

The relative efficacy of three recovery modalities following professional rugby league competition matches

Nicholas Webb

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Primary Supervisor: Dr Nigel Harris
Secondary Supervisor: Prof John Cronin

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Attestation of Authorship

I hereby declare that this submission is my own work and that to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements) nor material which to a substantial extent has been accepted for the qualification of any degree or diploma of a university or other institution of higher learning.

Signed:



Nicholas Webb

Date: 26 Oct 2011

Co-Authored Works

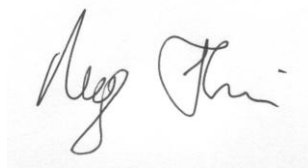
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(Nick Webb 90%, Nigel Harris and John Cronin 10% collectively).

Nigel Harris:

A handwritten signature in black ink that reads "Nigel Harris". The signature is written in a cursive style with a large initial 'N' and 'H'.

John Cronin:

A handwritten signature in black ink that reads "John Cronin". The signature is written in a cursive style with a large initial 'J' and 'C'.

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Dedication

To my parents, throughout my entire time as a student you have been there for me, supported and sacrificed for me in every way you can in order for me to succeed. I don't know how I can say thank you enough. Therefore this thesis is dedicated to you to say thank you and I hope I have made you proud.

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Abstract

Achieving a balance between training and competition stresses and recovery is important in maximizing the performance of athletes. Specifically, following contact sport where the degree of muscular damage and trauma caused by numerous collisions is substantial, the rate and quality of recovery is crucial for each player to optimally recover prior to the first training session of the training week following a game. The physiological response of specific recovery modalities and their effect on performance have been commonly investigated following exercise. However the investigation of recovery modalities following contact sport and their effect on important recovery markers leading into the first training session following a game is limited. The use of active recovery and various hydrotherapy procedures are common modalities that are implemented into a recovery regime following a game and are thought to enhance the recovery process. The objective of this thesis was to analyze whether these recovery modalities provided beneficial recovery effects following professional rugby league matches. Literature surrounding all recovery strategies (excluding nutritional strategies) and its possible influence on physiological recovery following both delayed onset of muscle soreness (DOMS) inducing exercise protocols and team contact sport matches was then appraised and discussed. Following these reviews an experimental study was conducted to investigate the relative efficacy of post game recovery modalities on jump height performance, perceived ratings of muscle soreness, and muscle damage 1, 18, and 42 hours following professional rugby league competition games. Twenty-one professional rugby league players performed three different recovery modalities (cold water immersion (Bleakley & Dawson, 2010), contrast water therapy (Vaile, Halson, Gill, & Dawson, 2008) and active recovery (Abraham, 1977)) following three competition games at 1, 18, and 42 hours post game. The effects of the recovery treatments were analyzed with mixed

modeling with a covariate included (fatigue score) to adjust for changes in the intensity of each match on the post-match values of dependent variables. Standardization of effects was used to make magnitude-based inferences, presented as mean; $\pm 90\%$ confidence intervals. CWI and CWT clearly improved jump height performance (CWI 2.3; $\pm 3.7\%$, CWT 3.5%; $\pm 4.1\%$), reduced muscle soreness (CWI -0.95; ± 0.37 , CWT -0.55; ± 0.37), and decreased creatine kinase (CWI -11.0; $\pm 15.1\%$, CWT 18.2; $\pm 20.1\%$) by 42 hours post game compared to ACT. CWT was however clearly more effective compared to CWI on the recovery of muscle soreness and creatine kinase by 42 hours post game. Therefore CWT recovery following team contact sport is recommended.

Chapter 1: Introduction

Purpose Statement

The purpose of this thesis is to investigate the relative efficacy of active recovery, cold water immersion and contrast water therapy recovery modalities following professional rugby league matches. Initially, the literature concerning all recovery strategies (excluding nutritional strategies) and its possible influence on physiological recovery following both DOMS inducing exercise protocols and contact sport matches will be appraised and discussed accordingly. Secondly, the relative efficacy of active recovery, cold water immersion and contrast water therapy protocols on the rate and magnitude of change of creatine kinase, countermovement jump measures (jump height), and perceived muscle soreness will be experimentally examined following professional rugby league matches. Furthermore, the associated recovery effects will be analysed against relative match workload scores and discussed thereafter.

Aims of Thesis

The aim of this thesis is to determine the relative efficacy of active recovery, cold water immersion and contrast water therapy recovery strategies on the rate and magnitude of change in creatine kinase, countermovement jump measures, and perceived muscle soreness following professional rugby league matches. A second aim is to provide coaches and practitioners with current scientific and evidence based information in the area of post exercise recovery and elite athletic performance in terms of recovery modality usage, specifically following contact sport.

Significance of Thesis

This thesis will enhance the body of knowledge within high performance sport and add to the understanding of the implementation of recovery strategies, particularly active recovery, cold

water immersion and contrast water therapy by exploring the recovery effects following contact sport. The findings from this thesis will provide coaches and practitioners with current scientific and evidence based information in the area of post exercise recovery modalities and elite athletic performance and allow for more informed decision making regarding recovery prescription. Furthermore, this thesis may provide the framework for future research to be implemented in the area of post exercise recovery.

Chapter 2: A Review of Current Literature Surrounding the Use of Post Exercise and Contact Sport Recovery Modalities

Overview

Achieving an appropriate balance between training and competition stresses and recovery is important in maximizing the performance of athletes. A wide range of recovery modalities are now used as integral parts of the training programs of elite athletes to help attain this balance. Numerous studies have incorporated eccentric and training interventions to invoke muscular damage prior to the use of recovery modalities (Ahmaidi, 1996; Berry, Bailey, & Simpkins, 1990; Duffield, Edge, Merrells, Hawke, Barnes, Simcock, & Gill, 2008; Gupta, Goswami, Sadhukhan, & Mathur, 1996; King & Duffield, 2009; Lane & Wenger, 2004; Martin, Zoeller, Robertson, & Lephart, 1998; Monedero & Donne, 2000; Sayers, Clarkson, & Lee, 2000; Taoutaou, Granier, & Mercier, 1996; Weber, Servedio, & Woodall, 1994) but there is a lack of scientific evidence that illustrates the efficacy of recovery modalities following high performance competition, particularly contact sport. Therefore, prescribing evidence-based recovery protocols following competition remains problematic. It is the aim of this review to provide coaches and practitioners with current scientific and evidence based information in the area of post contact sport exercise recovery and elite athletic performance in terms of recovery modality usage. The following review examines evidence available regarding the efficacy of popular recovery modalities following both training and contact sport interventions. Furthermore, practical recommendations and the direction of future research will be briefly discussed.

For the purposes of this review, only post-exercise recovery modalities were included. A literature search was performed using Sport Discus, Medline and Web of Science using the key words in English; recovery, cryotherapy, hydrotherapy, cold water immersion, contrast water

therapy, thermotherapy, hot water immersion, massage, compression, active recovery, stretching, post exercise and rugby.

Introduction

The muscular trauma and damage associated with contact sport is very different compared to non-contact sports due to its combative nature thus the rate and quality of recovery from contact sport is considered crucial. Consequently, any technique or modality that can facilitate the rate and quality of muscle repair and reduce soft tissue injury is of meaningful benefit to an athlete wanting to return to training in an optimal state of readiness as quickly as possible. Optimal recovery has been shown to result in the restoration of both physiological and psychological (Barnett, 2006). Athlete recovery following training and competition is very complex and is dependent on the application of numerous factors, typically dependent on the nature of the exercise performed and any other external factors outside of training and competition. Optimum recovery strategies will vary among athletes depending upon the type of fatigue, current levels of training and non-training stress, and capacity to cope with the stressors. Optimal recovery needs to include a range of methods and techniques that are all systematically integrated into athlete programs, ideally on an individual basis. Each method needs to be carefully planned and have a specific aim to ensure optimal return ().

A commonly investigated aspect of recovery is the physiological response of specific recovery modalities following exercise (Gill, Beaven, & Cook, 2006). Physiological markers used to assess recovery response usually are determined by the type of resultant fatigue induced by the exercise intervention (Smart, Gill, Beaven, Cook, & Blazevich, 2008). Typical methods employed to monitor recovery include the use of subjective muscle soreness ratings (Jemni, 2003; King & Duffield, 2009; Sayers, Clarkson, & Lee, 2000; Tessitore, Meeusen, Pagano,

Benvenuti, Tiberi, & Capranica, 2008; Weber, Servedio, & Woodall, 1994), strength and power measures to assess neuromuscular fatigue (King & Duffield, 2009; Tessitore, Meeusen, Pagano, Benvenuti, Tiberi, & Capranica, 2008; Weber, Servedio, & Woodall, 1994), limb range of movement (Sayers, Clarkson, & Lee, 2000), blood lactate (Coffey, Leveritt, & Gill, 2004; Connolly, Brennan, & Lauzon, 2003; Gupta, Goswami, Sadhukhan, & Mathur, 1996; Morton, 2007) and serum creatine kinase (Gill, Beaven, & Cook, 2006; Suzuki, Umeda, & Nakaji, 2004) which is used to monitor the rate and magnitude of change of muscle damage.

The presence of muscle proteins and enzymes in the blood is a commonly reported indicator of muscle damage (Ehlers, Ball, & Liston, 2002; Hoffman, Maresh, & Newton, 2002; Sorichter, Puschendorf, & Mair, 1999; Thompson, Nicholas, & Williams, 1999; Tiidus & Ianuzzo, 1983). Analysing serum or plasma creatine kinase via venipuncture is the standard approach and used by many for indirectly determining skeletal muscle damage inflicted by exercise (Knoblauch, O'Connor, & Clarke, 2010). Specifically, creatine kinase is an important measure for the analysis of muscle damage recovery following contact sports due to the high number of impacts experienced by players in a game. Similar to creatine kinase, blood lactate (a metabolite) also accumulates as a result of exercise and is one of the main contributing factors in fatigue (Gupta, Goswami, Sadhukhan, & Mathur, 1996). Any exercise that involves one or a combination of repetitive power, strength, speed and acceleration bouts are likely to experience intramuscular accumulation of lactate and impaired force production (Connolly, Brennan, & Lauzon, 2003). The measurement of blood lactate clearance is another beneficial way to measure recovery rate following exercise (Morton, 2007).

The use of ballistic jump measures as a means of measuring neuromuscular performance and/or fatigue is commonly used within sports performance research (Cronin, Hing, & McNair,

2004). Countermovement jump measures have been shown to be a reliable measure of the neuromuscular system with measures of mean force showing to have a coefficient of variation of 1.08% (Cormack, Newton, McGuigan, & Doyle, 2008), mean power 4.4% and peak power 3.2% (Alemany, Pandorf, Montain, Castellani, Tuckow, & Nindl, 2005).

Over time strength and conditioning coaches of elite athletes have started incorporating questionnaires pre/post training sessions and competition as a tool for subjectively quantifying the occurrence of recent stress on an athlete (Stone & Neale, 1984), the extent of subjective stress (Weyer & Hodapp, 1975), the frequency of stressful daily hassles (Kanner, Coyne, Schaefer, & Lazarus, 1981), and mood state (McNair, Lorr, & Droppleman, 1971, 1992). Kallus (1995) has shown that the test-retest reliability of all general stress and recovery scales is moderately high after 24 hours for an instrument that records variable states. This is also true for scales that only show satisfactory internal consistency (Kallus, 1995; Kellmann & Wolfgang Kallus, 2001). The authors stated test-retest reliability always lies clearly above $r = .79$, which implies that intraindividual differences in the recovery-stress states can be well reproduced.

Recovery Modality Interventions

Active Recovery

Active recovery is a form of low intensity exercise commonly used by athletes, coaches and trainers post training and competition, and is believed to be an integral component of physical recovery (Calder, 2000). It is usually completed at a sub-maximal intensity (normally at an intensity less than the anaerobic threshold <65% VO₂ max) in the form of cross-training type exercises such as walking, jogging, cycling, or swimming.

Increased blood flow during light-intensity exercise has been postulated as the mechanism that improves recovery. Signorile, Ingalls, and Tremblay (1993) proposed that the

pumping (contraction-relaxation) action of active muscles may increase the disposal of metabolic waste. By increasing blood flow the removal of metabolites, such as lactate, and the replenishment of substrates within the muscle could be enhanced (Bonen & Balcasro, 1977). Over the short-term, active recovery may increase the contractile ability of the muscles and over the long-term aid in the healing process (Cortis, Tessitore, D'Artibale, Meeusen, & Capranica, 2010; Sayers, Clarkson, & Lee, 2000). Furthermore, studies incorporating a combination of recovery modalities which include aspects of active recovery, have demonstrated encouraging effects on lactate removal (Jemni, 2003; Monedero & Donne, 2000; Watts, 2000).

Investigation into the efficacy of active recovery has primarily focused on post exercise lactate removal. While this effect is well ascertained (Ahmaidi, 1996; Belcastro & Bonen, 1975; Gisolfi, Robinson, & Turrell, 1966; Hermansen & Stensvold, 1972; Monedero & Donne, 2000; Taoutaou, Granier, & Mercier, 1996; 2000), there seems to be some conflicting opinions on whether lactate removal is a valid indicator of recovery quality (Barnett, 2006). The clearance of lactate from the circulation is related directly to the exercise intensity (Bond, Adams, Tearney, Gresham, & Ruff, 1991; Monedero & Donne, 2000). Studies that utilize active recovery as a post exercise recovery modality have generally used some kind of damage-inducing performance protocol (Ahmaidi, 1996; Gupta, Goswami, Sadhukhan, & Mathur, 1996; King & Duffield, 2009; Lane & Wenger, 2004; Martin, Zoeller, Robertson, & Lephart, 1998; Monedero & Donne, 2000; Sayers, Clarkson, & Lee, 2000; Taoutaou, Granier, & Mercier, 1996; Weber, Servedio, & Woodall, 1994) compared to only a few using game/competition as a fatigue protocol (Gill, Beaven, & Cook, 2006; Suzuki, Umeda, & Nakaji, 2004; Tessitore, Meeusen, Pagano, Benvenuti, Tiberi, & Capranica, 2008).

Sayers et al (2000) investigated whether light activity would affect the recovery of muscle function after high force eccentric exercise of the elbow flexors using 26 male volunteers. The exercise regime/protocol consisted of 50 maximal eccentric contractions of the elbow flexors of the non-dominant arm. The investigators established that both light exercise and immobilization aided the recovery of maximal isometric force; also stating that recovery from muscular soreness was aided by light exercise but deferred by immobilization. Lane and Wenger (2004) investigated the effect of four (active recovery, passive recovery [control], massage and cold water immersion) recovery modalities following repeated bouts of high-intensity cycling separated by 24 hours in 10 physically active men. For the active recovery component, the athletes completed 15 minutes cycling at 30% $\dot{V}O_2\text{max}$. The investigators concluded that active recovery appeared to facilitate the recovery process between two high-intensity, intermittent exercise sessions separated by 24 hours.

Conversely, a study investigating the effect of three different interventions (massage, electrical stimulation, and light exercise) reported no support for the use of light exercise to reduce or alleviate muscle soreness and force deficits associated with delayed onset muscle soreness (DOMS) (Weber, Servedio, & Woodall, 1994). McAinch (2004) also established that active recovery did not assist in the maintenance of performance nor did it alter either lactate accumulation or muscle glycogen content between bouts of intense aerobic exercise when compared to passive recovery. The investigators proposed there to be no justification for the practice of active recovery following intense aerobic exercise.

Active recovery for contact sport

Contact sports, specifically rugby union and league involve extensive collision contact and hence invoke high degrees of muscular damage (Quarrie & Hopkins, 2008; Smart, Gill,

Beaven, Cook, & Blazevich, 2008). Collectively associated with the damage from contact sports is the increased magnitude of fatigue placed on the neuromuscular and metabolic systems, thus prompt post-match recovery strategies are imperative.

A number of studies have incorporated methods to assess the post-match effect of active recovery on these systems following team contact sports. Gill et al (2006) examined post-match recovery of 23 professional rugby union players by means of creatine kinase in forearm transdermal exudates samples to indicate muscle damage over an 84 hour period. Subjects were monitored over four competition matches (four weeks) where they were randomly assigned to one of four recovery intervention groups (active recovery, contrast water immersion therapy, compression garments and passive recovery). Active recovery, contrast water immersion therapy, and lower-body compression garments resulted in 88.2%, 85.0% and 84.4% creatine kinase recovery 84 hours post match respectively. Passive recovery was significantly less ($p < 0.05$) than all other recovery interventions at both 36 and 84 hour time points. There were no significant differences in creatine kinase recovery between active recovery, contrast water immersion therapy, and lower-body compression garments at any testing time point post match. On the contrary, Suzuki et al (2004) reported no difference in CK activity between an active and a passive recovery group following an 80 minute rugby match. Even so, a perceptual increase in psychological state was promoted following the active recovery intervention compared to the passive group. In contrast to the study by Gill et al (2006) where the recovery intervention was immediately post-match only, the active recovery group carried out one hour of low intensity exercise in water once a day for two days.

Active recovery conclusion

While research on the efficacy of active recovery is clear regarding lactate removal, further recovery benefits remain equivocal. The discrepancy in study results using eccentric damaging protocols versus high intensity contact matches (rugby union and league) may be due to the extent of muscle damage that occurs with each type of fatiguing exercise and the different mechanisms that may be involved in the recovery process. The role of active recovery in reducing DOMS, enhancing range of motion and the effect it has on neuromuscular regeneration following high intensity contact sport competition warrants further investigation.

