a slower return to values reported at 1h. This may indicate a greater level of muscle pain still been recorded by the contrast bath group as a result of the effect of the training week and simulated game. Muscle soreness scores indicate that the level of muscle soreness remained 20% below baseline scores for the control group and 24% below baseline scores for the CWI group after the weekly schedule. With regard to the contrast bath group, the DOMS readings indicated that scores were 40% below baseline values after the completion of the weekly cycle. With a substantial difference in muscle soreness reported between both the control group and CWI and the contrast bath group, these findings suggest that contrast baths were least effective in attenuating the effects of DOMS across a weekly cycle, which included a simulated game and squad training.

These findings are in contrast to those of previous research into recovery from simulated team sport (Ingram, et al., 2009). Ingram et al. (2009) reported that contrast baths facilitated a greater reduction in muscle soreness 24h exercise. However, the difference between timeframes between this study and that of Ingram et al. (2009) (24h and weekly) may explain the contrasting findings with regard to DOMS.

With the CMJ, an indicator of lower body power, the control group and CWI group reported a 13% decrease in mean scores with the contrast bath group reporting a decrease of 10%. In contrast, previous research investigating recovery from simulated team sport (Ingram, et al., 2009) identified cold water facilitating a more rapid return to isometric forces in the legs (Ingram, et al., 2009). The conflicting results may be a result of differing testing protocols with the use of a functional power test with a CMJ in this research as opposed to Ingram et al.'s use of an isometric test. It is the authors' opinion that a functional test is more relevant as a measure for sporting performance. Of interest during the period from the last training session (96h) to the scheduled next game testing (144h) the control group reported a greater decrease in performance in comparison with both treatment groups. The control group reported a 20% decrease in CMJ compared to CWI (5.5%) and contrast baths (3%).

Circumference measurements of the upper thighs demonstrated similar patterns across all 3 groups (Figure 5.3). These measurements have previously been used to identify osmotic fluid shifts associated with muscle damage attributed to exercise (Vaile, Halson, Gill, & Dawson, 2007b). At only 1 time point was there any notable difference between circumference measurements between groups, at 72h a notable although non-significant ($p = 0.08$) difference between contrast baths and the control group. Contrast baths did display a larger increase in circumference measurement in comparison to the other 2 groups. At the same time point, indications are that the control group had a slight improvement in the osmotic fluid shifts, as displayed by a decrease in circumference measurements, at all other time points, similar trends were reported.

Partial eta squared indicated the recovery treatment had small to large effects on osmotic fluid movements (η_ρ^2 = 0:02, 0:15, 0:09). The link to group association by η_ρ^2 is more a reflection that contrast baths had less of an effect on osmotic fluid than other groups offering a more beneficial response.

Session RPE scores as reported in AU identified a significant difference at 96 hours ($p = 0.015$); further pair-wise analysis identified differences between cold water immersion and contrast baths and the control group and contrast baths (Figure 5.7). Although all the subjects under-went the same squad training with equivalent workloads, as one group, across the 3 training sessions the contrast bath group consistently reported a greater perception of exertion culminating with the significant difference at 96h. As with this research, Rowsell et al. (2009) reported that cold water immersion enhanced players perception of leg soreness ($p = 0.004$) and general fatigue ($p = 0.007$) after successive days of competition. The similar findings in both of these studies lead to stronger support for cold water immersion aiding in players perception of exertion during successive days of high-intensity activity.

This may be of great importance for coaches and trainers in team sport. With professional Rugby Union, coaching staff operate on a balance of fitness training, strength training, skill acquisition and team play in preparation for competition. This results in multiple training sessions across the week throughout a competition. If players' perception of back to back, high-intensity sessions can benefit from cold water immersion, players maximum adherence to training tasks may also be maintained.

In percentage terms, the contrast groups' perception of the intensity of work load during squad training sessions was 25% greater than that of the CWI group and 10% greater than that of the control groups. The relevance of these findings may lie in the motivation of the participants at training and their perception of the given task. If player's physical load is governed by their perception of exertion while they train, their ability to train at an optimal level may be compromised, if this was to continue throughout the season a situation of ineffectual training by players could eventuate with players subsequent fitness levels falling and with it subsequent game performance.

Mechanisms behind cold water immersion benefitting recovery have been previously reported (Ingram, et al., 2009) and include a reduction in oedema, neutrophil migration, cell necrosis, and a decrease in cell metabolism. As a result of cold water immersion, the symptoms of DOMS were able to be alleviated to a greater extent than contrast baths. Although the reported mechanisms behind contrast baths may be theoretically possible, which includes aiding removal of metabolic waste products through enhancing the muscle pump via vasoconstriction and vasodilatation, it may be that the time immersed whilst alternating between baths is insufficient to bring significant changes in muscle tissue temperature that would be required to aid in vasoconstriction and vasodilation.

The purpose of this research was to evaluate whether either cold water immersion or contrast baths, would be more beneficial than passive recovery as treatment protocols for recovery from a simulated game of Rugby Union and a week of high-intensity training. Although the results are inconclusive between cold water immersion and passive recovery this study would indicate that contrast baths have little benefit in enhancing recovery from a simulated game of Rugby Union and weekly training. Trends indicated that contrast baths proved to be less effective than either cold water immersion or passive recovery in attenuating the effects of leg muscle pain after a cycle weekly activity including a simulated game of Rugby Union and a week of high-intensity training.

Further, if a player’s perception of exertion at training is greater than levels coaching staff have assigned to the session, the player may not be able to generate the motivational drive to perform at the required levels. If participants are unable to train at the designated training intensity, generating the optimal levels of a physiological response to enhance and/or maintain athletic performance then performance levels may be compromised. Generally coaches and trainers design training regimes to meet the requirements of their current competition and if participants underperform at training because of physiological or psychological reasons, resulting athletic performances may be adversely affected.

The absence of a clear indication as to the benefits of hydrotherapy for recovery as measured by traditional one off measurements is in support of previous research into recovery from a simulated team sport (Ingram, et al., 2009). Ingram et al. (2009) discuss the ability of well-trained athletes to generate near maximal exertions in one of tests. The use of a one off maximal test has traditionally been used to measure recovery of neuromuscular function after performance in laboratory based research. However, in field sport, one off maximal test may not reflect requirements of athletes. Field sports generally require multiple, maximal repeat efforts, as such testing that is more reflective of game situations and performances may be better equipped to identify athletes level of recovery.

5.1.6 Practical applications

During competitive seasons, athletes undergoing high-intensity fitness training across consecutive days and then conducting 2 x 5 minute cold water immersion after each session may be provided with relief from DOMS and their overall perception of exertion at training in comparison to contrast baths. This would allow for coaches and trainers to apply fitness stimulants with an overall intensity high enough to maintain physical performance. However, the further use of contrast baths for recovery across a cyclic week of Rugby Union needs to be questioned, as indications are that contrast baths offer little benefit in recovery from high-intensity team sport.

Although aiding muscle pump function has been discounted, this would not explain why contrast baths were less effective for recovery than the control group, specifically in regards to DOMS. It has been proposed that short durations of immersion in cold water may increase free-radicals production (Bleakley & Davison, 2010). An increase in free-radicals production above physiological protection and repair mechanisms has been reported to lead to oxidative stress (Bleakley & Davison, 2010). Furthermore, in the event of increasing levels of oxidative stress, subsequent increases in muscle stress would occur. As oxidative stress occurs as a result of aerobic and anaerobic exercise, to induce additional oxidative stress during recovery would delay the recovery process (Bleakley & Davison, 2010). Bleakley and Davison (2010) reported the increase in free-radicals production was associated with immersions of less than three minutes. In our research contrast bath immersions included five by one minute immersions, alternating from hot and cold. With the continuing exposure to short durations of CWI, free-radicals production and subsequent increases in oxidative stress would have led to greater stress on muscle than the exercise activity alone. The increase in stress on muscle in the contrast bath group would then have increased the inflammatory response. This increased inflammatory response may be the mechanism explaining the higher scores for DOMS in the contrast bath group compared to both CWI and control groups.

5.1.7 Acknowledgments

This research was completed as part of a doctoral degree at the Australian Catholic University and was funded entirely by that university. Trevor Higgins was supported by an Australian Postgraduate Award (scholarship).

5.1.8 References

Alexiou, H., & Coutts, A. J. (2008). A comparison of methods used for quantifying internal training load in women soccer players. *International Journal of Sports Physiology & Performance*, *3*, 320-330.

Atkinson, G. (2007). What's behind the numbers? important decisions in judging practical significance. *Sportscience*, *11*, 12-15.

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology & Performance*, *1*(1), 50-57.

Bleakley, C. M., & Davison, G. W. (2010). What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. British Journal of Sports Medicine, *44*(3), 179-187.

Cohen, J. (1990). Things I have learned so far. *American Psychology*, *45*, 1304-1312.

Dadebo, B., White, J., & George, K. P. (2004). A survey of flexibility training protocols and hamstring strains in professional football clubs in England. *British Journal of Sports Medicine, 38*, 388-394.

Dawson, B., Gow, S., Modra, S., Bishop, D., & Stewart, G. (2005). Effects of immediate post-game recovery procedures on muscle soreness, power and flexibility levels over the next 48 hours. *Journal of Science & Medicine in Sport, 8*(2), 210-221.

French, D. N., Thompson, K. G., Garland, S. W., Barnes, C. A., Portas, M. D., Hood, P. E., et al. (2008). The effects of contrast bathing and compression therapy on muscular performance. *Medicine & Science in Sports & Exercise, 40*(7), 1297-1306.

Heyman, E., De Geus, B., Mertens, I., & Meeusen, R. (2009). Effects of four recovery methods on repeated maximal rock climbing performance. *Medicine & Science in Sports & Exercise, 41*, 1303-1310.

Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science & Medicine in Sport, 12*(3), 417-421.

Kinugasa, T., & Kilding, A. E. (2009). A comparison of post-match recovery strategies in youth soccer players. *Journal of Strength & Conditioning Research, 23*(5), 1402-1407.

Montgomery, P. G., Pyne, D. B., Hopkins, W. G., Dorman, J. C., Cook, K., & Minahan, C. L. (2008). The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *Journal of Sports Sciences, 26*(11), 1135-1145.

Reilly, T., & Ekblom, B. (2005). The use of recovery methods post-exercise. Journal of Sports Sciences, 23(6), 619-627.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal of Sports Sciences, 27*(6), 565-573.

Sellwood, K. L., Brukner, P., Williams, D., Nicol, A., & Hinman, R. (2007). Ice-water immersion and delayed-onset muscle soreness: A randomised controlled trial. *British Journal of Sports Medicine, 41*, 392-397.

Stoove, M. A., & Andersen, M. B. (2003). Research without tears; What are we looking at, and how big is it? *Physical Therapy in Sport, 4*, 93-97.

Vaile, J., Gill, N., & Blazevich, A. J. (2007). The effect of contrast water therapy on symptons of delayed onset muscle soreness. *Journal of Strength & Conditioning Research, 21*(3), 697-702.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2007). Effect of hydrotherapy on recovery from fatigue. *International Journal of Sports Physiology & Performance, 29*, 539-544.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008). Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. *Journal of Sports Sciences, 26*(5), 431-440.

Yanagisawa, O., Niitsu, M., Takahashi, H., Goto, K., & Itai, Y. (2003). Evaluations of cooling exercised muscle with MR imaging and PMR spectroscopy. *Medicine and Science in Sports and Exercise, 35*(9), 1517-1523.

Chapter 6

6.1 Evaluation of passive recovery, cold water immersion, and contrast baths for recovery, as measured by game performances markers, between two simulated games of Rugby Union.

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6.1.1 Abstract

Higgins, T. R., Cameron, M., & Climstein, M. (In Press). Evaluation of passive recovery, cold water immersion, and contrast baths for recovery, as measured by game performances markers, between two simulated games of rugby union. *Journal of Strength and Conditioning Research*, X(X), XX. In team sports, during the competitive season, peak performance in each game is of utmost importance to coaching staff and players. To enhance recovery from training and games a number of recovery modalities have been adopted across professional sporting teams. To date there is little evidence in the sport science literature identifying the benefit of modalities in promoting recovery between sporting competition games. This research evaluated hydrotherapy as a recovery strategy following a simulated game of Rugby Union and a week of recovery and training, with dependent variables between two simulated games of Rugby Union evaluated. Twenty-four male players were randomly divided into three groups: one group (n=8) received cold water immersion therapy (2 X 5 min at 10^{o}C), whilst one group (n=8) received contrast bath therapy (5 cycles of 10^{o}C/38^{o}C) and the control group (n=8) underwent passive recovery (15 mins, thermoneutral environment). The two forms of hydrotherapy were administered following a simulated Rugby Union game (8 circuits x 11 stations) and after three training sessions. Dependent variables were generated from five physical stations replicating movement characteristics of Rugby Union and one skilled based station, as well as session RPE values between two simulated games of Rugby Union. No significant differences were identified between groups across simulated games, across dependent variables. Effect size analysis via Cohen's d and ηp2 did identify medium trends between groups. Overall trends indicated that both treatment groups

had performance results in the second simulated game above those of the control group of between 2% and 6% across the physical work stations replicating movement characteristics of Rugby Union. In conclusion, trends in this study may indicate that ice baths and contrasts baths may be more advantageous to athlete's recovery from team sport than passive rest between successive games of Rugby Union.

6.1.2 Introduction

It has been postulated by sports scientists from the Australian Institute of Sport, professional coaches and strength and conditioning trainers, that recovery is an important factor in athletic performance, and that optimal recovery may prevent underperformance (Kellmann, 2002). For athletic performance to be maintained throughout a season, an optimal balance between training load and recovery is essential (Tessitore, Meeusen, Pagano, et al., 2008). Training generates overload, with the sport science community utilizing the overload principle to induce improvements in performance; however, overtraining often results in athletic breakdown (Bishop, et al., 2008). If the recovery rate could be improved, greater training volumes would be feasible without the negative impact of overtraining (Bishop, et al., 2008).

A review of the current literature on recovery from team sport has generally shown that recovery is evaluated through all-out tests and biochemical markers (Ingram, et al., 2009; Rowsell, et al., 2009; Vaile, Gill, et al., 2007; Vaile, et al., 2008a). However, recent research (Bishop, et al., 2008; Ingram, et al., 2009) has identified that well-trained athletes may have sufficient motivational drive to be able to perform at near-maximal levels in one-off tests regardless of the state of fatigue (Bishop, et al., 2008; Ingram, et al., 2009). More importantly, it is not always possible to translate laboratory observations to real life competitive situations (Tessitore, et al., 2008).

The most important variable in evaluating sport is performance (Bishop, et al., 2008). Therefore, when examining recovery modalities, researchers should concentrate on actual sporting performance (Bishop, et al., 2008). However, this in itself brings about a series of complications as team field sports are of an intermittent nature, with random, discrete bouts of activity varying both in intensity and duration throughout match-play (Stagno, Thatcher, & Van Someren, 2006). The intensity and therefore load during match-play differs considerably between playing positions and between games (Stagno, et al., 2006).

There have been limited studies which have evaluated hydrotherapy and its effect on performance in team sports (Ingram, et al., 2009; Rowsell, et al., 2009). In these studies, the researchers were able to evaluate the acute response of recovery. However, it is essential for research to examine the cycle of weekly activity in competition, particularly in reference to residual fatigue (Reilly & Ekblom, 2005). In addition, to date there is a scarcity of literature available on recovery from competitive Rugby Union (Gill, et al., 2006), particularly regarding hydrotherapy. Therefore, it is the purpose of this research to evaluate the benefits of two forms of hydrotherapy. The research evaluated performance between two simulated games of Rugby Union across a cyclic week of activity, which included three training sessions.

The aim was to identify if hydrotherapy as a recovery modality was beneficial towards game performance across successive games. Based upon findings in previous research, it was hypothesised that cold water immersion would be more beneficial for recovery than either contrast baths or the non-intervention control, as measured in performance across two games of simulated Rugby Union and three weekly training sessions between games.

6.1.3 Method

6.1.3.1 Experimental Approach to the Problem

Despite the widespread use of cold water immersion (CWI) as a post-match recovery protocol in Rugby Union, there is relatively little evidence supporting its use. Performance indicators from two simulated games of Rugby Union were used to address the null hypothesis, that neither cold water immersion nor contrast baths would be beneficial for recovery. The current between groups study examined the effect between two recovery interventions and a control had on performance in six physical and one skill based stations.

The benefit of measuring changes in sporting performance is to allow coaches and athletes to make decisions on recovery modalities by identifying how different recovery modalities will directly affect sporting performance. This has been supported by Bishop et al. (2008), who stated that in the sporting community, it is the performance in competition that is of the upmost importance to both coaches and athletes (Bishop, et al., 2008). The aim of this study was to determine the effectiveness of cryotherapy as recovery from Rugby Union for Rugby Union coaches and highly trained players.

6.1.3.2 Subjects

This study was performed on well-trained male participants (n=24) from an under-20 Rugby Union team (mean ± standard deviation, age 19.5±0.8y, body mass 82.4±11.1kg, height 179±6cm). The study was conducted after 26 weeks of training which included 10 weeks of pre-season training (5.5 h/3 sessions-weekly), followed by 16 weeks of the scheduled 22 week competition (6.5 h/3 sessions-weekly).

Pre-season training included two weekly training sessions, Saturday beach sessions first six weeks) and trial games (weeks 7-9). Training sessions were structured to include a 15 minute warm-up followed by 40 minutes (first six weeks) and 20 minutes (weeks 7-10) of conditioning. Conditioning focused on speed and acceleration running drills, contact drills and small sided games. Work to rest ratio ranged from 1: 2-3 (first six weeks) to 1:1 and 2:1 (weeks 7-10). After the conditioning phase, training of rugby skill sets became the focus. Intensity of the conditioning elements ranged between 75% HRmax to 95% HRmax. Skill set drills intensity ranged between 50% HRmax to 70% HRmax.

Beach sessions were structured around conditioning elements only. Each session commenced with a 15 minute warm up followed by 70 minutes of conditioning. The conditioning included speed and agility drills, wrestling drills, small sided games and team based relay shuttles. Intensity of the beach sessions ranged between 70% HRmax to 90% HRmax with a work to rest ratio of 1:3.

After six weeks, the beach training sessions were replaced with trial games of Rugby Union for three weeks. The last Saturday before the competition commenced was a scheduled rest day to mark the end of pre-season training. Trial games were played with standard laws of the game applying. However the first two trials were played with 20 minute periods. Players would rotate throughout the day, with most players competing in three 20 minute periods. The third trial was played under standard laws with 30 minute periods. Players would rotate throughout the day, with majority of players competing in two 30 minute periods.

During the competition phase, two training sessions were conducted during the week. Training sessions were structured to include a 10 minute warm-up followed by a conditioning period of between 10 minutes and 20 minutes. Conditioning sessions would vary between sprint work and small sided games. Intensity of conditioning elements would range between 85% HRmax and 100% HRmax, with a work to rest ratio ranging from 1-3:1. The remainder of the training sessions were structured around skills, Rugby Union units, team play and semi-opposed runs. Intensity would range from 50% HRmax to 85% HRmax. Volume of training throughout pre-season ranged from 6000 m to 7200 m and throughout the competition phase of the season ranged from 6000 m to 6500m.

Participants had no history of musculoskeletal injury in the previous four weeks prior to participating in the study. All the subjects were free of illness during the testing period. Each participant signed an informed consent form prior to taking part in the study, which was approved by The Australian Catholic University's Human Research Ethics Committee (N200708-24). We excluded from our participant pool players who were involved in labour-intensive jobs, as well as those who had either been injured or suffered an illness prior to or during the study period.

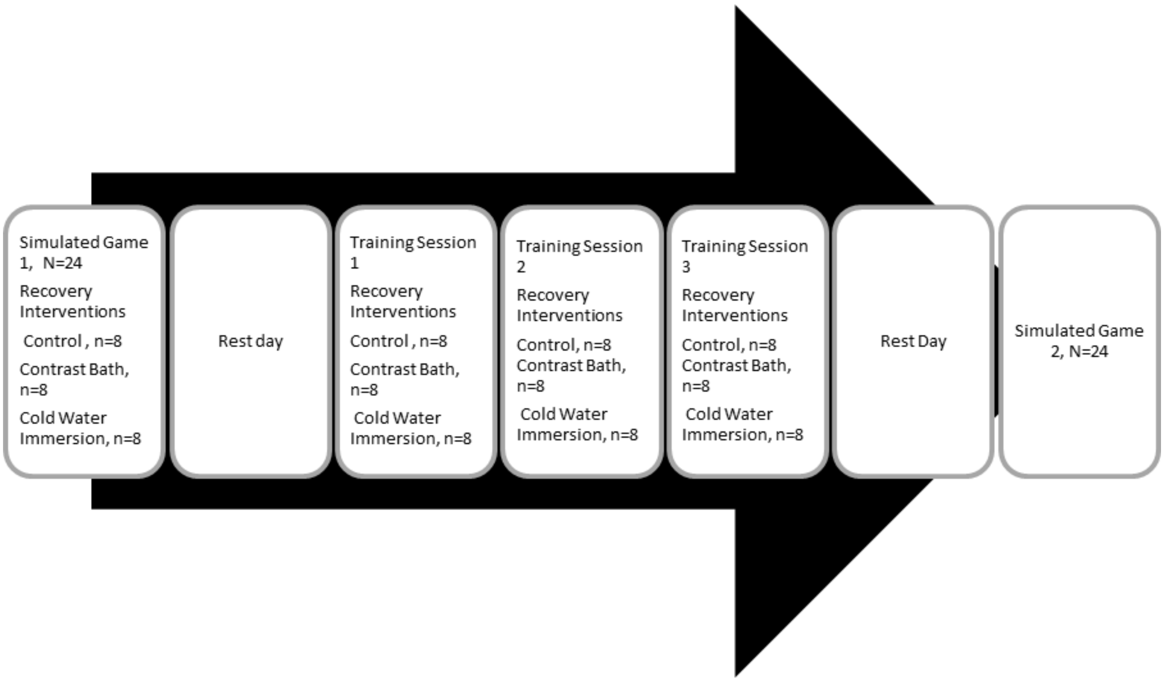

Figure 6.1 Research methodology and design

The study included two simulated games of Rugby Union six days apart during the competition and included three training sessions and was conducted over six consecutive days (Figure 6.1). The simulated games were conducted during the team's regularly scheduled game times 15:00 hours to 16:30 hours. The training sessions were conducted at the teams scheduled training time 18:30 hours to 20:00 hours.

Prior to the first simulated game, participants performed the team's standardised pre-game warm-up conducted prior to competition games. The warm-up commenced with a dynamic walking lunge for 25 metres followed by a walking sumo squat for 25 metres. Dynamic flexibility exercises were then performed consisting of butt kicks, high knees, lateral steps, fast feet and finally cross-overs. Participants then performed 10 swing throughs and 10 swings across on each leg. In addition, participants performed dynamic groin lunges and calf pumps. In total, the warm-up duration was 25 minutes.

The simulated game adopted for this study has previously been defined (Hamlin, et al., 2008; Stuart, et al., 2005). Two simulated games were adopted due to the nature of individual games and the varying workloads associated with each game. As each game of Rugby Union is totally independent from any previous or future game of Rugby Union, and different positions have different roles and work outputs, the circuit allowed for control of each participant's work output.

Dependent variables used included scores from each working station in the simulated game. Times at each sprinting station were recorded (Swift Performance, Sydney Australia), and heart rate was accessed via telemetry with each participant wearing a polar heart rate monitor (Polar USA, Inc., Montvale, NJ). Mean heart rate and peak heart rate values for both simulated half's and mean heart rate for the entire simulated game were recorded.

The simulated game consisted of 11 stations set up as a circuit. Stations included straight line sprints, defensive sprints, attacking sprints, power output in a rugby specific action (hit and drive), tackling and passing skills. Additionally; the circuit included three rest stations (Table 6.1). Participants performed the task at each station, then immediately progressed to the next station. The participants completed four circuits, which equated to one half of a Rugby Union game, prior to having a 10 minute break followed by completion of the circuit another four times, equating to the second half of a Rugby Union game.

Table 6.1 Station descriptors for simulated game of Rugby Union

Station identification Number	Station Task
Station 1	20 metre straight sprint
Station 2	22 metre swerving sprint with tackle
Station 3	Rest and hydration station
Station 4	Hit and drive X 2
Station 5	Rest and hydration station
Station 6	Defensive up, slide and back run, 3 times
Station 7	Rest and hydration station
Station 8	Multiple task defensive station
Station 9	Skill station, passing
Station 10	30 metre straight sprint
Station 11	Walking recovery return to station 1

Note: participants move from station to station, performing the stated task, every 30 seconds

Trial runs for familiarisation were conducted through the circuit on four occasions in the preceding two weeks. Each station was manned by two trained researchers who assisted with data collection at each station. Researchers were tasked with operating the timing gates as well as recording the scores obtained by each participant throughout the simulated game of Rugby Union. At completion of the simulated game of Rugby Union, participants were randomly assigned through blind allocation to one of three recovery protocols, cold water immersion, contrast baths and passive recovery (control group).

Cold water immersion has previously been identified as the most common method used for recovery in the Australian Rugby Championship (Higgins & Heazlewood, 2008). Participants were asked to climb into the cold water immersion and assume a seated, upright position. Water depth was individualized to the superior iliac spines (Sellwood, et al., 2007), with a temperature range of between 10-12^{o}C (Ingram, et al., 2009; Vaile, et al., 2008a). Participants underwent two x five minute immersions in the cold water immersion, separated by two and half minutes seated out of the baths at room temperature (Ingram, et al., 2009).

The contrast bath protocol involved alternating from cold water baths (temperature range 10-12^{o}C) to warm water baths (temperature range 38-40^{o}C) for 60 seconds in each. Participants performed a total of five cycles in each bath for a total of 10 minutes recovery and approximately 75-90 seconds out of the baths (Ingram, et al., 2009). Cold water immersion and warm water baths were adjacent to one another. Participants stepped from the cold water immersion to the adjacent hot water bath every minute. The researcher monitored the time and instructed participants to change recovery conditions with the use of a standard stop watch (Seiko, Japan).

Baths used were 220-litre commercial storage tubs, with the temperatures continually monitored with floating temperature gauges with ice and hot water added when temperatures rose to 11.5^{o}C (cold water immersion) or fell to 38.5^{o}C (warm water baths). The control group initiated a passive recovery strategy involving remaining seated for 15 minutes in thermoneutral rooms.

A second simulated game commenced 144hrs after the first game simulation; the protocol previously stated and used in the first simulated game of Rugby Union was repeated for the second simulated game of Rugby Union.

6.1.3.3 Statistical Analysis

All statistical analyses were completed using SPSS (ver 17.0), which included between-group and within-group analyses. To examine the effects of recovery strategies on game performances dependent variables from the first and second simulated games were analysed. The dependent variables included mean heart rates for the simulated first half and second half as well as mean heart rate for entire simulated games. Additional dependent variables included total scores calculated in seconds for each individual station, with the use of timing gates. There were six stations in total which provided data for statistical analysis. The stations included station 1 (20 metre sprint), station 2 (22 meter swerving sprint and tackle), station 6 (sliding defence pattern), 8 (defensive drill including multiple tackles and shuttle run) and station 10 (30 meter sprint). Effect of fatigue on skill was assessed using passing scores from station 9.

In addition to scores from individual stations, analysis of overall work output was also analysed. Dependent variables included mean scores for total work output (secs) across the two simulated games (stations 1, 2, 6, 8. 10), as well as total work output from the first half and total work output from second half (mean scores). In addition, Session RPE values calculated into arbitrary units (AU) (Alexiou & Coutts, 2008; Impellizzeri, et al., 2004; Wallace, et al., 2008) were also analysed. Statistical power was calculated at 0.60 for a sample size of N = 24, with an alpha level of 0.05 and an effect size of 0.8. Independent variables for weekly cyclic activity included contrast baths, cold water immersion and a control group undergoing passive recovery.

To eliminate initial differences at pre-test levels, based on participant scores, ANCOVA tests were conducted on the second simulated game scores as the dependent variable; the between-group factors were the treatments and the scores from the first simulated game were defined as the covariate. Additional analysis through effect sizes (Cohen's *d* and η_p^2) were also conducted to identify in detail outcomes based on treatment effects.

6.1.4 Results

To verify work intensities between groups throughout the simulated games, mean heart rates and blood lactate levels were recorded. There was no significant difference in mean scores for heart rates, between groups in either of the simulated games (Game 1; sig dif p= 0.21, Game 2; sig dif p= 0.44). Heart rate mean scores as a percentage of peak heart rate for simulated game 1 were, cold water immersion 73%HRpeak, contrast baths 74%HRpeak, control 77%HRpeak. Heart rate mean scores as a percentage of peak heart rate for simulated game 2 were, cold water immersion 81%HRpeak, contrast baths 79%HRpeak, control 78%HRpeak. Blood lactate scores also indicated there was no significant difference between groups in either of the simulated games. With no significant differences between groups during the simulated games, the researchers were able to analyse results of tests with the view that any differences identified were a result of interventions applied in this study.