Table 1: Eccentric/DOMS inducing & performance based interventions using active recovery

Author	Exercise/Fatigue Intervention	Subjects	Recovery Modes	AR Protocol	Outcome Measures/Timings	Main Findings
Ahmaidi (1996)	2 x incremental aerobic tests followed by either: 5-min PR or 5min-AR.	10 males	1. Active recovery 2. Passive Recovery	5 min at 32% of maximal aerobic power on cycle ergometer	Bla (pre, between, post test and recovery)	No sig. diff between AR & PR but Sig ↓ Bla at higher braking forces with ↑ anaerobic power after AR compared to PR.
Martin, et al (1998)	3 x successive Wingate cycle tests, with 2-minute rest intervals between recovery conditions initiated 5min after last Wingate.	10 male cyclists	1. Active recovery 2. Rest (PR) 3. Massage	20 minutes at 80 RPM at an intensity equal to 40% VO ₂ peak	Bla (Pre, post each Wingate, 5min post final Wingate, every 5min during recovery)	Bla ↓ by 59.38% (AR), 36.21% (massage), 38.67% (rest). AR provided ↓ in all Bla values compared to massage & rest following successive Wingate tests.
Monedero, et al (2000)	2 x simulated 5 km maximal effort cycling tests (T1 & T2) separated by a 20 min recovery.	18 trained male cyclists	1. Active Recovery 2. Passive Recovery 3. Massage 4. Combined (AR + MAS)	Cycle 50% of individual V̇O ₂ max for 15min. Combined used 3.5 min with 7.5min massage	Performance time (T1, T2) BLa (during T1, T2, & every 3 min during recovery) HR (during the recovery intervention and T2)	Combined method sig. better in maintenance of performance time during T2 than other methods. Bla removal sig. better for AR at min 9 & 12 compared to others. Combined most efficient for performance maintenance, AR best for Bla removal.
Watts, et al (2000)	Subjects attempted to climb a 20m difficult climbing route set on an indoor climbing wall.	15 expert rock climbers	1. Active recovery 2. Passive Recovery	Cycling at 25 Watts	Bla (pre climb, 1min, 10min, 20min & 30 min post climb)	Bla remained elevated in the PR group until 30 minutes post-climb, but had returned to pre-climb level by 20 minutes in the AR group. Low intensity AR appears to ↓ accumulated Bla within 20 min following difficult climbing,
Sayers, et al (2000)	Subjects performed an exercise regimen consisting of 50 maximal eccentric contractions of the elbow flexors of the non dominant arm.	26 male volunteers	1. Light Exercise 2. Immobilization 3. Control	50 biceps curls with a 5-lb dumbbell daily	Relaxed arm angle (RANG), flexed arm angle (FANG), maximal isometric force (MIF), and perceived muscle soreness (SOR) were obtained pre-exercise (baseline), immediately post-exercise, and for 8 consecutive days after recovery treatment period	Subjects showed a prolonged decrease in RANG, increase in FANG, loss in MIF, and increase in SOR in the days after eccentric exercise. Recovery of MIF was facilitated by light exercise and immobilization. Recovery from SOR was facilitated by light exercise and delayed by immobilization.
Jemni, et al (2003)	Participants completed routine performances in the six Olympic gymnastic events, which were separated by 10 min of recovery. All gymnasts performed two recovery protocols between events on separate days.	12 male gymnasts	1. Combined protocol (AR+ rest) 2. Rest protocol (control)	5 min self selected AR. Typically, light jogging separated by handstands, single somersault movements, and swings to handstand on the parallel bars.	Bla (2.5 & 10min following each of the six events)	Gymnasts showed ↑ Bla concentration (p > .05) and significantly (p < .05) higher scoring performances (as rated by a panel of certified judges) when they used a combined recovery between gymnastics events rather than a passive recovery (ΔBla = 40.51% vs. 28.76% of maximal BLA)

Dupont, et al (2004)	Subjects performed a graded test and two intermittent exercises to exhaustion. The intermittent exercises (15s) were alternated with recovery periods (15 s), which were either passive or active recovery	12 males	1. Active recovery 2. Passive Recovery	On a cycle ergometer at 40% of V [·] O ₂ max for 15s between sets	Bla (3min post exercise) Time to exhaustion (sec)	Bla levels from AR (12.6±1.7mmol/L) showed no sig difference to the Bla readings of passive recovery (13.1±2.7mmol/L) following intermittent exercise bouts on a cycle ergometer. Time to exhaustion for intermittent exercise alternated with PR (962 ±314 s) was significantly longer (P<0.001) than with AR (427 ±118 s).
Lane & Wenger (2004)	Subjects were asked to take part in 2 intermittent cycling sessions; 18 minutes of varying work intervals performed in succession at a resistance of 80 g/kg body weight separated by 24 hours. One of four 15-minute recovery conditions immediately followed the first session.	10 physically active men aged 18–30	1. Active Recovery 2. Massage (MR) 3. Cold Water Immersion (CR) 4. Seated rest (control)	Cycling at 30% V [·] O ₂ max for 15 min	Total work (kj), total number of pedal revolutions in each work bout	Only the control condition showed a ↓ in total work completed between the first and second exercise sessions (108.1 ± 5.4 kJ vs. 106.0 ± 5.0 kJ, p <.05). Thus, AR, MR, and CR appeared to facilitate the recovery process between 2 high-intensity, intermittent exercise sessions separated by 24 hours.
Coffey, Leveret & Gill (2004)	Participants performed two pairs of treadmill runs to exhaustion at 120% and 90% of peak running speed (PRS) over a 4-hour period. Recovery modalities were performed for 15-min after the first pair of treadmill runs.	14 males	1. Active Recovery 2. Passive Recovery 3. Contrast Water Immersion	Running at 40% PRS (peak running speed) for 15 minutes	HR, RPE and Bla (at rest, immediately and 4, 8, 12, 16 and 20-minutes after the first pair of treadmill runs to exhaustion. Also at rest before and immediately after the last pair of treadmill runs to exhaustion.	Recovery modality did not have a sign. effect on change in time to cover 400 m, 1000 m or 5000 m. Post exercise Bla concentration was lower in ACT and CTW compared with PAS. Participants reported an increased perception of recovery in the CTW compared with ACT and PAS. Blood pH was not sign. influenced by recovery modality. Data suggest both ACT and CTW reduce lactate accumulation after high intensity running.
McAinch (2004)	Participant performed as much work as possible during two 20 minute cycle exercise bouts on two separate occasions, separated by an allocated 15-min recovery period.	7 trained men	1. Active recovery 2. Passive Recovery	On a cycle ergometer at 40% of V [·] O ₂ peak for 15min	Bla and glycogen (at rest and every 5min throughout each trial)	No sig. difference in muscle glycogen or Bla when comparing AR and PR at any point. lactate plasma concentration was ↑ (p ≤.05) in PR versus AR during the recovery period. Subjects commenced the second bout of intense exercise with a ↓ (p <.05) plasma lactate concentration in AR (4.4 ± 0.7 vs. 7.7 ± 1.4 mmol.L following AR and PR respectively). Results do not support the benefit of AR compared to PR in the maintenance of intense aerobic exercise performance.
Tessitore, et al (2008)	Four futsal games, scheduled on a twice-weekly basis for a period of 2 weeks each followed by a randomised recovery intervention.	10 male futsal players	1. Seated rest 2. Active Recovery (dry exercises) 3. Shallow water exercises 4. Electrostimulation	20 minutes AR (dry exercises) [8 minutes of jogging, 8 minutes of walking and running sideways and backward, and 4 minutes of stretching],	Anaerobic performance (countermovement jump [CMJ], bounce jumping, 10-m sprint) Hormones (salivary cortisol, urinary catecholamine's) Subjective ratings [RPE, leg muscle pain, Questionnaire of Recovery Stress for Athletes [RestQ Sport] Hours of sleep	No sign. effect due to recovery interventions was found on anaerobic performances, hormones, rating of muscle pain, recovery-stress state, and amount of sleep. Players perceived ↑ benefit (P ≤ 0.01; power = 0.91) from the electrostimulation (7.8 ± 1.4 points) and water exercises (7.6 ± 2.1 points) compared to AR (dry exercises) (6.6 ± 1.8 points) and seated rest (5.2 ± 0.8 points). Large effect sizes (>1.8) were always found with respect to seated rest.

King & Duffield (2009)	Four randomized simulated netball exercise circuit sessions on consecutive days. Each condition consisted of two identical sessions (Session 1 and 2), with the recovery intervention implemented at the completion of Session 1.	10 female netball players	1. Active Recovery 2. Passive Recovery 3. Cold Water Immersion 4. Contrast Water Therapy	15min cycling at 40% V̇ O ₂ max	Bla, PH, Bicarbonate, HR, RPE and MS measured at rest, post warm-up and performance tests, during each rest interval in the exercise circuit, after exercise, and post recovery interventions.	CWT demonstrated a ↓ (p = 0.04) in Bla post-intervention compared to ACT recovery. ACT recovery resulted in a ↑ (p, 0.01) HR compared to all other conditions post intervention and demonstrated ↑ (p, 0.01) rating of RPE post intervention and MS pre exercise Session 2. The 24-hour recovery period between exercise bouts was sufficient to allow performance to be maintained, regardless of recovery interventions.
Kinugasa & Kilding (2009)	On separate days, participants played 3 soccer matches on separate days each randomly followed by 1 of 4 recovery modalities	28 young soccer players	1. Cold water immersion COLD 2. Contrast water immersion CONT 3. Combination (cold water immersion & active recovery) COMB 4. Passive recovery PAS	Used in a combination: Using a cycle ergometer (60–80 rpm, 90–110 W) for 2 minutes following 1 minute immersion at 12°C and repeating this 3 times	Performance (vertical jump height) Physiological (HR and tympanic temperature) Perceptual measures (perceived quality of recovery) at pre-match, 10 minutes post-match, after each recovery method, and after 24 hours.	Perceived quality of recovery immediately after COMB was ↑ than CONT and PASS, but the effect did not last more than 24 hours. Players perceived lighter legs after COMB, compared with PASS, at post-24 hours. COMB modality (cold water immersion and active recovery) after a soccer match did not have a substantial effect on vertical jump height performance compared with CONT & PAS alone. Perceived recovery after COMB modality suggests that this approach may be effective for young players after intense soccer match play. This effect cannot be attributed to AR alone.

Contact sport Interventions using active recovery

Suzuki, et al (2004)	Elite male rugby players were monitored following one competition rugby game (80min) where players were then randomly divided into 1 of 2 recovery groups.	15 male Japanese rugby players	1. Passive Recovery 2. Low intensity exercise	Low intensity exercises in water for 60min	Blood samples (CK, leucocyte and neutrophil counts, GOT, GPT, and LDH)	Immediately after the match, muscle damage, decreases in neutrophil functions, and mental fatigue were observed in both groups. Muscle damage and neutrophil functions recovered in equal time in both recovery groups. POMS scores were ↓ only in subjects in the low intensity exercise group.
Gill, Beaven, & Cook (2006)	Elite male rugby players were monitored over four competition games during the New Zealand Provincial Championship competition. Players were randomly assigned to complete one of four post-match strategies.	23 elite male rugby players	1. Contrast water therapy (CWT) 2. Compression garment (GAR) 3. Low intensity active exercise (ACT) 4. passive recovery (PAS)	Cycle (80– 100 rpm, 150W) for 7 minutes	CK pre game, immediately post match, 36 & 84 hours post match	↑ in CK activity observed as a result of the rugby match (p ≤ 0.01). The magnitude of recovery in the PAS intervention was ↓ than in the ACT, CWT, and GAR interventions at the 36 and 84 hour time points (p ≥ 0.05). The ACT intervention showed 88.2% recovery after 84 hours which was the highest out of all interventions.

AR - Active Recovery; **ACT** - Active Recovery; **PR** - Passive Recovery; **PAS** - Passive Recovery; **MR** - Massage; **MAS** - Massage; **CR** - Cold water immersion; **COLD** - Cold water immersion; **CTW** - Contrast water therapy; **CWT** - Contrast water therapy; **COMB** - Combined recovery method, **GAR** - Compression Garment; **CK** - Creatine kinase; **Bla** - Blood lactate; **RANG** - Relaxed arm angle; **FANG** - Flexed arm angle; **MIF** - Maximal isometric force; **MS** - Muscle soreness; **SOR** - Muscle soreness; **HR** - Heart rate; **PRS** - Peak running speed; **VO₂.max** - Maximal oxygen consumption; **CMJ** - Countermovement jump, **RPE** - Rate of perceived exertion; **GOT** - Glutamate oxaloacetate transaminase; **GPT** - glutamate pyruvate transaminase; **LDH** - lactate dehydrogenase ↓- Significantly lower/worse; ↑ - Significantly higher/better; **Sign.**- Significant; Δ-Change in

Compression Garments

There are three varieties of compression garments: (i) graduated compression stockings worn for the prevention and treatment of deep vein thrombosis; (ii) compression sleeves worn over limbs and joints to provide support or reduce swelling; and (iii) elastic tights and tops worn as exercise clothing. There appears to have been a general anecdotal acceptance that compression garments aid in post-exercise recovery (Barnett, 2006). Compression garments externally compress the lower/upper limb and have been proposed to assist in improving sporting performance (Duffield, Edge, Merrells, Hawke, Barnes, Simcock, & Gill, 2008) by clearing metabolic by-products (Gill, Beaven, & Cook, 2006), increased venous blood flow, venous return, and reduced swelling (Bringard, 2006), enhance proprioception (Kraemer, Bush, Newton, Duncan, Volek, Denegar, Canavan, Johnston et al., 1998), and reduce muscle oscillation (Doan, Kwon, & Newton, 2003; McComas, 2006).

Highly fit male college students who wore graduated compression stockings during both exercise (3 minutes cycling at 100% maximal oxygen uptake) and recovery had lower recovery blood lactate concentrations than when wearing the stockings only during exercise or not at all (Berry & McMurray, 1987). As no plasma volume shifts were observed the authors suggested that the lower blood lactate values were due to lactate being retained in the muscular bed, rather than greater lactate removal. Chatard, Ataloui, and Farjanel (2004) reported that wearing graduated compression stockings during an 80-minute recovery with the legs elevated decreased blood lactate concentrations in elderly trained cyclists and led to a significantly better post-recovery performance than a control trial.

An intervention study conducted by Kraemer et al (2001) used fifteen healthy, non strength trained athletes to complete a muscle-damage protocol which involved performing two

sets of 50 repetitions on a Biodex System 2 isokinetic dynamometer set for passive motion at 60°/s with three minutes rest between sets. Every fourth repetition, the subjects performed a maximal concentric contraction with an isometric hold at end range (to maximize response to the protocol), followed by an eccentric contraction in which the subject resisted mechanically forced elbow extension. The subjects were divided into one of two groups, a compressive sleeve group or a control group. Immediately after the eccentric-damage protocol, the subjects in the compression sleeve group donned the compression garment which was worn 24 h /day over the 3-day recovery period after exercise. Arm soreness significantly ($p < .05$) increased throughout the recovery period in the control group. The compression sleeve group experienced peak soreness on recovery day two, with a reduction in soreness on post exercise day 3 to a significantly ($p < .05$) lower value than that of the control group, using a visual analog scale for pain assessment. Serum creatine kinase (CK) concentrations (units/L) were significantly elevated in both groups ($p < .05$) at recovery day 3 when compared with baseline measurement. Although muscle damage was present in both groups, the control group experienced significantly greater ($p < .05$) muscle damage than the compression sleeve group did, as indicated by the more dramatic increase in serum CK concentration at 72 hours.

In a similar study by Kraemer, Bush, and Wickham (2001), twenty non-strength-trained women were randomly divided in to either an experimental or control group. The experimental group wore a compressive sleeve garment for 5 days following eccentric exercise (two sets of 50 arm curls); the control group wore no compression. Creatine kinase was significantly elevated ($p < .05$) from the baseline values in both compression and control groups. The experimental compression group revealed a significantly decreased ($p < .05$) magnitude of creatine kinase elevation following the eccentric exercise. Compression sleeve use prevented loss of elbow

motion, decreased perceived soreness, reduced swelling, and promoted recovery of force production. In contrast, French et al (2008) reported no hierarchy of acute recovery effects from the use of compression garments from exercise induced muscle damage (EIMD) any more than passive recovery conditions. Subjects performed a resistance exercise challenge (6 x 10 parallel squats at 100% body weight with 5-s one repetition maximum eccentric squat superimposed onto each set) followed by one of three recovery interventions; contrast bathing, compression garments or control. Performance measures (countermovement jump, multidirectional agility and 10m sprints) were not significantly changed within or between groups at any time point. Additionally, there was no difference in muscle soreness (VAS) scores between the groups (contrast bathing, 233.8 ± 11.6 ; compression garment, 256.5 ± 14.8 ; control, 264.2 ± 18.1 ; $p > 0.05$) (French, Thompson, Garland, Barnes, Portas, Hood, & Wilkes, 2008).

A study conducted by Trenell, Rooney, Sue, and Thompson (2006) also used an eccentric protocol to induce muscular damage. The objective of the study was to observe the effects of graduated compression garments following 30 minutes of downhill walking ($6 \text{ km}\cdot\text{h}^{-1}$, 25% grade). The protocol was adapted from a previously reported procedure shown to induce eccentric muscle damage. Eleven male recreational athletes wore graduated compression garments on one leg. The non-compressed leg acted as an internal control. This study showed that eccentric exercise can cause disruption to skeletal muscle pH control and induce cellular metabolic changes consistent with inflammatory and repair processes. Compression garments had no effect on pH, or perceived muscle soreness, which was significantly elevated at all time points post exercise ($p < .05$). The authors suggested that wearing compression garments in the recovery from eccentric exercise might alter the inflammatory response to damage and accelerate the repair processes inside the muscle. In direct comparison, Duffield et al (2008) reported the

use of compression garments neither improved nor impaired simulated team-sport performance on consecutive days. Despite benefits of reduced self-reported muscle soreness (obtained from a 10 point scale) when wearing garments during and following exercise each day (2.5 ± 1.7 vs. 3.5 ± 2.1 for garment and control; $p = .01$), no improvements in performance or recovery were apparent. Furthermore, Berry, Bailey, and Simpkins (1990) also found no difference between wearing tights during exercise and recovery, during exercise alone or not at all for all variables measured (blood lactate concentrations, oxygen consumption and heart rate).

Compression garments for contact sport

Athletes in sports involving high-intensity, intermittent-sprint exercise, combined with high levels of body contact collision, such as the various football codes (including rugby), have commonly adopted the use of compression garments as a method to improve recovery between sessions. A number of studies have shown an increased recovery effect as a result of donning compression garments following training interventions, mostly using eccentric training protocols (Berry & McMurray, 1987; Chatard, Ataloui, & Farjanel, 2004) as there is limited research that has used contact sport matches in order to impose muscular damage.

A study by Gill et al (2006) reported that professional rugby players who wore a lower body compression garment for 12 hours post-game experienced greater enhancement in recovery from muscle damage compared with passive recovery, but not compared with active recovery or contrast water therapy. It must be noted that the trauma associated with such contact sports is significantly different than eccentric and training protocols. Therefore, the implications of the findings of this study for post-exercise recovery would not be relevant following eccentric training protocols due to the differing types of muscle damage and fatigue accumulated compared to a contact sport match. Further investigation is needed on the use of compression

garments following contact sport and their effect on limb range of motion, muscle damage and the recovery response it provides the neuromuscular system.

Compression garment conclusion

Exercise induced muscle damage (EIMD) and delayed onset muscle soreness (DOMS) are detrimental side effects of high intensity exercise and sport. The use of compression garment therapy has become increasingly common among athletes as they have been claimed to promote an enhanced recovery from muscle damage and the pain associated with DOMS. Current research and evidence regarding the efficacy of compression garments post exercise would suggest that continuous compression immediately after strenuous exercise promotes faster recovery of function and enhances the local tissue environment to promote the healing process (Chatard, Ataloui, & Farjanel, 2004; Kraemer, Bush, & Wickham, 2001; Kraemer, Bush, Wickham, Denegar, Gomez, Gotshalk, Duncan, Volek et al., 2001). However, when comparing the type and magnitude of muscular damage and trauma associated with such contact sports and eccentric training protocols, they differ as a result of very different external forces e.g. structural damage caused by eccentrically controlling an external weight versus body contact.

Further studies are warranted following un-simulated contact sports to confirm any alteration in muscle recovery consequent to wearing of compression garments. Determination of the mechanisms underlying the use of compression garments, quantification of compression gradient and the treatment of other anatomical regions, and other types of soft tissue injury (e.g. ankle sprains, muscle strains) is also needed. Furthermore, various exposure times to compression garments have been used by previous studies, confounding our ability to draw conclusions on the most effective protocol. Investigations should concentrate on finding the most

beneficial and practical exposure time following contact sports, specifically rugby union and league.

Table 2: Eccentric/DOMS-Inducing & performance based interventions using compression garments for recovery

Author	Exercise/Fatigue Intervention	Subjects	Recovery Modes	Compression Protocol	Outcome Measures/Timings	Summary of Main Findings
Berry,et.al (1987)	1st experiment (E1) - subjects performed two tests of VO2max on a treadmill with and without graduated compression stockings (GCS).Subjects completed three bouts on a motor driven treadmill. 2nd experiment (E2) - subjects performing three separate three minute tests on a bicycle at 110% of their VO2max.	6 males in each experiment	E1 - 1. With GCS 2. Without GCS E2 - 1. GCS worn during the test and recovery 2.GCS only worn during the test (GCS-O/O) 3.no GCS worn during either the test or recovery (NO-GCS)	Length of exercise protocol and/or 60min recovery period	VO2 measured at rest, throughout the duration of all the tests and during recovery in both experiments. Blood samples (Bla & hematocrit) were obtained at rest and at 5, 15, 30, 45 and 60 minutes post exercise in the first experiment and at rest and at 5, 15 and 30 minutes post.	Use of GCS in the first experiment resulted in no sig diff in VO2max, recovery VO2 or plasma volume shifts. Bla values lower throughout the recovery period with the 15min values being sig diff with the use of GCS. Post exercise Bla showed significant difference in the second experiment. The GCS trial resulted in ↓ Bla when compared to the GCS-O/O and NO-GCS trials. No sig diff in post exercise Bla values between NO-GCS and GCS-O/O trials. Results of both experiments showed recovery Bla values to be lower with the use of CGS.
Berry,et.al (1990)	Subjects completed three bouts on a motor driven treadmill for up to three minutes at 110% VO2max. Participants were exposed to one of three conditions.	8 males	1. elastic tights worn during exercise and recovery 2.elastic tight worn only during exercise 3.no elastic tights worn during exercise or recovery	Length of exercise protocol and/or recovery period (duration not specified)	Oxygen consumption, HR, venous Bla and hematocrit were obtained a rest and 5, 15 and 30 min post exercise.	No sig diff ($P \geq 0.05$) in any of the variables between the three trials at any of the measurement times. Results indicate that the use of elastic tights will not significantly affect post exercise response or circulating lactate levels.
Kraemer,et al (2001a)	2x50reps arm curl on Biodex isokinetic dynamometer. Every fourth repetition, subject performed a maximal concentric contraction with isometric hold at end range followed by an eccentric contraction. Divided into two recovery groups following fatigue protocol.	15 non strength-trained men	1. Compression Sleeve (CS) 2.Control (C).	CS - 3 days	Relaxed elbow angle, blood serum CK, LDH & perception of soreness (MS) measures pre fatigue protocol and there after daily for 3 days	↑ in CK levels for both CS & C although not as much in CS. CS Incr loss of elbow extension, decr perception of soreness, swelling. Incr recovery of force production
Kraemer,et al (2001b)	2x50reps arm curl on Biodex isokinetic dynamometer. Every fourth repetition, subject performed a maximal concentric contraction with isometric hold at end range followed by an eccentric contraction. Divided into two recovery groups following fatigue protocol.	20 non-impaired strength trained women	1. Compression Sleeve (CS) 2.Control (C).	CS - 5 days	Relaxed elbow angle, blood serum CK, LDH & perception of soreness (MS) measures pre fatigue protocol and there after daily for 5 days	↑ in CK levels for both CS & C although not as much in CS. CS Incr loss of elbow ext, decr perception of soreness, swelling. Incr recovery of force production
Chatard,et.al (2004)	For 2 weeks, 12 subjects, aged 63 years old, performed two 5min maximal exercises, Plim1 and Plim2, separated by an 80min recovery period, twice a week with a 2 day rest interval. During the 80min recovery period, subjects randomly wore or did not wear grip-top elastic compression stockings (ECS).	12 trained elderly cyclists (63yo)	1. ECS exposure 2. ECS non-exposure	80min between Plim1 and Plim 2	Bla concentrations, hematocrit and plasma volume were measured after a 60min rest and every 20min during recovery. Leg sensations were assessed using a questionnaire.	Decr in maximal power between Plim1 and Plim2 was lower when wearing ECS during 80min recovery; expressed as a percentage of plim1, the difference reached 2.1 (1.4)%.Bla and hematocrit were ↓ when wearing ECS. The 12 cyclists stated that wearing ECS had a positive effect on leg pain. It was concluded that wearing ECS during 80min recovery period significantly increased performance. This was associated with a reduction in Bla & hematocrit.

Duffield, et al (2008)	Performed 2 randomised testing conditions involving consecutive days of a simulated team sport exercise protocol, separated by 24hrs of recovery within each condition and 2 weeks between conditions. Each day involved 80min high-intensity circuit.	14 male rugby players	1. CG exposure 2. Control	15 hours	Performance measured by 20m sprints and peak power on a single man scrum machine. Nude mass, HR, skin and tympanic temp and La- were recorded each day; CK and muscle soreness were recorded each day and 48hrs following exercise.	HR, tympanic temp and body mass did not sig differ between conditions. Skin temp was higher under the compression garments. No differences (p=0.50) in La- or CK were present, although participants felt reduced levels of perceived muscle soreness in the ensuing 48hr post exercise when wearing CG (2.5± 1.7 vs. 3.5 ± 2.1) compared to the control (P=.01). No improvements in performance or recovery were apparent by wearing CG.
French, et al (2008)	Subjects performed a resistance exercise challenge (REC) to induce exercise induced muscle damage (EIMD): 6x10 parallel squats at 100% BW with 5sec one rep max eccentric squat superimposed into each set. Subjects were separated into 3 recovery intervention groups	26 young men	1. CG 2. Contrast bathing (CB) 3. Control (CONT)	12 hours	Baseline values of MS, CK and Mb, joint ROM, limb girth, 10-30m sprint, CMJ, and 5RM were completed and retested 48 hours after intervention.	Ck elevated at 24hr in CB, CG & CONT. Mb elevated at 1hr in CG, CG & CONT. Sig diff from baseline in all groups for CMJ (CG 5.1%, CB 4.4%; CONT 8.5%) and soreness (213%; 284%; 284%). 30-m sprint time incr with CG. NO hierarchy of recovery effects found.
Davies, et al (2009)	Subjects completed 5 x 20 maximal drop-jumps separated by 1 week in a randomized crossover experimental design, followed immediately after exercise by one of two recovery interventions.	7 trained females and 4 trained males	1. CG 2. Control (CONT)	48 hours	CK, LDH, mid-thigh girth, and PMS were retested at base line and after 24 and 48 hours of recovery.	For female subjects, CK values elevated after 24-hour recovery (p = 0.020) and greater PMS observed after 48-hour recovery in CON condition (p = 0.002) but not for CG condition. For all subjects, greater PMS was observed after 48-hour recovery in the CON condition (p = 0.001) but not the CG condition. CK responses and PMS might be attenuated by wearing CG in some participants after drop-jump training.
Montgomery, et al (2009)	Subjects performed in a 3-day tournament style basketball competition where they were assigned to 1 of 3 recovery treatment groups following each game.	29 male basketball players	1. Carbohydrates + stretching 2. CWI 3. CG	18 hours	Physical performance: 20-m acceleration, basketball line-drill, Yoyo Level 1 intermittent recovery test, vertical jump, a basketball-specific agility test, and the sit-and-reach flexibility test was measured at baseline and post tournament.	Sprint and agility performance decreased by 0.7% (s = 1.3) and 2.0% (s = 1.9) respectively. Vertical jump decreased substantially after the first day for all treatments, and remained suppressed post-tournament. CWI was substantially better in maintaining 20-m acceleration with only a 0.5% (s = 1.4) reduction in 20-m time after 3 days compared with a 3.2% (s = 1.6) reduction for CG. CWI (-1.4%, s = 1.7) and CG (-1.5%, s = 1.7) showed similar substantial benefits in maintaining line-drill performance over the tournament, whereas carbohydrate + stretching elicited a 0.4% (s = 1.8) reduction. CWI appears to promote better restoration of physical performance measures than carbohydrate + stretching routines and compression garments.
Jakeman (2010)	Participants completed 10 x 10 plyometric drop jumps from a 0.6-m box to induce muscle damage. Participants were randomly allocated to one of two recovery intervention groups	17 female volunteers	1. CG 2. PAS (Control)	12 hours	Muscle soreness, CK activity, knee extensor concentric strength, and vertical jump performance were assessed prior to and 1, 24, 48, 72, and 96 h following plyometric exercise.	Plyometric exercise had a significant effect (p ≤ 0.05) on all indices of muscle damage. The CG reduced decrements in countermovement jump performance (PAS 88.1 ± 2.8% vs. CG 95.2 ± 2.9% of pre-exercise), squat jump performance (82.3 ± 1.9% vs. 94.5 ± 2%), and knee extensor strength loss (81.6 ± 3% vs. 93 ± 3.2%), and reduced muscle soreness (4.0 ± 0.23 vs. 2.4 ± 0.24), but had no sign effect on CK activity.

Kraemer, et al (2010)	A within-group (each subject acted as their own control), balanced, and randomized treatment design was implemented. An 8-exercise whole body heavy resistance exercise protocol using barbells (3 sets of 8–10 repetition maximum, 2.0-to 2.5-minute rest) was performed after which the subject performed a CG or control (CONT) protocol in randomised order.	11 trained males and 9 trained females	1. CG 2. Internal control (CONT)	24 hours	Sleep quality, vitality rating, resting fatigue rating, muscle soreness, muscle swelling via ultrasound, reaction movement times, bench throw power, countermovement vertical jump power, a CK were measured at baseline and 24hrs following.	Significant ($p \leq 0.05$) differences between CG and CON conditions in both men and women for vitality, resting fatigue ratings, muscle soreness, ultrasound measure swelling, bench press throw, and CK were observed. The use of compression appears to help the recovery process after an intense heavy resistance training workout in men and women.
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Contact sport interventions using compression garments for recovery

Gill, et al (2006)	Elite male rugby players were monitored over four competition games during the New Zealand Provincial Championship competition. Players were randomly assigned to complete one of four post-match strategies.	23 elite male rugby players	1. Contrast water therapy (CWT) 2. Compression garment (GAR) 3. Low intensity active exercise (ACT) 4. passive recovery (PAS)	12 hours	CK pre game, immediately post match, 36 & 84 hours post match	Incr rate and magnitude of recovery observed in ACT, CWT, and CG treatment groups compared to PAS group. Low impact exercise immediately after comp, wearing CG or carrying out CWT enhances CK clearance more than passive recovery. The GAR intervention showed 84.4% recovery after 84 hours which proved to be third best out of all interventions. No significant differences in CK recovery profile were observed between the ACT, CWT, or GAR interventions at any time point.
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CS-Compression sleeve; **CG**-Compression garment; **GAR** - Compression garment; **COMP** - Compression garment; **C**-Control; **CONT**-Control; **CK**-Creatine Kinase; **CWT**-Contrast water therapy; **ACT**-Active recovery; **PAS**-Passive recovery; **MS**-Muscle soreness; **MB**-Myoglobin; **ROM**-Range of movement; **CMJ**-Countermovement jump; **EIMD**-Exercise induced muscle damage; **HR**-Heart rate; **RPE**-Rate of perceived exertion; **La**--Lactate concentration; **Bla** - Blood lactate concentration; **VO2max**-Maximum oxygen uptake; **GCS**-Graduated compression stockings; **ECS**- Elastic compression stocking; **PMS**- Perceived muscle soreness; **LDH**- Lactate dehydrogenase; ↓- Significantly lower/worse; ↑ - Significantly higher/better; **Sign**- Significant; **Incr**- Increased; **Decr**- Decreased

Hydrotherapy

Introduction

Hydrotherapy procedures are a generally popular and common component of athlete recovery routines (Vaile, Halson, & Graham, 2010). Nevertheless, information regarding these modalities is relatively anecdotal. Some physiological responses to water immersion are well investigated and understood, however, in terms of post exercise recovery, the underlying mechanisms, optimal exposure times and water temperatures for various types of exercise are poorly understood (Vaile, Halson, & Graham, 2010). The human body reacts to water immersion with changes in cardiac response, peripheral resistance, and changes in blood flow (Bonde-Petersen, Schultz-Pedersen, & Dragsted, 1992b; Wilcock, Cronin, & Hing, 2006; Yun, Choi, & Park, 2004). Immersion of the body in water can result in an inward and upward displacement of fluid from the extremities to the central cavity due to hydrostatic pressure. As acknowledged by Wilcock et al.(2006), the displacement of fluid may bring about an increase in the translocation of metabolites from the muscle. Therefore, post-exercise oedema may be reduced and muscle function sustained (Vaile, Halson, & Graham, 2010). Whilst the effects of hydrostatic pressure exerted on the body during water immersion may be beneficial, the water temperature the body is exposed to is also thought to manipulate the efficacy and success of hydrotherapy interventions (Vaile, Halson, & Graham, 2010). The main physiological effect of cold water immersion is a reduction in blood flow due to peripheral vasoconstriction (Cochrane, 2004; Meeusen & Lievens, 1986b). In contrast, immersion in hot water increases blood flow due to peripheral vasodilation (Bonde-Petersen, Schultz-Pedersen, & Dragsted, 1992a; Cochrane, 2004; Knight & Londeree, 1980; Myrer, Draper, & Durrant, 1994).

There are four types of hydrotherapy modalities that can be utilized as part of an athlete's recovery regime; cold water immersion (CWI) which is also referred to as cryotherapy, thermo-neutral water, hot water (HWT), and contrast water therapy (CWT) which alternates hot and cold water exposure. The majority of research has concentrated on the physiological responses to water immersion whereas limited research has been conducted on the exposure time and temperatures of water which may be the most important factors in physiological and muscular recovery than water immersion itself. The subsequent sections will cover the background, and current research on the benefit of four hydrotherapy modalities (cold water immersion, contrast water therapy, hot water immersion and pool/deep water activity) and their recovery effect post exercise. Following each section the current literature using each hydrotherapy modality following contact sport matches and their effect on recovery will be discussed.

Cold Water Immersion (Cryotherapy)

Cold water immersion, also commonly referred to as cryotherapy (meaning “cold treatment”) is the most frequently utilized modality for the treatment of acute soft tissue sports injuries, due to its ability to reduce the inflammatory response and reduce spasm and pain (Eston & Peters, 1999; Meeusen & Lievens, 1986a; Merrick, 1999). Several physiological responses to a variety of cooling methods have been observed, consisting of a reduction in heart rate and cardiac output, and an increase in arterial blood pressure and peripheral resistance (Sramek, 2000; Wilcock, Cronin, & Hing, 2006). Other physiological responses to such treatment include a reduction in core and tissue temperature (Enwemeka, 2002; Lee, 1997), acute inflammation (Yanagisawa, 2004), and pain (Bailey, 2007; Washington, Gibson, & Helme, 2000). Multiple studies have investigated the effect of cold water immersion on the recovery response of athletes following eccentric muscle damaging (Eston & Peters, 1999; Paddon-Jones & Quigley, 1997;

Sellwood, 2007) and sports match and competitive simulation protocols (Bailey, 2007; Higgins, Heazlewood, & Climstein, 2010; Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; Lane & Wenger, 2004; Montgomery, Pyne, Hopkins, Dorman, Cook, & Minahan, 2009).

The effectiveness of cryotherapy as a treatment of muscle damage and exercise induced fatigue remains unclear. Eston and Peters (1999) studied the effects of cold water immersion on the symptoms of exercise-induced muscle damage following eccentric exercise. The muscle damaging exercise consisted of eight sets of five maximal isokinetic contractions (eccentric and concentric) of the elbow flexors of the dominant arm ($0.58 \text{ rad}\cdot\text{s}^{-1}$ and 60 s rest between sets) followed by cold water immersion of the exercised limb in 15°C for 15 minutes. The indicators used to assess the presence of exercise induced muscle damage included plasma CK concentration, isometric strength of the elbow flexors, relaxed arm angle, local muscle tenderness, and upper arm circumference. Eston and Peters (1999) found reduced CK levels and a greater relaxed elbow angle for the cold water immersion group 24 and 48 hours following the eccentric exercise, concluding that the use of cold water immersion may reduce the degree to which the muscle and connective tissue unit becomes damaged and shortened following eccentric exercise. Vaile, Halson, Gill, and Dawson (2008) also used an eccentric muscle damaging protocol to assess the effect of specific hydrotherapy protocols (Cold water immersion: $n = 12$, hot water immersion: $n = 11$ or contrast water therapy: $n = 15$) for 72 hours post exercise on the physiological and functional symptoms of delayed onset muscle soreness (DOMS). Subjects performed a DOMS-inducing leg press protocol followed by passive recovery or one of the hydrotherapy interventions for 14 min. Isometric squat, weighted squat jump (30% of isometric squat force), perceived pain, thigh girths and blood variables were measured prior to, immediately after, and at 24, 48 and 72 hours post exercise. Squat jump performance and

isometric force recovery were significantly enhanced ($p < 0.05$) at 24, 48 and 72 hours post exercise following contrast water therapy and at 48 and 72 hours post exercise following cold water immersion when compared to passive recovery. Isometric force recovery was also greater ($p < 0.05$) at 24, 48, and 72 hours post exercise following hot water immersion when compared to passive recovery. Perceived pain improved ($p < 0.01$) following contrast water therapy at 24, 48 and 72 hours post exercise. The authors concluded that cold water immersion and contrast water therapy were effective in reducing the physiological and functional deficits associated with DOMS, including improved recovery of isometric force and dynamic power and a reduction in localised oedema. While hot water immersion was effective in the recovery of isometric force, it was ineffective for recovery of all other markers compared to passive recovery.