As pre-test scores were different, a Univariate ANCOVA analysis was conducted, using baseline scores as covariates across dependent variables. No significant difference was identified for station 1, station 2, station 8, station 9 or station 10. Furthermore, no significant difference was identified between total work performed in the first half or second half or across the full game.

A significant difference was identified between the first simulated game and the second simulated game (Figure 6.2) for station 6 (p = 0.05). Pairwise analysis identified a significant difference between the control group and cold water immersion (p = 0.02). However, the significant difference only occurred in the first half and no significant difference was identified between contrast baths and cold water immersion or between contrast baths and control group.

Table 6.2 Total mean scores in secs, for each station across both simulated games

	Game 1				Game 2			
	First Half		Second Half		First Half		Second Half	
Station/Treatment	Ẋ	SD	Ẋ	SD	Ẋ	SD	Ẋ	SD
Stat 1 Control	13.64	0.99	13.53	1.26	13.15	1.14	13.33	1.27
Stat 1 CWI	14.84	0.65	15.03	0.94	14.3	0.64	14.04	0.62
Stat 1 Contrast	14.54	0.79	14.27	1	13.62	0.78	13.59	0.82
Stat 2 Control	25.33	2.26	24.77	2.12	22.24	1.32	21.69	1.65
Stat 2 CWI	27.03	1.34	26.99	1.67	23.5	1.34	22.97	1.67
Stat 2 Contrast	26.61	1.76	26.23	1.82	22.67	1.76	22.1	1.82
Stat 6 Control	43.17	3.78	41.01	3.73	43.86*	2.98	43.18	3.89
Stat 6 CWI	44.73	2.37	43.64	3.03	47.69*	3.00	45.4	2.65
Stat 6 Contrast	44.13	2.62	43.38	2.2	46.3	3.38	44.39	3.48
Stat 8 Control	39.69	3.95	38.88	3.37	42.92	3.86	42.54	4.29
Stat 8 CWI	43.02	2.38	44.68	3.38	15.71	2.74	44.6	2.88
Stat 8 Contrast	42.12	2.09	43.72	4.53	44.73	2.64	43.87	2.69
Stat 10 Control	18.96	1.32	18.85	1.59	17.95	1.47	18.16	1.34
Stat 10 CWI	20.45	0.85	20.8	0.73	19.64	0.74	19.67	0.72
Stat 10 Contrast	19.96	0.86	20.09	0.97	18.68	0.93	18.89	1.15

Note * ANCOVA analysis identified a significant difference (p = 0.02) with game 1 scores as the covariate

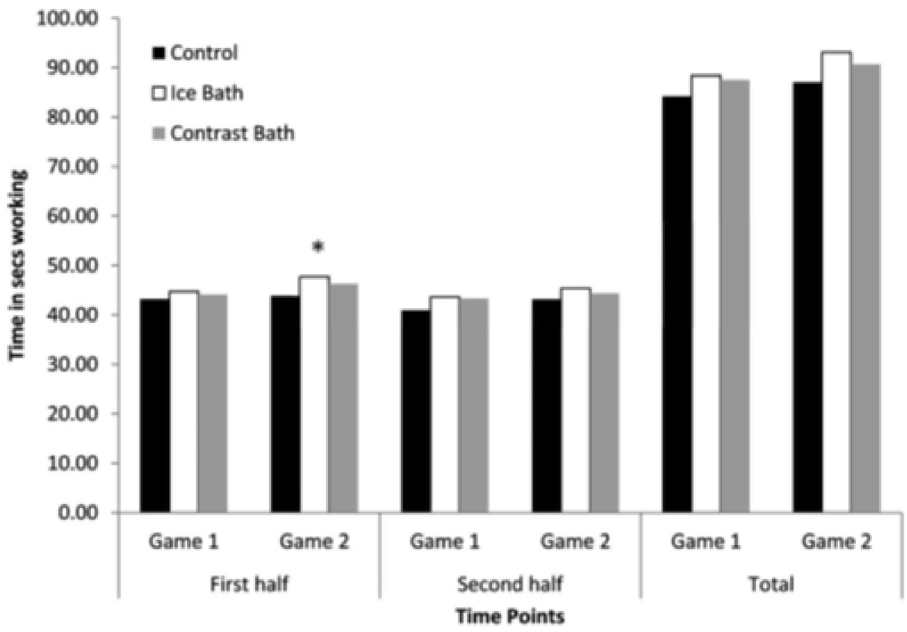

Figure 6.2 Mean times in seconds for station 6

Further analysis examining trends through effect sizes identified contrasting results across stations. Partial eta squared (η_p^2) indicated group association to show a wide range of scores from small to large. In addition, further contrasting results were identified with magnitude of change (Cohen's *d*) between simulated games 1 and 2. Cohen's *d* values ranged from large positive values to large negative values.

Table 6.3 Magnitude of effect across treatment groups (η_p^2/Cohen's *d*)

Stations	η_p^2			Control (*d*)			CWI (*d*)			Contrast baths (*d*)		
Time Points	1st	2nd	Tot	1st	2nd	Tot	1st	2nd	Tot	1st	2nd	Tot
Station 1	0.11	0.07	0.08	-0.49	-0.16	-0.32	-0.83	-1.05	-1.12	-1.16	-0.68	-0.92
Station 2	0.02	0.02	0.03	-1.37	-1.45	-1.51	-2.63	-2.41	-2.62	-2.24	-2.27	-1.56
Station 6	0.25	0.02	0.09	0.18	0.58	0.38	1.25	0.58	0.91	0.83	0.46	0.70
Station 8	0.02	0.02	0.01	0.82	1.09	0.98	1.13	-0.02	0.53	1.25	0.03	0.44
Station 9	0.04	0.01	0.01	-0.9	-0.86	-1.24	-2.11	-0.6	-1.44	-0.78	-0.57	-1.08
Station 10	0.12	0.03	0.08	-0.77	-0.43	-0.59	-0.95	-1.55	-1.24	-1.49	-1.24	-1.44

Note: η_p^2 small at < 0.02, medium at < 0.08 and large at > 0.12
Cohen's *d* trivial *d* = 0.02, medium *d* = 0.05, large *d* = 0.08 and greater than large *d* = 0.08

Session RPE scores were collated from both games and three training sessions conducted across the week. Although significant differences were found throughout the training, as previously reported in unpublished research, no significant differences were identified between Session RPE scores between simulated game 1 and simulated game 2.

Table 6.4 Changes in session RPE mean scores (AU) across weekly cycle

Treatment		Game 1	48h Post	72h Post	96h Post	Game 2
	Mean	480.00	437.50	600.00	563.50	465.00
Control	N	8	8	8	8	8
	S.D	192.43	140.79	106.90	140.31	76.90
	Mean	435.00	400.00	599.00	501.00	525.00
Ice Bath	N	8	8	8	8	8
	S.D	156.00	185.16	92.63	75.65	127.28
	Mean	375.00	450.00	650.00	651.00	420.00
Contrast Bath	N	8	8	8	8	8
	S.D	100.14	141.42	75.59	118.11	90.71
	Mean	430.00	429.17	616.33	571.83	470.00
Total	N	24	24	24	24	24
	S.D	153.91	151.74	91.76	126.21	105.67

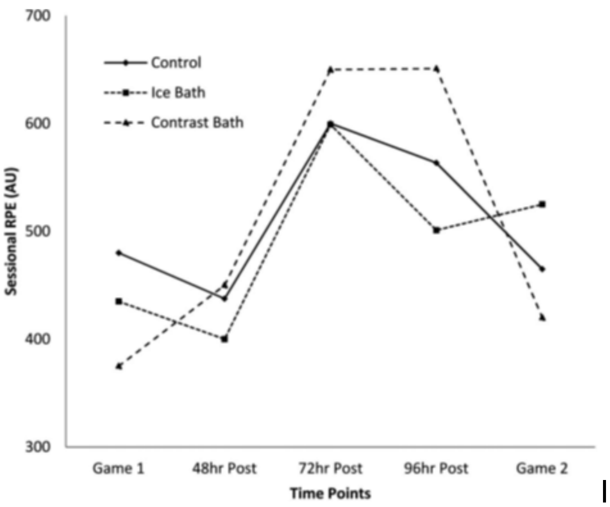

Figure 6.3. Session rating of perceived exertion trend lines across the weekly cycle of game and training activity

6.1.5 Discussion

This study evaluated the effects of cold water immersion and contrast water immersion on recovery from simulated team sport. Furthermore, although traditionally, recovery from fatigue in sport has used one-off maximal tests of power and speed and/or passive tests including DOMS and biochemical markers, this study assessed changes in measured performance indicators from the two simulated games of Rugby Union. In addition, to date most studies into recovery from sport/exercise have examined the acute response. This study was designed to examine recovery modalities across a cycle of weekly training activity and competition games, currently absent from the literature.

Firstly, only one time point showed a significant difference between treatments and performance. No other dependent variables reported significant differences between treatments. Furthermore, both the magnitude of change (Cohen's *d*) and level of group association (η_p^2) reported effect size trends of small to moderate for performance scores for each station.

The significant difference was identified in the multiple defensive sprint pattern station 6. Evaluation of station 6 identified that the cold water immersion group suffered a 6% decrease in performance from simulated game 1 to simulated game 2 in the first halves. In comparison the control group suffered a 1.6% decrease in performance between the first halves of simulated game 1 and simulated game 2.

However, this result was not repeated during the second half performance. The cold water immersion group suffered a 4% decrease in performance compared to a 5.3% decrease in performance for the control group. As the differences in performances between cold water immersion and the control group were not consistent, it is advised that examination of performances across the entire game be the deciding factor. With this in mind the total work for station 6 showed differences between all groups of only 1.5%. With each group showing decreases in performance for station 6 from simulated game 1 to simulated game 2.

Both treatment groups for station 1 reported improvements in performance from simulated game 1 to simulated game 2 of approximately 5.5%, whereas the control group reported an improvement of 2.6% between simulated games. Station 2 reported a similar trend with performance improvements by all three groups with the control group reporting an improvement of 14%, cold water immersion reporting one of 16.4% and contrast baths reporting an improvement of 18% between simulated groups. Station 8, a defensive pattern drill, reported decreases in performances similar to station 6. However, in station 8, the control group reported an overall decrease in performance of 8% across the entire game. Both treatment groups reported decreases in performance of only 3% across the entire game. The final station, station 10, reported improvements in performances across all groups of approximately 5-6%.

Of interesting note in this study, were the contrasting changes in performances between the two types of stations, single all-out maximal effort (stations 1, 2, 10) or multiple repeat effort (stations 6, 8). Each station that involved a single all-out maximal effort such as sprinting showed improvements in performance, between simulated games. In contrast, each station that involved repeated efforts or multiple tasks showed performance decrements between simulated games.

The contrasting results between the two types of stations may reflect the effect motivational drive has on participants. In a single all-out effort, the motivational factors may be sufficient to overcome levels of muscular fatigue. However, when multiple repeat efforts are called upon, impact of muscular fatigue may be the defining factor in performance, surpassing motivational aspects.

This trend of the level of group association with scores of total work conducted across two simulated games suggests that both cold water immersion and contrast baths offer more for recovery between games than conducting only a passive recovery of seated rest. The magnitude of change identified via Cohen's *d* identifies a similar trend. This trend includes improvements across each treatment group and control group at station 1, station 2 and station 10 and decreases in performance at station 6 and station 8.

Arbitrary Unit scores for Session RPE did not identify a significant difference between groups between simulated game 1 and simulated game 2. In addition, trend lines (Figure 6.3) identified similar patterns between groups. Partial eta squared did report a very large ($\eta_p^2 = 0.17$) group association with scores; however, this result needs to take into account the significant difference previously reported between training sessions. The large change in scores for contrast baths from 96hrs post simulated game 1 to simulated game 2 may reflect the large η_p^2 reported.

A number of limitations are evident in this study. Firstly, no biochemical markers were used, which is in contrast to the majority of published studies into recovery. However, there is little evidence in the available literature showing a link between the most common markers, including lactate and CK, a faster clearance or lower levels of these biomarkers and improved athletic performance. Secondly, although a simulated game allows for control of work intensities and work output, it does not include impact and collision events associated with Rugby Union. The effect that these events have on fatigue, both physical and psychological, cannot be underestimated. However controlling, monitoring and measuring fatigue associated with them in itself is problematic, which cannot be replicated in a simulated game. The final limitation is the lack of equipment to perform and measure participants at station 4. Although the actions were replicated on a standard scrum machine, there was no way to measure each participant’s actual performance.

In conclusion, trends in this study may indicate that cold water immersion and contrasts baths may offer more to athletes recovering from team sport than passive rest between successive games of Rugby Union. Along with previous studies identifying similar findings (Ingram, et al., 2009; Rowsell, et al., 2009), a clearer picture is starting to unfold in regards to hydrotherapy and enhancing recovery from field team sport. Currently, there appears to be more evidence supporting the use of cold water immersion in recovery as opposed to passive recovery and contrast baths.

Future research should be structured to examine recovery across longer periods. If residual fatigue does have an impact on performance across a season, evaluating performance across a number of weeks would identify a more relevant effect on hydrotherapy in team sport recovery. In addition, if testing is to be relevant to identify changes in performance in team sport, the development of appropriate tests should be carried out. As has been shown here and stated in other studies, the use of repeated efforts may be more appropriate to identify fatigue. Furthermore, specificity has been identified to be important in training, thus it should also be reflected in testing.

6.1.6 Practical Application

As most sports involve a number of short periods of high-intensity, sport-specific actions and movement patterns interspersed with low intensity active recovery tests should be developed to reflect this. Using the one-off maximal tests commonly in use to date may not give a true indication of the state of recovery of athletes. The development of more sport-specific tests should be undertaken to offer a specific test for each individual sport.

Finally, at this time it is important for coaches and athletes to understand the importance of identifying which recovery study is best associated with their sport. Examining the available literature can lead to conflicting results, which may lead to confusion. Firstly, coaches need to assess whether the population in the study is similar to their own athletes. Comparing results from untrained subjects and generalising the finding to well-trained athletes is erroneous (Halson, 2011; Leeder, et al., 2012). Coaches and athletes need to identify subjects in a study as close to their own athletes' status as possible. Secondly, comparing different exercise/sports can also be problematic. In many field sports, a high level of eccentric contractions and collision impacts occur. Examining results from studies with lower levels of eccentric action may not identify a true result as the levels of exercise-induced muscle damage may be significantly different (Halson, 2011; Leeder, et al., 2012). It is expected that with the increase in research into recovery entering the sport science literature, a more definitive answer will follow.

6.1.7 Acknowledgments

The authors thank the contribution to the research design and methodology provided by Associate Professor Aaron Coutts (UTS, Australia) and the coaches and players from the Eastwood District Rugby Union Football Club for their support and participation is this study.

6.1.8 References

Alexiou, H., & Coutts, A. J. (2008). A comparison of methods used for quantifying internal training load in women soccer players. *International Journal of Sports Physiology & Performance*, 3, 320-330.

Bishop, P. A., Jones, E., & Woods, A. K. (2008). Recovery from training: A brief review. *Journal of Strength & Conditioning Research,* 22(3), 1015-1024.

Gill, N. D., Beaven, C. M., & Cook, C. (2006). Effectiveness of post-match recovery strategies in rugby players. *British Journal of Sports Medicine*, 40(3), 260-263.

Halson, S. L. (2011). Does the time frame between exercise influence the effectiveness of hydrotherapy for recovery?. [Review]. *International Journal of Sports Physiology & Performance*, 6(2), 147-159.

Hamlin, M. J., Hinckson, E. A., Wood, M. R., & Hopkins, W. G. (2008). Simulated rugby performance at 1550-m altitude following adaptation to intermittent normobaric hypoxia. *Journal of Science and Medicine in Sport*, 11, 593-599.

Higgins, T. R., & Heazlewood, T. (2008). Evaluation of Contrast Baths and Ice Baths for Recovery in U/20 Rugby Union. Paper presented at the ASICS Conference of Science and Medicine in Sport, Hamilton Island, Australia.

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine & Science in Sports & Exercise*, 36(6), 1042-1047.

Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science & Medicine in Sport*, 12(3), 417-421.

Kellmann, M. (Ed.). (2002). Current status and directions of recovery research. In enhancing recovery: Preventing underperformance in athletes. Champaign, IL: Human Kinetics.

Leeder, J., Gissane, C., van Somerson, K., Gregson, W., & Howatson, G. (2012). Cold water immersion and recovery from strenuous exercise: a meta-analysis. *British Journal of Sports Medicine*, 46, 233-240.

Reilly, T., & Ekblom, B. (2005). The use of recovery methods post-exercise. *Journal of Sports Sciences*, 23(6), 619-627.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal of Sports Sciences*, 27(6), 565-573.

Sellwood, K. L., Brukner, P., Williams, D., Nicol, A., & Hinman, R. (2007). Ice-water immersion and delayed-onset muscle soreness: A randomised controlled trial. *British Journal of Sports Medicine*, 41, 392-397.

Stagno, K. M., Thatcher, R., & Van Someren, K. A. (2006). A modified TRIMP to quantify the in-season training load of team sport players. *Journal of Sports Science*, 25(6), 1-6.

Stuart, G. R., Hopkins, W. G., Cook, C., & Cairns, S. P. (2005). Multiple effects of cafeine on simulated high-intensity team-sport performance. *Medicine & Science in Sports & Exercise*, 37(11), 1998-2005.

Tessitore, A., Meeusen, R., Pagano, R., Benvenuti, C., Tiberi, M., & Capranica, L. (2008). Effectiveness of active versus passive recovery strategies after futsal games. *Journal of Strength & Conditioning Research*, 22(5), 1402-1412.
Vaile, J., Gill, N., & Blazevich, A. J. (2007). The effect of contrast water therapy on symptons of delayed onset muscle soreness. *Journal of Strength & Conditioning Research*, 21(3), 697-702.
Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008). Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. *Journal of Sports Sciences*, 26(5), 431-440.
Wallace, L. K., Slattery, K. M., & Coutts, A. J. (2008). The ecological validity and application of the session-RPE method for quantifying training loads in swimming. *Journal of Strength & Conditioning Research*, 23(1), 33-38.

Chapter 7

7.1 The effects of cold water immersion and contrast water therapy for recovery from team sport: A systematic review and meta-analysis

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7.1.1 Abstract

Higgins, T. R., Greene, D. A., & Baker, M. K. (Under Review). The effects of cold water immersion and contrast water therapy for recovery from team sport: A systematic review and meta-analysis. *Journal of Strength and Conditioning Research*, xx(x), xx. To enhance recovery from sport, cold water immersion (CWI) and contrast water therapy (CWT) have become common practice within high level team sport. Initially, athletes relied solely upon anecdotal support. As there has been an increase in the volume of research into recovery including a number of general reviews, an opportunity existed to narrow the focus specifically examining the use of hydrotherapy for recovery in team sport. A Boolean logic [AND] keyword search of databases was conducted: SPORTDiscus; AMED; CINAHL; MEDLINE. Data was extracted and the standardised mean differences were calculated with 95% CI. The analysis of pooled data was conducted using a random-effect model, with Heterogeneity assessed using I2. Twenty three peer reviewed papers (n=606) met the criteria. Meta-analyses results indicated CWI was beneficial for recovery at 24h (CMJ: p= 0.05, CI -0.004 to 0.578; All-out sprint: p=0.02, -0.056 to 0.801) following team sport. CWI was beneficial for recovery at 72h (fatigue: p=0.03, CI 0.061 to 1.418) and CWT was beneficial for recovery at 48h (fatigue: p=0.04, CI 0.013 to 0.942) following team sport. CWI was beneficial for neuromuscular recovery 24h following team sport, whereas CWT was not beneficial for recovery following team sport. In addition, when evaluating accumulated sprinting, CWI was not beneficial for recovery following team sports. In evaluating subjective measures, both CWI (72h) and CWT (24h) were beneficial for recovery of perceptions of fatigue, following team sport. However neither CWI nor CWT was beneficial for recovery, of perceptions of muscle soreness, following team sport.

7.1.2 Introduction

It is widely accepted that optimising recovery after competition and training are essential to either maintain or enhance performance (Kinugasa & Kilding, 2009). As a result post-training and post-competition recovery practices, to speed/enhance recovery, have become common practice (Bleakley & Davison, 2010; Leeder, Gissane, van Somerson, Gregson, & Howatson, 2012; Poppendieck, Faude, Wegmann, & Meyer, 2013). Initially, athletes relied solely upon anecdotal support from other athletes. The absence of scientific evidence for recovery protocols has led to an increase in the quantity of such research (Leeder, et al., 2012). However, findings remain unclear into the effectiveness of many recovery strategies currently in use.

There have been a number of factors postulated as to the lack of a definitive answer into the efficacy of recovery protocols (Higgins, Cameron, & Climstein, 2013; Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; Jakeman, Byrne, & Eston, 2010b; Jones, Lander, & Brubaker, 2013; Juliff et al., 2014; Montgomery, Pyne, Hopkins, et al., 2008; Rowsell, Coutts, Reaburn, & Hill-Haas, 2009). Such factors have included small sample sizes, variations in training status of subjects, limitations in study designs and methodology, different time points evaluated and differing physiological stressors (Halson, 2011; Leeder, et al., 2012). In an attempt to clarify the efficacy of recovery methods, a number of reviews/meta-analyses have subsequently been conducted (Bleakley & Davison, 2010; Leeder, et al., 2012; Poppendieck, et al., 2013). However, despite their work, findings into the various recovery protocols remain equivocal.

Authors from these reviews have drawn to the reader’s attention limitations that currently exist in recovery research. In particular, the practice of comparing results from trained and untrained participants. Poppendieck et al. (2013) highlighted that interpretation and transfer of both data and results between untrained and trained participants is difficult (Poppendieck, et al., 2013). In addition to limitations associated with varying training status of participants, the variation between different exercise stressors was also raised. Leeder et al. (2012) stated that the nature of physiological stress will vary considerably between different types of exercise stressors (Leeder, et al., 2012). Further to this, the potential for reduced performance will vary depending on the exact exercise stressor that an athlete is recovering from (Halson, 2011; Leeder, et al., 2012). Further, Halson (2011) identified that weight-bearing activities, including running and weight training respond differently, in physiological stress and recovery response, to non-weight-bearing activities such as cycling and swimming (Halson, 2011).

Despite these issues, a number of reviews included papers encompassing both a range of participants and a range of exercise stressors. With the increase in research into recovery, the opportunity prevails to extend the work initiated by these reviews, and to narrow the focus on specific methods and athletic populations. It has been identified that team sport comprises of a number of high intensity repeat efforts, including a multitude of directional changes, jumping efforts and physical impacts/collisions (Delextrat, Calleja-González, Hippocrate, & Clarke, 2013; Takeda et al., 2014). That each event adds to the physiological stress confronting the athletes' ability to recover (Delextrat, et al., 2013; Takeda, et al., 2014). Furthermore, although there are a vast array of recovery modalities, actively used in team sport, including stretching, massage, electrical stimulation, active recovery and compression garments, they were not included as part of this review. As hydrotherapy has grown in popularity for recovery in team sport, without clear scientific support (Bahnert, Norton, & Lock, 2013), it was deemed to be more suitable to narrow the focus of the investigation to hydrotherapy. Therefore, the purpose of this paper was to systematically review the available research evaluating hydrotherapy for recovery in team sport. This critical appraisal of recovery methods is necessary to inform the translation of this evidence base into guidelines for enhancing recovery in team sport athletes.

7.1.3 Methods

7.1.3.1 Design

The systematic review was carried out following the recommendations outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (Moher, Liberati, Tetzlaff, Altman, & Group, 2010). A computerised literature search was undertaken by one author (T.H), between September 9th 2014 and September 20th 2014. Databases searched included: SPORTDiscus with Full Text; AMED - The Allied and Complementary Medicine Database; CINAHL Complete; MEDLINE Complete. Search strategy included a combination of Boolean logic [AND] keyword search (Interventions, recovery, team sport) (Figure 7.1).

7.1.3.2 Interventions

To be included, studies were required to use a physiological stressor associated with team sport. This could include competitive games, simulated competitive games, team training or combinations of the above. Studies were to include comparison between post exercise recovery modalities associated with hydrotherapy and at least one other group, and examined a time period of no less than 24 hours post physiological stressor. Studies that only evaluated the immediate response (≤ 1h) following hydrotherapy were excluded (Buchheit, Horobeanu, Mendez-Villanueva, Simpson, & Bourdon, 2011; Dawson, Gow, Modra, Bishop, & Stewart, 2005)

7.1.3.3 Participants

Studies comprising of participants either male or female or both were included. Participants were required to be reported as free from injury or illness and further classified as either/or well-trained, athletic, elite/semi-elite, professional/semi-professional, academy/institute team athletes. Studies evaluating untrained or recreational athletes were excluded.

7.1.3.4 Outcome measures

Studies were required to measure the effect recovery interventions on one or more outcome measure. Measures could include biochemical markers, physical performance, and subjective measures of performance and/or muscle soreness, power, acceleration, fitness tests, neuromuscular performance or passive assessments.

7.1.3.5 Data extraction

Data relating to types of interventions (cold water immersion, contrast water therapy, thermal-neutral water immersion), physiological stressor (competitive game, simulated game, team training), data collection time points, mean totals and standard deviations, were extracted by one author (TH). Where insufficient information was provided, attempts to contact authors were made via emails to obtain the missing data.

7.1.3.6 Assessment of methodological quality

To be included, studies were to meet the minimum quality threshold, defined as having met all inclusion criteria. Further quality assessment was conducted using a modified Delphi Scale (Faulkner, Gleadon, McLaren, & Jakeman, 2013; Hsu & Sandford, 2007) and Jadad Scale (Miyamoto, Senjyu, Tanaka, et al., 2014).

7.1.3.7 Meta-analysis

All meta-analysis calculations were conducted with the Comprehensive Meta-Analysis software (Version 2.2.057; Biostat inc., Englewood, *New jersey, USA*). The standardised mean differences were calculated and 95% CI for trials with sufficient data (Leeder, et al., 2012). The analysis of pooled data was conducted using a random-effect model. Heterogeneity was assessed using the I^2 which describes the percentage of variability in effect estimates that is due to heterogeneity rather than chance (Leeder, et al., 2012).