In a randomised controlled trial, Sellwood (2007) studied the effect of ice water immersion on DOMS. Following a leg extension muscle damaging protocol (5×10 sets at 120% concentric 1RM) participants performed three, 1-min water exposure separated by 1-min in either 5°C or 24°C (control) water. Pain, swelling, muscle function (one legged hop for distance), maximal isometric strength, and serum CK were recorded at baseline, 24, 48, and 72 hours post intervention. The only significant difference observed between the groups was reduced pain in the sit-to-stand test at 24 hours post exercise intervention in the ice water immersion group. In accordance with Yamane (2006), it was found that ice-water immersion was no more beneficial than tepid water immersion in the recovery from DOMS following the immersion of the exercised limb at a temperature of 5°C . In a similar study, Paddon-Jones and Quigley (1997) induced muscular damage using a 64 eccentric elbow flexor protocol on both arms followed by immersion in 5°C water for 5×20 min, with 60 min between immersions for one arm, while the other acted as a control. No significant differences between the immersed and

control arms were observed for any variable (isometric and isokinetic torque, soreness, and limb volume) over the course of the six-day testing period. In relation to the aforementioned studies, cold water immersion seemed to have no significant effect following eccentrically induced muscular damage, specifically when immersing an isolated limb in 5°C water.

In contrast to the above studies, Bailey (2007) incorporated a prolonged intermittent exercise protocol to induce muscular damage and fatigue. Participants completed a 90-minute intermittent shuttle run followed by either a 10-minute cold water immersion (mean 10°C \pm 0.5°C) or a non-immersion (control). Ratings of perceived soreness, changes in muscular function (maximal voluntary contraction of the knee extensors and flexors) and blood variables were monitored before exercise, during allocated recovery, and during regular intervals seven days post exercise. The authors found that cold water immersion had no effect on CK response but suggested that cold water immersion immediately after prolonged intermittent exercise is a beneficial recovery modality as a reduction in muscle soreness, a reduced decrement of performance, and a reduction in serum myoglobin concentration one hour post-exercise. Ingram et al.(2009) also used a simulated team sport protocol to assess the efficacy of cold water immersion (2 x 5 minute immersions separated by 2.5 minutes sitting upright at room temperature [22°C]), contrast water therapy (CWT), and no recovery (control) post exercise. Findings were similar to those of Bailey (2007) whereby cold water immersion resulted in significantly lower ($p < 0.05$) muscle soreness ratings, as well as in reduced decrements to isometric leg extension and flexion strength in the 48 hours post exercise period. No significant differences in CK between the three recovery conditions were found at any time point. Indices of muscle damage and inflammation were also found to be unaffected by cold water immersion (10 \pm 0.5°C) performed between four consecutive soccer matches in four days (Rowell, Coutts,

Reaburn, & Hill-Haas, 2009). However, a reduction in the perception of general fatigue and leg soreness between each match was evident compared to a thermo-neutral ($34\pm 0.58^{\circ}\text{C}$) immersion protocol. In addition, Rowsell, Coutts, Reaburn, and Hill-Haas (2011) also reported a reduction in the perception of fatigue ($p = 0.007$, $d = -0.91$) and leg soreness ($p = 0.004$, $d = 0.92$) following cold water immersion (5 x 1 min at 10°C) compared to thermoneutral immersion (5 x 1 min at 34°C) during a four day soccer tournament. The aim of this study was to investigate the effect of two hydrotherapy protocols on perceptual measures and running performance, while comparatively the earlier study by Rowsell et al (2009) measured physiological responses to cold water immersion following a soccer tournament. Both studies provide valuable information whereby cold water immersion was ineffective in reducing indices of muscle damage and inflammation, in comparison to the enhanced restoration of some match related running performance measures in conjunction with the mediation of perceptive soreness and fatigue (Rowsell, Coutts, Reaburn, & Hill-Haas, 2011).

Montgomery et al (2009) evaluated the effectiveness of three recovery strategies (carbohydrate and stretching 7.7 g/kg/day and 10 stretches completed bilaterally for 15 seconds 15 seconds, cold water immersion 11°C 5 x 1 minute, full leg compression 18 hours) on physical performance and accumulative fatigue during a 3-day tournament style basketball competition. Accumulated fatigue was evident via small to moderate impairments in performance tests over the course of the tournament. Sprint and agility performance decreased by 0.7% and 2.0% respectively where vertical jump decreased substantially after the first day for all treatments, and remained suppressed post-tournament. Cold water immersion was substantially better in maintaining 20-m acceleration with only a 0.5% reduction in 20-m time after 3 days compared with a 3.2% reduction for compression. The authors concluded that cold water

immersion promoted superior restoration of physical performance measures than carbohydrate and stretching routines and compression garments. This is an important study as multi-day tournaments and competitive seasons accumulate residual fatigue/metabolic byproducts and are detrimental to an athlete's ability to consistently perform at an optimal level on the days following a match or training. More studies are needed to determine which recovery modality(s) assist in maintaining training/match performance, neuromuscular function, strength markers and perceived fatigue/soreness on consecutive days and within the 48 hour post competition match recovery window.

Cryotherapy for contact sports

Muscle soreness and damage from intense exercise and contact sport is associated with a loss of muscular force generating capacity (Connolly, Sayers, & McHugh, 2003). Research examining the factors influencing muscle soreness and damage has shown that eccentric muscular work is the major contributor to increases in CK which peaks 2-3 days after a damaging exercise bout (Nosaka, Newton, & Sacco, 2002; Sorichter, Puschendorf, & Mair, 1999). However, increasing evidence suggests that a greater CK may result from physical impact or blunt trauma (Ehlers, Ball, & Liston, 2002; Hoffman, Maresh, & Newton, 2002; Takarada, 2003; Zuliani, Bonetti, & Franchini, 1985) as so in contact sports. Currently, research specifically investigating the relative efficacy of cold water immersion following contact sports matches which invoke muscular damage, soreness and reduces muscular function is scarce. The specific application by coaches, practitioners and strength and conditioning coaches of cold water immersion for recovery purposes to exercise-induced muscle damage remains predominantly anecdotal using various temperature and exposure protocols.

One study conducted by Higgins et al (2010) compared cold water immersion (5 minutes 10-12 °C), contrast water therapy (1min 10-12°C, 1min 38-40°C x 7 cycles) and passive recovery over four under-20 competition matches across four weeks. Participants were randomly allocated into one of three recovery modality groups, performing each protocol after each competition match and training (one match and two trainings per week). A 300m sprint and phosphate decrement test were used as pre-post anaerobic performance measures (week 1 and week 5) where subject ratings of perceived rest, muscle tightness and perceived modality benefit were used. No significant difference was identified between pre-post measures in the phosphate decrement test or the 300-m test. Effect size calculations revealed medium to large effect ($d = 0.72$) for 300-m tests for contrast water therapy against control and a trivial effect for ice baths ($d = 0.17$) in the 300-m test against control. Effect scores across contrast baths, cold water immersion, and passive recovery indicated a trend toward contrast baths benefiting recovery in rugby. From subjective reports, five of seven participants from the cold water immersion group reported feeling more tight two days after games than when previously adopting no recovery strategies. All seven 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 sense of being more relaxed and finding it easier to rest and sleep post-game and post-training.

Five minute cold water immersion appears to be a commonly adopted recovery protocol in sport (Higgins, Heazlewood, & Climstein, 2010). However results from Higgins et al (2010) indicated that cold water immersion of five minutes had a negative effect on players' performance recovering from competition and training. Evidence supporting five minute ice baths is limited due to the lack of research investigating this specific exposure time. It may be that five minutes exposure to cold water is an insufficient time to lower tissue temperature

enough to deliver benefits associated with cryotherapy. Furthermore, in the Higgins et al (2010) study no direct markers of muscle damage and/or fatigue (e.g. CK, lactate) were measured to identify a true physiological and biochemical recovery response for each recovery modality. Having done so would have provided crucial evidence on the time course of each marker response following each intervention. Additionally, an attempt to incorporate match and training statistics to quantify the volume and intensity of each match and training would have been beneficial to investigate the effect of each modality according to the volume and intensity (e.g. minutes played, number of contacts etc) placed on each participant.

Cryotherapy conclusion

The physiological benefits of CWI and its ability to reduce symptoms associated with DOMS and muscle damage following repetitive high intensity exercise, eccentric muscle damage and sport related injuries is well documented and supported in the majority of research. However, there is limited evidence to support cryotherapy following more dynamic whole-body exercise, arguably of greater validity in a sports performance environment. The time course and severity of muscle soreness, muscular dysfunction, and appearance of markers of muscle damage in the systemic circulation can vary considerably depending on the duration, intensity, and type of exercise performed. Therefore, further refined investigations are needed to determine the recovery effects of various cold water immersion exposure and temperatures. Furthermore, the quantification of competition and/or training volume and intensity should be incorporated into analysis to assess the recovery response associated with the trialed cold water immersion protocol specific to each participants accumulated volume, intensity and muscular stress. By doing so, more specific and less anecdotal prescription of cold water immersion can be applied to individualise recovery according to a performed work load.

Table 3: Eccentric/DOMS-Inducing & performance based interventions using cold water immersion for recovery

Author	Exercise/Fatigue Intervention	Subjects	Recovery Modes	CWI Protocol	Outcome Measures/Timings	Summary of Main Findings
Eston & Peters (1990)	Participants performed a bout of damage-inducing eccentric exercise (eight sets of five maximal reciprocal contractions at 0.58 rad .s ⁻¹) of the elbow flexors on an isokinetic dynamometer,	15 females	1. CWI 2. Control	Immersed exercised arm in 15C for 15 min immediately after eccentric exercise and then every 12 h for 15 min for a total of seven sessions.	Muscle tenderness, plasma CK, relaxed elbow angle, isometric strength and swelling (upper arm circumference) were measured immediately before and for 3 days after eccentric exercise.	There were significant interactions ($P \leq 0.05$) of group time for relaxed elbow angle and CK activity. Relaxed elbow angle was greater and CK activity lower for the CWI group than the controls on days 2 and 3 following eccentric exercise. It is concluded that although CWI may reduce muscle stiffness and the amount of post-exercise damage after strenuous eccentric activity, there appears to be no effect on the perception of tenderness and strength loss.
Paddon-Jones & Quigley (1997)	Participants performed 64 eccentric elbow flexions with each arm. One arm was subjected to a CWI treatment and the non-immersed arm served as the control.	8 resistance-trained males	1. CWI 2. Control (internal)	5x 20 minute immersions in a 5 ± 1 °C ice-water bath interspersed by 60 minute rest periods	Isometric torque, MS, limb volume measures pre, immediately post, and every 24 hrs for 120 hours	A main effect for time was observed for all dependent variables ($p \leq 0.05$). Isometric torque decr from a pre-exercise value of 87.9 ± 4.5 Nm to 65.2 ± 4.5 Nm immediately post-exercise. All torque measures returned to pre-test levels by 72 h. MS peaked 48 h post-exercise and was evident until 120 h. No sig difference between the CWI and control arms was observed for any variable. Result suggest that the use of CWI immediately following damaging eccentric exercise may not provide the same therapeutic benefits commonly attributed to cryotherapy following traumatic muscle injury.
Burke, D (2000)	Subjects exercised only their right lower limb using static muscular contractions, consisting of 1 set of 4 repetitions, for 5 consecutive days. On the first day, after a few warm-up contractions, subjects were measured for maximum isometric force production (MIFP) of the hip extensor (HE) musculature at the end range of hip flexion. After this initial measure, subjects underwent their randomly assigned treatments.	45 non-injured males and females	1. CWI 2. Hot 3. Control	Cold water group- 8 +/- 1°C for 10 minutes	Maximal isometric force production (MIFP) of the hip extensor (HE) pre and post intervention	All 3 groups had significant improvements in HE isometric force production (pre to post). The increase in MIFP for the cold group was significantly greater than that of the control and hot groups. Sex differences were evident in the cold group only, with men experiencing greater increases.
Lane & Wenger (2004)	Subjects were asked to take part in 2 intermittent cycling sessions; 18 minutes of varying work intervals performed in succession at a resistance of 80 g/kg body weight separated by 24 hours. One of four 15-minute recovery conditions immediately followed the first session.	10 physically active men	1. Active Recovery 2. Massage (MR) 3. Cold Water Immersion (CR) 4. Seated rest (control)	15min leg immersion at 15°C	Total work (kJ),total number of pedal revolutions in each work bout	Only the control condition showed a significant decline in the total work completed between the first and second exercise sessions (108.1 ± 5.4 kJ vs. 106.0 ± 5.0 kJ, $p \leq .05$). AR, MR, and CR appeared to facilitate the recovery process between 2 high-intensity, intermittent exercise sessions separated by 24 hours.

Yamane, M (2006)	The influence of regular post-exercise cold application to exercised muscles trained by ergometer cycling (leg muscles) or handgrip exercise using a weight-loaded handgrip ergometer (forearm flexor muscles) was studied. Participants performed an exercise programs three to four times a week for 4–6 weeks where they performed a recovery protocol with in 3 min post training.	Subjects were non-athlete, healthy students (number not provided)	1. CWI 2. Internal control (room temperature)	Exercise leg immersed in 5±1 C for 20min Exercise arm immersed in 10°C for 20min	MS, degree of exhaustion, and femoral and brachial artery diameter	Significant training effects were three times more frequent in the control than in the CWI group, including increases in artery diameters in the control but not in the CWI group. Training-induced molecular and humeral adjustments, including muscle hyperthermia, are physiological, transient and essential for training effects (myofiber regeneration, muscle hypertrophy and improved blood supply). Therefore, CWI was no more beneficial than tepid water immersion in the recovery from DOMS
Sellwood, K (2007)	Participants performed an eccentric loading protocol with their non-dominant leg. Participants were randomised to one of two recovery groups	40untrained volunteers	1. CWI 2. Tepid water immersion	3 x 1-min immersions in either ice water (5±1°C) or tepid water (24°C) [2 intervention groups]	Pain and tenderness (visual analogue scale), swelling (thigh circumference), function (one-legged hop for distance), maximal isometric strength and serum CK recorded at baseline, 24, 48 and 72 h after exercise	No significant differences were observed between groups with regard to changes in most pain parameters, tenderness, isometric strength, swelling, hop-for-distance or serum CK over time. There was a sign-difference in pain on sit-to-stand at 24 h, with the intervention group demonstrating a greater increase in pain than the control group (median change 8.0 vs. 2.0 mm, respectively, p=0.009). The protocol of CWI used in this study was ineffectual in minimizing markers of DOMS in untrained individuals.
Bailey, D (2007)	Participants completed a 90-min intermittent shuttle run previously shown to result in marked muscle damage and soreness. After exercise, participants were randomly assigned to one of two recovery intervention groups.	20 males	1. CWI 2. Control	Immersion for 10min at 10°C	Ratings of perceived soreness, changes in muscular function and efflux of intracellular proteins were monitored before exercise, during treatment, and at regular intervals up to 7 days post-exercise	CWI administered immediately after exercise reduced muscle soreness at 1, 24, and 48 h ($P \leq 0.05$). IMVC of the knee flexors were reduced after CWI at 24 (mean 12%, sx = 4) and 48 h (mean 3%, sx = 3) compared with control group (mean 21%, sx = 5 and mean 14%, sx = 5 respectively; $P \leq 0.05$). Exercise-induced increases in serum myoglobin concentration and CK activity peaked at 1 and 24 h, respectively ($P \leq 0.05$). CWI had no effect on the CK response, but reduced myoglobin 1 h after exercise ($P < 0.05$). CWI immediately after prolonged intermittent shuttle running reduces some indices of exercise-induced muscle damage.
Vaile, Halson, Gill & Dawson (2007)	Subjects performed a DOMS-inducing leg press protocol followed by PAS or one of the hydrotherapy interventions for 14 min. There were two experimental trials separated by 8 months in a randomised crossover design; one trial involved passive recovery (PAS, control), the other a specific hydrotherapy protocol	38 strength trained males	1. Control (1st trial) 2. CWI 3. HWI 4. CWT	Entire body immersion (incl head and neck) in a plunge pool at 15°C for 14min	Weighted squat jump, isometric squat, perceived pain, thigh girths and blood variables were measured prior to, immediately after, and at 24, 48 and 72 h post-exercise.	Squat jump performance and isometric force recovery were sig ↑ ($P \leq 0.05$) at 24, 48 and 72 h post exercise following CWT and at 48 and 72 h post-exercise following CWI when compared to PAS. Perceived pain improved ($P \leq 0.01$) following CWT at 24, 48 and 72 h post-exercise.

Goodall & Howatson (2008)	Subjects completed a bout of 100 drop jumps. Following the bout of damaging exercise, participants were randomly but equally assigned to either a 12 min CWI group who experienced immersions immediately post-exercise and every 24 h thereafter for the following 3 days, or a control group (no treatment).	18 males	1. CWI 2. Control	12 min in 15°C ± 1°C up to the iliac crest	MVC of the knee extensors, CK, MS (DOMS), ROM) and limb girth were measured pre-exercise and then for the following 96 h at 24 h increments. MVC was also recorded immediately post-exercise.	Significant time effects were seen for MVC, CK, DOMS and limb girth ($p \leq 0.05$) indicating muscle damage was evident. No group effect or interaction observed showing that CWI did not attenuate any of the dependent variables ($p \geq 0.05$). Results suggest that repeated CWI do not enhance recovery from a bout of damaging eccentric contractions.
Halson, Quod, Martin, Gardner, Ebert & Laursen (2008)	Subjects completed two simulated approximately 40-min time trials at 34.3 ± 1.1°C. All subjects completed both a CWI trial and a control condition in a randomized cross-over design.	11 male endurance trained cyclists	1. CWI 2. Control	11.51°C of water for 60 s repeated three times	HR, skin and rectal temperature (Tsk, Tre), T, cortisol, growth hormone (GH), prolactin, adrenaline, noradrenaline, CK, C-reactive protein (CRP), insulin-like growth factor-1 (IGF-1), and interleukin-6 (IL-6) were measured immediately after exercise and at the end of the recovery period (40 minutes post exercise) in 7 out of 11 subjects.	CWI elicited a significantly lower HR and Tsk, Tre. All other measures were not significantly different between conditions. All participants subjectively reported enhanced sensations of recovery following CWI. CWI did not result in hypothermia and can be considered safe following high intensity cycling in the heat, using the prescribed protocol. CWI significantly reduced HR and core temperature; however, all other metabolic and endocrine markers were not affected by CWI.
Vaile, Halson, Gill & Dawson (2008)	Subjects underwent five consecutive exercise days of 105 min duration including 66 maximal effort sprints (cycle). Subjects performed a total of 9 min sustained effort (time trial - TT). Following each exercise session, subjects performed one of four recovery interventions randomly assigned to each trial.	12 endurance trained male cyclists	1. CWI 2. HWI 3. CWT 4. PAS	Entire body immersion (incl head and neck) in a plunge pool at 15°C for 14min	Core temperature, HR (at end of each sprint, pre-post recovery), RPE, TT performance, Peak power average power and total work(during exercise)	Performance was enhanced in all tasks across the five day trial period following CWI and CWT when compared to HWI and PAS. No sig. differences were observed in HR and RPE regardless of day of trial/intervention. CWI and CWT appear to improve recovery from high intensity cycling when compared to HWI and PAS with athletes better able to maintain performance in a five day period.
Banfi, et al. (2009)	Subjects underwent five training sessions on alternate days once daily for 1 week. During the study period, the training workload was the same as that of the previous weeks. Training consisted of 3h of daily exercises: 1h of maximal training in the morning followed by 1h of sub maximal effort, then 1h of sub maximal training in the afternoon in addition to conditioning exercises.	10 national rugby union players	1.WBC (Whole body cryotherapy)	1min -60°C cold air then 2min -110°C cold air daily for 7 days	Muscle enzymes (CK, LAD) and other immunological parameters were compared before and after whole-body cryotherapy (WBC) in 10 top-level Italian	Compared to baseline values, immunological parameters remained unchanged, while CK and LAD levels ↓ after treatment. As measured by Δ CK and LAD concentrations, and cytokines pathway, short-term WBC improved recovery from exercise-induced muscle injury and/or damage associated with intense physical training.

King & Duffield (2009)	Four randomized simulated netball exercise circuit sessions on consecutive days. Each condition consisted of two identical sessions (Session 1 and 2), with the recovery intervention implemented at the completion of Session 1.	10 female netball players	1. Active Recovery 2. Passive Recovery 3. Cold Water Immersion 4. Contrast Water Therapy	9.3 ± 1.6 C to the iliac crest for 5 minutes followed by 2.5 minutes seated at air temperature, which was performed twice	Bla, PH, Bicarbonate, HR, RPE and MS measured at rest, post warm-up and performance tests, during each rest interval in the exercise circuit, after exercise, and post recovery interventions.	A decline in 5 x 20-m sprints and vertical jump were observed for CWT and CWI, respectively. Participants reported a lower MS in both the CWI and CWT conditions (effect size 0.84 and 0.88, respectively) compared to PAS after 24 hrs. The 24-hour recovery period between exercise bouts was sufficient to allow performance to be maintained, regardless of recovery interventions.
Ingram, et al (2009)	Participants then performed 80min of simulated team sports exercise followed by a 20-m shuttle run test to exhaustion. Upon completion of the exercise, and 24h later, participants performed one of the post-exercise recovery procedures for 15min. At 48h post-exercise, the performance tests were repeated.	11 male team sport athletes	1. CWI (COLD) 2. CWT 3. Control	2min x 5min immersions in 10°C separated by 2.5min sitting upright at room temp (22°C)	Baseline measures of performance (10mx20m sprints and isometric strength of quadriceps, hamstrings and hip flexors). MS, CK and c-reactive protein (CRP) were taken before and immediately after post-exercise, and at 24h and 48h post-exercise.	CWT treatments and COLD resulted in ↓ (p<0.05) MS ratings, as well as in reduced decrements to isometric leg extension and flexion strength in the 48-h post-exercise period compared to control. COLD facilitated a more rapid return to baseline repeated sprint performances. This study demonstrated that COLD following exhaustive simulated team sports exercise offers greater recovery benefits than CWT or control treatments.
Kinugasa & Kilding (2009)	On separate days, participants played 3 soccer matches on separate days each randomly followed by 1 of 4 recovery modalities	28 young (age: 14.3 ± 0.7 years) soccer players	1. Cold water immersion COLD 2. Contrast water immersion CONT 3. Combination (cold water immersion & active recovery) COMB 4. Passive recovery PAS	1 minute at 12°C in combination with active recovery using a cycle ergometer (60–80 rpm, 90–110 W) for 2 minutes and repeating this 3 times	Performance (vertical jump height), physiological (heart rate and tympanic temperature), and perceptual measures (perceived quality of recovery) were determined before each match, 10 minutes after each match, after each recovery method, and after 24 hours.	Perceived quality of recovery immediately after COMB was ↑ than CONT and PAS, but the effect did not last more than 24 hours. Players perceived lighter legs after COMB, compared with PASS, at post-24 hours. COMB modality (cold water immersion and active recovery) after a soccer match did not have a substantial effect on vertical jump height performance compared with CONT & PAS alone. Perceived recovery after COMB modality suggests that this approach may be effective for young players after intense soccer match play. This effect cannot be attributed to COLD alone.
Montgomery, et al (2009)	Subjects performed in a 3-day tournament style basketball competition where they were assigned to 1 of 3 recovery treatment groups following each game.	29 male basketball players	1. Carbohydrates + stretching 2. CWI 3. CG	5 x 1 min in 11°C immersion separated by 2min	Physical performance: 20-m acceleration, basketball line-drill, Yoyo Level 1 intermittent recovery test, vertical jump, a basketball-specific agility test, and the sit-and-reach flexibility test was measured at baseline and post tournament.	Sprint and agility performance decreased by 0.7% (s = 1.3) and 2.0% (s = 1.9) respectively. Vertical jump decreased substantially after the first day for all treatments, and remained suppressed post-tournament. CWI was substantially better in maintaining 20-m acceleration with only a 0.5% (s = 1.4) reduction in 20-m time after 3 days compared with a 3.2% (s = 1.6) reduction for CG. CWI (-1.4%, s = 1.7) and CG (-1.5%, s = 1.7) showed similar substantial benefits in maintaining line-drill performance over the tournament, whereas carbohydrate + stretching elicited a 0.4% (s = 1.8) reduction. CWI appears to promote better restoration of physical performance measures than carbohydrate + stretching routines and compression garments.

Rowvall, et al (2009)	Junior male soccer players played four matches in 4 days and undertook either 1 of 2 hydrotherapy protocols after each match.	20 male high performance junior soccer players	1. CWI 2. TNWI (thermo neutral water immersion)	5 x alternating 1min in 10 ± 0.5°C separated by 1min seated at room temperature (22°C)	Physical performance tests; CMJ height, HR, and RPE after a standard 5-min run and 1220-m repeated sprint test, CK, LDH were recorded approximately 90 min before and 22 h after the final match. Perceptual measures of recovery (physical, mental, leg soreness, and general fatigue) were recorded 22 h after each match.	Non-significant reductions in CMJ height (1.7-7.3%, P = 0.74, η ² = 0.34) and repeated sprint ability (1.0-2.1%, P = 0.41, η ² = 0.07) over the 4-day tournament with no differences between groups was observed. Post-shuttle run RPE increased over the tournament in both groups (P ≤ 0.001, η ² = 0.48), whereas the perceptions of leg soreness (P = 0.004, η ² = 0.30) and general fatigue (P = 0.007, η ² = 0.12) were lower in the CWI group than the TNWI group over the tournament. CK (P = 0.004, η ² = 0.26) and LDH (P ≤ 0.001, η ² = 0.40) concentrations increased in both groups but there were no changes over time for any inflammatory markers. Immediate post-match CWI does not affect physical test performance or indices of muscle damage and inflammation but does reduce the perception of general fatigue and leg soreness between matches in tournaments.
Rowvall, et al (2011)	Junior male soccer players played four matches in 4 days and undertook either 1 of 2 hydrotherapy protocols after each match.	20 male high performance junior soccer players	1. CWI 2. TNWI (thermo neutral water immersion)	5 x alternating 1min in 10°C separated by 1min seated at room temperature (22°C)	Performance measures: High-intensity running distance (>15 km/h) and total distance covered, time spent in low (<80% maximum heart rate), moderate (80–90% maximum heart rate), and high (>90% maximum heart rate) heart rate zones, and RPE. Perceptual measures of recovery were recorded 22 h after each match.	Cold-water immersion was more effective than thermo neutral immersion for reducing the perception of leg soreness (P=0.004, d=-0.92) and general fatigue (P=0.007, d=-0.91), ameliorating the decrement in total distance run (P=0.001, d=0.55), and maintaining time in the moderate heart rate zone (P=0.01, d=1.06).

Contact Sport Interventions using cold water immersion for recovery

Higgins, Heazlewood, & Climstein (2010)	Subjects from a premier rugby club participated in 4 x 80min game of rugby union across four weeks where they were then randomly assigned to 1 of 3 recovery treatments.	26 under-20 club rugby volunteers	1. CWT 2. CWI (ice baths) 3. Control (no recovery)	5 min above waistline at 10-12°C	Pre and post field tests including a 300-m test and a phosphate decrement test and subjective reports (how rested they felt, how tight they felt, and whether they felt the treatment was beneficial) were conducted during the trial.	Trivial effects were identified for ice baths (d = 0.17) in the 300-m test against control. Effect size calculations in the phosphate decrement test showed a negative effect (d = -0.62) for ice baths. 5 of 7 participants from CWI group reported feeling more tight 2 days after games than when previously adopting no recovery strategies. All 7 participants in the CWI group had a negative feeling toward the baths. Participants from the CWT group reported having a more positive feeling after the treatment.
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AR - Active Recovery; **ACT** - Active Recovery; **PAS** - Passive Recovery; **COLD** - Cold water immersion; **CWI** - Cold water immersion **CTW** - Contrast water therapy; **CWT** - Contrast water therapy; **COMB** - Combined recovery method, **TNWI** - Thermoneutral water immersion; **HWI** - Hot water immersion; **WBC** - Whole body cryotherapy **GAR** - Compression Garment; **CG** - Compression garment **CK** - Creatine kinase; **CRP** - C-reactive protein; **Bla** - Blood lactate; **RANG** - Relaxed arm angle; **FANG** - Flexed arm angle; **MIF** - Maximal isometric force; **MS** - Muscle soreness; **SOR** - Muscle soreness; **DOMS** - Delayed onset muscle soreness; **HR** - Heart rate; **PRS** - Peak running speed; **CMJ** - Countermovement jump, **RPE** - Rate of perceived exertion; **LDH** - lactate dehydrogenase; ↓ - Significantly lower/worse; ↑ - Significantly higher/better

Contrast Water Therapy (CWT)

During contrast water therapy participants/athletes alternate between hot water and cold water exposure respectively. This technique has been used extensively in sports medicine as a recovery modality and is now becoming more frequently used in aiding recovery after physical training and competition (Calder, 2001a). The application of cold ice or water is thought to cause vasoconstriction of the blood vessels (Cochrane, 2004). Vasoconstriction decreases swelling and inflammation by slowing the metabolism and production of metabolites and limiting the degree of injury (Cochrane, 2004). Thermotherapy (heat) has been shown to cause vasodilation of the blood vessels (Cochrane, 2004; Myrer, Draper, & Durrant, 1994). This increases blood flow and the supply of oxygen to the area, which results in an increased amount of antibodies and an improved ability to clear metabolites (Cochrane, 2004). Promoting vasodilation and vasoconstriction via hot and cold temperature exposure, commonly referred to as causing a ‘pumping’ action, may explain the many anecdotal reports of reduced post exercise stiffness and the accelerated return to basal and metabolic resting levels. Contrast water therapy may bring about other changes such as increased or decreased tissue temperature, increased or decreased blood flow, changes in blood flow distribution, reduced muscle spasm, hyperaemia of superficial blood vessels, reduced inflammation, and improved range of motion (Myrer, Draper, & Durrant, 1994). Active recovery has traditionally been considered a superior recovery modality to passive recovery. Contrast water therapy may elicit many of the same benefits of active recovery such as lactate clearance caused by a pumping action providing oxidative metabolism to removing metabolites. Although active recovery often requires additional energy that further depletes valuable energy stores, contrast water therapy may be justified as a superior option as a recovery tool (Wilcock, Cronin, & Hing, 2006).

Research investigating contrast water therapy as a recovery modality for muscle soreness and exercise-induced fatigue has been frequently reported (Coffey, Leveritt, & Gill, 2004; Hamlin, 2007; Morton, 2007; Sanders, 1996). Sanders (1996) found that blood lactate concentrations recovered at similar rates when implementing either contrast water therapy or active recovery protocols following a sequence of Wingate tests, compared to a significantly lower blood lactate clearance which was observed during passive recovery. Coffey et al (2004) compared the effectiveness of three different recovery modalities; active recovery (40% peak running speed for 15minutes), passive recovery (standing stationary for 15minutes) and contrast water therapy (60s cold [10°C] and 120s hot [42°C]) on the performance of repeated treadmill running, lactate concentration and pH levels. Significant differences ($p < 0.05$) were found between active recovery and passive recovery for blood lactate concentration at 8, 12, 16 and 20 minutes post exercise. While blood lactate was lower at these time points for contrast water therapy compared with passive recovery, these differences were not statistically significant. Participants reported an increased perception of recovery from the contrast water therapy compared with active and passive recovery modalities. Both active recovery and contrast water therapy reduced blood lactate accumulation by similar amounts following high intensity running. Nevertheless, high intensity treadmill running performance was returned to baseline four hours after the initial exercise bout regardless of the recovery modality used.

More recently, Vaile et al (2008) investigated the effects of contrast water therapy on the signs and symptoms of DOMS using a leg press protocol on two separate occasions with only the recovery modalities changing. Weighted squat jump (30% of isometric squat force), isometric squat, perceived pain, thigh girths and blood variables were measured prior to, immediately after, and at 24, 48 and 72 hours post the DOMS inducing protocol. All hydrotherapy interventions

(cold water immersion, hot water immersion, and contrast water therapy) studied improved the recovery of isometric force compared to passive recovery throughout the 72 hours post exercise data collection period. However, only cold water immersion and contrast water therapy compared to passive recovery significantly improved dynamic power (squat jump). Hot water immersion appeared to have no effect on the recovery of power, following a similar trend produced by passive recovery. Participants indicated an improvement in perceived muscle pain ($p < 0.01$) following contrast water therapy at all time points post the leg press intervention. Furthermore, significantly reduced thigh volume measures compared to passive recovery were reported following contrast water therapy indicating that a decrease in tissue oedema levels is a consequence of such a modality. Overall, the reported results indicate that contrast water therapy along with cold water immersion were found to be effective in restoring the physiological and functional deficits associated with DOMS. Very similar results were found by Vaile et al (2007) where contrast water therapy was used following a similar leg press protocol inducing DOMS. Conversely, French et al (2008) reported no difference in recovery effects following contrast water therapy or compression garments. The investigators used a resistance exercise challenge (REC) to induce exercise induced muscle damage (6 x10 parallel squats at 100% body weight with 5sec one repetition maximum eccentric squat superimposed onto each set) with muscle soreness, serum creatine kinase and myoglobin, joint range of motion, limb girth, 10- or 30-m sprint, countermovement jump (CMJ), and five repetition maximum squat measures obtained at baseline, 1-hour, 24 and 48 hours post REC. It was concluded that while within-groups differences were observed in physiological, physical, performance and perceptual measures after these recovery modalities, there was little evidence to indicate contrast water therapy and/or compression garments were any more effective than passive rest at augmenting recovery and

regeneration in trained athletes (French, Thompson, Garland, Barness, Portas, Hood, & Wilkes, 2008).

For athletes it is of equal importance to recover from not only resistance based training but also from competitive match play, at times playing multiple matches or performing repeated high intensity sprint exercise on the same or consecutive days. The type of muscle damage and fatigue can be somewhat different depending on the mode, intensity, volume of exercise performed and recovery time allowed. Versey, Halson, and Dawson (2010) investigated whether contrast water therapy had a dose–response effect on recovery from consecutive high-intensity cycling bouts separated by two hours using three different exposure times (6 minutes, 12 minutes and 18 minutes with each using one minute hot [$38.4 \pm 0.6^{\circ}\text{C}$], one minute cold [$14.6 \pm 0.3^{\circ}\text{C}$] protocols). Results indicated the 6-minute protocol substantially improved time-trial ($1.5 \pm 2.1\%$) and sprint performance ($3.0 \pm 3.1\%$) compared with control. The 12-minute protocol substantially improved sprint total work ($4.3 \pm 3.4\%$) and peak power ($2.7 \pm 3.8\%$) in exercise bout two. All contrast water therapy exposures generally enhanced thermal sensation, whole body fatigue and muscle soreness compared with the control condition. This study is notable as it was the first to assess the dose response of different exposure times in a sport performance setting.