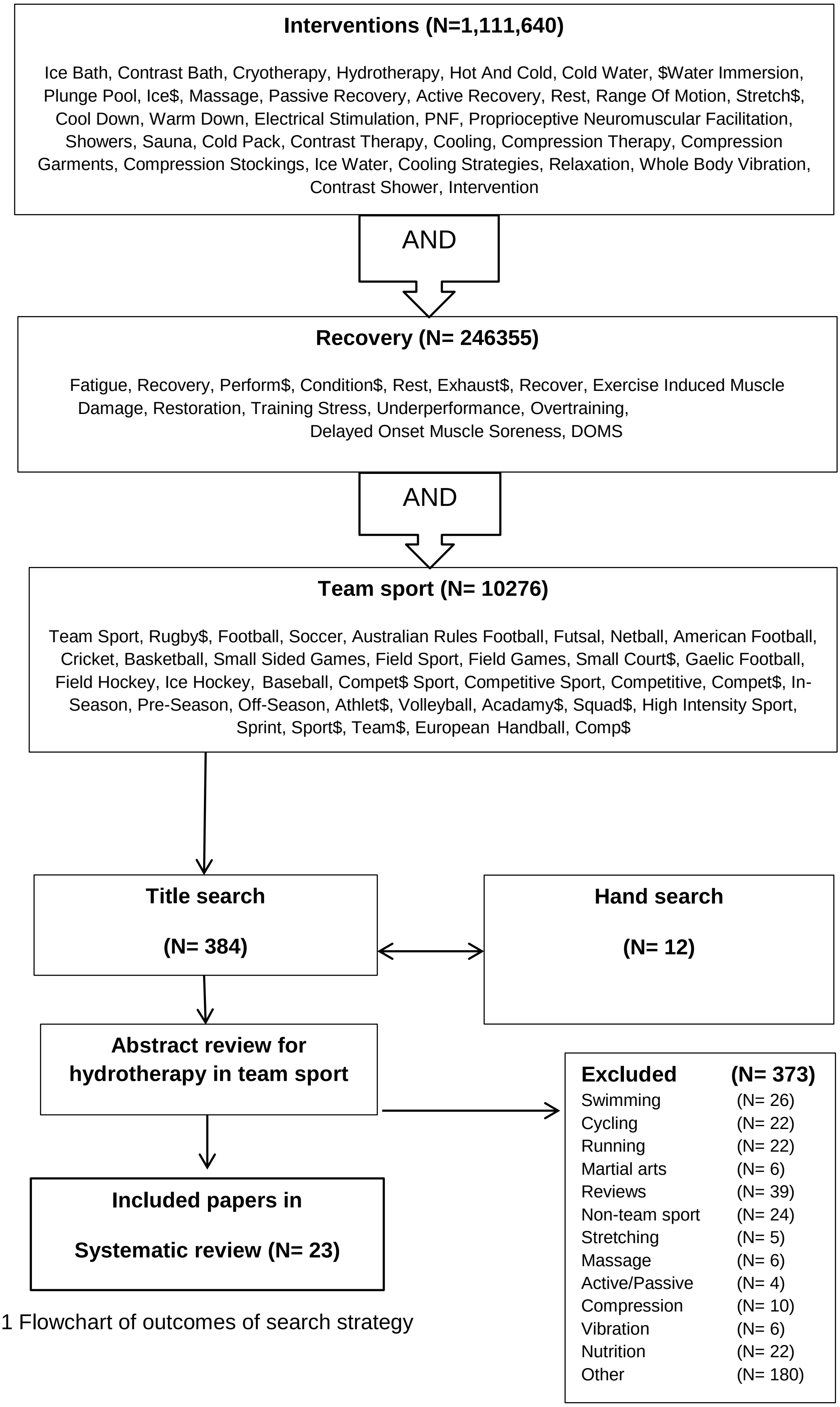

Figure 7.1 Flowchart of outcomes of search strategy

Table 7.1 Quality assessment table

Reference	Eligibility criteria specified	Randomised allocation	Allocation concealed	Equality in baseline scores	Participant blinding	Assessor blinding	85% of outcome measures obtained	Validity	Reliability	Time point data collection
Bahnert et al (2013)	Y	N	N	N	N	N	Y	N	N	Y
Buchheit et al (2011)	Y	N	N	Y	N	N	Y	N	N	Y
Delextrat et al (2013)	Y	Y	Y	Y	Y	Y	N	N	N	Y
Dawson et al (2005)	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Getto et al (2013)	Y	Y	Y	Y	Y	Y	N	N	N	Y
Gill et al (2006)	Y	Y	Y	N	Y	Y	N	N	Y	Y
Higgins et al (2011)	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Higgins et al (2013[a])	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Higgins et al (2013[b])	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Higgins et al (in press)	Y	Y	Y	Y	Y	Y	Y	N	N	Y

References	Statistical analysis reported	*P* value reported	Effect size reported	Drop outs/missing data reported
Bahnert et al (2013)	Y	N	N	N
Buchheit et al (2011)	Y	N	Y	N
Delextrat et al (2013)	Y	Y	Y	Y
Dawson et al (2005)	Y	Y	Y	Y
Getto et al (2013)	Y	Y	Y	Y
Gill et al (2006)	Y	Y	N	Y
Higgins et al (2011)	Y	N	Y	Y
Higgins et al (2013[a])	Y	Y	Y	N
Higgins et al (2013[b])	Y	Y	Y	N
Higgins et al (in press)	Y	Y	Y	N

Table 7.1 Quality assessment table cont'd

Reference	Eligibility criteria specified	Randomised allocation	Allocation concealed	Equality in baseline scores	Participant blinding	Assessor blinding	85% of outcome measures obtained	Validity	Reliability	Time point data collection
Ingram et al (2009)	Y	Y	Y	N	Y	Y	Y	N	Y	Y
Jones et al (2013)	Y	Y	Y	N	Y	Y	N	N	N	Y
Juliff et al (2014)	Y	Y	Y	Y	N	N	Y	N	N	Y
King et al (2009)	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Kinugasa et al (2009)	Y	Y	Y	Y	Y	N	N	N	N	Y
Montgomery et al (2008[a])	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Montgomery et al (2008[b])	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Pointon et al (2012[a])	Y	Y	Y	Y	Y	Y	N	N	Y	Y
Pointon et al (2012[b])	Y	Y	Y	Y	Y	Y	N	N	Y	Y

References	Statistical analysis reported	P value reported	Effect size reported	Drop outs/missing data reported
Ingram et al (2009)	Y	Y	Y	N
Jones et al (2013)	Y	Y	N	N
Juliff et al (2014)	Y	N	N	N
King et al (2009)	Y	Y	Y	N
Montgomery et al (2008[a])	Y	N	Y	N
Montgomery et al (2008[b])	Y	N	Y	N
Pointon et al (2012[a])	Y	Y	N	N
Pointon et al (2012[b])	Y	Y	N	N

Table 7.1 Quality assessment table cont'd

Reference	Eligibility criteria specified	Randomised allocation	Allocation concealed	Equality in baseline scores	Participant blinding	Assessor blinding	85% of outcome measures obtained	Validity	Reliability	Time point data collection
Pournot et al (2011)	Y	N	N	Y	N	N	Y	N	Y	Y
Rowsell et al (2009)	Y	Y	Y	Y	Y	Y	N	N	Y	Y
Rowsell et al (2011)	Y	Y	Y	Y	Y	Y	N	N	Y	Y
Rupp et al (2012)	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Takeda et al (2014)	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Webb et al (2013)	Y	Y	Y	Y	Y	Y	Y	N	Y	Y

References	Statistical analysis reported	*P* value reported	Effect size reported	Drop outs/missing data reported
Pournot et al (2011)	Y	Y	N	N
Rowsell et al (2009)	Y	Y		Y
Rowsell et al (2011)	Y	Y	Y	Y
Rupp et al (2012)	Y	Y	Y	N
Takeda et al (2014)	Y	Y	N	N
Webb et al (2013)	Y	N	Y	N

7.1.4 Results

7.1.4.1 Identification and selection of studies

The original search produced 10 276 papers. After reviewing the titles and abstracts as well as conducting a hand search through the reference lists of manuscripts, the total number of papers was reduced to 396. Further elimination of papers based on the eligibility criteria provided the final total of papers at 23 (Figure 7.1).

7.1.4.2 Cohort Characteristics

Across the included studies a combined total of 606 participants (506 male; 47 female; 53 not reported) participated in trials. Three studies evaluated both male and female participants, two studies evaluated female participants only, and 19 studies evaluated male participants only. A further 2 studies did not report gender of participants. Participants were recruited from 8 different team sports, (AFL [2], American Football [1], Basketball [4], Netball [2], Football [5], Futsal[1], Rugby Union [10], Rugby League [3], Volleyball [2]), with one study describing participants as team sport athletes. Four of the included studies recruited participants from multiple sports whereas the rest of the studies recruited participants from only one of the above mentioned team sports (Table 7.2). Thirteen of the studies were conducted during the competition phase of the sporting calendar. Five studies were carried out during the pre-season phase of the sporting calendar and 2 studies were conducted during the off-season phase of the sporting calendar. Six studies did not report the phase of the sporting calendar they were conducted in (Table 7.2).

7.1.4.3 Physiological stressor

Seven studies incorporated team training sessions as their physiological stressor with eleven studies incorporating competition games as the physiological stressor. Six studies incorporated both competition games and team training sessions as the physiological stressors and six studies incorporated simulated team sport games as the physiological stressor (Table 7.3). Hydrotherapy interventions applied included cold water immersion (CWI) (n=21), contrast water therapy (CWT) (n=13) and showers (n=2). Several studies included additional recovery interventions which included compression garments (n=4), saunas (n=1), massage (n=2) and active recovery (n=5). Control protocols included seated rest (n=20), thermoneutral water immersion (n=3), nutritional intake (n=1), placebo (n=1), stretching (n=3), and several groups evaluating response of more than one recovery intervention without a control group.

Studies used a range of times for immersion when applying CWI including a total time immersed of 10 minutes (n=12), which included seven studies applying two cycles of five minute immersions and one study applying five cycles of two minute immersions. Additional immersion times included a single 15 minute immersion (n=2), five minute immersion (n=7) either as a single five minute immersion (n=3) or five cycles of one minute immersion (n=4). Temperatures for cold water ranged between 5-15^{0}C with the majority of studies applying cold water between 10-12^{0}C (n=20). Hot/warm water temperatures ranged between 38-42^{0}C in the majority of studies (n=13) applying CWT with immersion times of between 1-3 min (Table 7.3).

Data collection points across all studies ranged from immediately post stressor through to seven days post stressor. Fifteen studies collected data immediately post stressor, three studies collected data 1 hour post, 18 studies collected data 24 hours post, eight studies collected data 48 hours post, 1 study collected data 72 hours post, 2 studies collected data 96 hours post and three studies collected data 7 days post. Six studies included other data collection points.

Table 7.2 Participant characteristics

Reference	N	Team Sport	Status	Age	Phase	BMI*
Bahnert et al (2013)	44 (M)	AFL	Pro/Semi-Pro	23 (±4.2)	In season	24
Buchheit et al (2011)	104 (M)	Football	Academy	12-17	In season	18-20.2
Delextrat et al (2013)	8 (M)	Basketball	Premier League	23 (±3)	In season	24.9
	8 (F)			22 (±2)		24.2
Dawson et al (2005)	17 (M)	AFL	Semi-Pro	24.2 (±2.9)	In season	23.9
Getto et al (2013)	13 (M)	American Football n=18 Volleyball n=10 Basketball n=2	Collegiate athletes	NR	Summer workout program	31.9
	10 (F)			NR		23.7
Gill et al (2006)	23 (M)	Rugby	Elite	25 (±3)	In season	29.1
Higgins et al (2011)	26 (M)	Rugby	Under 20	19 (±<1)	In season	25.8
Higgins et al (2013[a])	24 (M)	Rugby	Under 20	19.5 (±<1)	In season	25.5
Higgins et al (2013[b])	24 (M)	Rugby	Under 20	19.5 (±<1)	In season	25.5
Higgins et al (in press)	24 (M)	Rugby	Under 20	19.5 (±<1)	In season	25.5
Ingram et al (2009)	11 (M)	Athletes	Team games	27.6 (±6)	NR	23.9
Jones et al (2013)	10 (M)	7s Rugby	Premier	20 (±2)	NR	27.05[#]
Juliff et al (2014)	10 (F)	Netball	Elite	18.5-20.7	Pre-season	23.1
King et al (2009)	10 (F)	Netball	Trained	19.5 (±1.5)	Mid-season	22.4
Kinugasa et al (2009)	12 (NR)	Football	School Soccer Academy	14.3 (±<1)	3 Football games	19.6
Montgomery et al (2008[a])	29 (M)	Basketball	State	19.1 (±2.1)	Pre-season	26.1
Montgomery et al (2008[b])	29 (M)	Basketball	State	19.1 (±2.1)	Pre-season	24.1
Pointon et al (2012[a])	10 (M)	Rugby Union/League	Trained	21 (±1.7)	NR	26.3
Pointon et al (2012[b])	10 (M)	Rugby Union/League	Trained	19.9 (±1.1)	NR	24.5

Table 7.2 Participant characteristics cont'd

Reference	N	Team Sport	Status	Age	Phase	BMI*
Pournot et al (2011)	41 (NR)	Football Rugby Volleyball	Elite	21.5 (±4.6)	NR	23.4
Rowsell et al (2009)	20 (M)	Football	SAIS	15.9 (±<1)	Pre-season	N/A
Rowsell et al (2011)	20 (M)	Football	SAIS	15.9 (±<1)	Pre-season	N/A
Rupp et al (2012)	13 (M) 9 (F)	Football	Division 1	19.9 (±1.1)	Out of season	23.8
Takeda et al (2014)	20 (M)	Rugby	Collegiate	20.3 (±<1)	In season	28.2
Webb et al (2013)	21 (M)	Rugby League	NRL Professional	23.6 (±2.6)	In season	28.8

Note: Rugby (Rugby Union), SAIS (South Australian Institute of Sport), NR (not recorded)
BMI* (Body Mass Index: estimated via mean scores only), # (BMI score published)
NRL (National Rugby League), M (male), F (female), Football (inclusive of soccer)
Athletes (non-classified team sport athletes), AFL (Australian Football League),
N/A (BMI estimate unable to be calculated as participants height missing)

Table 7.3 Study protocols

Reference	Interventions	Control	Temp.	Time frame	Total Immersions	Baseline timeframe	Data point timeframe	Physiological stressor
Bahnert et al (2013)	CWI	NA	6-11^{0}C	8min	1	NR	NR	23 AFL games
	CWT		6-11^{0}C 38^{0}C	1min 2min	4 4			
	Compression garments				NA			
Buchheit et al (2011)	Hot Shower	NA	33-43^{0}C	2min		Game 1	Game 2 Post 48h	2 Club football matches
	Sauna		85-90^{0}C	2min				
	Hydro-massage		36^{0}C	2min				
	CWI		12^{0}C	2min				
Delextrat et al (2013)	Effleurage massage	Seated rest		30min		1 week Pre 1st Game	Immediately Post game Post Intervention 24h* post game	Basketball Game
	CWI		11^{0}C	2min	5			
Dawson et al (2005)	Stretch	Fruit & water/soft drink)		15min		45h Pre-match	15h Post 48h Post	12 Western Australia State AFL games
	Pool walk			15min				
	CWT		45^{0}C/12^{0}C	2min/1min	5 / 4			

Table 7.3 Study protocols cont'd

Reference	Interventions	Control	Temp.	Time frame	Total Immersions	Baseline timeframe	Data point timeframe	Physiological stressor
Getto et al (2013)	CWI	Seated rest	10^{0}C	10min	1	1 week Pre-treatment	Immediately post conditioning routine	Conditioning routine
	Active recovery			10min			24-28h Post	
Gill et al (2006)	Active recovery	Seated rest		8min	3	3.5h pre-game	Immediately Post	4 NPC Rugby games
	CWT		8-10^{0}C 40-42^{0}C	1min 2min			36h Post	
	Compression garment			12h			48h Post	
Higgins et al (2011)	CWI	Seated rest	10-12^{0}C	5min	1	120h & 72h Pre-game 1	48h Post 96h Post	4 U/20 Premier rugby games
	CWT		10-12^{0}C 38-40^{0}C	1min 1min	7			
Higgins et al (2013[a])	CWI	Seated rest	10^{0}C	5min	2	1h pre-game	Immediately Post 24h Post 48h Post	Simulated Rugby game
	CWT		10-12^{0}C 38-40^{0}C	1min 1min	5			
Higgins et al (2013[b])	CWI	Seated rest	10^{0}C	5min	2	1h pre-game	Immediately Post 48h Post 72h Post 96h Post 144h Post	Simulated Rugby game 3 x 90min field training days
	CWT		10-12^{0}C 38-40^{0}C	1min 1min	5			

Table 7.3 Study protocols cont'd

Reference	Interventions	Control	Temp.	Time frame	Total Immersions	Baseline timeframe	Data point timeframe	Physiological stressor
Higgins et al (in press)	CWI	Seated rest	10^{0}C	5min	2	1h pre-game	1 week Post	2 Simulated Rugby games
	CWT		$10\text{-}12^{0}$C $38\text{-}40^{0}$C	1min 1min	5			
Ingram et al (2009)	CWI	Seated rest	10^{0}C	5min	2	Pre-simulation	Post simulated 24h Post 48h Post	Simulated team sport
	CWT		$10\text{-}12^{0}$C $38\text{-}40^{0}$C	1min 1min	3			
Jones et al (2013)	Active recovery	Seated rest		15min		Pre-simulated 7s	24h Post	Simulated 7s Rugby
	CWI		10^{0}C	10min	1			
	CWI/Active recovery		10^{0}C	25min	1			
Juliff et al (2014)	CWT	Seated rest	38^{0}C 15^{0}C	1min 1min	7	Pre-simulated netball circuit	Immediately Post circuit 0.5h Post 24h Post	Simulated netball circuit
	Contrast shower		38^{0}C 18^{0}C	1min 1min	7			
King et al (2009)	Active recovery	Seated rest		10min		Pre- ISE	Immediately Post circuit 24h Post	ISE
	CWI		10^{0}C	5min	2			
	CWT		10^{0}C $38\text{-}39^{0}$C	1min/2min	5			

Table 7.3 Study protocols cont'd

Reference	Interventions	Control	Temp.	Time frame	Total Immersions	Baseline timeframe	Data point timeframe	Physiological stressor
Kinugasa et al (2009)	CWT CWI/Cycling	Static stretching & Legs raised	12^0C 38^0C 12^0C	1min 2min 1min/ 2min	3 3	2h Pre-match	Immediately Post match 24h Post	3 x 90min football matches
Montgomery et al (2008[a])	CWI Compression garment	Stretches	11^0C	1min	5	7 days pre-tourney 4-6h Pre-game	10min Post 6h Post 24h Post	3x3 day basketball tournament
Montgomery et al (2008[b])	CWI Compression garment	Stretches	11^0C	1min	5	7 days pre-tourney	10min post 6h Post 24h Post	3x3 day basketball tournament
Pointon et al (2012[a])	CWI	Seated rest	9.2^0C,	9min	2	Pre-ISE	10min Post 2h Post 24h Post	ISE
Pointon et al (2012[b])	CWI	Seated rest	8.9^0C	9min	2	Pre-ISE	10min Post 2h Post 24h Post	ISE
Pournot et al (2011)	CWI TWI CWT	Seated rest	10^0C 36^0C 10^0C 42^0C	15min 15min 90sec 90sec	5	Pre-exercise protocol	Immediately Post 1h Post 24h Post	Intermittent exercise protocol

Table 7.3 Study protocols cont'd

Reference	Interventions	Control	Temp.	Time frame	Total Immersions	Baseline timeframe	Data point timeframe	Physiological stressor
Rowsell et al (2009)	CWI TWI	NA	10^0C 34^0C	1min 1min	5 5	90min Pre 1st game	90min Pre games 2,3 and 4 22h Post game 4	4 x football games
Rowsell et al (2011)	CWI TWI	NA	10^0C 34^0C	1min 1min	5 5	7 Days Pre-game	22h Post 4 x games	4 x football games
Rupp et al (2012)	CWI	Seated rest	12^0C	15min	1	Pre-Yo-Yo	Immediate post 24h Post 48h Post	Yo-Yo test
Takeda et al (2014)	CWI	Seated rest	15^0C	10min	1	Pre-Training	Post training 24h Post	Rugby simulation training
Webb et al (2013)	CWI CWT	NA	10-12^0C 8-10^0C 40-42^0C	5min 1min 2min	1 3	24h Pre-Games	1h Post 18h Post 42h Post	3 x Competitive NRL games

Note: Cold water immersion (CWI); Contrast water therapy (CWT); Thermoneutral water immersion (TWI); National Provincial Championship (NPC); Australian Football League (AFL); National Rugby League (NRL); football (includes soccer); Intermittent sprint exercise (ISE)

7.1.4.4 Countermovement jump

The results showing the effect of hydrotherapy on countermovement jump, as a recovery modality, are summarised in table 7.4 (Appendix D) and displayed in Figures 7.2 and 7.3. Overall, results for CMJ indicated that CWI was beneficial for recovery of neuromuscular recovery 24h following the exercise stressor (p= 0.05, CI -0.004 to 0.578). However at all other time points, CWI did not enhance neuromuscular recovery (1h: p= 0.39, CI -0.202 to 0.514; 48h: p=0.56, CI -0.244 to 0.451; 72h: p=0.38, CI -0.360 to 0.954). Furthermore, results for CMJ indicated CWT did not enhance neuromuscular recovery at any time points following the exercise stressor (1h: p= 0.07, CI -0.004 to 0.863; 24h: p=0.46 CI -0.227 to 0.498; 48h: p=0.39, CI -0.191 to 0.489).

7.1.4.5 Best Sprint

The results showing the effect of hydrotherapy on best sprint time in a one all-out maximal sprint test, as a recovery modality, are summarised in table 7.5a (Appendix D) and displayed in Figure 7.4. When evaluating performance of all-out sprint performance, CWI enhanced recovery 24h following the exercise stressor (p=0.02, -0.056 to 0.801). However, overall results for one all-out maximal sprints indicated that CWI had minimal effect on enhancing recovery as measured in one all-out sprint performance 1h, 48h and beyond 90h following the exercise stressor (1h: p=0.07, CI -0.039 to 0.873; 48h: p=0.15, CI -0.159 to 1.068; >90h: p=0.15, CI -0.093 to 0.591). When evaluating the effect of CWT as a recovery modality with a one all-out maximal sprint test, data from only one study at each time point was available, therefore a meta-analysis was unable to be conducted.

Study name	Std diff in means	Lower limit	Upper limit	p-Value
Getto et al (2013)	0.122	-0.859	1.102	0.808
Higgins et al (2013b)	0.208	-0.695	1.111	0.652
King et al (2009)	0.061	-0.839	0.962	0.894
Pournot et al (2011)	0.134	-0.691	0.959	0.750
Rupp et al (2012)	0.194	-0.738	1.126	0.684
Takeda et al (2014)	0.203	-0.572	0.978	0.608
Delextrat et al (2013) F	0.933	-0.099	1.965	0.076
Delextrat et al (2013) M	0.467	-0.526	1.460	0.357
Getto et al (2013)	0.108	-0.845	1.061	0.824
Higgins et al (2013a)	0.000	-1.014	1.014	1.000
King et al (2009)	0.910	-0.011	1.831	0.053
Montgomery et al (2008a)	0.485	-0.428	1.399	0.298
Pournot et al (2011)	0.000	-0.850	0.850	1.000
Rowsell et al (2009)	0.137	-0.740	1.015	0.759
Rupp et al (2012)	0.040	-0.800	0.879	0.926
Takeda et al (2014)	0.025	-0.851	0.902	0.955
Higgins et al 48 CWI (2013a)	0.190	-0.792	1.172	0.704
Higgins et al 48 CWI (2013b)	0.190	-0.792	1.172	0.704
King et al 48 CWI (2009)	0.107	-0.770	0.984	0.811
Rowsell et al 48 CWI (2009)	0.137	-0.740	1.015	0.759
Rupp et al 48 CWI (2012)	0.105	-0.735	0.944	0.807
Higgins et al 72 CWI (2013b)	0.341	-0.646	1.328	0.499
Rowsell et al 72 CWI (2009)	0.261	-0.619	1.142	0.560

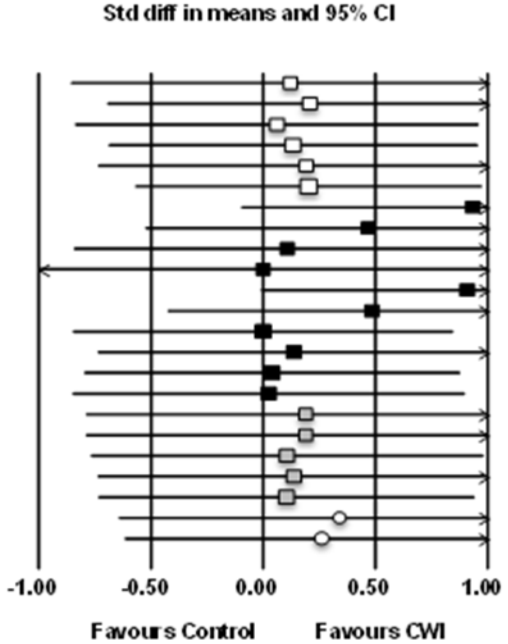

Figure 7.2: Forest plot for meta-analysis illustrating comparison of CWI versus Control for measures of CMJ. Squares represent individual studies standard difference in means with 95% CIs (I^2 =0.00). Size is proportional to weight of study. White squares, black squares, grey squares, white circles, represent time points 1h, 24h, 48h, 72h following team sport activity, respectively.

Study name	Std diff in means	Lower limit	Upper limit	p-Value	Relative weight
Higgins et al (2013b)	0.081	-0.784	0.946	0.854	6.99
King et al (2009)	0.751	-0.156	1.658	0.104	6.35
Kinugasa et al (2009)	0.699	-0.318	1.716	0.178	5.05
Pournot et al (2011)	0.240	-0.602	1.082	0.577	7.37
Dawson et al (2005)	0.333	-0.344	1.010	0.334	11.40
Higgins et al (2013a)	0.000	-0.980	0.980	1.000	5.44
King et al (2009)	0.093	-0.784	0.970	0.835	6.79
Kinugasa et al (2009)	0.000	-0.730	0.730	1.000	9.79
Pournot et al (2011)	0.150	-0.752	1.052	0.744	6.42
Dawson et al (2005)	0.000	-0.672	0.672	1.000	11.56
Higgins et al (2013a)	0.227	-0.756	1.211	0.650	5.41
Higgins et al (2013b)	0.227	-0.756	1.211	0.650	5.41
King et al (2009)	0.499	-0.391	1.389	0.272	6.60
Higgins et al (2013b)	0.173	-0.809	1.154	0.730	5.42

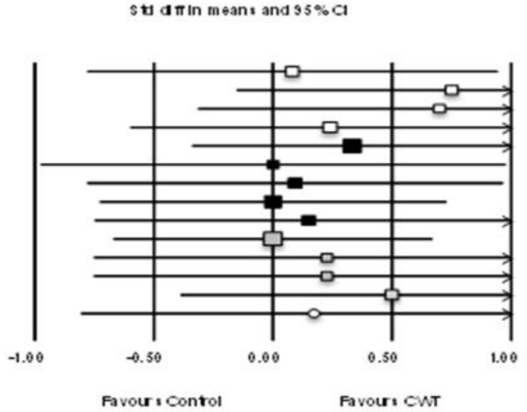

Figure 7.3: Forest plot for meta-analysis illustrating comparison of CWT versus Control for measures of CMJ.
Squares represent individual studies standard difference in means with 95%CIs (I^2 =0.00). Size is proportional to weight of study.
White squares, black squares, grey squares, white circles, represent time points 1h, 24h, 48h, 72h following team sport activity, respectively.

Study name	Std diff in means	Lower limit	Upper limit	p-Value	Relative weight
Getto et al (2013) 20m	0.142	-0.840	1.123	0.777	4.47
King et al (2009) 20m	0.370	-0.514	1.254	0.412	5.51
Pointon et al (2012b) 20m	0.771	-0.138	1.679	0.096	5.22
Takeda et al (2014) 50m	0.353	-0.530	1.236	0.433	5.52
Getto et al (2013) 20m	1.067	0.020	2.115	0.046	3.93
King et al (2009) 20m	0.089	-0.788	0.966	0.842	5.60
Montgomery et al (2008a) 20m	0.174	-0.728	1.076	0.705	5.29
Pointon et al (2012b) 20m	0.470	-0.419	1.358	0.300	5.46
Rowsell at al (2009) 20m	0.874	-0.043	1.792	0.062	5.12
Takeda et al (2014) 50m	0.113	-0.765	0.990	0.801	5.60
Ingram et al (2009) 20m	0.599	-0.255	1.454	0.169	5.90
Rowsell at al (2009) 20m	0.300	-0.582	1.181	0.505	5.54
Higgins et al (2011) 300m	0.171	-0.778	1.121	0.723	4.78
Higgins et al (in press) First half 20m	0.533	-0.465	1.530	0.295	4.33
Higgins et al (in press) Second half 20m	0.426	-0.565	1.418	0.399	4.39
Higgins et al (in press) First half 22m	0.262	-0.722	1.246	0.602	4.45
Higgins et al (in press) Second half 22m	0.063	-0.917	1.043	0.900	4.48
Higgins et al (in press) First half 30m	0.559	-0.440	1.558	0.273	4.32
Higgins et al (in press) Second half 30m	0.073	-0.907	1.053	0.884	4.48
Rowsell at al (2009) 20m	0.000	-0.877	0.877	1.000	5.61

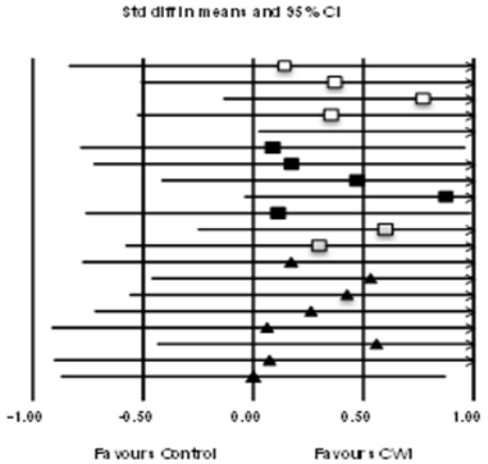

Figure 7.4 : Forest plot for meta-analysis illustrating comparison of CWI versus Control for measures of Best sprint. Squares represent individual studies standard difference in means with 95% CIs (I^2 =0.00) . Size is proportional to weight of study.

White squares, black squares, grey squares, black triangles represent time points 1h, 24h, 48h, >90h following team sport activity, respectively.

7.1.4.6 Accumulated sprint time

The results showing the effect of hydrotherapy on accumulated sprint time, as a recovery modality, are summarised in table 7.5b (Appendix D) and displayed in Figure 7.5. Overall, results indicated that at 24h, 48h and 72h following the exercise stressor, CWI was not beneficial in enhancing recovery when evaluated with accumulated sprinting (24h: p=0.29, CI -0.189 to 0.637; 48h: p=0.44, CI -0.171 to 0.392; 72h: p=0.07, CI -0.062 to 1.209). No studies examining accumulated sprinting, evaluated the effects of CWT.

Study name	Std diff in means	Lower limit	Upper limit	p-Value	Relative weight
Delextrat et al F (2013)	0.254	-0.730	1.238	0.613	4.93
Delextrat et al M (2013)	0.080	-0.900	1.061	0.872	4.97
Montgomery et al (2008a)	0.549	-0.368	1.466	0.241	5.68
Rowsell et al (2009)	0.190	-0.689	1.068	0.672	6.19
Rowsell et al (2011)	0.054	-0.823	0.931	0.904	6.22
Buchheit et al (2011)	0.007	-0.629	0.643	0.983	11.81
Buchheit et al (2011) HIR	0.084	-0.552	0.720	0.796	11.80
Buchheit et al (2011) VHIR	0.153	-0.484	0.789	0.639	11.78
Buchheit et al (2011) VHIA	0.177	-0.460	0.815	0.585	11.77
Rowsell et al (2009)	0.225	-0.655	1.104	0.617	6.18
Ingram et al (2009)	0.045	-0.791	0.881	0.916	6.84
Rowsell et al (2009)	0.309	-0.573	1.190	0.493	6.14
Rowsell et al (2011)	0.859	-0.057	1.775	0.066	5.69

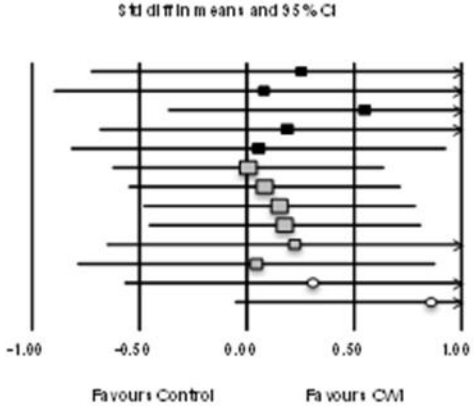

Figure 7.5: Forest plot for meta-analysis illustrating comparison of CWI versus Control for measures of accumulated sprint time.
Squares represent individual studies standard difference in means with 95%CIs (I 2 =0.00) . Size is proportional to weight of study.
Black squares, grey squares, white circles represent time points 24h, 48h, 72h following team sport activity, respectively.
High intensity running (HIR), very high intensity running (VHIR), very high intensity activity (VHIA)

7.1.4.7 Muscle soreness

The results showing the effect of hydrotherapy on muscle soreness, as a recovery modality, are summarised in table 7.6 (Appendix D) and displayed in Figures 7.6 and 7.7. Combined results for perceptions of muscle soreness, indicated that CWI did not enhance participants perception of muscle soreness (1h: p=0.20, CI -0.192 to 0.920; 24h: p=0.08, CI -0.092 to 1.936; 48h: p=0.41, CI -1.632 to 4.011; 72h: p=0.09, CI -0.121 to 1.555). Furthermore, as with the findings with CWI, CWT did not enhance perceptions of muscle soreness, following exercise stressor (24h: p=0.12, CI -0.233 to 2.082; 48h: p=0.25, CI -0.999 to 3.803).

7.1.4.8 Subjective measures of fatigue and exertion

The results showing the effect of hydrotherapy on participants' subjective measures of fatigue and exertion are summarised in table 7.7 (Appendix D) and displayed in figures 7.8 and 7.9. Combined results for perceptions of fatigue indicated that CWI enhanced athletes perception of fatigue and recovery 72h following the exercise stressor (p=0.03, CI 0.061 to 1.418). However, in contrast CWI did not enhance athletes perception of fatigue and recovery at all other time points (24h: p=0.44, CI -0.264 to 0.611; 48h: p=0.28, CI -0.309 to 1.063; >90h: p=0.16, CI -0.240 to 1.422). As with CWI at 72h, at 48h CWT enhanced athletes perceptions of fatigue and recovery following exercise stressor (p=0.04, CI 0.013 to 0.942) but did not enhance perceptions of fatigue and recovery 24h or 72h following exercise stressor (24h: p=0.59, CI -0.373 to 0.661; 72h: p=0.08, CI -0.082 to 1.408).

Study name	Std diff in means	Lower limit	Upper limit	p-Value	Relative weight
Getto et al (2013)	0.595	-0.406	1.597	0.244	7.12
Higgins et al (2013a)	0.029	-0.951	1.009	0.953	7.18
Montgomery et al (2008b)	0.462	-0.450	1.375	0.321	7.35
Getto et al (2013)	0.605	-0.397	1.607	0.236	7.12
Ingram et al (2009)	0.000	-0.836	0.836	1.000	7.54
Montgomery et al (2008b)	0.859	-0.082	1.800	0.074	7.28
Pournot et al TWI (2011)	3.527	2.182	4.871	0.000	6.21
Pournot et al (2011)	0.080	-0.770	0.930	0.854	7.51
Higgins et al (2013a)	0.356	-0.667	1.378	0.495	7.07
Higgins et al (2013b)	0.356	-0.667	1.378	0.495	7.07
Ingram et al (2009)	200.000	140.899	259.101	0.000	0.01
Montgomery et al (2008b)	1.502	0.483	2.522	0.004	7.08
Higgins et al (2013b)	0.405	-0.619	1.430	0.438	7.06
Montgomery et al (2008a)	1.600	0.566	2.634	0.002	7.04
Montgomery et al (2008b)	0.215	-0.688	1.118	0.641	7.37

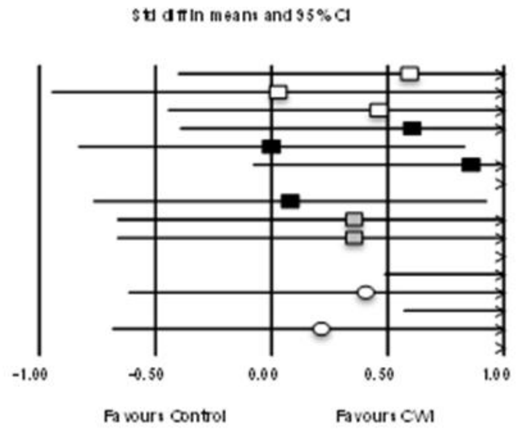

Figure 7.6: Forest plot for meta-analysis illustrating comparison of CWI versus Control for measures of muscle soreness.
Squares represent individual studies standard difference in means with 95%CIs ($I^2 = 84.41$). Size is proportional to weight of study.
White squares, black squares, grey squares, white circles represent time points 1h, 24h, 48h, 72h following team sport activity, respectively.
Thermoneutral water immersion (TWI) acts as control

Study name	Std diff in means	Lower limit	Upper limit	p-Value	Relative weight
Dawson et al (2005)	0.667	-0.024	1.357	0.059	15.08
Ingram et al (2009)	0.000	-0.836	0.836	1.000	14.66
Pournot et al TWI (2011)	3.513	2.078	4.947	0.000	12.52
Pournot et al (2011)	0.057	-0.844	0.957	0.902	14.45
Dawson et al (2005)	0.543	-0.141	1.228	0.120	15.09
Higgins et al (2013a)	0.871	-0.154	1.896	0.096	14.04
Higgins et al (2013b)	0.871	-0.154	1.896	0.096	14.04
Ingram et al (2009)	100.000	70.441	129.559	0.000	0.13

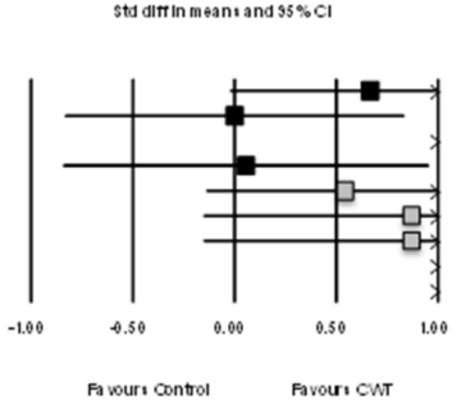

Figure 7.7: Forest plot for meta-analysis illustrating comparison of CWT versus Control for measures of muscle soreness.
Squares represent individual studies standard difference in means with 95%CIs (I 2 = 81.67). Size is proportional to weight of study.
Black squares, grey squares, represent time points 24h, 48h, following team sport activity, respectively.
Thermoneutral water immersion (TWI) acts as control

Study name	Statistics for each study				Relative weight
	Std diff in means	Lower limit	Upper limit	p-Value	
Jones et al (2013) TQR	0.120	-0.758	0.997	0.789	985
Montgomery et al (2008a) VAS	0.313	-0.593	1.219	0.498	924
Rowsell et al (2009) RPE	0.000	-0.877	0.877	1.000	987
Rupp et al (2012) VAS	0.263	-0.580	1.105	0.541	10.68
Higgins et al (2013b) RPE	0.049	-0.931	1.029	0.922	7.90
Rowsell et al (2009) RPE	0.000	-0.877	0.877	1.000	987
Rupp et al (2012) VAS	1.058	0.162	1.953	0.021	9.46
Higgins et al (2013b) RPE	0.443	-0.549	1.435	0.381	7.71
Rowsell et al (2009) RPE	1.000	0.070	1.930	0.035	877
Higgins et al (2013b) RPE	0.151	-0.830	1.133	0.762	7.87
Rowsell et al (2009) RPE	1.000	0.070	1.930	0.035	877

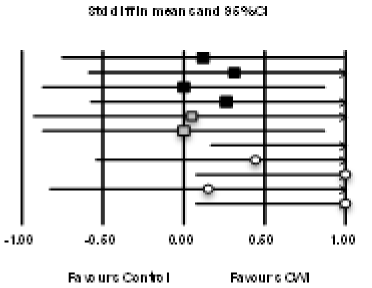

Figure 7.8: Forest plot for meta-analysis illustrating comparison of CWI versus Control for measures of fatigue.
Squares represent individual studies standard difference in means with 95%CIs (I^2 = 40.51). Size is proportional to weight of study.
Black squares, grey squares, white squares represent time points 24h, 48h, 72h following team sport activity, respectively.
Black diamond represents overall standard difference in means.

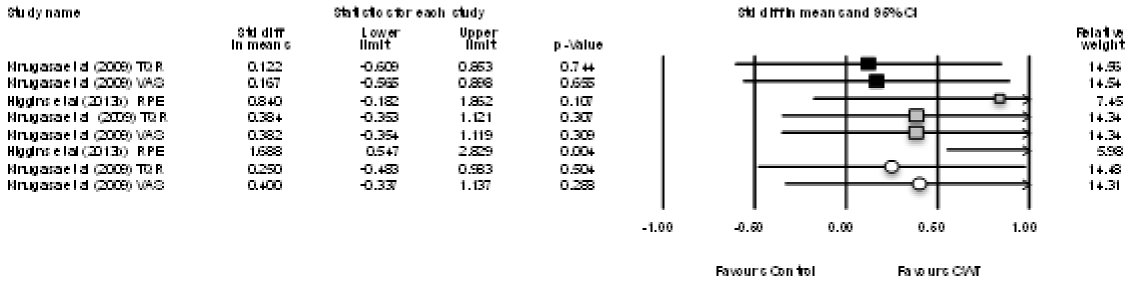

Figure 7.9: Forest plot for meta-analysis illustrating comparison of CWT versus Control for measures of fatigue.
Squares represent individual studies standard difference in means with 95%CIs (I2 = 56.72). Size is proportional to weight of study.
Black squares, grey squares, white circles represent time points 24h, 48h, 72h following team sport activity, respectively.

Although flexibility and/or range of motion, has anecdotal support to indicate recovery, a lack of studies were available to conduct a meta-analysis. Data from only two studies were available for evaluation of each hydrotherapy intervention (table 7.8; Appendix D).

7.1.4.9 Biochemical markers

A number of markers were used across studies including creatine kinase (CK), interleukin-6 (IL-6) aspartate aminotransferase (AST), C-reactive protein (CRP), lactate dehydrogenase (LDH) and lactate and pH. With the exception of CK, a dearth of studies evaluating IL-6, AST, CRP and LDH were available for meta-analyses to be conducted. Eight studies evaluated the effect of hydrotherapy on CK, with the results summarised in table 7.9 (Appendix D) and displayed in Figure 7.10. Overall, results for CK indicated that CWI did not enhance clearance levels of CK 24h following the exercise stressor (P=0.06, CI -0.009 to 0.658). There was insufficient data available at additional time points to conduct a meta-analysis beyond 24h with CWI. Furthermore, there was insufficient data on CWT to conduct a meta-analysis at any time point (Ingram, et al., 2009; Montgomery, Pyne, Cox, et al., 2008; Rowsell, et al., 2009).

Study name	Statistics for each study			
	Std diff in means	Lower limit	Upper limit	p-Value
Ingram et al (2009)	0.178	-0.701	1.056	0.692
Montgomery et al (2008a)*	0.395	-0.515	1.304	0.395
Pointon et al (2012a)	0.279	-0.602	1.160	0.535
Pointon et al (2012b)	0.294	-0.587	1.175	0.513
Pournot et al* (2011)	0.396	-0.462	1.253	0.366
Rowsell et al (2009)	0.355	-0.528	1.239	0.431
Takeda et al (2014)	0.376	-0.508	1.261	0.404

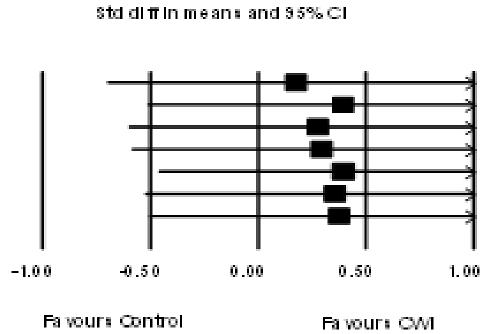

Figure 7.10: Forest plot for meta-analysis illustrating comparison of CWI versus Control for measures of CK.
Squares represent individual studies standard difference in means with 95%CIs (I2 = 0.000). Size is proportional to weight of study.
Black squares, represent time points 24h following team sport activity

7.1.5 Discussion

This was the first systematic review with meta-analyses to specifically investigate hydrotherapy as a recovery protocol with well-trained, team sport athletes. Although a number of reviews have been conducted into hydrotherapy and recovery, all have included considerable variation between training status and physiological stressors of participants Overall, results indicated that in enhancing neuromuscular recovery following team sport, only CWI (24h) enhanced neuromuscular recovery. However, benefits in neuromuscular recovery identified at 24h were not evident at any other time point. In evaluating subjective measures, CWI (72h) and CWT (24h) enhanced perceptions of fatigue, following team sport. However, neither CWI nor CWT was identified as enhancing recovery of perceived muscle soreness following team sport.

This systematic review with meta-analyses identified 23 papers from the sport science literature that investigated hydrotherapy for recovery in team sport. Reflecting the increasing amount of research into recovery, 15 of these papers were published after 2011. However, despite this increase a paucity of scientific research into team sport recovery still exists. Previously, the need to extend the period of research in team sport recovery to beyond 48 hours was identified (Dawson, et al., 2005). Despite this recommendation, only six of the 23 studies evaluated periods longer than the 48 hour period. As team sport predominantly involves a cyclic week of competition and multiple training sessions, the effect of common recovery interventions, specifically hydrotherapy, needs to be evaluated beyond 48 hours.

The majority of studies evaluated the effect of hydrotherapy 24 hours following physiological stressor; only three studies extended the research to 72 hours following; and only three studies extended research to 90 hours or beyond. In addition, a number of studies evaluated extended time periods. Extended time periods included the compounding effect of three and four day tournaments (Montgomery, Pyne, Cox, et al., 2008; Montgomery, Pyne, Hopkins, et al., 2008; Rowsell, et al., 2009; Rowsell, Coutts, Reaburn, & Hill-Haas, 2011). Extending time points included evaluating a number of interventions over an AFL season (Bahnert, et al., 2013), evaluating a four week period of a rugby union competition and a weekly cycle of simulated rugby union inclusive of training (Higgins, Climstein, & Cameron, 2013) and finally, an investigation over several weeks of an NRL competition (Webb, Harris, Cronin, & Walker, 2013).

Limitations in study designs were also identified. Blinding of participants in research is problematic, particularly with hydrotherapy, leaving participants open to the placebo effect. Unfortunately, blinding of participants from different interventions is not possible. A randomised, cross-over design may aide against the placebo effect in some cases but not all, specifically subjective measures of pain or fatigue (Bahnert, et al., 2013; Takeda, et al., 2014).

7.1.5.1 Neuromuscular function

The CMJ and one all out sprint running performance are routinely used as indices of neuromuscular performance (Takeda, et al., 2014). It has been suggested, that after exercise induced muscle damage, a decline in CMJ and sprinting performance is a result of compromised neuromuscular function and neuromuscular efficiency (Takeda, et al., 2014). Across studies in this review, the reliability of these tests was reported. However, validity of the tests, to reflect recovery with well-trained team sport athletes, was not.

Compromised neuromuscular function has been associated with a number of factors. These factors include muscle activation and muscle coordination, as the nervous system may facilitate changes in recruitment patterns (Bieuzen et al., 2014; Pruscino, Halson, & Hargreaves, 2013). With myofibrillar damage or disruption (Hill, Howatson, Van Someren, Walshe, & Pedlar, 2014) the nervous system would bypass the more severely damaged muscle fibres, specifically fast twitch (Pruscino, et al., 2013). This would then bring about changes in recruitment patterns and the coordination of muscle activation (Bieuzen, et al., 2014). With the change in muscle activation and coordination, a slowing of peak velocity would result (Jakeman, Byrne, & Eston, 2010a).

It has been proposed that the CMJ may not be sensitive enough to evaluate recovery of power in well-trained athletes (Dawson, et al., 2005; Higgins, Climstein, et al., 2013; Rowsell, et al., 2011). Dawson et al. (2005) speculated that well-trained athletes may have sufficient motivational drive to record near maximal efforts in one off all out tests. Others postulated that the level of exercise-induced muscle damage would be less with well-trained athletes due to adaptation processes (Higgins, Climstein, et al., 2013; Rowsell, et al., 2011). Well-trained athletes would therefore have a larger portion of functioning motor units and intact muscle fibres allowing for near maximal efforts (Rowsell, et al., 2011).

Although results indicated that CWI was beneficial for recovery, it should be noted that at 1 hour and 24 hours following team sport activity, irrespective of recovery intervention, the power of athletes as measured by a CMJ was still compromised. Athletes recorded below baseline scores of 5-15% 1 hour and 3-10% at 24 hour following team sport activity. The benefits in recovery from both CWI and CWT, during the first 24 hours, appear to be attenuating the detrimental effects of team sport. However, by 48 hours, irrespective of recovery intervention, control and hydrotherapy intervention groups had returned to within 2% of baseline scores for CMJ. Only two studies (Rowsell, et al, 2009; Higgins, et al, 2013b) evaluated the effectiveness of CWI and CWT in CMJ performance beyond 48 hours. In both studies results were unclear as to whether CWI or CWT provided any beneficial effect in restoring CMJ performance.

In evaluating recovery with one all-out maximal sprinting performance, CWI (24h) was beneficial. However, as with the CMJ, all participants recorded decrements in scores for sprinting performances irrespective of recovery intervention. The reported benefits of CWI at 24 hours were in attenuating the decrements in all-out maximal sprinting performances. Despite the common use of CWT in team sport recovery, only one study evaluated the effects CWT and one all-out sprinting performance. Meaningful evaluation through meta-analysis of CWT was therefore not possible in this review.

This review noted a dearth of research into recovery of sprinting performance beyond 24 hours was noted. In evaluating hydrotherapy and sprinting performance, there was data from only two studies to evaluate the effect of CWI at 48h following team sport with unclear results identified. Three studies evaluated the effect of hydrotherapy on sprinting beyond 48 hours following team sport (Higgins, Climstein, et al., 2013; Higgins, Heazlewood, & Climstein, 2011; Rowsell, et al., 2009). However, in each case different time points were assessed. Rowsell et al. (2009) evaluated 90 hours post; Higgins et al. (2011) evaluated at 96 hours post; Higgins et al. (2013b) evaluated at 144 hours post, discounting any feasibility of conducting a meaningful meta-analysis.

This systematic review and meta-analyses indicated that within 24 hours following team sport, CWI was beneficial in attenuating the detrimental effects of fatigue on neuromuscular function. However, beyond 24 hours the beneficial effect of CWI in recovery of neuromuscular function was unclear when evaluated with either a CMJ or one all-out sprint. Several studies evaluated neuromuscular function via EMG measurements (Pointon & Duffield, 2012; Pointon, Duffield, Cannon, & Marino, 2012). Due to methodological differences, additional meta-analysis evaluation was not possible. However, each study reported that CWI offered greater benefits in recovery of neuromuscular function of the knee extensors (Pointon, et al., 2012). However, these results need to be viewed with some level of caution. It has been suggested that functional tests best reflect recovery of performance in team sport (Dawson et al., 2005), whereas these studies using EMG utilised a seated knee extension testing protocol. Furthermore, hip extensors and knee flexors have been previously identified as the primary movers in team sport activities (Gabbett, 2005, 2008). Therefore, further research is required to confirm that a reported recovery of the knee extensors (Pointon, et al., 2012) can be duplicated with a similar recovery response of the hip extensors and/or knee flexors. In future research, EMG evaluation of the hip extensors and knee flexors whilst performing functional exercises may provide a greater insight into the effectiveness of either CWI or CWT in facilitating recovery in neuromuscular function with well-trained team sport athletes.

Finally, results from across the review indicated that, irrespective of the recovery intervention, neuromuscular function returned to near baseline levels within 48 hours of team sport activity. This may suggest that the effectiveness of such intervention strategies in enhancing recovery before the next competition is limited.

7.1.5.2 Perception of muscle soreness and fatigue

Perceptual measures of muscle soreness and fatigue are widely accepted tools in the monitoring of athlete's recovery. It has been proposed that athletes will instinctively regulate intensity (Delextrat, et al., 2013) and govern physical workloads (Morgans, Adams, Mullen, McLellan, & Williams, 2014) according to their perceptions (Delextrat, et al., 2013; Morgans, et al., 2014). Individually, a number of studies in this review did report CWI and/or CWT to be more beneficial in alleviating perceptions of muscle soreness during the acute response (Getto & Golden, 2013; Higgins, Cameron, et al., 2013; Higgins, Climstein, et al., 2013; Ingram, et al., 2009; Montgomery, Pyne, Hopkins, et al., 2008; Pournot et al., 2011; Rupp et al., 2012). Indications from the meta-analysis were that neither CWI nor CWT was beneficial in attenuating perceived muscle soreness.

The reported beneficial effects of CWI and CWT with muscle soreness, can be linked with an acute analgesic affect (García-Manso et al., 2011). The mechanisms associated with the acute analgesic effect of CWI and CWT centre primarily on the reduction of muscle soreness through pain inhibition and lower pain sensation (García-Manso, et al., 2011; Jakeman, et al., 2010b; Pournot, et al., 2011; Rupp, et al., 2012). The effect of cold water immersion reduces nerve conduction velocity (García-Manso, et al., 2011; Jakeman, et al., 2010b; Rupp, et al., 2012) which in turn reduces muscle spindle activity allowing the muscle to relax, and alleviating the perception of pain (García-Manso, et al., 2011; Rupp, et al., 2012).

There have also been additional mechanisms attributed to lower perceptions of muscle soreness and fatigue after CWI and/or CWT. The effect CWI and CWT has on changes in skin temperature has been associated with enhanced perceptions of recovery (Juliff, et al., 2014). Juliff et al. (2014) discussed the relationship between changes in skin temperature and human's perception of fatigue and comfort. They postulated that the perception of recovery after CWI and CWT is a result of an increase in skin temperature post immersions, and that the sensation of skin warming enhances perceptions of recovery (Juliff, et al., 2014). Alternatively, Montgomery et al. (2008) discussed that immersion therapy was associated with partial weightlessness and hydrostatic pressure, both inducing inhibitory mechanisms towards muscle contractions, which allows muscle to relax, reducing stress on muscle and subsequently reducing perceptions of muscle soreness (Montgomery, Pyne, Hopkins, et al., 2008).

Although it is believed that hydrostatic pressure generated during water immersion will impact on recovery mechanisms (Halson, 2011), it was not evident when CWI and thermoneutral water immersion (TWI) were evaluated jointly (Rowsell, et al., 2009). As CWI was identified to be more beneficial than TWI in enhancing perceptions of recovery (Rowsell, et al., 2009), this would suggest that the underlying mechanisms enhancing perceptions of recovery are associated with the cold temperature rather than hydrostatic pressure.

The authors also postulated that CWI and CWT benefitted perceptions of muscle soreness through the reduction of inflammation after exercise-induced muscle damage (Bahnert, et al., 2013). The reduction in inflammation has been attributed to a number of mechanisms. Cold therapy has been reported to reduce oedema through vasoconstriction altering lymph evacuation and lymph flow as well as blood flow (Montgomery, Pyne, Cox, et al., 2008; Rupp, et al., 2012). Reducing oedema would result in a reduction in pressure on pain receptors (Delextrat, et al., 2013; Montgomery, Pyne, Cox, et al., 2008; Rupp, et al., 2012) and reduced cell necrosis alleviating muscle soreness (Ingram, et al., 2009). Furthermore, reduced cellular permeability and cellular diffusion has been associated with vasoconstriction (Pournot, et al., 2011) reducing both neutrophil migration (Ingram, et al., 2009) and inflammation, subsequently inducing inhibitory influences on pain (Pournot, et al., 2011).

Within this review, it is probable that CWI and CWT only offered an acute analgesic effect on muscle soreness, as the beneficial effects towards muscle soreness were not evident at later time points. Although a number of authors postulated that benefits of either CWI or CWT within one to two hours post immersions could be expected to occur at later time points, these beneficial effects of CWI or CWT were not evident 24 hours following (Montgomery, Pyne, Cox, et al., 2008; Pointon & Duffield, 2012; Pointon, et al., 2012). Montgomery et al. described a rebound effect in perceptions of muscle soreness from the CWI and CWT groups [10]. If CWI and CWT had had an effect on the reported physiological mechanisms, including reduced oedema, reduced cellular metabolism, reduced diffusion and reduced neutrophil migration, the beneficial effects would be expected at later time points. In addition, the previously discussed link between perceptions of pain and fatigue and intensity regulation was not evident in this review. Individually, a number of papers did report greater beneficial effects of CWI and/or CWT with perceptual measures of recovery; however, no beneficial effects in performance measures were reported (Bahnert, et al., 2013; Dawson, et al., 2005; Delextrat, et al., 2013; Higgins, Climstein, et al., 2013; Jones, et al., 2013; Juliff, et al., 2014; King & Duffield, 2009; Kinugasa & Kilding, 2009; Rowsell, et al., 2009).

7.1.5.3 Repeat effort testing

Although it was previously suggested repeat effort testing may be more appropriate in assessing recovery (Dawson, et al., 2005), there has been a subsequent lack of research. In all, seven studies were identified in this systematic review that evaluated repeat effort performances, which included actual game performance (Buchheit, et al., 2011; Rowsell, et al., 2011), simulated game performance (Higgins, Cameron, & Climstein, In Press) and sprint repeat performance (Delextrat, et al., 2013; Ingram, et al., 2009; Montgomery, Pyne, Hopkins, et al., 2008). A complete meta-analysis could not be conducted due to variations in study protocols, which included variations in running speeds, sprinting distances, recording of results (seconds or metres).

Furthermore, as with neuromuscular performance and subjective measures, only two studies evaluated beyond 48 hours (Higgins, et al., In Press; Rowsell, et al., 2009).

Two of the studies did report some notable findings (Buchheit, et al., 2011; Higgins, et al., In Press). Although Buchheit et al. (2011) reported differences in overall running distances between groups, the volume of high intensity running showed no differences. This may provide an example of players regulating intensity when fatigued, as previously discussed. In attempting to conserve energy for high intensity activities associated with soccer, players reduced their levels of incidental movement throughout the second game. This led the authors to postulate that hydrotherapy was beneficial for recovery when consecutive games of football were played (Buchheit, et al., 2011).

Additionally, when evaluating performances between two simulated games of rugby union, athletes performed all out maximal sprints in times equal to or improved above baseline scores (Higgins, et al., In Press). However, when athletes performed multi-task rugby specific actions, performances in the second simulated game were (although not significant) below baseline measures (Higgins, et al., In Press). This may in itself reflect the complexity of measuring fatigue and recovery with well-trained athletes. The level of exercise-induced muscle damage may not be severe enough, due to adaptations bought about through training. As such, when using well-trained athletes, these athletes may have significant motor units functioning to record near maximal efforts in all-out maximal tests (Higgins, et al., In Press). As has been previously recommended, repeat effort testing which reflects actual game requirements may be better suited to assess recovery for well-trained team sport athletes (Dawson, et al., 2005).

7.1.5.4 Biochemical measures

The studies reviewed in this paper that evaluating biochemical markers of muscle damage and inflammation indicated that team sports elicit a high level of muscle damage and inflammation, as evident with significant increases in biochemical markers. Although evaluating recovery biochemical markers of both muscle damage and inflammation are routinely assessed, this review highlights the paucity of research evaluating biochemical responses to hydrotherapy and recovery from team field sport. The review identified that CK was the most commonly used biochemical marker evaluated and the only marker with sufficient data to apply a meta-analysis. From the meta-analysis, the overall effect of both CWI and CWT was greater in reducing CK levels at 24 hours post than control groups; no other time points had sufficient data available to conduct meta-analyses. In addition, there was insufficient data across the other biochemical markers, including AST, myoglobin, CRP, IL-6, LDH and FABP to conduct meta-analyses.

Despite a large overall effect in reducing CK levels, individually research papers from within the review offered conflicting results. The beneficial effect of CWI and/or CWT in reducing CK levels was reported by several papers (French et al., 2008; Hamlin et al., 2012; Pournot, et al., 2011), whereas no beneficial effect of CWI and/or CWT in reducing CK levels was reported in other studies (Bieuzen, et al., 2014; Pointon, et al., 2012; Rowsell, et al., 2009). The conflicting results may be related to the time course of peak CK levels. The majority of time course responses evaluated were less than 48 hours, and although one study reported peak CK levels at 24 hours post (Gill, Beaven, & Cook, 2006), peak CK levels have been reported to generally occur up to 96 hours post physiological stressor (Kraemer et al., 2009). The conflicting results may reflect the time frames of studies missing peak CK levels. Extended time periods of research would be required to truly evaluate the effect CWI or CWT has on CK levels.