Kinugasa and Kilding (2009) implemented three post-match recovery modalities (contrast water therapy, combination of cold water immersion and active recovery, passive recovery) on physical performance, physiological measures, and players' perceptions of recovery after 90 minutes of soccer match play. Performance (vertical jump height), physiological (heart rate and tympanic temperature), and perceptual measures (perceived quality of recovery) were determined before each match, 10 minutes post match, after each recovery method, and 24 hours

post match. It was found that there was no significant benefit of employing a combined recovery modality on physical performance compared with commonly used standard single recovery modalities (contrast water therapy or passive recovery). However, immediately following the combined and contrast water therapy methods a greater perceived recovery and lighter legs were reported (ES = 0.62 and ES = 1.11, respectively) when compared with passive recovery although the trend only continued for the combined modality at post 24 hours (ES = 0.75). Supporting the results of the previous study, King and Duffield (2009) also found no significant differences ($p > 0.05$) between conditions for exercise performance (vertical jump, 20m sprint, 10m sprint, total circuit time) between two sessions separated by 24 hours where one of four recovery interventions (contrast water immersion, cold water immersion and active recovery) were performed. Notably blood lactate (La) was significantly reduced post contrast water therapy ($p = 0.04$) compared to active recovery (2.6 ± 1.0 mmol.L⁻¹ and 3.9 ± 1.3 mmol.L⁻¹, respectively). Furthermore, perceived muscle soreness was significantly reduced ($p = 0.01$) compared to the active recovery with participants reporting a lower muscle soreness in both the contrast water therapy and cold water immersion conditions 24 hours following session two compared to passive recovery. Hamlin (2007) also observed a reduction in blood lactate following contrast water therapy between two intermittent sprint exercise sessions and recovery effects on sprint performance were small to trivial and unclear. Due to the absence of a passive control group, Hamlin (2007) questioned whether such changes were attributable to the contrast temperature water therapy per se, or to the passive nature of this modality, i.e. inactivity.

Contrast water therapy for contact sports

Several studies have investigated the use of contrast water therapy following intermittent contact sport (Dawson, Gow, Modra, Bishop, & Stewart, 2005; Gill, Beaven, & Cook, 2006;

Higgins, Heazlewood, & Climstein, 2010; Ingram, Dawson, Goodman, Wallman, & Beilby, 2009), using multiple measures at varying time points to quantify the rate and magnitude of change following the modality. A study by Gill et al (2006) on professional rugby union players examined the rate and magnitude of muscle damage recovery (measured by creatine kinase [CK]) following four recovery interventions including contrast water therapy (1 minute in cold water [8–10°C] and 2 minutes in hot water [40–42°C] x3) (Gill, Beaven, & Cook, 2006). The reported rates of recovery were very similar for active recovery (88.2% post 84 hours), contrast water immersion therapy (85% post 84 hours), and lower-body compression garments (84.4% post 84 hours). The authors suggested that the active recovery, compression garments, and contrast water therapy modalities were more useful forms of recovery than passive recovery following rugby union. It was conjectured that a greater recovery effect may have been observed if the duration of each were to be increased. Although the time constraints imposed in a competitive environment were acknowledged.

Ingram et al.(2009) used a simulated team sport method to assess the efficacy of cold water immersion, contrast water therapy (2 minutes in cold water [10°C] and 2 minutes in hot water [40°C]) and no recovery (control) post exercise. Upon completion and at 24 hours post the team sport simulation participants performed one of three recovery modalities for 15 minutes. Both contrast water immersion and cold water immersion resulted in significantly lower ($p < 0.05$) muscle soreness ratings and strength measures within the 48 hours post intervention compared to the control. CK was found to have increased throughout the 48 hours post exercise, peaking after 24 hours. No significant differences in creatine kinase between the three recovery conditions were found at any time point

As previously mentioned, Higgins et al (2010) compared the effect of cold water immersion (5 minutes 10-12 °C), contrast water therapy (1min 10-12°C, 1min 38-40°C x 7 cycles) and passive recovery following four under-20 competition matches across four weeks, on the rate and magnitude of anaerobic recovery using two performance tests (300m sprint and phosphate decrement test). Contrast water therapy provided a medium to large effect size ($d = 0.72$) for the 300-m tests and a small effect size ($d = 0.18$) for the phosphate decrement test scores. Participants from the contrast water therapy group reported being more relaxed and finding it easier to rest and sleep post-game and post-training compared to the cold water immersion group. Even though no significant treatment or interaction effects were identified, effect size calculations identified that there was justification for the use of contrast water therapy following rugby union as it may assist in the maintenance of performance (rather than improve outright performance). Dawson et al (2005) examined the effects of four recovery interventions (contrast water therapy, pool walking, stretching and control) on the recovery of explosive power (vertical jump and 6-second cycle ergometer) at 15 and 48 hours post Australian football matches. At 15 hours postgame, measures of vertical jump and 6-second work and power were significantly lower than pregame measures in the control condition, which were no longer evident 48 hours post match. No significant differences were evident between the conditions in vertical jump measures, even though subjects still reported significantly higher ratings of muscle soreness. Dawson et al (2005) concluded that recovery of muscle soreness, flexibility and power at 48 hr post-game was not significantly enhanced by performing an immediate post-game recovery beyond that achieved by performing only next day recovery training.

Contrast water therapy conclusion

The physiological responses of undertaking contrast water therapy are well known, however the physiological mechanisms underlying its apparent beneficial responses remain unclear. It is evident that contrast water therapy is widely used as a recovery method and has been proposed to assist in the maintenance of performance rather than enhance it. Additional research is needed to confirm the rate and magnitude of the recovery effect and relative efficacy of performing such a modality. Quantifying the relative efficacy of contrast water therapy to the volume, intensity and/or amount of contact performed in each competition match, specifically following contact sport, would allow coaches, practitioners and trainers to prescribe specific recovery protocols according to workload performed. In addition to this, future research is required to establish optimal water temperatures, duration of exposure, and the number and timing of rotations completed for each exposure.

Table 4: Eccentric/DOMS-Inducing & performance based interventions using contrast water therapy for recovery

Author	Exercise/Fatigue Intervention	Subjects	Recovery Modes	CWT Protocol	Outcome Measures/Timings	Summary of Main Findings
Coffey, Leveritt & Gill (2004)	Participants performed two pairs of treadmill runs to exhaustion at 120% and 90% of peak running speed (PRS) over a 4-hour period. Recovery modalities were performed for 15-min after the first pair of treadmill runs.	14 males	1. Active Recovery 2. Passive Recovery 3. Contrast Water Immersion	Alternating between 1min cold (10°C) and 2min hot (42°C) water immersion for a total of 15 minutes	HR, RPE and Bla (at rest, immediately and 4, 8, 12, 16 and 20-minutes after the first pair of treadmill runs to exhaustion. Also at rest before and immediately after the last pair of treadmill runs to exhaustion.	Recovery modality did not have a sign. Effect on change in time to cover 400 m, 1000 m or 5000 m. Post exercise Bla concentration was lower in ACT and CTW compared with PAS. Participants reported an increased perception of recovery in the CTW compared with ACT and PAS. Blood pH was not sign. influenced by recovery modality. Both ACT and CTW reduce lactate accumulation after high intensity running.
Morton, R (2007)	Participants on two occasions undertook four successive 30-s Wingate tests separated by 30-s rest periods. On each occasion, plasma lactate concentration during recovery was measured 5min post-exercise and thereafter at 5min intervals for 30min. On one occasion (determined randomly), the subjects recovered passively on a recovery bed and, on the other, they alternated partial body immersion in water baths	11 subjects (6male 5 female)	1. CWT 2. PR (Passive recovery)	Alternated in hot (36°C) and cold (12°C) water baths for a total of 30min. hot (9), cold (1), hot (4), cold (1), hot (4), cold (1), hot (4), cold (1), hot (4) and cold (1); time in minutes.	Bla was sampled 5 min after the end of the fourth Wingate test and thereafter at 5min intervals for 30 min.	The rate of decrease in Bla over the 30-min recovery period was significantly higher ($p \leq 0.001$) in CWI; $0.28 (\pm 0.02) \text{ mmolL}^{-1} \text{ min}^{-1}$ (CWI) compared to $0.22 (\pm 0.02) \text{ mmolL}^{-1} \text{ min}^{-1}$ (PR). CWT is a valid method of hastening plasma Bla decrease during recovery after intense anaerobic exercise for both males and females.
Vaile, Gill & Blazeovich (2007)	Participants performed 2 experimental trials separated by 6 weeks in a randomized crossover design. On each occasion, subjects performed a DOMS-inducing leg press protocol consisting of 5 x10 eccentric contractions (180 seconds recovery between sets) at 140% of 1 repetition maximum (1RM). This was followed by a 15-minute recovery period incorporating 1 of 2 recovery interventions.	13 recreational athletes	1. CWT 2. PAS (Passive recovery)	60 seconds cold water (8–10°C) 120 seconds hot water (40–42°C) for 15 minutes total	CK, perceived pain, thigh volume, isometric squat strength, and weighted jump squat performance were measured prior to the eccentric exercise, immediately post recovery, and 24, 48, and 72 hours post recovery.	Jump squat peak power was ↓ ($p \leq 0.05$) following both PAS ($20.9 \pm 13.4\%$) and CWT ($12.8 \pm 8.0\%$). Thigh volume measured immediately following CWT was ↓ than PAS. No significant differences in the changes in CK were found. There were no significant ($p < 0.01$) differences in perceived pain between treatments. CWT was associated with a smaller reduction, and faster restoration, of strength and power measured by isometric force and jump squat production following DOMS-inducing leg press exercise when compared to PAS. CWT seems to be effective in reducing and improving the recovery of functional deficiencies that result from DOMS, as opposed to passive recovery.
French, et al (2008)	Subjects performed a resistance exercise challenge (REC) to induce exercise induced muscle damage (EIMD): 6x10 parallel squats at 100% BW with 5sec one rep max eccentric squat superimposed into each set. Subjects were separated into 3 recovery intervention groups	26 young men	1. CG 2. Contrast bathing (CB) 3. Control (CONT)	1min cold (8–10°C) X4 3min hot (37–40°C) X3 water baths	Baseline values of MS, CK and Mb, joint ROM, limb girth, 10-30m sprint, CMJ, and 5RM were completed and retested 48 hours after intervention.	Ck elevated at 24hr in CB, CG & CONT. Mb elevated at 1hr in CG, CG & CONT. Sig diff from baseline in all groups for CMJ (CG 5.1%, CB 4.4%; CONT 8.5%) and soreness (213%; 284%; 284%). 30-m sprint time incr with CG. NO hierarchy of recovery effects found.

Vaile, Halson, Gill & Dawson (2008)	Subjects underwent five consecutive exercise days of 105 min duration including 66 maximal effort sprints (cycle). Additionally, subjects performed a total of 9 min sustained effort (time trial - TT). Following each exercise session, subjects performed one of four recovery interventions randomly assigned to each trial.	12 endurance trained male cyclists	1. CWI 2. HWI 3. CWT 4. PAS	Entire body immersion (incl head and neck) alternating 1 min cold (15°C) and 1 min hot (38°C) water for a total of 14 min (seven cycles).	Core temperature, HR (at end of each sprint, pre-post recovery), RPE, TT performance, Peak power average power and total work(during exercise)	Performance was enhanced in all tasks across the five day trial period following CWI and CWT when compared to HWI and PAS. No sig. differences were observed in HR and RPE regardless of day of trial/intervention. CWI and CWT appear to improve recovery from high intensity cycling when compared to HWI and PAS with athletes better able to maintain performance in a five day period.
Kinugasa & Kilding (2009)	On separate days, participants played 3 soccer matches on separate days each randomly followed by 1 of 4 recovery modalities	28 young (age: 14.3 ± 0.7 years) soccer players	1. Cold water immersion COLD 2. Contrast water immersion CONT 3. Combination (cold water immersion & active recovery) COMB 4. Passive recovery PAS	1 minute in cold water (12°C) immediately followed by a hot shower (front and rear of body at 38°C) for 2 minutes and repeated 3 times	Performance (vertical jump height), physiological (heart rate and tympanic temperature), and perceptual measures (perceived quality of recovery) were determined before each match, 10 minutes after each match, after each recovery method, and after 24 hours.	Perceived quality of recovery immediately after COMB was ↑ than CONT and PAS, but the effect did not last more than 24 hours. Players perceived lighter legs after COMB, compared with PAS, at post-24 hours. COMB modality (cold water immersion and active recovery) after a soccer match did not have a substantial effect on vertical jump height performance compared with CONT & PAS alone. Perceived recovery after COMB modality suggests that this approach may be effective for young players after intense soccer match play.
Ingram, et al (2009)	Participants then performed 80min of simulated team sports exercise followed by a 20-m shuttle run test to exhaustion. Upon completion of the exercise, and 24h later, participants performed one of the post-exercise recovery procedures for 15min. At 48h post-exercise, the performance tests were repeated.	11 male team sport athletes	1. CWI (COLD) 2. CWT 3. Control	Alternating 2 min in cold (10°C) or warm/hot water (40 °C) X3 with 30 sec transfer time.	Baseline measures of performance (10mX20m sprints and isometric strength of quadriceps, hamstrings and hip flexors). MS, CK and c-reactive protein (CRP) were taken before and immediately after post-exercise, and at 24h and 48h post-exercise.	CWT treatments and COLD resulted in ↓ (p ≤ 0.05) MS ratings, as well as in reduced decrements to isometric leg extension and flexion strength in the 48-h post-exercise period compared to control. COLD facilitated a more rapid return to baseline repeated sprint performances. This study demonstrated that COLD following exhaustive simulated team sports exercise offers greater recovery benefits than CWT or control treatments. The only benefit of CWT over control was a ↓ in muscle soreness 24 h post-exercise.
King & Duffield (2009)	Four randomized simulated netball exercise circuit sessions on consecutive days. Each condition consisted of two identical sessions (Session 1 and 2), with the recovery intervention implemented at the completion of Session 1.	10 female netball players	1. Active Recovery 2. Passive Recovery 3. Cold Water Immersion 4. Contrast Water Therapy	Alternated in 1min cold (9.7 ± 1.4 °C) water and 2 min warm (39.1 ± 2.0 °C) shower to the level of the iliac crest.	Bla, PH, Bicarbonate, HR, RPE and MS measured at rest, post warm-up and performance tests, during each rest interval in the exercise circuit, after exercise, and post recovery interventions.	CWT demonstrated a ↓ (p ≤ 0.04) in Bla post-intervention compared to ACT recovery. ACT recovery resulted in a ↑ (p ≤ 0.01) HR compared to all other conditions post intervention and demonstrated ↑ (p , 0.01) rating of RPE post intervention and MS pre exercise Session 2. The 24-hour recovery period between exercise bouts was sufficient to allow performance to be maintained, regardless of recovery interventions.

Versey, Halson & Dawson (2010)	Participants completed four trials, each commencing with a 75min cycling protocol containing six sets of five 15-s sprints and three 5min time-trials in thermo neutral conditions. Ten minutes post-exercise, participants performed one of four recovery CWT protocols. The cycling protocol was repeated 2 h after completion of exercise bout one.	11 trained male cyclists	1. CWT 6min 2. CWT 12min 3. CWT 18min 4. Control	Alternated hot water (38.4 ± 0.6°C) and cold water (14.6 ± 0.3°C) every minute with a 5sec changeover.	Cycle performance (work, power), core temperature, HR, RPE at the end each sprint set, time-trial, and exercise bout. Thermal sensation, whole body fatigue, and MS were measured pre and post each exercise bout, and during seated rest.	Core temperature was lower in CWT12 and CWT18 than control prior to bout two. Compared with control, CWT6 ↑time-trial and sprint performance. CWT12 ↑sprint total work and peak power in exercise bout two. All CWT conditions generally improved thermal sensation, whole body fatigue and muscle soreness compared with control, but no differences existed between conditions. Results suggest that CWT of up to 12 min might be more effective as a recovery protocol than longer durations such as 18 min.
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Contact sport Interventions using contrast water therapy for recovery

Dawson, B (2005)	Participants were studied across 12 Australian football games where they completed each of four allocated recovery treatments at least once. .	17 Australian football players	1. Control 2. Stretch 3. Pool walking 4. Hot/cold (CWT)	Alternating with 2min hot shower (45°C) x5 and 1min ice water waist deep (12°C)	MS ratings and measures of flexibility (sit and reach) and power (6-s cycling sprint and vertical jump) were obtained 45 hr pre-game (Thursdays) (baseline), 15 hr post-game (Sundays) and 48 hr post-game (Mondays)	MS was ↑ (p<0.01) than baseline on both Sunday and Monday in all conditions, but no differences between the three recoveries and control were evident. On Sunday, vertical jump and 6-s work and power scores were only ↓ than baseline values in control. No differences were found between the three experimental recoveries. On Monday no significant differences were recorded in performance between the recoveries and the effect sizes were of lower magnitude. Recovery of MS, flexibility and power at 48 hr post-game was not significantly enhanced by performing an immediate post-game recovery beyond that achieved by performing only next day recovery training.
Gill, et al(2006)	Elite male rugby players were monitored over four competition games during the New Zealand Provincial Championship competition. Players were randomly assigned to complete one of four post-match strategies.	23 elite male rugby players	1. Contrast water therapy (CWT) 2. Compression garment (GAR) 3. Low intensity active exercise (ACT) 4. Passive recovery (PAS)	Alternating 1 min in cold water (8–10°C) and 2 min in hot water (40–42°C) X3	CK pre game, immediately post match, 36 & 84 hours post match	Incr rate and magnitude of recovery observed in ACT, CWT, and CG treatment groups compared to PAS group. Low impact exercise immediately after comp, wearing CG or carrying out CWT enhances CK clearance more than passive recovery. The CWT intervention showed 85% recovery after 84 hours which proved to be second best out of all interventions. No significant differences in CK recovery profile were observed between the ACT, CWT, or GAR interventions at any time point.
Higgins, Heazlewood, & Climstein (2010)	Subjects from a premier rugby club participated in 4 x 80min game of rugby union across four weeks where they were then randomly assigned to 1 of 3 recovery treatments.	26 under-20 club rugby volunteers	1. CWT 2. CWI (ice baths) 3. Control (no recovery)	Alternating 1 minute cold (10–12°C) and hot (38–40°C) for seven cycles	Pre and post field tests including a 300-m test and a phosphate decrement test and subjective reports (how rested they felt, how tight they felt, and whether they felt the treatment was beneficial) were conducted during the trial.	Effect size calculations identified a medium to large effect (d = 0.72) for 300-m tests for contrast baths against control and a trivial effect (d = 0.18) for contrast baths in the phosphate decrement test. Treatment–treatment analysis identified a large effect for contrast baths (d = 0.99) in the phosphate decrement test and a medium effect for contrast baths (d = 0.53) in the 300-m test. Participants from the CWT group reported having a more positive feeling after the treatment compared to CWI.