In addition to the conflicting results into the efficacy of CWI and/or CWT in enhancing clearance of biochemical markers discussed, conflicting positions have been raised by a number of authors. Gill et al. (2006) concluded that enhanced clearance of CK after rugby union reflected enhanced recovery whereas Pournot et al. (2011), professed that changes in intracellular proteins in venous blood were merely a reflection of increased clearance and or appearance of proteins such as CK without reference to recovery. Importantly, opposing positions were identified in relation to biochemical markers and performance. Ingram et al. (2009) reported that there was no significant correlation between either muscle soreness or performance capabilities and plasma concentrations of either CK or CRP, whereas in contrast it was reported that reduced CK levels indicated recovery (Gill, et al., 2006). It has also been postulated that the acute elevations of myoglobin and FABP compared with the sustained elevation of CK made them a more effective marker (Montgomery, Pyne, Cox, et al., 2008).

This systematic review identified that team sport does elicit high levels of muscle damage and inflammation, whether in a contact or non-contact sport. In addition, when multiple days of team sport competition and/or training are conducted, levels of muscle damage and inflammation will be compounded (Montgomery, Pyne, Cox, et al., 2008; Rowsell, et al., 2009). Therefore, the importance of recovery after competition and training cannot be overstated. However, there is still a dearth of research evaluating CWI and CWT and biochemical markers, specifically beyond 48 hours, and therefore the efficacy and utility of such therapies remains unclear. The conflicting results discussed above fail to provide a definitive answer in relation to the beneficial effects of either CWI and/or CWT on the subsequent clearance of biochemical markers and enhanced recovery.

7.1.5.5 Limitations

In response to the commentary provided by Halson (2011), this review focused on highly trained team sport athletes. Despite narrowing the focus of the review to well-trained athletes, it is accepted that different team sports still have variations to physical and psychological strains. Although most team sports include contact/collisions, the two rugby codes have a higher incidence of contact, eliciting higher degrees of muscle trauma (Gabbett, 2002, 2008; Gill, et al., 2006; Takeda, et al., 2014). Whereas both football and AFL have greater physiological and biochemical loads placed on athletes as a result of the greater distances covered in running in competition games (Buchheit, et al., 2011; Dawson, et al., 2005; Ingram, et al., 2009; Rowsell, et al., 2009). With small court games such as basketball and netball, athletes are required to perform a higher number of high explosive jumps and rapid changes in directions, again eliciting variations in physiological loads

(Delextrat, et al., 2013; Juliff, et al., 2014; Montgomery, Pyne, Cox, et al., 2008). As postulated by authors within this review, responses to recovery may be highly individualised between athletes and between sports (Halson, 2011).

7.1.5.6 Conclusions

This systematic review with meta-analysis has confirmed well-trained team sport athletes undergo high levels of physiological, psychological and mechanical strain, leading to fatigue, through competition and training. In addition, that when competition and/or training occurs on successive days, there is a compounding effect of the physiological, psychological and mechanical strain, indicating the presence of residual fatigue (Higgins, et al., In Press; Montgomery, Pyne, Cox, et al., 2008; Rowsell, et al., 2009). Therefore, the importance placed upon appropriate recovery is not misplaced. Although CWI and CWT were beneficial in attenuating decrements in neuromuscular performance 24 hours following team sport, the indications of this systematic review are that those benefits were not evident 48 hours following team sport.

However, the beneficial effects of CWI and CWT and the athlete's improved perceptions of fatigue were supported with the meta-analysis conducted within this review. The author's postulated that greater perceptions of recovery may extend beyond the timeframes evaluated. Those greater perceptions of recovery may provide athletes with a better frame of mind enhancing the athlete's physical performance at training and competitions. However, at present, supporting evidence that improved athlete's perceptions of muscle soreness and fatigue will enhance performance at training is not available, nor was it supported by the pooled evidence within this review.

7.1.5.7 Recommendations

From this review, hydrotherapy interventions to attenuate the detrimental effects of team sport activity should utilise the following protocols. CWI should incorporate two x 5 minute immersions of 10^{o}C with 2 minute seated rest in ambient temperature between immersions. CWT would be advised to utilise a protocol incorporating CWI with 10^{o}C, and warm/hot water immersions 38-40^{o}C. Total immersion times for CWT should total not less than 10 minutes with similar immersion times for both cold and warm/hot employed. Halson (2011) recommendations for immersion of whole body (head out) should be employed, or ensure as much body is immersed as facilities allow.

As a scarcity of research into recovery from team sport and hydrotherapy still exists, further research evaluating hydrotherapy for recovery from team sport is required. Research encompassing team sports should be directed towards various sports, including, but not limited to, AFL, basketball, football, netball and both codes of rugby. It is paramount that future research incorporates both competition and training and that research focuses on the period 48 hours following team sport activity. Only by extending the research beyond the initial 48 hours can the compounding effects of residual fatigue, and subsequent benefits of hydrotherapy be fully evaluated. In addition, hydrostatic pressure generated with hydrotherapy and its effect on recovery should be evaluated with the use of thermoneutral water immersion. Although temperatures for TWI have been previously defined as 34-36^{o}C (Stocks, Taylor, Tipton, & Greenleaf, 2004), authors who have used TWI in this review have employed temperatures of approximately 25^{o}C. Investigations of the two different temperature ranges for TWI, is required to clarify the optimal temperature for TWI.

Physical performance measurements including either game or simulated game performances and functional performance tests should be employed. Furthermore, functional tests need to be specific to the sport being investigated. It may provide greater insight into neuromuscular function recovery to incorporate the use of EMG whilst performing functional performance tests. The use of EMG may aide in the identification of altered motor unit recruitment with well-trained athletes.

Perceptual measures continue to be an important tool in monitoring an athlete’s response to games, training, fatigue and recovery. With this in mind, the association between perceived recovery and enhanced performance in games and/or training needs additional exploration. Future research should include the monitoring of athlete's perceptions of fatigue/recovery and the athlete's physical performance in competition games and at successive training sessions.

7.1.6 References

Bahnert, A., Norton, K., & Lock, P. (2013). Association between post-game recovery protocols, physical and perceived recovery, and performance in elite Australian Football League players. *Journal of Science & Medicine in Sport*, *16*(2), 151-156.

Bieuzen, F., Brisswalter, J., Easthope, C., Vercruyssen, F., Bernard, T., & Hausswirth, C. (2014). Effect of wearing compression stockings on recovery after mild exercise-induced muscle damage. *International Journal of Sports Physiology & Performance*, *9*(2), 256-264.

Bleakley, C. M., & Davison, G. W. (2010). What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. *British Journal of Sports Medicine*, *44*(3), 179-187.

Buchheit, M., Horobeanu, C., Mendez-Villanueva, A., Simpson, B. M., & Bourdon, P. C. (2011). Effects of age and spa treatment on match running performance over two consecutive games in highly trained young soccer players. *Journal of Sports Sciences*, *29*(6), 591-598.

Dawson, B., Gow, S., Modra, S., Bishop, D., & Stewart, G. (2005). Effects of immediate post-game recovery procedures on muscle soreness, power and flexiblity [sic flexibility] levels over the next 48 hours. *Journal of Science & Medicine in Sport*, *8*(2), 210-221.

Delextrat, A., Calleja-González, J., Hippocrate, A., & Clarke, N. D. (2013). Effects of sports massage and intermittent cold-water immersion on recovery from matches by basketball players. *Journal of Sports Sciences*, *31*(1), 11-19.

Faulkner, J. A., Gleadon, D., McLaren, J., & Jakeman, J. R. (2013). Effect of lower-limb compression clothing on 400-m sprint performance. *Journal of Strength & Conditioning Research*, *27*(3), 669-676.

French, D. N., Thompson, K. G., Garland, S. W., Barnes, C. A., Portas, M. D., Hood, P. E., et al. (2008). The effects of contrast bathing and compression therapy on muscular performance. *Medicine & Science in Sports & Exercise*, *40*(7), 1297-1306.

Gabbett, T. J. (2002). Physiological characteristics of junior and senior rugby league players. *British Journal of Sports Medicine*, *36*(5), 334-339.

Gabbett, T. J. (2005). Changes in physiological and anthropometric characteristics of rugby league players during a competitive season. *Journal of Strength and Conditioning Research*, *19*(2), 400-408.

Gabbett, T. J. (2008). Influence of fatigue on tackling technique in rugby league players. *Journal of Strength and Conditioning Research*, *22*(2), 625-632.

García-Manso, J. M., Rodríguez-Matoso, D., Rodríguez-Ruiz, D., Sarmiento, S., de Saa, Y., & Calderón, J. (2011). Effect of cold-water immersion on skeletal muscle contractile properties in soccer players. *American Journal of Physical Medicine & Rehabilitation*, *90*(5), 356-363.

Getto, C. N., & Golden, G. (2013). Comparison of active recovery in water and cold-water immersion after exhaustive exercise. *Athletic Training & Sports Health Care: The Journal for the Practicing Clinician*, *5*(4), 169-176.

Gill, N. D., Beaven, C. M., & Cook, C. (2006). Effectiveness of post-match recovery strategies in rugby players. *British Journal of Sports Medicine*, *40*(3), 260-263.

Halson, S. L. (2011). Does the time frame between exercise influence the effectiveness of hyydrotherapy for recovery?. [Review]. *International Journal of Sports Physiology & Performance*, *6*(2), 147-159.

Hamlin, M. J., Mitchell, C. J., Ward, F. D., Draper, N., Shearman, J. P., & Kimber, N. E. (2012). Effect of compression garments on short-term recovery of repeated sprint and 3-km running performance in rugby union players. *Journal of Strength & Conditioning Research*, *26*(11), 2975-2982.

Higgins, T. R., Cameron, M., & Climstein, M. (In Press). Evaluation of passive recovery, cold water immersion, and contrast baths for recovery, as measured by game performances markers, between two simulated games of rugby union. *Journal of Strength and Conditioning Research*, *X*(X), XX.

Higgins, T. R., Cameron, M. L., & Climstein, M. (2013). Acute response to hydrotherapy after a simulated game of rugby. *Journal of Strength & Conditioning Research*, *27*(10), 2851-2860.

Higgins, T. R., Climstein, M., & Cameron, M. (2013). Evaluation of hydrotherapy, using passive tests and power tests, for recovery across a cyclic week of competitive rugby union. *Journal of Strength & Conditioning Research*, *27*(4), 954-965.

Higgins, T. R., Heazlewood, I. T., & Climstein, M. (2011). A random control trial of contrast baths and ice baths for recovery during competition in u/20 rugby union. *Journal of Strength & Conditioning Research*, *25*(4), 1046-1051.

Hill, J. A., Howatson, G., Van Someren, K. A., Walshe, I. A. N., & Pedlar, C. R. (2014). Influence of compression garments on recovery after marathon running. *Journal of Strength & Conditioning Research 28*(8), 2228-2235.

Hsu, C., & Sandford, B. A. (2007). The delphi technique: making sense of consensus. *Practical Assessment, Research & Evaluation*, *12*(10).

Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science & Medicine in Sport*, *12*(3), 417-421.

Jakeman, J. R., Byrne, C., & Eston, R. G. (2010a). Efficacy of lower limb compression and combined treatment of manual massage and lower limb compression on symptoms of exercise-induced muscle damage in women. *Journal of Strength & Conditioning Research*, *24*(11), 3157-3165.

Jakeman, J. R., Byrne, C., & Eston, R. G. (2010b). Lower limb compression garment improves recovery from exercise-induced muscle damage in young, active females. *European Journal of Applied Physiology*, *109*(6), 1137-1144.

Jones, B., Lander, J., & Brubaker, D. (2013). The effects of different recovery interventions following a repeated rugby union (sevens) game simulated protocol. *Journal of Australian Strength & Conditioning*, *21*(4), 5-13.

Juliff, L. E., Halson, S. L., Bonetti, D. L., Versey, N. G., Driller, M. W., & Peiffer, J. J. (2014). Influence of contrast shower and water immersion on recovery in elite netballers. *Journal of Strength & Conditioning Research*, *28*(8), 2353-2358.

King, M., & Duffield, R. (2009). The effects of recovery interventions on consecutive days of intermittent sprint exercise. *Journal of Strength and Conditioning Research*, *23*(6), 1795-1802.

Kinugasa, T., & Kilding, A. E. (2009). A comparison of post-match recovery strategies in youth soccer players. *Journal of Strength & Conditioning Research*, *23*(5), 1402-1407.

Kraemer, W. J., Spiering, B. A., Volek, J. S., Martin, G. J., Howard, R. L., Ratamess, N. A., et al. (2009). Recovery from a national collegiate athletic association division I football game: Muscle damage and hormonal status. *Journal of Strength and Conditioning Research*, *23*(1), 2-10.

Leeder, J., Gissane, C., van Somerson, K., Gregson, W., & Howatson, G. (2012). Cold water immersion and recovery from strenuous exercise: a meta-analysis. *British Journal of Sports Medicine*, *46*, 233-240.

Miyamoto, N., Senjyu, H., Tanaka, T., Asai, M., Yanagita, Y., Yano, Y., et al. (2014). Pulmonary rehabilitation improves exercise capacity and dyspnea in air pollution-related respiratory disease. *Journal of Experimental Medicine*, *232*(1), 1-8.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2010). Preferred reporting items for systematic reviews and meta-analyses:The PRISMA Statement. *International Journal of Surgery*, *8*(5), 336-341.

Montgomery, P. G., Pyne, D. B., Cox, A. J., Hopkins, W. G., Minahan, C. L., & Hunt, P. H. (2008). Muscle damage, inflammation, and recovery interventions during a 3-day basketball tournament. *European Journal of Sport Science*, *8*(5), 241-250.

Montgomery, P. G., Pyne, D. B., Hopkins, W. G., Dorman, J. C., Cook, K., & Minahan, C. L. (2008). The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *Journal of Sports Sciences*, *26*(11), 1135-1145.

Morgans, R., Adams, D., Mullen, R., McLellan, C., & Williams, M. (2014). An English championship league soccer team did not experience impaired physical match performance in a second match after 75 hours of recovery. *Journal of Australian Strength & Conditioning*, *22*(4), 16-23.

Pointon, M., & Duffield, R. (2012). Cold water immersion recovery after simulated collision sport exercise. *Medicine & Science in Sports & Exercise*, *44*(2), 206-216.

Pointon, M., Duffield, R., Cannon, J., & Marino, F. E. (2012). Cold water immersion recovery following intermittent-sprint exercise in the heat. *European Journal of Applied Physiology*, *112*, 2483–2494.

Poppendieck, W., Faude, O., Wegmann, M., & Meyer, T. (2013). Cooling and performance recovery of trained athletes: A meta-analytical review. *International Journal of Sports Physiology & Performance*, *8*, 227-242.

Pournot, P., Bieuzen, F., DuYeld, R., Lepretre, P.-M., Cozzolino, C., & Hausswirth, C. (2011). Short term effects of various water immersions on recovery from exhaustive intermittent exercise. *European Journal of Applied Physiology*, *111*, 1287–1295.

Pruscino, C., Halson, S., & Hargreaves, M. (2013). Effects of compression garments on recovery following intermittent exercise. *European Journal of Applied Physiology*, *113*(6), 1585-1596.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal of Sports Sciences*, *27*(6), 565-573.
Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2011). Effect of post-match cold-water immersion on subsequent match running performance in junior soccer players during tournament play. *Journal of Sports Sciences*, *29*(1), 1-6.
Rupp, K. A., Selkow, N. M., Parente, W. R., Ingersoll, C. D., Weltman, A. L., & Saliba, S. A. (2012). The effect of cold water immersion on 48-hour performance testing in collegiate soccer players. *Journal of Strength & Conditioning Research*, *26*(8), 2043-2050.
Stocks, J. M., Taylor, N. A. S., Tipton, M. J., & Greenleaf, J. E. (2004). Human physiological responses to cold exposure. *Aviation, Space and Environmental Medicine, 75*(5), 444-457.
Takeda, M., Sato, T., Hasegawa, T., Shintaku, H., Kato, H., Yamaguchi, Y., et al. (2014). The effects of cold water immersion after rugby training on muscle power and biochemical markers. *Journal of Sport Science and Medicine*, *13*, 616-623.
Webb, N. P., Harris, N. K., Cronin, J. B., & Walker, C. (2013). The relative efficacy of three recovery modalities after professional rugby league matches. *Journal of Strength & Conditioning Research*, *27*(9), 2449-2455.

Chapter 8

8.1 Conclusions, implications and future research

8.1.1 Conclusions

The purpose of this thesis was to evaluate the effectiveness of both CWI and CWT as recovery modalities after simulated team sport. Initially, results identified a significant difference for each dependent variable (p=0.000), immediately after the simulated game, suggesting a significant level of fatigue was generated. Therefore, the simulated game was an effective physiological stressor to evaluate CWI and CWT for recovery over three phases of Rugby Union. The first phase evaluated the acute period of time immediately after the simulated game (48 hours). The second phase evaluated a cyclic week of Rugby Union including the simulated game and three Rugby Union training sessions. The third and final phase evaluated CWI and CWT on recovery of performance between two simulated games.

Results from the acute response supported previous research indicating CWI to be superior to both CWT and passive recovery in attenuating subjective measures of muscle pain after a simulated game. However, neither CWI nor CWT was superior to passive recovery (Cohen’s d = trivial) in enhancing recovery of CMJ, hamstring flexibility, or thigh circumference. Furthermore, after 48 hours each group was demonstrating signs of recovery, irrespective of muscle soreness.

As with the acute response, results across a cyclic week of Rugby Union which included a simulated game and three training session suggested CWI to be superior to both CWT and passive recovery in attenuating subjective measures of muscle pain. Cohen’s d values reported only trivial effects for CMJ, hamstring flexibility or thigh circumference between each group. As with the acute response CWI, CWT and passive recovery showed similar trends towards baseline scores across the week, irrespective of muscle soreness. Additionally, Cohen’s *d* values suggested that CWI and passive recovery were superior to CWT in subjective measures of muscle pain across a cyclic week. Additional subjective measures (Session RPE) reported similar findings to subjective measures of muscle pain, suggesting CWI to be superior to CWT and passive recovery in enhancing player's perception of exertion during successive days of high-intensity activity.

Finally, the majority of research into recovery, to date, has evaluated the acute response (<48 hours following activity) of hydrotherapy. This thesis extended the research to evaluate the effect of hydrotherapy after a traditional team sport week which included firstly, a competitive team sport activity, secondly, multiple training sessions and concluded with a second competitive team sport activity. Although traditionally, evaluation of recovery applies maximal tests, in the final research study in this thesis, participant's performance across two simulated games of Rugby Union was employed.

Effect size results (Cohen's *d* and partial eta squared) suggested CWI and CWT may be more beneficial than passive rest, in attenuating the decrements in performance in simulated sporting performance. Furthermore, trends indicated that CWI may be superior to CWT as well as passive recovery in attenuating decrements in performance in simulated team sport.

As there has been an increase in published research into hydrotherapy and recovery, a systematic review was conducted, combining data from the research conducted in this thesis with the increasing volume of data available from similar studies. Although an increase in the volume of research was identified, a shortfall still exists beyond the acute response. Results from the meta-analysis are in-line with the findings of the research conducted in this thesis. Results from the meta-analysis we can surmise that CWI and CWT are beneficial for recovery of subjective measures of fatigue, exertion and muscle soreness. However, neither CWI nor CWT was beneficial for recovery of neuromuscular function or sporting performance.

Although a lack of research existed beyond 48 hours, a number of authors postulated that benefits of CWI and CWT during the acute phase would also be seen at later time points. However, these assumptions were not supported by the results of the meta-analysis. The meta-analysis supported a rebound effect associated with subjective measures (Montgomery, Pyne, Hopkins, et al., 2008). Therefore, assumptions of continued benefits in regards to subjective measures, beyond the acute response need further clarification.

8.1.2 Practical implications

The findings of this study suggests that if there is sufficient time between sessions (>48 hours), and muscular power functions are of primary importance, recovery interventions may offer athletes minimal benefits in recovery over no recovery intervention. However, the present data suggests that cold water immersion may be the best option if coaches are concerned about the impact of leg muscle soreness (DOMS). If an athlete's approach to subsequent games and/or training while suffering with leg muscle soreness is compromised, then the use of cold water immersion may be an appropriate recovery intervention.

In addition, if athletes are required to perform multiple repeat effort activities and there is insufficient time to recover (<48 hours) between games and/or training, then the recovery intervention of cold water immersion offers more to the athlete in attenuating the effects of DOMS, attenuating decrements in game related repeated efforts, players' subjective perceptions of tasks, and hastening the return of power in comparison to either passive recovery or contrast water baths.

For players in Rugby Union aiming to attenuate the effects of fatigue from multiple high-intensity sessions, the present study's protocol for cold water immersions, of 2 X 5 minute baths at 10°C, should be applied immediately after the game. Further, it should be noted that this research demonstrates that contrast baths are less effective as a recovery modality than either cold water immersion or passive recovery with subjective measures of muscle pain and fatigue, and should be discontinued as a recovery protocol.

8.1.3 Directions for future research

The findings of this study suggest that CWI may be of more benefit in recovery from team field sport than either CWT or passive recovery. However, as a scarcity in research beyond the acute phase following team field sport still exists, additional research is still required. Future research into recovery from Rugby Union may benefit with repeat effort tests and/or multiple high intensity activities replicating movement patterns as previously recommended (Dawson et al., 2005). To date there are currently two tests which may be able to give a greater insight into recovery from Rugby Union. The first test that should be considered is the non-modified phosphate decrement test. As previously discussed, work events in Rugby Union consist of a multiple number of high intensity efforts of less than 10 sec followed by periods of recovery of approximately 20 sec, followed by stoppages in play. The phosphate decrement test replicates these work-to-rest ratios. The second testing protocol which would enhance the findings of research into recovery from prior exercise would be the Bath University Rugby Shuttle Test (BURST) (Roberts, Stokes, Weston, & Trewartha, 2010). The BURST incorporates multiple movement patterns associated with Rugby Union, whereas the phosphate decrement test only incorporates straight-line sprinting. The use of both tests in conjunction with neuromuscular tests and subjective measures of performance is recommended to provide a valid measure of recovery from fatigue in Rugby Union.

The research conducted in this thesis has contributed to the knowledge currently available in regards to recovery from team sport, specifically Rugby Union, across both a cyclic week of training and simulated games. Findings suggest that providing ample time to rest (>48 hours), players recovery will not be enhanced to any greater extent by applying either cold water immersion or contrast water therapy compared to passive rest alone. However, where time periods are less than 48 hours, between training and/or competition, cold water immersion is more beneficial in attenuating the effects of fatigue than either passive recovery or contrast water therapy. Specifically, Furthermore, contrast water therapy appears to offer the least in attenuating the effects of residual fatigue and may increase player's perceptions of exertion and their level of muscle soreness.

The question of residual fatigue and maintenance of performance across extended seasons remain unanswered. Future research into recovery should therefore extend beyond the acute phase and weekly cycle to include periods of multiple weeks and multiple weeks across different periods of the season.

References

Abdelkrim, N. B., Castagna, C., El Fazaa, S., Tabka, Z., & El Ati, J. (2009). Blood metabolites during basketball competitions. *Journal of Strength & Conditioning Research, 23*(3), 765-773.

Adhihetty, P. J., Irrcher, I., Joseph, A., Ljubicic, V., & Hood, D. A. (2003). Plasticity of skeletal muscle mitochondria in response to contractile activity. *Experimental Physiology, 88*(1), 99-107.

Alexiou, H., & Coutts, A. J. (2008). A comparison of methods used for quantifying internal training load in women soccer players. *International journal of sports physiology & performance, 3*, 320-330.

Anttila, K., Mänttäri, S., & Järvilehto, M. (2008). Testosterone and Ca2+ regulation in skeletal muscle. *International Journal of Sports Medicine, 29*(10), 795-802.

Argus, C. K., Gill, N. D., Keogh, J. W. L., Hopkins, W. G., & Beaven, C. M. (2009). Changes in strength, power, and steroid hormones during a professional rugby union competition. *Journal of Strength & Conditioning Research, 23*(5), 1583-1592.

Arnheim, D. D., & Prentice, W. E. (Eds.). (1993). *Therapeutic Modalities. In: Principles of Athletic Training.* Baltimore, MD: Mosby

Atkinson, G. (2007). What's behind the numbers? important decisions in judging practical significance. *Sportscience, 11*, 12-15.

Bahnert, A., Norton, K., & Lock, P. (2013). Association between post-game recovery protocols, physical and perceived recovery, and performance in elite Australian Football League players. *Journal of Science & Medicine in Sport, 16*(2), 151-156.

Baird, M. F., Graham, S. M., Baker, J. S., & Bickerstaff, G. F. (2012). Creatine-Kinase- and exercise-related muscle damage implications for muscle performance and recovery. *Journal of Nutrition and Metabolism, 2012*, Article ID 960363.

Baldari, C., Bonavolonta, V., Emerenziani, G. P., Gallotta, M. C., Silva, A. J., & Guidetti, L. (2009). Accuracy, reliability, linearity of Accutrend and Lactate Pro versus EBIO plus analyzer. *European Journal of Applied Physiology, 107*, 105-112.

Barnett, A. (2006). Using recovery modalities between training sessions in elite athletes. *Sports Medicine, 36*(9), 781-796.

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International journal of sports physiology & performance, 1*(1), 50-57.

Beaven, M., Gill, N. D., & Cook, C. (2008). Salivary testosterone and cortisol responses in professional rugby players after four resistance exercise protocols *Journal of Strength & Conditioning Research, 22*(2), 426-432.

Beck, T. W., Housh, T. J., Johnson, G., Schmidt, R. J., Housh, D. J., Coburn, J. W., et al. (2007). Effects of a protease supplement on eccentric exercise-induced markers of delayed-onset muscle soreness and muscle damage. *Journal of Strength & Conditioning Research, 21*(3), 661-667.

Becker, L. (2008). Effect size (ES). Retrieved August 26, 2008, from http://web.uccs.edu/lbecker/Psy590/es.htm.

Belfry G., Raymer G., Marsh G., Paterson D., Thompson R., Thomas S. (2012). Muscle metabolic status and acid-base balance during 10-s work:5-s recovery intermittent and continuous exercise. *J Appl Physiol 113,* 41 –417.

Bennell, K., Wajswelner, H., Lew, P., Schall-Riaucour, A., Leslie, S., Plant, D., et al. (1998). Isokinetic strength testing does not predict hamstring injury in Australian Rules footballers. *British Journal of Sports Medicine, 32*, 309-314.

Bieuzen, F., Brisswalter, J., Easthope, C., Vercruyssen, F., Bernard, T., & Hausswirth, C. (2014). Effect of wearing compression stockings on recovery after mild exercise-induced muscle damage. *International Journal of Sports Physiology & Performance, 9*(2), 256-264.
Bishop, P. A., Jones, E., & Woods, A. K. (2008). Recovery from training: A brief review. *Journal of Strength & Conditioning Research, 22*(3), 1015-1024.
Bleakley, C. M., & Davison, G. W. (2010). What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. *British Journal of Sports Medicine, 44*(3), 179-187.
Bo, H., Zhang, Y., & Ji, L. L. (2010). Redefining the role of mitochondria in exercise: a dynamic remodeling. *Annals of the New York Academy of Science, 1201*, 121-128.
Borg, G., Hassmén, P., & Lagerström, M. (1987). Perceived exertion related to heart rate and blood lactate during arm and leg exercise. *European Journal of Applied Physiology and Occupational Physiology, 56*(6), 679-685.
Borresen, J., & Lambert, M. I. (2008). Quantifying training load: a comparison of subjective and objective methods. *International journal of sports physiology & performance, 3*(1), 16-30.
Brancaccio, P., Maffulli, N., & Limongelli, F. M. (2007). Creatine kinase monitoring in sport medicine. *British Medical Bulletin, 81 and 82*, 209-230.
Buchheit, M., Horobeanu, C., Mendez-Villanueva, A., Simpson, B. M., & Bourdon, P. C. (2011). Effects of age and spa treatment on match running performance over two consecutive games in highly trained young soccer players. *Journal of Sports Sciences, 29*(6), 591-598.
Buckley, J. D., Bourdon, P. C., & Woolford, S. M. (2003). Effect of measuring blood lactate concentrations using different automated lactate analyzers on blood lactate transition thresholds. *Journal of Science & Medicine in Sport, 6*, 408-421.
Burke, D. G., Holt, L. E., Rasmussen, R., Mackinnon, N. C., Vossen, J. F., & Pelhame, T. W. (2001). Effects of hot or cold water immersion and modified proprioceptive neuromuscular facilitation flexibility exer-cise on hamstring length. *Journal of Athletic Training, 36*, 16-19.
Chen, T. C. (2006). Variability in muscle damage after eccentric exercise and the repeated bout effect. *Research Quarterly for Exercise & Sport, 77*(3), 362-371.
Cheung, K., Hume, P., & Maxwell, L. (2003). Delayed onset muscle soreness: Treatment strategies and performance factors. [Review]. *Sports Medicine, 33*, 145-157.
Christie, B. A., Wulforst, L., Krause, J., Crawford, S., & Docheff, D. (1997). Will the increase of paid coaches for youth sport travel teams or elite teams increase the pressures to win at all costs for the coach and players? *Journal of Physical Education, Recreation & Dance, 68*(4), 10-11.
Ciciliot, S., & Schiaffino, S. (2010). Regeneration of mammalian skeletal muscle. Basic mechanisms and clinical implications. *Current Pharmaceutical Design 16*(8), 906-914.
Cinar, V., Cakmakci, O., Mogulkoc, R., & Baltaci, A. K. (2009). Effects of exhaustion and calcium supplementation on adrenocorticotropic hormone and cortisol levels in athletes. *Biological Trace Element Research, 127*(1), 1-5.