AR - Active Recovery; **ACT** - Active Recovery; **PAS** - Passive Recovery; **COLD** - Cold water immersion; **CTW** - Contrast water therapy; **CWT** - Contrast water therapy; **COMB** - Combined recovery method, **TNWI** - Thermo neutral water immersion; **HWI** - Hot water immersion; **WBC** - Whole body cryotherapy **GAR** - Compression Garment; **CG** - Compression garment **CK** - Creatine kinase; **CRP** - C-reactive protein; **Bla** - Blood lactate; **RANG** - Relaxed arm angle; **FANG** - Flexed arm angle; **MIF** - Maximal isometric force; **MS** - Muscle soreness; **SOR** - Muscle soreness; **DOMS** - Delayed onset muscle soreness; **HR** - Heart rate; **PRS** - Peak running speed; **VO2.max** - Maximal oxygen consumption; **CMJ** - Countermovement jump, **RPE** - Rate of perceived exertion; **LDH** - lactate dehydrogenase; ↓ - Significantly lower/worse; ↑ - Significantly higher/better; **Incr** – Increase; **Decr** – Decrease

Hot Water Immersion (Thermotherapy)

Thermotherapy refers to the immersion of the body in temperatures at or exceeding 36°C which increases the core body temperature (Bonde-Petersen, Schultz-Pedersen, & Dragsted, 1992b; Vaile, Halson, Gill, & Dawson, 2008; Weston, 1987; Wilcock, Cronin, & Hing, 2006). Compared to other hydrotherapy modalities, little research has been conducted on the physiological or performance effect of hot water therapy. However, peripheral vasodilation is one physiological response that has been associated with heat exposure which results in an enhanced blood flow response. Hot water immersion has also been suggested to enhance the maintenance of neuromuscular performance capacity of athletes (Viitasalo, Niemelfi, Kaappola, Korjus, Levola, Mononen, Rusko, & Takala, 1995), increase healing via waste removal and increase nutrient delivery to and from cells (Cote, Prentice, Hooker, & Shields, 1988; Starkie, Hargreaves, Lambert, Proietto, & Febbraio, 1999), and aid rehabilitation of soft tissue injuries and athletic recovery (Brukner & Khan, 1993).

Anecdotally, numerous athletes commonly perform hot water therapy as prescribed by their support staff. Due to the scant research attention on hot water therapy as a recovery modality, the effect of this type of hydrotherapy procedure on the subsequent recovery of performance is inadequately understood. Viitasalo et al (1995) investigated the effects of three 20 minute warm (36.7-37.2°C) underwater water-jet massage immersions which were incorporated into a training week. Measures of neuromuscular function, selected biochemical markers and perceived muscle soreness among 14 junior track and field participants were taken throughout the study. Results demonstrated an enhanced maintenance effect of performance (measured by contact time and jump height from plyometric drop jumps and repeat bounding respectively) in company with a decrease in perceived muscle soreness during the treatment

week compared to the control week. However, significantly higher CK and myoglobin concentrations were observed following the water treatment, symptomatic of either greater damage to the muscular structure or an increased leakage of proteins from the muscle into the blood stream (Viitasalo, Niemelfi, Kaappola, Korjus, Levola, Mononen, Rusko, & Takala, 1995).

In another study, Vaile et al (2008) investigated the effect of three hydrotherapy interventions on next day performance following strenuous cycling sessions. In contrast to Viitasalo et al (1995) and in support of Vaile et al (2007), hot water immersion compromised next day performance, was ineffective in reducing perceptions of pain, and increasing and/or maintaining strength measures compared to other hydrotherapy interventions. It was proposed that continuous hot water therapy may be more detrimental than exposure to cooler water due to the increase in cardiovascular strain (Cochrane, 2004; Vaile, Gill, & Blazeovich, 2007).

Hot water therapy and contact sports

Despite the predicted benefits associated with hot water therapy, anecdotal evidence suggests that it is not generally prescribed on its own or as a substitute for other recovery interventions. To date there has been no evidence of hot water therapy protocols under investigation prescribed independently following contact sports. Athletes often immerse themselves in hot water in conjunction with a cold water immersion following contact sports due to its ability to increase blood flow and nutrients to specified areas, clear metabolites (Cochrane, 2004) and decrease perceived muscle soreness (Gill, Beaven, & Cook, 2006; Higgins, Heazlewood, & Climstein, 2010). As a consequence of the forceful contact and muscular damage that is caused by such sports, applying heat to specific bleeding/bruised/injured areas (soft tissue, joints, ligaments tears/ruptures) of the body could be detrimental to the acute healing process. However, by applying or immersing a bruised/injured/knocked area of the body in heat

immediately after cold/ice has been acutely applied following contact sport, an increase in neurotransmission (Cote, Prentice, Hooker, & Shields, 1988; Cotts, Knight, Myrer, & Schulthies, 2004), muscle elasticity, joint extensibility, blood flow and nutrients, and reduction of muscle spasm (Brukner & Khan, 1993; Cochrane, 2004; Coffey, Leveritt, & Gill, 2004; Wilcock, Cronin, & Hing, 2006) could be observed at the injured site.

Hot water therapy conclusion

There is a lack of scientific evidence to support the use of hot water immersion as a recovery tool without being combined with other recovery modalities. Anecdotal evidence provides the notion that hot water therapy is best used in conjunction with a cold water immersion, despite the proposed physiological benefits stated above. Furthermore, speculation surrounds the effects, exposure time, and optimal recovery intervention (following which type of exercise intensity and the type of fatigue/damage), for the use of hot water immersion.

Table 5: Eccentric/DOMS-Inducing & performance based interventions using hot water immersion for recovery

Author	Exercise/Fatigue Intervention	Subjects	Recovery Modes	HWI Protocol	Outcome Measures/Timings	Summary of Main Findings
Vitaspalo et al (1995)	In randomized order subjects performed two identical training weeks involving five strength/power training sessions. The training weeks differed from each other only in respect of underwater water-jet massage treatments (week 1) which were used three times (20 min each) during the treatment week and not used during the control week (week 2).	14 junior track & field athletes	1. Hot water jet massage 2. Control	Hot underwater water-jet massage (36.7-37.2°C) for 20 min	Neuromuscular function, CK, LDH, serum carbonic anhydrase, Mb, urine urea, creatinine and MS.	DOMS was non-significantly higher for the control groups compared to treatment weeks. A smaller decline in jumping power and a greater increase in continuous jumping contact time occurred when warm underwater water-jet massage was used as a treatment than when no treatment was given. CK and Mb concentrations were ↑ during the underwater water-jet massage week than during the control week, indicating an increased and more rapid leakage of proteins from the cells into the blood.
Vaile, Halson, Gill & Dawson (2008)	Subjects underwent five consecutive exercise days of 105 min duration including 66 maximal effort sprints (cycle). Additionally, subjects performed a total of 9 min sustained effort (time trial - TT). Following each exercise session, subjects performed one of four recovery interventions randomly assigned to each trial.	12 endurance trained male cyclists	1. CWI 2. HWI 3. CWT 4. PAS	Entire body immersion (incl head and neck) alternating 1 min cold (15°C) and 1 min hot (38°C) water for a total of 14 min (seven cycles).	Core temperature, HR (at end of each sprint, pre-post recovery), RPE, TT performance, Peak power average power and total work(during exercise)	Performance was enhanced in all tasks across the five day trial period following CWI and CWT when compared to HWI and PAS. No sig. differences were observed in HR and RPE regardless of day of trial/intervention. CWI and CWT appear to improve recovery from high intensity cycling when compared to HWI and PAS with athletes better able to maintain performance in a five day period. Significantly higher core temperatures were observed post recovery following HWI compared to the other recovery groups.
Vaile, Halson, Gill & Dawson (2007)	Subjects performed a DOMS-inducing leg press protocol followed by PAS or one of the hydrotherapy interventions for 14 min. There were two experimental trials separated by 8 months in a randomised crossover design; one trial involved passive recovery (PAS, control), the other a specific hydrotherapy protocol	38 strength trained males	1. Control (1st trial) 2. CWI 3. HWI 4. CWT	Immersion of entire body (excluding head and neck) in 38°C water for 14 min.	Weighted squat jump, isometric squat, perceived pain, thigh girths and blood variables were measured prior to, immediately after, and at 24, 48 and 72 h post-exercise.	Squat jump performance and isometric force recovery were sig ↑ (P < 0.05) at 24, 48 and 72 h post exercise following CWT and at 48 and 72 h post-exercise following CWI when compared to PAS. HWI did not positively influence the recovery of squat jump performance or isometric strength compared to PAS. Both CWI and HWI (P > 0.05) were ineffective in reducing perceptions of pain following intense eccentric exercise.

Contact Sport Interventions using hot water immersion for recovery

To date there has been no evidence of hot water therapy/immersion protocols under investigation prescribed independently as a recovery method following contact sports

PAS - Passive Recovery; **CWI** - Cold water immersion; **CWT** - Contrast water therapy; **HWI** - Hot water immersion; **CK** - Creatine kinase; **Bla** - Blood lactate; **Mb** - Myoglobin; **RANG** - Relaxed arm angle; **MS** - Muscle soreness; **DOMS** - Delayed onset muscle soreness; **HR** - Heart rate; **VO2.max** - Maximal oxygen consumption; **CMJ** - Countermovement jump, **RPE** - Rate of perceived exertion; **LDH** - lactate dehydrogenase; **TT** - Time trial ↓ - Significantly lower/worse; ↑ - Significantly higher/better

Pool Recovery

Pool recovery (also known as deep water recovery) sessions are widely used by many sporting codes for the purpose of preventing injury and to promote recovery from competition and training induced stresses. Teams and individual athletes utilize pool recovery sessions to perform light active movement patterns that are non weight bearing such as walking and jogging patterns, stretching and some swimming. Pool recovery sessions are usually used to decrease muscle soreness and stiffness and therefore are believed to be effective in sporting codes that involve eccentric muscle damage and/ or forceful contact.

In a study by Reilly, Cable, and Dowzer (2002) of previously untrained individuals, deep-water running (pool recovery) proved to be more effective than other supposed methods of reducing muscle soreness and re-establishing muscle strength following plyometric exercise (drop jumps from 50cm every seven seconds until voluntary exhaustion). Five recovery methods were employed for three consecutive days following the plyometric protocol; (1) rest on all days; (2) rest on day 1, deep-water running on remaining days; (3) rest on day 1, treadmill running on later days; (4) treadmill run on all days; and (5) deep-water running on all days. Deep-water running failed to prevent delayed-onset muscle soreness although soreness was eliminated while participants were running in deep water but returned post exercise. Additionally, deep-water running appeared to speed up the process of recovery for perceived muscle soreness and strength while enabling the maintenance of hip joint range of movement. CK concentrations peaked 24 hours earlier and at a lower value in the group performing deep-water running compared with the other recovery groups. These results nevertheless emphasize possible benefits for the use of deep-water running (pool recovery) as a recovery modality to reduce impact stresses (Reilly & Ekblom, 2005). Tessitore et al (2008) also found positive feelings and perceived recovery benefit

from shallow water pool exercises. Even so, dry-aerobic exercises (active recovery) and electro-stimulation were proven more physiologically beneficial ($p < 0.01$) than water exercises. Both dry-aerobic exercise (active recovery) and deep water running/pool exercises have proven post exercise recovery benefits; however current literature is scarce in terms of providing evidence on whether the known benefits of deep water recovery/pool recovery is due to the exercises being performed or the physiological and psychological effect being immersed in water has on the body.

Pool recovery for contact sports

Almost all professional rugby and football codes across New Zealand, Australia and the United Kingdom utilize pool recovery sessions usually the day after competition in an attempt to alleviate muscle soreness and stiffness and assist in recovering from the brutal and highly forceful contacts endured during competition. Dawson et al (2005) investigated whether or not immediate post-game pool walking is an effective recovery strategy following an Australian Rules Football competition match. Pool walking was compared to contrast water therapy, stretching and no recovery (control) protocols in their ability to enhance the rate of recovery in the 48 hours after a match. Subjective ratings of muscle soreness, flexibility (sit and reach), power (6 second cycling sprint and vertical jumps), which were measured 15 and 48 hours post game. Across all four recovery strategies subjective muscle soreness was increased at 15 hours post game, though only pool walking resulted in a significant reduction in subjective soreness from 15 to 48 hours post game but still significantly higher than baseline ratings. Lower flexibility and power scores at 15 hours post game were reported in the control trial. While there were no differences between all three recovery strategies in terms of flexibility and power, players subjectively reported pool walking as the most effective and preferable. The authors

hypothesize that the active, low intensity exercise with minimal weight bearing and impact stress, in conjunction with the hydrostatic pressure, is the reason why pool walking enhanced recovery.

Pool recovery conclusion

Pool based recovery/exercise sessions are one of the most utilized recovery modalities following training and competition due to its non weight bearing, low exertive nature and its perceived effectiveness in reducing muscular soreness and stiffness. For this reason it would be advantageous that further research be directed towards assessing the rate and magnitude of the physiological and perceived psychological response of performing pool recovery sessions immediately after, post 24 hours and on multiple days after competition and training. Additional investigations assessing the recovery response provided by performing pool recovery sessions and its effect on different types of fatigue and/or damage would be beneficial for future use.

Table 6: Eccentric/DOMS-Inducing & performance based interventions using pool/shallow water sessions/exercises for recovery

Author	Exercise/Fatigue Intervention	Subjects	Recovery Modes	Pool/Shallow water Protocol	Outcome Measures/Timings	Summary of Main Findings
Reilly (2002)	Participants performed plyometric drop jumps from a platform 50 cm in height once every 7 s until voluntary exhaustion. Exercise on the three subsequent days consisted of running for 30 min at 70 – 80% of heart rate reserve.	30 untrained individuals	1. Rest on all days 2. Rest on day 1, deep-water running on remaining days 3. Rest on day 1, treadmill running on later days 4. Treadmill run on all days 5. deep-water running on all days	Not specified	CK, Strength measures, perceived soreness, ROM measured daily during the exercise intervention	Most effective recovery was when deepwater running was incorporated in the training programme for all 3 days following the plyometric regimen. Deep-water running failed to prevent delayed-onset muscle soreness but appeared to speed up the process of recovery for muscle strength (determined using isokinetic dynamometry) and perceived soreness. CK concentrations peaked 24 h earlier and at a lower value in the group employing deep-water running compared with the other groups.
Tessitore, et al (2008)	Four futsal games, scheduled on a twice-weekly basis for a period of 2 weeks each followed by a randomised recovery intervention.	10 male futsal players	1. Seated rest 2. Active Recovery (dry exercises) 3. Shallow water exercises 4. Electro stimulation	20min exercises with no buoyancy aids (8 min jogging, 8 min walking & running sideways & backwards, & 4 min stretching)	Anaerobic performance (countermovement jump [CMJ], bounce jumping, 10-m sprint) Hormones (salivary cortisol, urinary catecholamine's) Subjective ratings [RPE, leg muscle pain, Questionnaire of Recovery Stress for Athletes [RestQ Sport] Hours of sleep	No sign. Effect due to recovery interventions was found on anaerobic performances, hormones, rating of muscle pain, recovery-stress state, and amount of sleep. Players perceived \uparrow benefit ($P < 0.01$; power = 0.91) from the electro stimulation (7.8 ± 1.4 points) and water exercises (7.6 ± 2.1 points) compared to AR (dry exercises) (6.6 ± 1.8 points) and seated rest (5.2 ± 0.8 points). Dry-aerobic exercises and electro stimulation were more physiologically beneficial ($p < 0.01$).
Cortis, et al (2010)	During three experimental sessions participants performed a morning and an afternoon sub maximal running test (4 x 5 min steps at incremental running velocities 6-12km/h). The recovery interventions were randomly administered following the first morning tests.	8 men	1. Low-intensity water exercises 2. Electro stimulation 3. Passive recovery	20min exercises with no buoyancy aids (8 min jogging, 8 min walking & running sideways and backwards, & 4 min stretching) performed at a moderate intensity (60 % of individual HR max)	Physiological (O_2 consumption, Bla , and % hemoglobin saturation in muscles). Psychological (subjective ratings of RPE, muscle pain, and feeling of recovery). Performance (CMJ) parameters measured at pre & post exercise & post recovery	No difference between the morning and afternoon physiological and performance parameters, demonstrating that post-exercise recovery interventions do not provide significant cant beneficial effects over a limited time period. Subjects perceived water exercises (60 %) and electro stimulation (40 %) as the most effective interventions, indicating that these recovery strategies improve the subjective feelings of wellbeing of the individual.

ACT - Active Recovery; **PAS** - Passive Recovery; **CWI** - Cold water immersion; **CWT** - Contrast water therapy; **HWI** - Hot water immersion; **GAR** - Compression Garment; **CG** - Compression garment **CK** - Creatine kinase; **Bla** - Blood lactate; **RANG** - Relaxed arm angle; **FANG** - Flexed arm angle; **MIF** - Maximal isometric force; **MS** - Muscle soreness; **DOMS** - Delayed onset muscle soreness; **VO2.max** - Maximal oxygen consumption; **CMJ** - Countermovement jump, **RPE** - Rate of perceived exertion; **LDH** - lactate dehydrogenase; \downarrow - Significantly lower/worse; \uparrow - Significantly higher/better

Hydrotherapy Summary

Hydrotherapy recovery modalities have been widely embraced despite a lack of clarity on specific implementation recommendations. The efficacy of hydrotherapy as a recovery modality following various types of exercise activities (strength vs. endurance, contact team sport vs. non contact team sport), and additionally quantifying the relative intensity, volume and workload performed by each participant and as a group as a whole is also needed. This would allow more specific prescription of hydrotherapy to what type of fatigue and/or muscle damage has been incurred and would be of great benefit specifically in team sports where workload varies relative to position. Single day vs. multiple day performance recovery from the use of hydrotherapy modalities is also warranted. To further assist in allowing more consistent prescription of hydrotherapy protocols, future research is also required to confirm optimal water temperatures, duration of exposure, and the number and timing of rotations completed during the protocol.