Coffey, V., Leveritt, M., & Gill, N. (2004). Effect of recovery modality on 4- hour repeated treadmill running performance and changes in physiological variables. *Journal of Science & Medicine in Sport, 7*.

Cohen, J. (1990). Things I have learned so far. *American Psychology, 45*, 1304-1312.

Coso, J. D., Gonza´lez-Milla´n, C., Salinero, J. J., Abia´n-Vice´n, J., Soriano, L., & al, e. (2012). Muscle damage and its relationship with muscle fatigue during a half-iron triathlon. *PLoS ONE [Electronic Resource], 7*(8), e43280.

Coutts, A. E., Reaburn, P., Piva, T. J., & Rowsell, G. J. (2007). Monitoring for overreaching in rugby league players. *European Journal of Applied Physiology, 99*, 313-324.

Crewther, B., Cronin, J. B., Keogh, J., & Cook, C. (2008). The salivary testosterone and cortisol response to three loading schemes. *Journal of Strength & Conditioning Research, 22*(1), 250-255.

Cunniffe, B., Hore, A. J., Whitcombe, D. M., Jones, K. P., Baker, J. S., & Davies, B. (2010). Time course of changes in immuneoendocrine markers following an international rugby game. *European Journal of Applied Physiology, 108*(1), 113-122.

Dadebo, B., White, J., & George, K. P. (2004). A survey of flexibility training protocols and hamstring strains in professional football clubs in England. *British Journal of Sports Medicine, 38*, 388-394.

Dahlstedt, A. J., Katz, A., Wieringa, B., & Westerblad, H. (2000). Is creatine kinase responsible for fatigue? Studies of isolated skeletal muscle deficient in creatine kinase. *FASEB, 14*, 982-990.

Dawson, B., Gow, S., Modra, S., Bishop, D., & Stewart, G. (2005). Effects of immediate post-game recovery procedures on muscle soreness, power and flexiblity [sic flexibility] levels over the next 48 hours. *Journal of Science & Medicine in Sport, 8*(2), 210-221.

Day, M. L., McGuigan, M. R., Brice, G., & Foster, C. (2004). Monitoring exercise intensity during resistance training using the session RPE scale. *18*(2), 353-358.

Delextrat, A., Calleja-González, J., Hippocrate, A., & Clarke, N. D. (2013). Effects of sports massage and intermittent cold-water immersion on recovery from matches by basketball players. *Journal of Sports Sciences, 31*(1), 11-19.

Deutsch, M. U., Maw, G. J., Jenkins, D., & Reaburn, P. (1998). Heart rate, blood lactate and kinematic data of elite colts (under-19) rugby union players during competition. *Journal of Sports Science, 16*(6), 561-570.

Duthie, G., Pyne, D., & Hooper, S. (2003). Applied physiology and game analysis of rugby union. *Sports Medicine, 33*, 973-989.

Ebbeling, C. B., & Clarkson, P. M. (1989). Exercise-induced muscle damage and adaptation. *Sports Medicine, 7*, 207-234.

Egan, A. D., Winchester, J. B., Foster, C., & McGuigan, M. R. (2006). Using session RPE to monitor diff erent methods of resistance exercise *Journal of Sports Science and Medicine & Science in Sports & Exercise, 5*, 289-295.

Ehlers, G. G., Ball, T. E., & Liston, L. (2002). Creatine kinase levels are elevated during 2-a-day practices in collegiate football players. *Journal of Athletic Training, 37*(2), 151-156.

Eliakim, A., Portal, S., Zadik, Z., Rabinowitz, J., Adler-Portal, D., Cooper, D. M., et al. (2009). The effect of a volleyball practice on anabolic hormones and

inflammatory markers in elite male and female adolescent players. *Journal of Strength & Conditioning Research, 23*(5), 1553-1559.
Elias, G.P., Varley, M.C., Wyckeisma, V.L., McKenna, M.L., Minahan, C.L., and Aughey, R.J. (2012). Effects of water immersion on post training recovery in Australian footballers. International *Journal of Sports Physiology and Performance, 7,* 357-366.
Eston, R., & Peters, D. (1999). Effects of cold water immersion on the symptons of exercise-induced muscle damage. *Journal of Sports Sciences, 17*, 231-238.
Falvo, M. J., & Bloomer, R. J. (2006). Review of exercise-induced muscle injury: Relevance for athletic populations. *Research in Sports Medicine, 14*, 65-82.
Faulkner, J. A., Gleadon, D., McLaren, J., & Jakeman, J. R. (2013). Effect of lower-limb compression clothing on 400-m sprint performance. *Journal of Strength & Conditioning Research 27*(3), 669-676.
Filaire, E., Filaire, M., & Le Scanff, C. (2007). Salivary cortisol, heart rate and blood lactate during a qualifying trial and an official race in motorcycling competition. *Journal of Sports Medicine & Physical Fitness, 7*, 413-417.
Foster, C., Daines, E., Hector, L., Snyder, A. C., & Welsh, R. (1996). Athletic performance in relation to training load. *Wis. Med. J, 95*, 370-374.
Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., et al. (2001). A new approach to monitoring exercise training. *Journal of Strength & Conditioning Research, 15*(1), 109-115.
Franzini-Armstrong, C. (1999). The sarcoplasmic reticulum and the control of muscle contraction. *FASEB, 13* (9002), s266-S270.
French, D. N., Thompson, K. G., Garland, S. W., Barnes, C. A., Portas, M. D., Hood, P. E., et al. (2008). The effects of contrast bathing and compression therapy on muscular performance. *Medicine & Science in Sports & Exercise, 40*(7), 1297-1306.
Gabbett, T. J. (2002). Physiological characteristics of junior and senior rugby league players. *British Journal of Sports Medicine, 36*(5), 334-339.
Gabbett, T. J. (2005). Changes in physiological and anthropometric characteristics of rugby league players during a competitive season. *Journal of Strength and Conditioning Research, 19*(2), 400-408.
Gabbett, T. J. (2008). Influence of fatigue on tackling technique in rugby league players. *Journal of Strength and Conditioning Research, 22*(2), 625-632.
García-Manso, J. M., Rodríguez-Matoso, D., Rodríguez-Ruiz, D., Sarmiento, S., de Saa, Y., & Calderón, J. (2011). Effect of cold-water immersion on skeletal muscle contractile properties in soccer players. *American Journal of Physical Medicine & Rehabilitation, 90*(5), 356-363.
Garraway, W. M., Lee, A. J., Hutton, S. J., Russell, E. B. A. W., & Macleod, D. A. D. (2000). Impact of professionalism on injuries in rugby union. Br J Sports Med 2000; 34:348–351. *British Journal of Sports Medicine, 34*, 348-351.
Getto, C. N., & Golden, G. (2013). Comparison of active recovery in water and cold-water immersion after exhaustive exercise. *Athletic Training & Sports Health Care: The Journal for the Practicing Clinician, 5*(4), 169-176.
Gill, N. D., Beaven, C. M., & Cook, C. (2006). Effectiveness of post-match recovery strategies in rugby players. *British Journal of Sports Medicine, 40*(3), 260-263.

Halson, S. L. (2011). Does the time frame between exercise influence the effectiveness of hydrotherapy for recovery?. [Review]. *International journal of sports physiology & performance, 6*(2), 147-159.

Hamlin, M. J., Hinckson, E. A., Wood, M. R., & Hopkins, W. G. (2008). Simulated rugby performance at 1550-m altitude following adaptation to intermittent normobaric hypoxia. *Journal of Science and Medicine in Sport, 11*, 593-599.

Hamlin, M. J., Mitchell, C. J., Ward, F. D., Draper, N., Shearman, J. P., & Kimber, N. E. (2012). Effect of compression garments on short-term recovery of repeated sprint and 3-km running performance in rugby union players. *Journal of Strength & Conditioning Research, 26*(11), 2975-2982.

Heyman, E., De Geus, B., Mertens, I., & Meeusen, R. (2009). Effects of four recovery methods on repeated maximal rock climbing performance. *Medicine & Science in Sports & Exercise, 41*, 1303-1310.

Higgins, T. R., Cameron, M., & Climstein, M. (In Press). Evaluation of passive recovery, cold water immersion, and contrast baths for recovery, as measured by game performances markers, between two simulated games of rugby union. *Journal of Strength and Conditioning Research, X*(X), XX.

Higgins, T. R., Cameron, M. L., & Climstein, M. (2013). Acute response to hydrotherapy after a simulated game of rugby. *Journal of Strength & Conditioning Research, 27*(10), 2851-2860.

Higgins, T. R., Climstein, M., & Cameron, M. (2013). Evaluation of hydrotherapy, using passive tests and power tests, for recovery across a cyclic week of competitive rugby union. *Journal of Strength & Conditioning Research, 27*(4), 954-965.

Higgins, T. R., Heazlewood, I. T., & Climstein, M. (2011). A random control trial of contrast baths and ice baths for recovery during competition in u/20 rugby union. *Journal of Strength & Conditioning Research, 25*(4), 1046-1051.

Higgins, T. R., & Heazlewood, T. (2008). *Evaluation of Contrast Baths and Ice Baths for Recovery in U/20 Rugby Union.* Paper presented at the ASICS Conference of Science and Medicine in Sport, Hamilton Island, Australia.

Higgins, T. R., Naughton, G. A., & Burgess, D. (2009). Effects of wearing compression garments on physiological and performance measures in a simulated game-specific circuit for netball. *Journal of Science and Medicine in Sport, 12*(1), 223-226.

Hill, J. A., Howatson, G., Van Someren, K. A., Walshe, I. A. N., & Pedlar, C. R. (2014). Influence of compression garments on recovery after marathon running. *Journal of Strength & Conditioning Research 28*(8), 2228-2235.

Holloszy, J. O. (2009). Skeletal muscle “mitochondrial deficiency” does not mediate insulin resistance. *American Journal of Clinical Nutrition, 89* (1), 463S-466S.

Howatson, G., & Van Someren, K. A. (2008). The prevention and treatment of exercise-induced muscle damage. *Sports Medicine, 38*, 483-503.

Hsu, C., & Sandford, B. A. (2007). The delphi technique: making sense of consensus. *Practical Assessment, Research & Evaluation, 12*(10).

Hubbard, T. J., Aronson, S. L., & Denegar, C. R. (2004). Does cryotherapy hasten return to participation? A systematic review. *Journal of Athletic Training, 39*, 88-94.

Idone, V., Tam, C., & Andrews, N. W. (2008). Two-way traffic on the road to membrane repair. *Trends in Cell Biology, 18*(11), 552-559.

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine & Science in Sports & Exercise, 36*(6), 1042-1047.

Ingram, J., Dawson, B., Goodman, C., Wallman, K., & Beilby, J. (2009). Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of Science & Medicine in Sport, 12*(3), 417-421.

Issurin V.B. (2010). New horizons for the methodology and physiology of training periodization. *Sports Medicine, 40*(3), 189-206.

Jakeman, J. R., Byrne, C., & Eston, R. G. (2010a). Efficacy of lower limb compression and combined treatment of manual massage and lower limb compression on symptoms of exercise-induced muscle damage in women. *Journal of Strength & Conditioning Research 24*(11), 3157-3165.

Jakeman, J. R., Byrne, C., & Eston, R. G. (2010b). Lower limb compression garment improves recovery from exercise-induced muscle damage in young, active females. *European Journal of Applied Physiology, 109*(6), 1137-1144.

Jakeman, J. R., Macrae, R., & Eston, R. (2009). A single bout of cold-water immersion therapy after strenuous plyometric exercise has no beneficial effect on recovery from the symptoms of exercise-induced muscle damage. *Ergonomics, 52*(4), 456-460.

Jones, B., Lander, J., & Brubaker, D. (2013). The effects of different recovery interventions following a repeated rugby union (sevens) game simulated protocol. *Journal of Australian Strength & Conditioning, 21*(4), 5-13.

Jones, T. W., Howatson, G., Russell, M., & French, D. N. (2013). Performance and neuromuscular adaptations following differing ratios of concurrent strength and endurance training. [Randomized Controlled Trial]. *Journal of Strength & Conditioning Research, 27*(12), 3342-3351.

Juliff, L. E., Halson, S. L., Bonetti, D. L., Versey, N. G., Driller, M. W., & Peiffer, J. J. (2014). Influence of contrast shower and water immersion on recovery in elite netballers. *Journal of Strength & Conditioning Research, 28*(8), 2353-2358.

Kellmann, M. (Ed.). (2002). *Current status and directions of recovery research. In enhancing recovery: Preventing underperformance in athletes*. Champaign, IL: Human Kinetics.

Kelly, V. G., & Coutts, A. J. (2007). Planning and monitoring training loads during the competition phase in team sports. *Strength and Conditioning Journal, 29*(4), 32-37.

King, M., & Duffield, R. (2009). The effects of recovery interventions on consecutive days of intermittent sprint exercise. *Journal of Strength and Conditioning Research, 23*(6), 1795-1802.

Kinugasa, T., & Kilding, A. E. (2009). A comparison of post-match recovery strategies in youth soccer players. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins), 23*(5), 1402-1407.

Kirk, R. E. (2003). Research Methods in Experimental Research Psychology. In S. F. Davis (Ed.), *The importance of effect magnitude* (pp. 83-10). Oxford, United Kingdom: Blackwell.

Kon, M., Tanabe, K., Akimoto, T., Kimura, F., & Tanimura, Y. (2008). Reducing exercise-induced muscular injury in kendo athletes with supplementation of coenzyme Q10. *The British Journal of Nutrition 100*(4), 903-909.

Kraemer, W. J., Spiering, B. A., Volek, J. S., Martin, G. J., Howard, R. L., Ratamess, N. A., et al. (2009). Recovery from a National Collegiate Athletic Association Division I football game: muscle damage and hormonal status. *Journal of Strength & Conditioning Research, 23*(1), 2-10.

Lazarim, F. L., Antunes-Neto, J. M. F., da Silva, F. O. C., Nunes, L. A. S., Bassini-Cameron, A., Cameron, L.-C., et al. (2009). The upper values of plasma creatine kinase of professional soccer players during the Brazilian National Championship. *Journal of Science and Medicine in Sport, 12*(1), 85-90.

Leeder, J., Gissane, C., van Somerson, K., Gregson, W., & Howatson, G. (2012). Cold water immersion and recovery from strenuous exercise: a meta-analysis. *British Journal of Sports Medicine, 46*, 233-240.

Linnamo, V., Pakarinen, A., Kraemer, W. J., & Häkkinen, K. (2005). Acute hormonal responses to submaximal and maximal heavy resistance and explosive exercises in men and women. *Journal of Strength & Conditioning Research, 19*(3), 566-571.

Magaudda, L., Di Mauro, D., Trimarchi, F., & Anastasi, G. (2004). Effects of physical exercise on skeletal muscle fiber: ultrastructural and molecular aspects. *Basic Applied Myology, 14*, 17-21.

Margaritis, I., Tessier, F., Verdera, F., Bermon, S., & Marconnet, P. (1999). Muscle enzyme release does not predict muscle function impairment after triathlon. *Journal of Sports Medicine & Physical Fitness, 39*(2), 133-138.

McNaughton, L. R., Thompson, D., Philips, G., Backs, K., & Crickmore, L. (2002). A comparison of the Lactate pro, Accusport, Analox GM7 and Kodak Ektachem analysers in normal, hot and humid conditions. *International Journal of Sports Medicine, 23*, 130-135.

Miyamoto, N., Senjyu, H., Tanaka, T., Asai, M., Yanagita, Y., Yano, Y., et al. (2014). Pulmonary rehabilitation improves exercise capacity and dyspnea in air pollution-related respiratory disease. [Research Support, Non-U.S. Gov't]. *Tohoku Journal of Experimental Medicine, 232*(1), 1-8.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2010). Preferred reporting items for systematic reviews and meta-analyses:The PRISMA Statement. *International Journal of Surgery, 8*(5), 336-341.

Montgomery, P. G., Pyne, D. B., Cox, A. J., Hopkins, W. G., Minahan, C. L., & Hunt, P. H. (2008). Muscle damage, inflammation, and recovery interventions during a 3-day basketball tournament. *European Journal of Sport Science, 8*(5), 241-250.

Montgomery, P. G., Pyne, D. B., Hopkins, W. G., Dorman, J. C., Cook, K., & Minahan, C. L. (2008). The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *Journal of Sports Sciences, 26*(11), 1135-1145.

Morgans, R., Adams, D., Mullen, R., McLellan, C., & Williams, M. (2014). An English championship league soccer team did not experience impaired physical match performance in a second match after 75 hours of recovery. *Journal of Australian Strength & Conditioning, 22*(4), 16-23.

Neubauer, O., König, D., & Wagner, K. H. (2008). Recovery after an Ironman triathlon: sustained inflammatory responses and muscular stress. *European journal of applied physiology, 104*(3), 417-426.

Newton, M. J., Morgan, G. T., Sacco, P., Nosaka, K., Chapman, P., & W, D. (2008). Comparison of responses to strenuous eccentric exercise of the elbow flexors

between resistance-trained and untrained men. *Journal of Strength and Conditioning Research, 22*(2), 597-607.
Paschalis, V., Koutedakis, Y., Jamurtas, A. Z., Mougios, V., & Baltzopoulos, V. (2005). Equal volumes of high and low intensity of eccentric exercise in relation to muscle damage and performance. *Journal of Strength & Conditioning Research, 19*(1), 184-188.
Patterson, S. M., Udermann, B. E., Doberstein, S. T., & Reineke, D. M. (2008). The effects of cold whirlpool on power, speed, agility, and range of motion. *Journal of Sports Science and Medicine, 7*, 387-394.
Peiffer, J. J., Abbiss, C. R., Watson, G., Nosaka, K., & Laursen, P. B. (2009). Effect of cold-water immersion duration on body temperature and muscle function. *Journal of Sports Sciences, 27*(10), 987-993.
Peiffer, J. J., Abbiss, C. R., Watson, G., Nosaka, K., & Laursen, P. B. (2010). Effect of cold water immersion on repeated 1-km cycling performance in the heat. *Journal of Science & Medicine in Sport, 13*, 112-116.
Philippou, A., Halapas, A., Maridaki, M., & Koutsilieris, M. (2007). Type I insulin-like growth factor receptor signaling in skeletal muscle regeneration and hypertrophy. *J Musculoskelet Neuronal Interact, 7*(3), 208-218.
Pointon, M., & Duffield, R. (2012). Cold water immersion recovery after simulated collision sport exercise. *Medicine & Science in Sports & Exercise, 44*(2), 206-216.
Pointon, M., Duffield, R., Cannon, J., & Marino, F. E. (2012). Cold water immersion recovery following intermittent-sprint exercise in the heat. *European Journal of Applied Physiology, 112*, 2483–2494.
Poppendieck, W., Faude, O., Wegmann, M., & Meyer, T. (2013). Cooling and performance recovery of trained athletes: A meta-analytical review. *International journal of sports physiology & performance, 8*, 227-242.
Pournot, P., Bieuzen, F., DuYeld, R., Lepretre, P.-M., Cozzolino, C., & Hausswirth, C. (2011). Short term effects of various water immersions on recovery from exhaustive intermittent exercise. *European Journal of Applied Physiology, 111*, 1287–1295.
Pruscino, C., Halson, S., & Hargreaves, M. (2013). Effects of compression garments on recovery following intermittent exercise. *European Journal of Applied Physiology, 113*(6), 1585-1596.
Ra¨mson, R., Ju¨ rima¨ e, J., Ju¨ rima¨ e, T., & Ma¨ estu, J. (2009). Behavior of testosterone and cortisol during an intensity-controlled high volume training period measured by a training task-specific test in men rowers. *Journal of Strength & Conditioning Research, 23*(2), 645-651.
Reddy, A., Caler, E. V., & Andrews, N. W. (2001). Plasma membrane repair is mediated by Ca2+ - regulated exocytosis of lysosomes. *Cell, 106*(2), 157-169.
Reilly, T., Dowzer, C. N., & Cable, N. T. (2003). The physiology of deep- water running. *Journal of Sports Science, 21*, 959-972.
Reilly, T., & Ekblom, B. (2005). The use of recovery methods post-exercise. *Journal of sports sciences, 23*(6), 619-627.
Roberts, S. P., Stokes, K. A., Weston, L., & Trewartha, G. (2010). The Bath University Rugby Shuttle Test (BURST): A Pilot Study. *International Journal of Sports Physiology & Performance, 5*(1), 64-74.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2009). Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal of Sports Sciences, 27*(6), 565-573.

Rowsell, G. J., Coutts, A. J., Reaburn, P., & Hill-Haas, S. (2011). Effect of post-match cold-water immersion on subsequent match running performance in junior soccer players during tournament play. *Journal of Sports Sciences, 29*(1), 1-6.

Rupp, K. A., Selkow, N. M., Parente, W. R., Ingersoll, C. D., Weltman, A. L., & Saliba, S. A. (2012). The effect of cold water immersion on 48-hour performance testing in collegiate soccer players. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins), 26*(8), 2043-2050.

Sakamoto, A., Maruyama, T., Naito, H., & Sinclair, P. J. (2009). Effects of exhaustive dumbbell exercise after isokinetic eccentric damage: recovery of static and dynamic muscle performance. *Journal of Strength & Conditioning Research, 23*(9), 2467-2476.

Saraslanidis, P. J., Manetzis, C. G., Tsalis, G. A., Zafeiridis, A. S., Mougios, V. G., & Kellis, S. E. (2009). Biochemical evaluation of running workouts used in training for the 400-m sprint. *Journal of Strength & Conditioning Research, 23*(8), 2266-2271.

Seiler, S., & Sjursen, J. E. (2004). Effect of work duration on physiological and rating scale of perceived exertion responses during self-paced interval training. *Scandinavian Journal of Medicine & Science in Sports, 14*, 318-325.

Sellwood, K. L., Brukner, P., Williams, D., Nicol, A., & Hinman, R. (2007). Ice-water immersion and delayed-onset muscle soreness: A randomised controlled trial. *British Journal of Sports Medicine, 41*, 392-397.

Shkurnikov, M. U., Donnikov, A. E., Akimov, E. B., Sakharov, D. A., & Tonevitsky, A. G. (2008). Free testosterone as marker of adaptation to medium-intensive exercise. *Bulletin of Experimental Biology and Medicine, 146*(9), 330-332.

Shorten, P. R., & Soboleva, T. K. (2007). Anomalous ion diffusion within skeletal muscle transverse tubule networks. *Theoretical Biology and Medical Modelling 4*(18).

Silva, J. R., Ascensa˜o, A., Marques, F., Seabra, A., Rebelo, A., & Magalha˜es, J. (2013). Neuromuscular function, hormonal and redox status and muscle damage of professional soccer players after a high-level competitive match. *European Journal of Applied Physiology, 113*, 2193–2201.

Singh, T. K. R., Guelfi, K. J., Landers, G., Dawson, B., & Bishop, D. (2011). A comparison of muscle damage, soreness and performance following a simulated contact and non-contact team sport activity. *Journal of Science and Medicine in Sport, 14*(5), 441-446.

Skurvydas, A., Brazaitis, M., & Kamandulis, S. (2010). Muscle-damaging exercise affects isokinetic torque more at short muscle length. *Journal of Strength and Conditioning Research, 25*(5), 1400-1406.

Smart, D., Gill, N., Beaven, C., Cook, C., & Blazevich, A. (2008). The relationship between changes in interstitial creatine kinase and game-related impacts in rugby union. *British Journal of Sports Medicine, 42*(3), 198-201.

Soebbing, B. P., & Mason, D. S. (2009). Managing legitimacy and uncertainty in professional team sport: the NBA's draft lottery *Team Performance Management: An International Journal 15*(3/4), 141-157.

St Clair Gibson, A., & Noakes, T. D. (2004). Evidence of complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans. *British Journal of Sports Medicine, 38*, 797-806.

Stagno, K. M., Thatcher, R., & Van Someren, K. A. (2006). A modified TRIMP to quantify the in-season training load of team sport players. *Journal of Sports Science, 25*(6), 1-6.

Stocks, J.M., Taylor, N.A.S., Tipton, M.J., & Greenleaf, J.E. (2004). Human physiological responses to cold exposure. *Aviation, Space and Environmental Medicine. 75*(5):444-457.

Stoove, M. A., & Andersen, M. B. (2003). Research without tears; What are we looking at, and how big is it? *Physical Therapy in Sport, 4*, 93-97.

Stuart, G. R., Hopkins, W. G., Cook, C., & Cairns, S. P. (2005). Multiple effects of cafeine on simulated high-intensity team-sport performance. *Medicine & Science in Sports & Exercise, 37*(11), 1998-2005.

Su, Q., Tian, Y., Zhang, J., & Zhang, H. (2008). Effects of allicin supplementation on plasma markers of exercise-induced muscle damage, IL-6 and antioxidant capacity. *European Journal of Applied Physiology, 103*, 275-283.

Suzuki, M., Umeda, T., Nakaji, S., Shimoyama, T., Mashiko, T., & Sugawara, K. (2004). Effect of incorporating low intensity exercise into the recovery period after a rugby match. *British Journal of Sports Medicine, 38*, 436-440.

Sweet, T. W., Foster, C., McGuigan, M. R., & Brice, G. (2004). Quantitation of resistance training using the session rating of perceived exertion method. *Journal of Strength and Conditioning Research, 18*(4), 796-802.

Symons, T. B., Clasey, J. L., Gater, D. R., & Yates, J. W. (2004). Effects of deep heat as a preventative mechanism on delayed onset muscle soreness. *Journal of Strength & Conditioning Research, 18*(1), 155-161.

Takarada, Y. (2003). Evaluation of muscle damage after a rugby match with special reference to tackle plays. *British Journal of Sports Medicine, 37*(5), 416-419.

Takeda, M., Sato, T., Hasegawa, T., Shintaku, H., Kato, H., Yamaguchi, Y., et al. (2014). The effects of cold water immersion after rugby training on muscle power and biochemical markers. *Journal of Sport Science and Medicine, 13*, 616-623.

Tee, J. C., Bosch, A. N., & Lambert, M. I. (2007). Metabolic Consequences of Exercise-Induced Muscle Damage. *Sports Medicine, 37*(10), 827-836.

Tessitore, A., Meeusen, R., Pagano, R., Benvenuti, C., Tiberi, M., & Capranica, L. (2008). Effectiveness of active versus passive recovery strategies after futsal games. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins), 22*(5), 1402-1412.

Tessitore, A., Meusen, R., Demarie, S., Ugolotti, G., & Capranica, L. (2004). Effects of different recovery methods following soccer training. *Journal of Sports Science, 22*, 562-563.

Totsuka, M., Nakaji, S., Suzuki, K., Sugawara, K., & Sato, K. (2002). Break point of serum creatine kinase release after endurance exercise. *Journal of Applied Physiology, 93*, 1280-1286.

Vaile, J., Gill, N., & Blazevich, A. J. (2007). The effect of contrast water therapy on symptons of delayed onset muscle soreness. *Journal of Strength & Conditioning Research, 21*(3), 697-702.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2007). Effect of hydrotherapy on recovery from fatigue. *International Journal of Sports Physiology and Performance, 29*, 539-544.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2007b). Effect of hydrotherapy on recovery from fatigue. *International journal of sports physiology & performance, 29*, 539-544.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008a). Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. *Journal of Sports Sciences, 26*(5), 431-440.

Vaile, J., Halson, S., Gill, N., & Dawson, B. (2008b). Effect of hydrotherapy on recovery from fatigue. *International Journal of Sports Physiology and Performance, 29*, 539-544.

Versey, N.G., Halson, S.L., and Dawson, B.T (2013). Water immersion recovery for athletes: effect on exercise performance and practical recommendations. *Sports Med 43,* 1101–1130.

Wallace, L. K., Slattery, K. M., & Coutts, A. J. (2008). The ecological validity and application of the session RPE method for quantifying training loads in swimming. *Journal of Strength & Conditioning Research, 23*(1), 33-38.

Warhol, M. J., Siegel, A. J., Evans, W. J., & Silverman, L. M. (1985). Skeletal muscle injury and repair in marathon runners after competition. *American Journal Of Pathology, 118*(2), 331-339.

Webb, N. P., Harris, N. K., Cronin, J. B., & Walker, C. (2013). The relative efficacy of three recovery modalities after professional rugby league matches. *Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins), 27*(9), 2449-2455.

Weber, M., Kinscherf, R., Krakowski-Roosen, H., Aulmann, M., Renk, H., Künkele, A., et al. (2007). Myoglobin plasma level related to muscle mass and fiber composition – a clinical marker of muscle wasting? *Journal of Molecular Medicine, 85*, 887-896.

Wiacek, M., Andrzejewski, M., Chmura, J., & Zubrzycki, I. Z. (2011). The changes of the specific physiological parameters in response to 12-week individualized training of young soccer players. *Journal of Strength & Conditioning Research, 25*(6), 1541-1511.

Wilcock, I. M., Cronin, J. B., & Hing, W. A. (2006). Physiological response to water immersion: A method for sport recovery? . *Sports Medicine, 36*(9), 747-765.

Williams, J. H. (1997). Contractile apparatus and sarcoplasmic reticulum function: effects of fatigue, recovery, and elevated Ca2+. *Journal of Applied Physiology, 83*(2), 440-450.

Yamamoto, L. M., Judelson, D. A., Farrell, M. J., Lee, E. C., Armstrong, L. E., Casa, D. J., et al. (2008). Effects of hydration state and resistance exercise on markers of muscle damage. *Journal of Strength and Conditioning Research, 22*(5), 1387-1393.

Yanagisawa, O., Niitsu, M., Takahashi, H., Goto, K., & Itai, Y. (2003). Evaluations of cooling exercised muscle with MR imaging and PMR spectroscopy. *Medicine and Science in Sports and Exercise, 35*(9), 1517-1523.

Zuliani, U., Bonetti, A., Franchini, D., Serventi, G., Ugolotti, G., & Varacca, A. (1985). Effect of boxing on some metabolic indices of muscular contraction. *International Journal of Sports Medicine, 6*(4), 234-236.

Appendix A

I. Ethics approval

II. Ethics extension approval

III. Ethics extension for lactate modification

IV. Information letter to participants

V. Participant consent forms

VI. Explanatory notes

I. Ethics approval

Human Research Ethics Committee

Committee Approval Form

Principal Investigator/Supervisor: Dr Tim Heazlewood

Co-Investigators: Associate Professor Geraldine Naughton

Student Researcher: Mr Trevor Higgins

Ethics approval has been granted for the following project:

Assessment into the Effectiveness of Recovery Strategies in Team Sport, Measured by Field Performance Markers and the Athlete Burnout Questionnaire

for the period: 21 May 2007 to 30 December 2008

Human Research Ethics Committee (HREC) Register Number: N200607 41

II. Ethics extension approval

Dear Mike and Trevor,

Thank you for submitting the request to modify form for your project N200708-24 *Assessment into the effectiveness of Recovery Strategies in Team Sport, Measured by Field Performance Markers*.

The Chair of the Human Research Ethics Committee has approved the following modification(s):

1. Extension to 31 May 2010.
2. Addition of blood lactate sampling pre-,mid- and post-stimulus. Use of telemetry heart rate monitors.
3. Change PI from Tim Heazlewood to Mike Climstein.

We wish you well in this ongoing research project.

Kind Regards,

Kylie Pashley

Research Services

McAuley at Banyo Campus

PO Box 456

VIRGINIA QLD 4014

AUSTRALIA

I am available Monday, Thursday and Friday.

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Australian Catholic University Ltd

ABN 15 050 192 660

CRICOS Registration codes:00004G, 00112C, 00873F, 00885B

III. Ethics extension for lactate modification

Dear Mike and Trevor,

Thank you for submitting the request to modify form for your project N200708-24 *Assessment into the effectiveness of Recovery Strategies in Team Sport, Measured by Field Performance Markers*.

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3. Change PI from Tim Heazlewood to Mike Climstein.

We wish you well in this ongoing research project.

Kind Regards,

Kylie Pashley

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CRICOS Registration codes:00004G, 00112C, 00873F, 00885B

IV. Information letter to participants

INFORMATION LETTER TO PARTICIPANTS

(Rugby Union, Rugby League, Soccer)

Research project title: ASSESSMENT INTO THE EFFECTIVENESS OF RECOVERY STRATEGIES IN TEAM SPORT, MEASURED BY FIELD PERFORMANCE MARKERS

Student Researcher: Trevor Higgins B.Ex.Sci (hons)

Supervisor: Dr. Tim Heazlewood

Research: Doctor of Philosophy– Australian Catholic University

Dear Participant

You are invited to participate in a research project into the Assessment into the Effectiveness of Recovery Strategies in Team Sport, Measured by Field Performance Markers (Recovery Strategies Study)

This study is designed to provide scientific research for athletes, trainers, coaches and officials in team sports in regards to the field of recovery. The need to recover from game and training sessions has seen the adoption of various strategies, across a variety of sports. However, to date there is limited scientific research on the benefits of these strategies. The purpose of recovery is to ensure players have recovered, from either game or training, to a point where performance is not unduly affected by fatigue, at the next session. Your participation in this research will aide in identifying the most appropriate method/s of recovery to minimize the accumulation of fatigue across a competitive season in elite team sport competitions.

Despite the lack of sound scientific evidence a number of methods are in use at all levels of sport. Interviews across teams in the ARC, NRL and A-League competitions identified a number of practices in place. Ice Baths of 5 minutes at temperatures of 10-12 degrees Celsius, Contrast baths of varying ratios including 3 to 1 cold to warm and 1 to 1 with cold temperature of between 10-12 degrees and warm at temperatures ranging between 38 and 41 degrees, and 2 to 1 ratio warm to cold at similar temperatures are most common. The AIS also has recommendations of ice baths and contrast baths within these ranges for recovery purposes. Massage, stretching, electrolysis (TENS) and rest have also been identified as been in use for recovery

Participants will be asked to volunteer to participate in a Randomised Control Study of between 2 and 4 weeks during pre-season and pre-competition training phases. The study would be comparing three recovery methods, contrast baths, ice baths and TENS. Officials from each team would select two out of the three methods for their team to use. The study would then involve baseline testing of all players, then players assigned to one of the two recovery methods or a control group. After each conditioning session, each group would participate in their assigned recovery modality. After 2 weeks, testing would be carried out on all participants, 48 hours after the last session and results assessed against baseline scores. If teams are in agreement the study would continue for another 2 weeks along the same guidelines. Testing will be carried out at each team's normal training venues and take approximately 60 minutes. Depending on training modalities tests are listed below.

Aerobic Capacity Tests

Multi Stage Shuttle Run

2.4 km time trial

Power Tests

20m sprint	Berg et al.,
50m Sprint	Rusko et al.,
Plyometric 3 Step Leap	Berg et al.,

Anaerobic Capacity Tests

Phosphagen Test,	Sprint repeats 7 * 7sec sprint /21sec recovery
300 metre sprint test	Berg et al.,

If methods are identified to have benefits for recovery for particular training stimuli an additional study would be carried out during 4 weeks of competition. Time frame to be established with clubs agreeing to be involved, but generally would look to examine between week 6 to week 12 of competition.The participants who have volunteered are made up from players associated with teams involved with the NRL, A-League, and Tooheys New Shute Shield competitions. The clubs selected were identified during the information gathering stage of professional practices to be interested in further research.

Cold Water Immersion Protocol

Cold water immersion protocol will follow the guidelines set out by previous research published in International Journal of Sports Medicine (Paddon-Jones & Quigley, 1997) and established at the AIS recovery centre. It will involve players immersing in baths after training. The water temperature in baths will be kept between 10^0 C and 12^0 C and players immersed for 5 minutes.

Contrast Baths Protocol

The contrast bath protocol will be adapted from previous research (Dawson, 2002). It will consist of alternating from hot shower (38-41^o C) for one minute then sit in waist deep icy water (approx. 12^o C) for one minute. The cycle will consist of alternating seven times in the hot shower and ice water in line with established protocol at the AIS recovery centre.

TENS Recovery

Compex© Sport Elite unit (TENS) under the recovery setting to the Hamstrings and calf areas after game and training sessions. The programme runs for 24 minutes and is automatically set. TENS treatment will involve small electrical impulses, mimicking the signals sent via the Central Nervous System, been sent to the muscles activating muscle contractions. Players will feel a slight tingling sensation not unlike a pins and needles sensation. TENS does not cause harm and has non-impact benefits. No pain should be felt by the players.

Control Group

The control group will undergo passive recovery. Passive recovery will consist of seated rest, with legs raised for 10 minutes.

An additional assessment will be performed by approximately 50 participants on a Cybex 340 muscle extremity evaluation system performing leg extension/flexion exercisers. The tests will be performed at ACU's Strathfield Campus, Edwin Clancy Building. Tests will be carried out on three occasions in addition to the field tests, it is anticipated that the cybex testing will take approximately 45 minutes to complete, on each occasion.

There are minimal risks involved with the study apart from risk of injury already associated with the sport. Doctors, physiotherapists and trainers are provided at games and training to treat any injuries that may occur.

You should note that you are free to choose not to take part in the study and to withdraw from the research program at any time during the project without providing a reason and with no penalty. Withdrawing will not disadvantage your participation in your competition or team nor will any future position be disadvantaged due to your withdrawal.

Data collected from you during the study will remain within the confidence of the researchers. Reports will not identify individual participants and only group results will be made available. Data will remain kept securely within the School of Exercise Science office at the Australian Catholic University, North Strathfield. The group results from this project may be published in a sports science journal. A summary report will also be distributed for participants.

Any questions about the above information can be obtained by contacting Dr Tim Heazlewood in the School of Exercise Science at the North Strathfield (Mount. St. Mary) Campus of the Australian Catholic University 25a Barker Street Strathfield New South Wales 2135 Australia, phone 9701 4051, fax 9701 4289, email tim.heazlewood@acu.edu.au.

In the event that you have any complaints or concerns about the way you have been treated by researchers in this study or if you have any query that the researcher has not been able to satisfy, you may write to the Chair of the Human Research Ethics Committee from the Research Services Unit of the Australian Catholic University:

Chair, HREC, Research Services Australian Catholic University

Sydney Campus, Locked Bag 2002

STRATHFIELD NSW 2135

Telephone 02 9701 4159, Fax 02 9701 4350

Any complaint or concern will be treated in confidence and fully investigated. The participant will be informed of the outcome. If you agree to participate in the Recovery Strategies study, you should sign both copies of the Consent Form, retain one copy for your records and return the other to Dr. Tim Heazlewood at the above address.

Yours sincerely

Trevor Higgins — Student Researcher

Dr Tim Heazlewood — Supervisor

V. Participant consent forms

INFORMED CONSENT FORM
(RUGBY UNION, RUGBY LEAGUE, SOCCER)

Copy for Participant

TITLE OF PROJECT: ***ASSESSMENT INTO THE EFFECTIVENESS OF RECOVERY STRATEGIES IN TEAM SPORT, MEASURED BY FIELD PERFORMANCE MARKERS***

STAFF SUPERVISOR: Dr Mike Climstein
STUDENT RESEARCHER: Trevor Higgins B.Ex.Sci (Hons)
COURSE: Doctor of Philosophy

Participant Consent

I .... have read and understood the information provided in the Information Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in the Recovery Strategies Study, which will be conducted during pre-season training and include recovery sessions assigned to my group and testing sessions of approximately 20 minutes each every two (2) weeks. I realize that I can withdraw my consent at any time without jeopardizing my position within the team. I agree that research data collected for the study may be published or provided to other researchers in a form that does not identify me in any way.

I consent to Cold Water Baths Contrast Baths TENS Control Group

Field Tests Cybex Testing

Name of Participant: .. (block letters)

Signature: .... Date: ....

Staff Supervisor: Dr Mike Climstein Student Researcher Trevor Higgins ....

Signature: .... Signature ....

Date: .... Date: ....

VI. Explanatory notes

In some cases, information and details listed in the ethics application process are not found in the thesis, and I offer this summary of events to clarify these omissions.

Supervision, and principal investigator named in ethics applications: Throughout the research program I have undergone four changes in principal supervisor. Initially the thesis was commenced under the supervision of Dr Tim Heazlewood. At the end of 2008 Dr Heazlewood left ACU for a position at Charles Darwin University. Dr Mike Climstein then became the principal supervisor in 2009. In June of 2010 Dr Melainie Cameron became an associate supervisor for my research. In December 2011 Dr Climstein left ACU to take up a position at Bond University, at which time Dr Cameron became my principal supervisor. In February 2012, Dr Cameron left ACU for a position at University of the Sunshine Coast. Both Dr Climstein and Dr Cameron continue to provide supervision, albeit external to ACU. In December 2012 Associate Professor John Saunders became my fourth principal supervisor.

In U/20 Rugby Union it is not uncommon to have players aged 17 years. Parental consent forms were therefore originally provided in case a minor wished to volunteer for the study. At the time the research was conducted, there were two players at Eastwood who were under 18 years of age. Neither participant volunteered to participate in the study, therefore there is no reference to the use of minors in the thesis.

The Athlete burnout questionnaire (ABQ): This questionnaire was included in the initial ethics application as one tool to monitor fatigue, however, when I piloted it with the Eastwood U/20 players prior to the research program, I found there was a great deal of donkey voting among players such that results from the questionnaire would be flawed and fail to provide accurate information for the research program. The ABQ was not used in the research.

TENS intervention and Cybex testing: These procedures were specific to a Pilot study conducted with an NRL team. Results from the pilot study did not warrant additional investigation within the Rugby Union studies that constitute this thesis.

Appendix B

Pre-activity readiness questionnaire

Pre-Activity Readiness-Questionnaire (PAR-Q)

Title of project - ASSESSMENT INTO THE EFFECTIVENESS OF RECOVERY STRATEGIES IN TEAM SPORT, MEASURED BY FIELD PERFORMANCE MARKERS

Supervisor: Dr Tim Heazlewood

Student Researcher: Trevor Higgins. Email: t.heazlewood@mary.acu.edu.au

Subject Details (Please Print)

Name___________________________

Age________

Date of birth________

Gender____________

Height (m)_________

Weight (kg)________

BMI______________

Please circle **Y**=yes**, N**=no

1. Do you smoke? **Y/N**
2. Have you ever smoked? **Y/N**
   If yes, when did you last smoke?______________
3. Are you currently taking medication? **Y/N**
   If yes, please list medication__________________
   ____
4. Do you suffer from asthma? **Y/N**
5. Has your doctor ever said you have heart trouble? **Y/N**
6. Has your doctor said you should exercise only as recommended by a doctor? **Y/N**
7. Has your doctor ever said you have high blood pressure? **Y/N**
8. Do you have pain in your chest when you exercise? **Y/N**
9. Do you lose your balance because of dizziness, or do you ever lose consciousness? **Y/N**
10. Do you have bone or joint problems which may be aggravated by exercise? **Y/N**

Please answer the following additional questions.

Do you have a family history (mother, father, sister, brother) of:

Diabetes (Type if known)

____
____

Heart disease (Specify)

____
____
____

Hypertension

____
____
____

Hypercholesterolaemia____
____
____

How much exercise do you do per week?__________

Type of exercise you do each week

__________________________________ ____________________

__________________________________ ____________________

Appendix C

Session Rating of Perceived Exertion Scale

Session RPE instrument

1 - 10 Borg Rating of Perceived Exertion Scale	
0	Rest
1	Really Easy
2	Easy
3	Moderate
4	Sort of Hard
5	Hard
6	
7	Really Hard
8	
9	Really, Really, Hard
10	Maximal: Just like my hardest race

Appendix D

Results summary table from Systematic review-meta-analysis: Chapter 7

Table 7.4 Results summary for CMJ/VJ

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
											lower	upper
Getto et al (2013)	CWI	<1h Post	295.37	29.43	298.63	23.80	3.26	0.12	0.12	0.47	-0.81	1.04
	Control		295.11	22.68	300.51	7.34	5.40	0.32	0.30	0.50	-0.68	1.29
	AR		299.56	7.66	296.55	21.58	-3.01	-0.19	-0.18	0.47	-1.10	0.75
Higgins et al (2013b)	CWI		1.39	0.53	1.18	0.53	-0.21	-0.40	-0.37	0.54	-1.42	0.69
	CWT		1.15	0.40	1.01	0.33	-0.14	-0.38	-0.36	0.50	-1.35	0.63
	Control		1.27	0.38	1.16	0.42	-0.11	-0.27	-0.26	0.50	-1.24	0.72
King et al (2009)	CWI		6.2	4.50	6.90	5.00	0.70	0.15	0.14	0.45	-0.74	1.02
	AR		7.2	6.30	9.30	7.10	2.10	0.31	0.30	0.45	-0.58	1.18
	CWT		6.8	3.60	4.90	2.60	-1.90	-0.61	-0.58	0.46	-1.47	0.32
	Control		6.3	3.50	7.30	4.80	1.00	0.24	0.23	0.45	-0.65	1.11
Kinugasa et al (2009)	CWT		47.4	4.70	47.20	4.80	-0.20	-0.04	-0.04	0.33	-0.69	0.61
	Comb.		45.7	6.10	47.80	8.80	2.10	0.28	0.27	0.31	-0.34	0.88
	Control		48.5	6.20	45.30	3.50	-3.20	-0.64	-0.61	0.42	-1.43	0.21
Pournot et al	TWI		41.81	5.29	25.46	4.31	-16.35	-3.39	-3.23	0.72	-4.63	-1.83
	CWI		34.2	5.86	29.29	6.00	-4.91	-0.83	-0.80	0.41	-1.60	0.00
	CWT		33.32	7.80	29.20	6.99	-4.12	-0.56	-0.53	0.46	-1.42	0.36
	Control		37.74	4.80	32.00	6.45	-5.74	-1.01	-0.96	0.50	-1.94	0.01
Rupp et al (2012)	CWI		64.7	11.70	65.50	10.00	0.80	0.07	0.07	0.41	-0.73	0.87
	Control		64.4	10.70	67.40	12.30	3.00	0.26	0.25	0.45	-0.63	1.13
Takeda et al (2014)	CWI		47.1	6.90	44.30	7.60	-2.80	-0.39	-0.37	0.45	-1.25	0.51
	Control		45.1	9.30	43.90	8.40	-1.20	-0.14	-0.13	0.45	-1.01	0.75

Table 7.4 cont'd

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
Dawson et al (2005)	Stretch	24h Post	52.0	6.0	49.0	5.0	-0.70	-0.23	-0.22	0.50	-1.20	0.76
	Pool walking		53.0	5.0	52.0	5.0	-3.50	-1.17	-1.10	0.54	-2.15	-0.05
	CWT		54.0	6.0	51.0	6.0	-2.00	-0.69	-0.66	0.51	-1.66	0.35
	Control		54.0	5.0	49.0	6.0	-1.00	-0.19	-0.18	0.50	-1.17	0.80
Delextrat et al (2013) Female	CWI		34.5	3.0	33.8	3.0	-3.50	-0.66	-0.62	0.51	-1.63	0.38
	Control		34.5	3.0	31.0	3.0	-3.50	-1.17	-1.10	0.54	-2.15	-0.05
	Massage		34.5	3.0	32.5	2.8	-2.00	-0.69	-0.66	0.51	-1.66	0.35
Delextrat et al (2013) Male	CWI		50.0	5.1	49.0	5.2	-1.00	-0.19	-0.18	0.50	-1.17	0.80
	Control		50.0	5.1	46.5	5.5	-3.50	-0.66	-0.62	0.51	-1.63	0.38
	Massage		50.0	5.1	48.5	5.5	-1.50	-0.28	-0.27	0.50	-1.25	0.72
Getto et al (2013)	CWI		295.4	29.4	293.9	25.6	-1.46	-0.05	-0.05	0.47	-0.97	0.87
	Control		295.1	22.7	296.2	22.0	1.12	0.05	0.05	0.50	-0.93	1.03
	AR		299.6	7.7	300.7	8.0	1.11	0.14	0.14	0.47	-0.79	1.06
Higgins et al (2013a)	CWI		1.4	0.5	1.2	0.5	-0.21	-0.40	-0.37	0.54	-1.42	0.69
	CWT		1.2	0.4	1.0	0.3	-0.14	-0.38	-0.36	0.50	-1.35	0.63
	Control		1.3	0.4	1.1	0.4	-0.15	-0.37	-0.35	0.50	-1.34	0.63
King et al (2009)	CWI		6.2	4.5	4.4	2.7	-1.80	-0.49	-0.46	0.45	-1.35	0.42
	AR		7.2	6.3	7.7	3.7	0.50	0.10	0.09	0.45	-0.78	0.97
	CWT		6.8	3.6	8.1	5.8	1.30	0.27	0.26	0.45	-0.62	1.14
	Control		6.3	3.5	8.1	4.9	1.80	0.42	0.40	0.45	-0.48	1.29
Kinugasa et al (2009)	CWT		47.4	4.7	47.6	5.3	0.20	0.04	0.04	0.33	-0.61	0.69
	Comb.		45.7	6.1	45.9	5.9	0.20	0.03	0.03	0.31	-0.57	0.64
	Control		48.5	6.2	48.7	6.5	0.20	0.03	0.03	0.41	-0.77	0.83
Montgomery et al (2008a)	CWI		67.2	8.4	61.6	6.5	-5.60	-0.75	-0.71	0.46	-1.62	0.19
	CG		63.6	6.6	59.8	8.1	-3.80	-0.51	-0.49	0.45	-1.38	0.40
	Control		61.1	8.2	58.7	6.7	-2.40	-0.32	-0.31	0.47	-1.23	0.62

Table 7.4 cont'd

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
Pournot et al (2011)	TWI	24h Post	41.8	5.3	40.1	3.9	-1.72	-0.37	-0.35	0.48	-1.28	0.58
	CWI		34.2	5.9	33.4	6.5	-0.78	-0.13	-0.12	0.39	-0.89	0.65
	CWT		33.3	7.8	31.4	8.0	-1.88	-0.24	-0.23	0.45	-1.11	0.65
	Control		37.7	4.8	36.9	6.5	-0.83	-0.15	-0.14	0.47	-1.06	0.79
Rowsell et al (2009)	CWI		50.0	8.0	48.0	9.0	-2.00	-0.23	-0.22	0.45	-1.10	0.65
	TWI		51.0	5.0	50.0	5.0	-1.00	-0.20	-0.19	0.45	-1.07	0.69
Rupp et al (2012)	CWI		64.7	11.7	63.7	9.8	-1.00	-0.09	-0.09	0.41	-0.89	0.71
	Control		64.4	10.7	63.0	10.4	-1.40	-0.13	-0.13	0.45	-1.00	0.75
Takeda et al (2014)	CWI		47.1	6.9	43.6	5.6	-3.50	-0.56	-0.53	0.46	-1.43	0.36
	Control		45.1	9.3	41.4	9.6	-3.70	-0.39	-0.37	0.45	-1.26	0.51
Dawson et al (2005)	Stretch	48h Post	52.00	6.00	51.00	5.00	-1.00	-0.18	-0.18	0.34	-0.85	0.50
	Pool walking		53.00	5.00	54.00	6.00	1.00	0.18	0.18	0.34	-0.50	0.85
	CWT		54.00	6.00	54.00	6.00	0.00	0.00	0.00	0.34	-0.67	0.67
	Control		54.00	5.00	54.00	4.00	0.00	0.00	0.00	0.34	-0.67	0.67
Higgins et al (2013a)	CWI		1.39	0.53	1.32	0.49	-0.07	-0.14	-0.13	0.54	-1.18	0.92
	CWT		1.15	0.40	1.08	0.27	-0.07	-0.21	-0.19	0.50	-1.18	0.79
	Control		1.27	0.38	1.30	0.56	0.03	0.06	0.06	0.50	-0.92	1.04
Higgins et al (2013b)	CWI		1.39	0.53	1.32	0.49	-0.07	-0.14	-0.13	0.54	-1.18	0.92
	CWT		1.15	0.40	1.08	0.27	-0.07	-0.21	-0.19	0.50	-1.18	0.79
	Control		1.27	0.38	1.30	0.56	0.03	0.06	0.06	0.50	-0.92	1.04
King et al (2009)	CWI		6.20	4.50	6.40	3.00	0.20	0.05	0.05	0.45	-0.83	0.93
	AR		7.20	6.30	5.60	2.50	-1.60	-0.33	-0.32	0.45	-1.20	0.56
	CWT		6.80	3.60	5.30	3.00	-1.50	-0.45	-0.43	0.45	-1.32	0.45
	Control		6.30	3.50	6.20	2.60	-0.10	-0.03	-0.03	0.45	-0.91	0.85
Rowsell et al (2009)	CWI		50.00	8.00	47.00	9.00	-3.00	-0.35	-0.34	0.45	-1.22	0.55
	TWI		51.00	5.00	49.00	5.00	-2.00	-0.40	-0.38	0.45	-1.27	0.50
Rupp et al (2012)	CWI		64.70	11.70	63.70	8.80	-1.00	-0.10	-0.09	0.41	-0.89	0.71
	Control		64.40	10.70	62.40	10.40	-2.00	-0.19	-0.18	0.45	-1.06	0.70

Table 7.4 cont'd

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
Higgins et al (2013b)	CWI	72h Post	1.39	0.53	1.29	0.52	-0.10	-0.19	-0.18	0.54	-1.23	0.87
	CWT		1.15	0.40	1.18	0.30	0.03	0.08	0.08	0.50	-0.90	1.06
	Control		1.27	0.38	1.41	0.85	0.14	0.21	0.20	0.50	-0.78	1.18
Rowsell et al (2009)	CWI		50.00	8.00	48.00	9.00	-2.00	-0.23	-0.22	0.45	-1.10	0.65
	TWI		51.00	5.00	47.00	6.00	-4.00	-0.72	-0.69	0.46	-1.60	0.21
Higgins et al (2013b)	CWI	96h Post	1.39	0.53	1.29	0.39	-0.10	-0.21	-0.20	0.54	-1.25	0.85
	CWT		1.15	0.40	1.06	0.25	-0.09	-0.27	-0.26	0.50	-1.24	0.73
	Control		1.27	0.38	1.37	0.93	0.10	0.14	0.13	0.50	-0.85	1.11
Rowsell et al (2009)	CWI		50.00	8.00	46.00	8.00	-4.00	-0.50	-0.48	0.45	-1.37	0.41
	TWI		51.00	5.00	48.00	6.00	-3.00	-0.54	-0.52	0.45	-1.41	0.37

Note: Cold water immersion (CWI); Contrast water therapy (CWT); Thermoneutral water immersion (TWI); Active recovery (AR): Compression garment (GARM); Control group (Control)

Table 7.5a Results summary for one all out sprinting (secs)

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
											lower	upper
Getto et al (2013) 20m	CWI	<1h Post	2.48	0.45	2.40	0.58	-0.08	-0.15	-0.14	0.54	-1.19	0.91
	AR		2.38	0.56	2.77	0.39	0.39	0.81	0.76	0.52	-0.25	1.78
	Control		2.19	0.60	2.19	0.55	0.00	0.00	0.00	0.50	-0.98	0.98
King et al (2009) 20m	CWI		4.60	2.60	5.50	2.60	0.90	0.35	0.33	0.45	-0.55	1.21
	AR		5.40	3.80	5.40	3.30	0.00	0.00	0.00	0.45	-0.88	0.88
	CWT		3.90	2.40	5.70	2.90	1.80	0.68	0.65	0.46	-0.25	1.55
	Control		4.10	1.90	6.00	2.80	1.90	0.79	0.76	0.46	-0.15	1.67
Pointon et al (2012b) 20m	CWI		2.61	0.06	3.02	0.20	0.41	2.78	2.66	0.61	1.46	3.86
	Control		2.64	0.07	2.92	0.13	0.28	2.68	2.57	0.60	1.38	3.75
Takeda et al (2014) 50m	CWI		7.11	0.35	7.22	0.36	0.11	0.31	0.30	0.45	-0.58	1.18
	Control		7.19	0.40	7.16	0.43	-0.03	-0.07	-0.07	0.45	-0.95	0.81
Getto et al (2013) 20m	CWI	24h Post	2.48	0.45	2.75	0.41	0.27	0.63	0.58	0.55	-0.49	1.65
	AR		2.38	0.56	3.09	0.36	0.71	1.51	1.43	0.56	0.33	2.52
	Control		2.19	0.60	2.99	0.57	0.80	1.37	1.29	0.55	0.21	2.37
King et al (2009) 20m	CWI		4.60	2.60	4.4	2.8	-0.20	-0.07	-0.07	0.45	-0.95	0.81
	AR		5.40	3.80	5.4	3.7	0.00	0.00	0.00	0.45	-0.88	0.88
	CWT		3.90	2.40	4.1	2.1	0.20	0.09	0.08	0.45	-0.79	0.96
	Control		4.10	1.90	3.7	1.5	-0.40	-0.23	-0.22	0.45	-1.10	0.66
Montgomery et al (2008a) 20m	CWI		3.10	0.13	3.12	0.11	0.02	0.17	0.16	0.45	-0.72	1.04
	GARM		3.06	0.07	3.17	0.10	0.11	1.27	1.22	0.49	0.27	2.18
	Control		3.09	0.11	3.13	0.12	0.04	0.35	0.33	0.47	-0.60	1.26
Pointon et al (2012b) 20m	CWI		2.61	0.06	2.71	0.09	0.10	1.31	1.25	0.49	0.29	2.21
	Control		2.64	0.07	2.70	0.08	0.06	0.80	0.76	0.46	-0.14	1.67

Table 7.5a Cont'd

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size lower	Confidence Interval for Effect Size upper
Rowsell et al (2009) 20m	CWI	24h Post	3.50	0.16	3.61	0.19	0.11	0.63	0.60	0.46	-0.30	1.50
	TWI		3.60	0.12	3.58	0.09	-0.02	-0.19	-0.18	0.45	-1.06	0.70
Takeda et al (2014) 50m	CWI		7.11	0.35	7.27	0.35	0.16	0.46	0.44	0.45	-0.45	1.32
	Control		7.19	0.40	7.31	0.36	0.12	0.32	0.30	0.45	-0.58	1.18
Ingram et al (2009) 20m	CWI	48h Post	4.70	0.21	4.67	0.19	-0.03	-0.15	-0.14	0.43	-0.98	0.69
	CWT		4.60	0.17	4.64	0.16	0.04	0.24	0.23	0.43	-0.61	1.07
	Control		4.60	0.17	4.67	0.14	0.07	0.45	0.43	0.43	-0.41	1.28
Rowsell et al (2009) 20m	CWI		3.53	0.16	3.53	0.16	0	0.00	0.00	0.45	-0.88	0.88
	TWI		3.55	0.12	3.51	0.10	-0.04	-0.36	-0.35	0.45	-1.23	0.54
Higgins et al (2011) 300m	CWI	>90h Post	72.00	5.90	70.30	3.10	-1.70	-0.36	-0.34	0.54	-1.39	0.72
	CWT		74.00	4.70	72.10	4.30	-1.90	-0.42	-0.40	0.50	-1.39	0.59
	Control		72.00	7.50	69.80	2.80	-2.20	-0.39	-0.37	0.43	-1.22	0.47
Higgins et al (in press) 144h Post First half 20m	CWI		14.54	0.79	13.62	0.78	-0.92	-1.17	-1.11	0.54	-2.16	-0.06
	CWT		13.64	0.99	13.15	1.14	-0.49	-0.46	-0.43	0.51	-1.43	0.56
	Control		14.84	0.65	14.30	0.64	-0.54	-0.84	-0.79	0.52	-1.81	0.23
Higgins et al (in press) 144h Post Second half 20m	CWI		14.27	1.00	13.59	0.82	-0.68	-0.74	-0.70	0.52	-1.71	0.31
	CWT		13.53	1.26	13.33	1.27	-0.20	-0.16	-0.15	0.50	-1.13	0.83
	Control		15.03	0.94	14.04	0.62	-0.99	-1.24	-1.18	0.54	-2.24	-0.11
Higgins et al (in press) 144h Post First half 22m	CWI		26.61	1.76	22.67	1.76	-3.94	-2.24	-2.12	0.62	-3.34	-0.89
	CWT		25.33	2.26	22.24	1.32	-3.09	-1.67	-1.58	0.57	-2.70	-0.46
	Control		27.03	1.34	23.50	1.34	-3.53	-2.63	-2.49	0.67	-3.80	-1.18

Table 7.5a Cont'd

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size: lower	Confidence Interval for Effect Size: upper
Higgins et al (in press) 144h Post 2nd Half	CWI	>90h Post	26.23	1.82	22.10	1.82	-4.13	-2.27	-2.15	0.63	-3.38	-0.92
	CWT		24.77	2.12	21.69	1.65	-3.08	-1.62	-1.53	0.57	-2.65	-0.42
	Control		26.99	1.67	22.97	1.67	-4.02	-2.41	-2.28	0.64	-3.53	-1.02
Higgins et al (in press) 144h Post First half 30m	CWI		19.96	0.86	18.68	0.93	-1.28	-1.43	-1.35	0.55	-2.44	-0.26
	CWT		18.96	1.32	17.95	1.47	-1.01	-0.72	-0.68	0.51	-1.69	0.32
	Control		20.45	0.85	19.64	0.74	-0.81	-1.02	-0.96	0.53	-2.00	0.07
Higgins et al (in press) 144h Post Second half 30m	CWI		20.09	0.97	18.89	1.15	-1.20	-1.13	-1.07	0.53	-2.11	-0.02
	CWT		18.85	1.59	18.16	1.34	-0.69	-0.47	-0.44	0.51	-1.44	0.55
	Control		20.80	0.73	19.67	0.72	-1.13	-1.56	-1.47	0.56	-2.58	-0.37
Rowsell at al (2009) 20m	CWI		3.53	0.16	3.53	0.16	0.00	0.00	0.00	0.45	-0.88	0.88
	TWI		3.55	0.12	3.55	0.12	0.00	0.00	0.00	0.45	-0.88	0.88

Note: Cold water immersion (CWI); Contrast water therapy (CWT); Thermoneutral water immersion (TWI); Active recovery (AR): Compression garment (GARM); Control group (Control)

Table 7.5b Results summary for total accumulated sprinting (secs)

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size: lower	Confidence Interval for Effect Size: upper
Delextrat et al Female (2013)	CWI	24h Post	64.00	2.30	63.90	1.66	-0.10	-0.05	-0.05	0.50	-1.03	0.93
	Massage		64.00	2.30	64.10	2.10	0.10	0.05	0.04	0.50	-0.94	1.02
	Control		64.00	2.30	64.50	2.90	0.50	0.19	0.18	0.50	-0.80	1.16
Delextrat et al Male (2013)	CWI		58.00	2.90	58.00	2.00	0.00	0.00	0.00	0.50	-0.98	0.98
	Massage		58.00	2.90	58.60	2.10	0.60	0.24	0.22	0.50	-0.76	1.21
	Control		58.00	2.90	57.80	2.90	-0.20	-0.07	-0.07	0.50	-1.05	0.92
Rowsell et al (2009)	CWI		42.38	1.87	43.27	2.23	0.89	0.43	0.41	0.45	-0.47	1.30
	TWI		42.16	1.13	42.73	0.85	0.57	0.57	0.55	0.46	-0.35	1.44
Rowsell et al (2011)†	CWI		1170.00	463.00	1042.00	462.00	-128.00	-0.28	-0.27	0.45	-1.15	0.62
	TWI		1192.00	317.00	1045.00	183.00	-147.00	-0.57	-0.54	0.46	-1.44	0.35
Montgomery et al (2008a)	CWI		27.42	1.40	27.27	1.04	-0.15	-0.12	-0.12	0.45	-0.99	0.76
	Garm.		27.52	0.72	27.05	0.57	-0.47	-0.72	-0.69	0.46	-1.60	0.21
	Control		27.15	1.60	27.6	1.15	0.45	0.32	0.31	0.47	-0.62	1.24
Buchheit et al (2011)	Spa		451.00	188.00	450.00	156.00	-1.00	-0.01	-0.01	0.32	-0.64	0.63
	Control		471.00	140.00	471.00	140.00	0.00	0.00	0.00	0.32	-0.64	0.64
Ingram et al (2009)	CWI	48h Post	48.00	1.92	48.22	1.82	0.22	0.12	0.11	0.43	-0.72	0.95
	CWT		47.00	1.57	47.80	1.38	0.80	0.54	0.52	0.43	-0.33	1.37
	Control		48.00	1.39	48.29	1.25	0.29	0.22	0.21	0.43	-0.63	1.05
Buchheit et al (2011) HIR	Spa		770.00	272.00	746.00	468.00	-24.00	-0.06	-0.06	0.32	-0.70	0.57
	Control		732.00	368.00	673.00	357.00	-59.00	-0.16	-0.16	0.32	-0.80	0.48
Buchheit et al (2011) VHIR	Spa		405.00	110.00	368.00	176.00	-37.00	-0.25	-0.25	0.33	-0.89	0.39
	Control		388.00	192.00	327.00	136.00	-61.00	-0.37	-0.36	0.33	-1.00	0.28
Buchheit et al (2011) VHIA	Spa		1626.00	490.00	1547.00	728.00	-79.00	-0.13	-0.12	0.32	-0.76	0.51
	Control		1591.00	620.00	1406.00	429.00	-185.00	-0.35	-0.34	0.33	-0.98	0.30

Table 7.5b Cont'd

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
											lower	upper
Rowsell et al (2009)	CWI	48h Post	42.38	1.87	42.38	1.90	0.00	0.00	0.00	0.45	-0.88	0.88
	TWI		42.16	1.13	41.83	0.84	-0.33	-0.33	-0.32	0.45	-1.20	0.56
Rowsell et al (2009)	CWI	72h Post	42.38	1.87	42.96	2.02	0.58	0.30	0.29	0.45	-0.60	1.17
	TWI		42.00	1.13	43.07	0.98	1.07	1.01	0.97	0.47	0.04	1.90
Rowsell et al (2011)†	CWI		1170.00	463.00	1080.00	332.00	-90	-0.22	-0.21	0.45	-1.09	0.67
	TWI		1192.00	317.00	872.00	182.00	-320	-1.24	-1.19	0.48	-2.14	-0.24

Note: Cold water immersion (CWI); Contrast water therapy (CWT); Thermoneutral water immersion (TWI); Active recovery (AR): Compression garment (GARM); Control group (Control)

Table 7.6 Results summary for muscle soreness (VAS)

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
											Lower	Upper
Getto et al (2013)	CWI	≤ 1h Post	9.49	6.28	19.73	10.81	10.24	1.16	1.08	0.57	-0.04	2.20
	AR		15.03	11.76	17.51	9.30	2.48	0.23	0.22	0.50	-0.76	1.20
	Control		11.19	13.26	13.73	14.76	2.54	0.18	0.17	0.50	-0.81	1.15
Higgins et al (2013a)	CWI		38.93	8.65	28.98	7.91	-9.95	-1.20	-1.13	0.54	-2.19	-0.08
	CWT		45.03	7.60	30.83	4.16	-14.20	-2.32	-2.19	0.63	-3.43	-0.95
	Control		40.68	7.92	30.92	4.58	-9.76	-1.51	-1.43	0.56	-2.52	-0.33
Montgomery et al (2008b)	CWI		2.40	0.60	4.80	1.20	2.40	2.53	2.42	0.59	1.27	3.58
	Gar		2.40	0.60	3.60	1.40	1.20	1.11	1.07	0.48	0.13	2.00
	Control		3.20	1.20	6.20	1.40	3.00	2.30	2.19	0.60	1.02	3.36
Dawson et al (2005)	Stretch		2.90	0.60	4.60	1.00	1.70	2.06	2.01	0.42	1.19	2.84
	Pool walking		3.20	0.50	5.20	0.60	2.00	3.62	3.54	0.55	2.46	4.61
	CWT		2.60	0.50	4.60	0.60	2.00	3.62	3.54	0.55	2.46	4.61
	Control		2.80	0.60	4.40	0.60	1.60	2.67	2.60	0.47	1.69	3.52
Getto et al (2013)	CWI	24h Post	15.21	10.81	9.49	6.28	-5.72	-0.65	-0.60	0.55	-1.67	0.47
	Control		10.63	10.81	11.19	13.26	0.56	0.05	0.04	0.50	-0.94	1.02
	AR		15.03	11.76	14.87	7.63	-0.16	-0.02	-0.02	0.50	-1.00	0.96
Ingram et al (2009)	CWI		7.00	2.00	1.00	0.01	-6.00	-4.24	-4.08	0.75	-5.55	-2.61
	CWT		7.00	2.00	1.00	0.01	-6.00	-4.24	-4.08	0.75	-5.55	-2.61
	Control		7.00	2.00	1.00	0.01	-6.00	-4.24	-4.08	0.75	-5.55	-2.61
Montgomery et al (2008b)	CWI		3.60	1.40	2.40	0.60	-1.20	-1.11	-1.07	0.48	-2.00	-0.13
	Control		3.60	0.60	3.20	1.20	-0.40	-0.42	-0.40	0.48	-1.33	0.53
	Garm.		2.40	0.60	3.00	1.00	0.60	0.73	0.70	0.46	-0.21	1.60
Pournot et al (2011)	CWI		4.43	2.50	1.45	1.65	-2.98	-1.41	-1.36	0.44	-2.22	-0.51
	CWT		4.20	1.64	1.18	1.55	-3.02	-1.89	-1.83	0.47	-2.75	-0.92
	TWI		2.40	1.99	6.59	2.50	4.19	1.85	1.80	0.46	0.89	2.71
	Control		4.70	2.01	1.60	1.24	-3.10	-1.86	-1.80	0.46	-2.71	-0.89

Table 7.6 Results summary for muscle soreness (VAS)

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
											Lower	Upper
Dawson et al (2005)	Stretch	48h Post	2.90	0.60	4.10	0.90	1.20	1.57	1.53	0.39	0.77	2.30
	Pool walking		3.20	0.50	4.00	0.70	0.80	1.32	1.28	0.38	0.55	2.02
	CWT		4.00	0.60	2.60	0.50	-1.40	-2.54	-2.48	0.46	-3.37	-1.58
	Control		3.90	0.60	2.80	0.60	-1.10	-1.83	-1.79	0.41	-2.59	-0.99
Higgins et al (2013a)	CWI		33.62	5.60	38.98	8.65	5.36	0.74	0.68	0.55	-0.39	1.76
	CWT		29.97	6.56	45.03	7.60	15.06	2.12	2.01	0.61	0.80	3.21
	Control		32.38	5.74	40.68	7.92	8.30	1.20	1.13	0.54	0.08	2.19
Higgins et al (2013b)	CWI		33.62	5.60	38.98	8.65	5.36	0.74	0.68	0.55	-0.39	1.76
	CWT		29.97	6.56	45.03	7.60	15.06	2.12	2.01	0.61	0.80	3.21
	Control		32.38	5.74	40.68	7.92	8.30	1.20	1.13	0.54	0.08	2.19
Ingram et al (2009)	CWI		3.00	1.00	1.00	0.01	-2.00	-2.83	-2.72	0.59	-3.88	-1.56
	CWT		4.00	1.00	1.00	0.01	-3.00	-4.24	-4.08	0.75	-5.55	-2.61
	Control		5.00	1.00	1.00	0.01	-4.00	-5.66	-5.44	0.92	-7.25	-3.63
Montgomery et al (2008b)	CWI		4.80	1.60	2.40	0.60	-2.40	-1.99	-1.90	0.54	-2.96	-0.85
	Garm.		2.40	0.60	4.20	1.00	1.80	2.18	2.09	0.56	1.00	3.18
	Control		4.20	1.00	3.20	1.20	-1.00	-0.91	-0.86	0.49	-1.83	0.10
Higgins et al (2013b)	CWI	72h Post	34.07	2.88	38.98	8.65	4.91	0.76	0.71	0.55	-0.37	1.79
	CWT		45.03	7.6	32.88	4.04	-12.15	-2.00	-1.89	0.60	-3.07	-0.71
	Control		32.42	4.07	40.68	7.92	8.26	1.31	1.24	0.55	0.17	2.31
Montgomery et al (2008a)	CWI		3.30	1.10	1.40	0.50	-1.90	-2.22	-2.13	0.56	-3.23	-1.03
	Garm.		1.40	0.50	3.20	1.30	1.80	1.83	1.75	0.53	0.72	2.78
	Control		4.30	1.80	1.60	0.50	-2.70	-2.04	-1.95	0.57	-3.07	-0.82
Montgomery et al (2008b)	CWI		4.40	1.20	2.40	0.60	-2.00	-2.11	-2.02	0.55	-3.10	-0.94
	Garm.		2.4	0.6	4.20	1.40	1.80	1.67	1.60	0.51	0.59	2.61
	Control		5.40	2.00	3.20	1.20	-2.20	-1.33	-1.27	0.52	-2.28	-0.26

Note: Cold water immersion (CWI); Contrast water therapy (CWT); Thermoneutral water immersion (TWI); Active recovery (AR): Compression garment (GARM); Control group (Control)

Table 7.7 Results summary for subjective measures of fatigue

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
											lower	upper
Jones et al (2013) TQR	CWI	24h Post	16.30	2.21	15.40	1.71	-0.90	-0.46	-0.44	0.45	-1.32	0.45
	AR		16.40	1.58	15.40	1.43	-1.00	-0.66	-0.64	0.46	-1.53	0.26
	Comb.		15.60	1.96	15.60	2.91	0.00	0.00	0.00	0.45	-0.88	0.88
	Control		15.10	3.07	14.00	1.63	-1.10	-0.45	-0.43	0.45	-1.32	0.46
Kinugasa et al (2009) TQR	CWT		14.60	1.30	12.40	1.60	-2.20	-1.51	-1.48	0.38	-2.21	-0.74
	Comb.		14.10	1.60	12.10	1.50	-2.00	-1.29	-1.27	0.34	-1.93	-0.60
	Control		14.30	1.60	12.30	1.70	-2.00	-1.21	-1.17	0.44	-2.04	-0.30
Kinugasa et al (2009) VAS	CWT		3.00	0.50	3.90	0.70	0.90	1.48	1.45	0.37	0.71	2.18
	Comb.		3.20	0.60	4.00	0.80	0.80	1.13	1.11	0.33	0.46	1.76
	Control		3.00	0.01	4.00	0.40	1.00	3.53	3.41	0.64	2.16	4.67
Montgomery et al (2008a) VAS	CWI		3.30	1.50	4.50	0.90	1.20	0.97	0.93	0.47	0.01	1.85
	Garm.		3.10	0.90	4.30	1.60	1.20	0.92	0.89	0.47	-0.03	1.80
	Control		3.60	0.90	5.20	1.60	1.60	1.23	1.17	0.51	0.17	2.17
Rowsell et al (2009) RPE	CWI		11.00	2.00	14.00	1.00	3.00	1.90	1.82	0.53	0.78	2.86
	TWI		11.00	2.00	14.00	1.00	3.00	1.90	1.82	0.53	0.78	2.86
Rupp et al (2012) VAS	CWI		4.90	2.30	4.40	1.90	-0.50	-0.24	-0.23	0.45	-1.11	0.65
	Control		5.60	1.90	5.60	1.90	0.00	0.00	0.00	0.45	-0.88	0.88
Higgins et al (2013b) Sessional RPE	CWI		435.00	156.00	400.00	185.00	-35.00	-0.20	-0.19	0.50	-1.18	0.79
	CWT		375.00	100.00	450.00	141.00	75.00	0.61	0.58	0.51	-0.42	1.58
	Control		480.00	192.00	437.00	140.00	-43.00	-0.26	-0.24	0.50	-1.23	0.74
Kinugasa et al (2009) TQR	CWT	48h Post	14.60	1.30	14.20	1.60	-0.40	-0.27	-0.27	0.33	-0.92	0.39
	Comb.		14.10	1.60	14.50	1.60	0.40	0.25	0.25	0.31	-0.36	0.85
	Control		14.30	1.60	13.30	1.50	-1.00	-0.64	-0.62	0.42	-1.44	0.20
Kinugasa et al (2009) VAS	CWT		3.00	0.50	3.40	0.70	0.40	0.66	0.64	0.34	-0.03	1.31
	Comb.		3.20	0.60	3.20	0.80	0.00	0.00	0.00	0.31	-0.60	0.60
	Control		3.00	0.01	3.70	0.90	0.70	1.10	1.06	0.44	0.21	1.92

Table 7.7 Cont'd.

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
											lower	upper
Rowsell et al (2009) RPE	CWI		11.00	2.00	13.00	1.00	2.00	1.26	1.21	0.49	0.26	2.16
	TWI	48h Post	11.00	2.00	13.00	1.00	2.00	1.26	1.21	0.49	0.26	2.16
Rupp et al (2012) VAS	CWI		4.90	2.30	9.30	0.61	4.40	2.62	2.50	0.60	1.33	3.68
	Control		5.60	1.90	9.40	0.51	3.80	2.73	2.62	0.61	1.42	3.81
Higgins et al (2013b) Sessional RPE	CWI		435.00	156.00	599.00	92.00	164.00	1.28	1.21	0.54	0.14	2.28
	CWT		375.00	100.00	650.00	75.00	275.00	3.11	2.94	0.72	1.53	4.35
	Control		480.00	192.00	600.00	106.00	120.00	0.77	0.73	0.52	-0.28	1.74
Kinugasa et al (2009) TQR	CWT		14.60	1.30	14.10	1.60	-0.50	-0.34	-0.34	0.34	-0.99	0.32
	Comb.		14.10	1.60	14.30	1.70	0.20	0.12	0.12	0.31	-0.49	0.72
	Control	72h Post	14.30	1.60	13.40	1.60	-0.90	-0.56	-0.54	0.42	-1.36	0.27
Kinugasa et al (2009) VAS	CWT		3.00	0.50	3.20	0.50	0.20	0.40	0.39	0.34	-0.27	1.05
	Comb.		3.20	0.60	3.10	0.70	-0.10	-0.15	-0.15	0.31	-0.76	0.46
	Control		3.00	0.01	3.40	0.50	0.40	1.13	1.09	0.44	0.23	1.95
Rowsell et al (2009) RPE	CWI		11.00	2.00	14.00	1.00	3.00	1.90	1.82	0.53	0.78	2.86
	TWI		11.00	2.00	15.00	1.00	4.00	2.53	2.42	0.59	1.27	3.58
Higgins et al (2013b) Sessional RPE	CWI		435.00	156.00	501.00	75.00	66.00	0.54	0.51	0.51	-0.49	1.51
	CWT		375.00	100.00	651.00	118.00	276.00	2.52	2.39	0.65	1.10	3.67
	Control	96h Post	480.00	192.00	563.00	140.00	83.00	0.49	0.47	0.51	-0.53	1.46
Rowsell et al (2009) RPE	CWI		11.00	2.00	12.00	1.00	1.00	0.63	0.61	0.46	-0.29	1.50
	TWI		11.00	2.00	13.00	1.00	2.00	1.26	1.21	0.49	0.26	2.16

Note: Cold water immersion (CWI); Contrast water therapy (CWT); Thermoneutral water immersion (TWI); Active recovery (AR): Compression garment (GARM); Control group (Control); Total Quality Rest (TQR); Visual Analogue Scale (VAS); Rate of Perceived Exertion (RPE)

Table 7.8 Results summary for flexibility (cm)

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
											lower	upper
Dawson et al (2005)*	Stretch	24h Post	23.90	9.20	21.10	9.80	-2.80	-0.29	-0.29	0.34	-0.96	0.39
	Pool walk		23.00	10.10	18.80	9.70	-4.20	-0.42	-0.41	0.35	-1.09	0.27
	CWT		24.40	8.40	21.70	8.80	-2.70	-0.31	-0.31	0.35	-0.98	0.37
	Control		24.20	9.70	20.90	10.00	-3.30	-0.33	-0.33	0.35	-1.00	0.35
Higgins et al (2013a)	CWI		12.50	8.05	12.00	7.91	-0.50	-0.06	-0.06	0.50	-1.04	0.92
	CWT		10.31	9.50	9.94	9.82	-0.37	-0.04	-0.04	0.50	-1.02	0.94
	Control		8.94	7.19	7.94	7.06	-1.00	-0.14	-0.13	0.50	-1.11	0.85
Montgomery (2008a)	CWI		12.00	10.50	8.60	11.50	-3.40	-0.31	-0.30	0.45	-1.18	0.59
	Garm		11.50	7.90	3.00	9.10	-8.50	-1.00	-0.96	0.47	-1.88	-0.03
	Control		8.50	6.50	3.20	6.90	-5.30	-0.79	-0.75	0.49	-1.71	0.20
Dawson et al (2005)	Stretch	48h Post	23.90	9.20	23.40	9.40	-0.50	-0.05	-0.05	0.34	-0.72	0.62
	Pool walk		23.00	10.10	22.20	10.20	-0.80	-0.08	-0.08	0.34	-0.75	0.60
	CWT		24.40	8.40	23.50	8.10	-0.90	-0.11	-0.11	0.34	-0.78	0.57
	Control		24.20	9.70	22.70	10.60	-1.50	-0.15	-0.14	0.34	-0.82	0.53
Higgins et al (2013a)	CWI		12.50	8.05	13.44	6.76	0.94	0.13	0.12	0.50	-0.86	1.10
	CWT		10.31	9.50	9.75	8.24	-0.56	-0.06	-0.06	0.50	-1.04	0.92
	Control		8.94	7.19	9.56	6.01	0.62	0.09	0.09	0.50	-0.89	1.07
Higgins et al (2013b)	CWI		12.50	8.05	13.44	6.76	0.94	0.13	0.12	0.50	-0.86	1.10
	CWT		10.31	9.50	9.75	8.24	-0.56	-0.06	-0.06	0.50	-1.04	0.92
	Control		8.94	7.19	9.56	6.01	0.62	0.09	0.09	0.50	-0.89	1.07

Note: Cold water immersion (CWI); Contrast water therapy (CWT); Thermoneutral water immersion (TWI); Active recovery (AR): Compression garment (GARM); Control group (Control)

Table 7.9 Results summary for Creatine Kinase

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
											lower	upper
Gill et al (2006)	No mean values, alpha levels or E.S provided											
Ingram (2009)	CWI	24h Post	158.00	59.00	571.00	375.00	413.00	1.54	1.48	0.48	0.54	2.42
	CWT		172.00	108.00	582.00	357.00	410.00	1.55	1.50	0.48	0.55	2.44
	Control		166.00	75.00	681.00	720.00	515.00	1.01	0.97	0.45	0.08	1.85
Montgomery et al (2008a)*	CWI		384.00	256.00	512.00	256.00	128.00	0.50	0.48	0.45	-0.41	1.37
	CG		260.00	256.00	487.00	64.00	227.00	1.22	1.17	0.48	0.22	2.11
	Control		256.00	315.00	485.00	256.00	229.00	0.80	0.76	0.49	-0.20	1.72
Pointon et al (2012a)	CWI		247.00	143.00	567.00	346.00	320.00	1.21	1.16	0.48	0.21	2.10
	Control		281.00	193.00	503.00	357.00	222.00	0.77	0.74	0.46	-0.17	1.65
Pointon et al (2012b)	CWI		359.10	157.90	708.90	362.70	349.80	1.25	1.20	0.49	0.25	2.15
	Control		308.10	189.70	551.70	359.50	243.60	0.85	0.81	0.47	-0.10	1.72
Pournot et al* (2011)	TWI		500.00	250.00	800.00	700.00	300.00	0.57	0.54	0.48	-0.40	1.48
	CWI		500.00	250.00	590.00	380.00	90.00	0.28	0.27	0.39	-0.50	1.04
	CWT		500.00	250.00	950.00	710.00	450.00	0.85	0.81	0.47	-0.10	1.72
	Control		500.00	250.00	790.00	650.00	290.00	0.59	0.56	0.48	-0.38	1.50
Rowsell et al (2009)	CWI		207.00	127.00	614.00	161.00	407.00	2.81	2.69	0.62	1.48	3.90
	TWI		258.00	129.00	575.00	320.00	317.00	1.30	1.24	0.49	0.29	2.20
Takeda et al (2014)	CWI		350.00	149.00	621.00	261.00	271.00	1.28	1.22	0.49	0.27	2.18
	Control		431.00	276.00	850.00	491.00	419.00	1.05	1.01	0.47	0.08	1.94
Ingram (2009)	CWI	48h Post	158.00	59.00	337.00	218.00	179.00	1.12	1.08	0.46	0.18	1.97
	CWT		172.00	108.00	332.00	168.00	160.00	1.13	1.09	0.46	0.19	1.98
	Control		166.00	75.00	391.00	436.00	225.00	0.72	0.69	0.44	-0.17	1.55
Montgomery et al (2008a)*	CWI		384.00	256.00	512.00	256.00	128.00	0.50	0.48	0.45	-0.41	1.37
	CG		260.00	256.00	490.00	64.00	230.00	1.23	1.18	0.48	0.23	2.13
	Control		256.00	315.00	512.00	256.00	256.00	0.89	0.82	0.49	-0.15	1.78
Rowsell et al (2009)	CWI		207.00	127.00	955.00	502.00	748.00	2.04	1.96	0.54	0.89	3.02
	TWI		258.00	129.00	912.00	715.00	654.00	1.27	1.22	0.49	0.26	2.17

Table 7.9 Cont'd

Authors	Treatment	Time Point	Baseline mean scores	± S.D	Post mean scores	± S.D	Change between Baseline & Post	Effect Size	Bias corrected (Hedges)	Standard Error of E.S. estimate	Confidence Interval for Effect Size	
											lower	upper
Montgomery et al (2008a)*	CWI	72h Post	384.00	256.00	512.00	256.00	128.00	0.63	0.61	0.46	-0.29	1.50
	CG		260.00	256.00	490.00	64.00	252.00	1.25	1.19	0.49	0.24	2.14
	Control		256.00	315.00	512.00	256.00	256.00	1.06	1.01	0.50	0.03	2.00
Rowsell et al (2009)	CWI		207.00	127.00	955.00	502.00	722.00	1.61	1.54	0.51	0.54	2.54
	TWI		258.00	129.00	912.00	715.00	550.00	1.13	1.08	0.48	0.15	2.02

Note: Cold water immersion (CWI); Contrast water therapy (CWT); Thermoneutral water immersion (TWI); Active recovery (AR): Compression garment (GARM); Control group (Control)