Massage

The use of massage between training, prior to and following competition is another tool widely used to enhance recovery after exercise induced muscle damage in order for athletes to train and compete in the best physical state possible. Massage is defined as a mechanical manipulation of body tissues with rhythmical pressure and stroking for the purpose of promoting health and well being (Best, 2008).

It has been suggested that the use of massage has numerous physiological benefits, such as increase local circulation, loosen muscle spasms and adhesions, stimulate muscle spindles and golgi tendon organs, reduce local inflammatory responses , facilitate muscle relaxation and increase circulation (Moraska, 2005; Weerapong, Hume, & Kolt, 2005), decrease lactate concentrations, reduce the symptoms of delayed onset muscle soreness (DOMS) and improve range of motion (Arroyo-Morales, 2009; Best, 2008; Crosman, Chateauvert, & Weisburg, 1984; Hilbert, Sforzo, & Swensen, 2003; Mancinelli, Davis, & Aboulhosn, 2006; McKechnie, Young, & Behn, 2007; Moraska, 2005; Weerapong, Hume, & Kolt, 2005). For the purpose of this review, massage will be discussed in the context of recovery only.

Effect of massage on performance

Studies investigating the effects of massage performed following exercise on the recovery of performance measures are limited. Brooks (2005) investigated the effects of manual massage on power-grip performance immediately following maximal hand exercise. Forearm massage was shown to improve post exercise grip performance compared to non-massage. Six other studies have examined the effects of massage in performance, five of the studies using cycling interventions (Brooks, 2005; Lane & Wenger, 2004; Martin, Zoeller, Robertson, &

Lephart, 1998; Monedero & Donne, 2000; Robertson, Watt, & Galloway, 2004) and one using a boxing intervention (Hemmings, Smith, Graydon, & Dyson, 2000) to induce fatigue and/or muscular damage. Lane and Wenger (2004) reported the use of massage along with active recovery and cold water immersion resulted in the maintenance of power output following high intensity exercise (cycling). Comparatively, studies by Robertson et al (2004) and Monedero and Donne (2000) found massage did not have any performance enhancing/maintenance effect in cyclists. However, a combination of massage and active recovery significantly increased performance above passive recovery and isolated massage (Monedero & Donne, 2000). Martin et al (1998) and Monedero and Donne (2000) reported massage was no more efficient in removing blood lactate than other recovery modalities following high intensity exercise. Hemmings et al (2000) also reported massage had no significant effect on performance or blood lactate concentrations between two 5 x 2 min simulated boxing bouts (one minute between rounds) on a boxing ergometer compared to passive rest. However, an increased perception of recovery was reported following massage in both Hemmings et al (2000) and Robertson et al (2004).

Effect of massage following eccentric exercise

The use of massage therapy following DOMS inducing eccentric exercise is a widely used as a recovery modality. Hilbert et al (2003) investigated massage and a control massage on the recovery of peak torque and range of motion two hours following six sets of eight maximal eccentric contractions of the right hamstring. Results suggested massage had no treatment effect on peak torque recovery or range of motion, however subjective muscle soreness ratings were decreased 48 hours following eccentric exercise. A decrement in muscle soreness 48 hours post eccentric exercise along with no effect on strength markers and creatine kinase following eccentric exercise were also reported by Farr (2002). Weber et al (1994) examined the recovery

effect of elbow flexor force using massage, aerobic exercise, microcurrent stimulation or passive recovery immediately and 24 hours after eccentric exercise. No significant treatment effect was found for any recovery modality on muscle soreness, maximal isometric contraction and peak torque production. Dawson, Dawson, and Tiidus (2004) reported no effect of massage immediately after a marathon on quadriceps peak torque, muscular function and soreness in addition to similar findings by Jonhagen, Ackermann and Eriksson (2004) following 300 maximal eccentric contractions of the quadriceps. Conversely, significant changes in vertical jump displacement ($p = 0.0033$) were reported following high intensity exercise in female college athletes (Mancinelli, Davis, & Aboulhosn, 2006).

Effect of massage following contact sport

For athletes participating in contact sport such as rugby union and league, receiving some kind of muscular trauma or injury as a result of forceful collisions is inevitable. The incorporation of massage one day following contact matches is widely prescribed and recommended on an anecdotal basis to reduce symptomatic relief of muscular soreness, increase range of motion, loosen muscle spasms and adhesions, and facilitate athlete relaxation. However to date no studies have assessed the efficacy of incorporating massage following a contact sport competition match and its effect on the rate and magnitude of ensuing fatigue and structural damage. It was suggested that it is possible that post training massage may cause further tissue damage (Bishop, Jones, & Woods, 2008). This may also be the case following contact sport, however different effects may occur as different muscular damage and trauma is caused by weight training compared to collisions experienced during contact sport. Further research is needed to investigate the rate and magnitude of recovery of resultant fatigue types (neural, endocrine, biochemical), structural damage and trauma following immediate post game massage

in contact sports. In addition, the investigation of performing individual massage immediately post game, one day post game only, on continuous days post game or in combination with other recovery modalities would be of benefit for future use following contact sport.

Massage conclusion

Numerous physiological and biomechanical benefits as a result of massage have been reported as mentioned above. While there is limited scientific support for the use of massage as a recovery modality, the lack of scientific evidence in this area and the use of various techniques and timings must be considered. Furthermore, the outcome measures of such studies as mentioned above are often not deemed critical in determining an accurate overall analysis of recovery. Studies have shown that massage effectively reduced delayed onset muscle soreness, while others have not seen any effect. Nevertheless, the psychological benefit of massage on recovery should not be discounted. There are only a small number of studies which have examined the recovery effect of massage on performance and evidence of massage following contact sport is nonexistent. Future research should be directed towards investigating massage techniques and timing appropriate for enhancing the recovery of performance outcomes. Additionally, due to the wide use of anecdotal prescription of massage following contact sports it would be of benefit for investigations to determine the rate and magnitude of recovery of resultant fatigue types (neural, endocrine, biochemical), and structural damage immediately post and the subsequent days following massage.

Table 7: Eccentric/DOMS-Inducing & performance based interventions using massage for recovery

Author	Exercise/Fatigue Intervention	Subjects	Recovery Modes	Massage Protocol	Outcome Measures/Timings	Summary of Main Findings
Weber (1994)	Sets of 10 repetitions followed by 1-minute rest until exhaustion	40 healthy and untrained females	1. Electrical stimulation (ES) 2. Upper body ergometry (UBE) 3. Massage therapy (MT) 4. Control	1 session, 8-minute full body massage immediately AE (Effleurage leading to petrissage followed by quick effleurage)	Muscle soreness rating using VAS and peak torque (PT) at 60 degrees/second measured 24 and 48 hours after exercise (AE)	No significant differences ($P \geq 0.05$) between MT, ES, UBE, and control groups in PT or VAS rating
Tiidus & Shoemaker (1995)	7 sets of 20 quadriceps maximum contractions between knee angles 180 degrees and 90 degrees at 90 degrees sec-1	9 healthy university-aged volunteers (5 men and 4 women)	1. Massage (one leg) 2. Internal control (other leg)	First session, 10-min massage within 1 hour AE and repeated similar sessions at 24 and 72 hours AE (Superficial and deep effleurage strokes)	Quadriceps peak torque (PT) at 0, 60, and 180 degrees sec-1 and DOMS after exercise (AE), 24, 48, 72 hrs.	Massage had no sign ($P \geq 0.05$) effect on muscle strength 96 hours AE, and perceived level of DOMS reduced only at 48 hours AE.
Martin, et al (1998)	3 x successive Wingate cycle tests, with 2-minute rest intervals between with recovery conditions initiated 5min after last Wingate.	10 male cyclists	1. Active recovery (AR) 2. Rest (PR) 3. Massage (MAS)	Effleurage, petrissage, tapotement, and compression for 20min	Bla (Pre, post each Wingate, 5min post final Wingate, every 5min during recovery)	Bla ↓ by 59.38% (AR), 36.21% (massage), 38.67% (rest). MAS had no significant effect on Bla, when compared with the PR
Monedero, et al (2000)	2 x simulated 5 km maximal effort cycling tests (T1 & T2) separated by a 20 min recovery.	18 trained male cyclists	1. Active Recovery 2. Passive Recovery 3. Massage 4. Combined (AR + MAS)	1 session, 15-minute massage immediately after cycling performance (Effleurage, stroking, and atonement)	Performance time (T1, T2) BLa (during T1, T2, & every 3 min during recovery) HR (during the recovery intervention and T2)	Combined method sig. better in maintenance of performance time during T2 than other methods. BLa were ↑ ($P \leq 0.01$) following passive and massage interventions.

Hemmings, Smith, Graydon, & Dyson (2000)	Two interventions separated by one week. 80 straight punches per round. Total of 10 rounds (5 rounds per performance)	8 male amateur boxers with minimum of 2 years experience	1. Massage (MAS) 2. Passive supine rest	1 session, 20-min massage routine immediately after first performance (Effleurage and petrissage)	Boxing ergometer output (BEO), peak heart rate (PHR), and perceived recovery ratings (PRR) assessed before, during, and after performances (PF)	Massage observed to have psychological benefits (PRR), but no significant ($P \geq 0.05$) benefits on boxing performance.
Farr, et al (2002)	40-minute downhill treadmill walk carrying a load 10% of their body mass	8 healthy males	1. Massage (one leg) 2. Internal control (other leg)	One leg 30-minute massage (Effleurage and petrissage) 2 hours after completion of exercise	Baseline DOMS, isometric (IMS), and isokinetic strength (IKS) compared post downhill walk (PDW)	Massage may attenuate early soreness associated with DOMS but did not significantly ($P \geq 0.05$) improve IMS and IKS
Hilbert (2003)	6 sets of 10 maximal eccentric contractions with the right hamstring with 1-min rest	18 male and female volunteers	1. Massage 2. Non massaged control	1 session; 20-minute duration given 2 hours AE(Classical Swedish techniques: effleurage, tapotement, petrissage)	Peak torque (PT) immediately (IAE) and at 2, 6, 24, and 48 hours after exercise (AE); range of motion (ROM) and intensity of soreness (IS) at 6, 24, and 48 hours AE	Massage AE did not significantly ($P \geq 0.05$) improve hamstring function, but it did reduce IS 48 hours AE
Lane & Wenger (2004)	2 x intermittent cycling sessions; 18 minutes of varying work intervals performed in succession at a resistance of 80 g/kg body weight separated by 24 hours. One of four 15-minute recovery conditions immediately followed the first session.	10 physically active men	1. Active Recovery 2. Massage (MR) 3. Cold Water Immersion (CR) 4. Seated rest (control)	1 session immediately after first intermittent cycling session; 15-minute duration (Deep effleurage, compressions, deep muscle stripping, jostling, cross-fiber frictions)	Total work (kj) ,total number of pedal revolutions in each work bout	Only the control condition showed a \downarrow in total work completed between the first and second exercise sessions (108.1 ± 5.4 kJ vs. 106.0 ± 5.0 kJ, $p < .05$). Thus, AR, MR, and CR appeared to facilitate the recovery process between 2 high-intensity, intermittent exercise sessions separated by 24 hours.
Dawson (2004)	Completed a half marathon (21.1 km). Participants ran on an average of 35.0 6 11.7 km \square week-1	8 men and 4 women healthy recreational runners from St. John's Marathon, ON, Canada	1. Massage (one leg) 2. Internal control (other leg)	All participants had 1 leg randomly massaged after marathon. No massaged leg served as the control. Massage sessions 30 minutes in duration post race on days 1, 4, 8, and 11 (Effleurage with flushing, petrissage (deep strokes), and stretching)	Quadriceps peak torque (PT) of body weight (BW), leg swelling (LS), and soreness perception (SP) at baseline and post-race days (PRD)	Massage had no significant ($P \geq 0.05$) physiological or psychological benefits following half marathon

Robertson, Watt & Galloway (2004)	6 x standardized 30-second high intensity exercise bouts on cycle ergometer	9 healthy male rugby, football & hockey athletes	1. Massage (MAS) 2. Passive supine rest	1 session, massage applied after 5 minutes of recovery; 20 minutes in duration (Effleurage)	Blood lactate (Bla), mean power (MP), heart rate (HR), and fatigue index (FI) recorded for massage and rest post exercise bouts (PEB)	No significant ($P \geq 0.05$) measurable physiological effects of leg massage observed. FI lowered following massage
Jonhagen, Ackermann & Eriksson (2004)	300 maximal eccentric contractions of the quadriceps muscle bilaterally	8 active men and 8 active women	1. Massage (one leg) 2. Internal control (other leg)	First session within 10 minutes of exercise for 12 min on randomly chosen leg and then once daily for 2 days	Max strength (MS) and functional tests based on 1-leg long jumps (LJ). Pain evaluated using VAS before, immediately after exercise (IAE) and 2 days after exercise (2d AE)	Massage treatment did not significantly ($P \geq 0.05$) affect pain or the loss of strength or function after exercise
Brooks (2005)	3 minutes of maximal exercise with a hand exerciser on both hands that produced fatigue to at least 60% of baseline	13 male and 39 female university students	1. Massage 2. Passive seated rest	1 session of 5-minute hand massage IAE (Effleurage and circular friction)	Power-grip measurements (PGM) after no massage to dominant hand (NMDH) and massage to dominant (MDH) and non dominant hand (MNDH) immediately after exercise (IAE) compared to baseline	Massage IAE had a significantly ($P \leq 0.05$) greater effect than non massage on immediate grip performance after fatigue
Mancinelli (2006)	Endurance training and upper/lower extremity resistive exercises 3 consecutive days	22 NCAA Division I female basketball and volleyball players	1. Massage 2. Non massaged control	1 session; 17-minute duration after recording outcome measures, day 4 IAE (Effleurage, petrissage, and vibration)	Vertical jump displacement (VJD) and delayed-onset muscle soreness (DOMS) using visual analog scale (VAS) immediately after exercise (IAE)	Massage in women collegiate athletic training significantly ($P \leq 0.05$) improved VJD and decreased DOMS

Contact Sport Interventions using massage for recovery

To date there has been no evidence of massage protocols under investigation prescribed independently as a recovery method following contact sports

AR- Active recovery; **AE**- After exercise; **BEO**- Boxing ergometer output; **BW** - Body weight; **Bla**- Blood lactate; **CR**- Cold water immersion/cryotherapy; **COMB**- Combination recovery method; **CK**- Creatine kinase; **DOMS**- Delayed onset muscle soreness; **ES** -Electrical stimulation; **FI**- Fatigue index; **HR**- Heart rate; **IAE**- Immediately after exercise; **IMS**- Isometric strength; **IKS**- Isokinetic strength; **Kj**- Kilojoules; **LJ**- Long jumps; **LS**- Leg swelling; **MS**- Muscle soreness; **MAS** - Massage; **MT**- Massage therapy; **MP**- Mean power; **MDH**- Massage to dominant hand; **MNDH**- Massage to non-dominant hand; **NMDH**- No massage to dominant hand; **PT**- Peak torque; **PHR**- Peak heart rate; **PRR**- Perceived recovery ratings; **PDW**- Post downhill walk; **PRD**- Post race days; **PEB**- Post exercise bouts; **PGM**- Power grip measurements; **PAS**- Passive recovery; **PR**- Passive rest; **ROM**- Range of motion; **SP**- Soreness perception; **UBE**- Upper body ergometry; **VAS**- Visual analog scale; **VJD**- Vertical jump displacement; ↓- Significantly lower/worse; ↑ - Significantly higher/better

This summary of current literature on massage for recovery was assisted by Best (2008)

Stretching

Stretching has long been a commonly used recovery modality following training. It's perceived function is to increase joint and muscular range of motion, and this has been shown to occur following various types of stretching (Thacker, Gilchrist, & Stroup, 2004). Other theories of function exist such as the prevention of injury, relaxation of the muscle as well as reducing muscular soreness and stiffness (Andersen, 2005; Cheung, Hume, & Maxwell, 2003; Thacker, Gilchrist, & Stroup, 2004). The reason for stretching during the recovery period following exercise remains oblique and warrants further investigation. For the purpose of this review, the use of stretching following exercise as a means of recovery will be discussed.

Despite a mechanism by which post exercise stretching improves the recovery process has thus far failed to be identified, stretching has been suggested to disperse oedema accumulated during tissue damage (Barnett, 2006; Bobbert, Hollander, & Huijing, 1986). Oedema is considered an important component in the inflammation process and is essential for recovery and adaptation. For that reason, dispersion of oedema as a general principle may not be a sufficient outcome during recovery (Bobbert, Hollander, & Huijing, 1986). Delayed onset muscle soreness involves an acute inflammatory response with oedema formation, and stretching following eccentric exercise appears to have no preventative effect on delayed onset muscle soreness (Andersen, 2005; Cheung, Hume, & Maxwell, 2003; Jayaraman, 2004; McGlynn, Laughlin, & Rowe, 1979; Thacker, Gilchrist, & Stroup, 2004; Wessel & Wan, 1994). Jayaraman (2004) investigated the recovery effects of static stretching on strength, muscle pain and multi-echo magnetic resonance imaging (MRI) following eccentric knee extension exercise. Static stretching of the quadriceps, hamstrings and calf muscles were applied 36 hours following eccentric exercise to evade any detrimental effects during the acute injury/inflammation period.

Static stretching post eccentric exercise was demonstrated to have not increased muscle recovery. Additionally, there were no proven differences between the treatment applied and muscle pain, swelling and recovery of strength markers. It was concluded that the use of static stretching post eccentric exercise did not enhance the recovery of muscular damage and that the prescription for recovery purposes following eccentric exercise is not recommended.

Numerous other studies have found static stretching to be non effective in enhancing recovery and reducing the signs and symptoms of delayed onset muscle soreness (Buroker & Schwane, 1989; McGlynn, Laughlin, & Rowe, 1979; Wessel & Wan, 1994). However, on the contrary studies conducted by DeVries (1966) and Abraham (1977) reported an improvement in muscle soreness/pain following static stretching after an eccentric exercise regime. In a recent study by Mika (2007), static stretching, active recovery and passive recovery were examined following a fatiguing leg extension and flexion protocol (three sets to failure at 50% MVC separated by a 5 minute recovery intervention). Subjects were then required to perform an isometric knee extension at 50% MVC until fatigue. Results suggested that the most effective recovery strategy was active recovery as subsequent MVC's were significantly greater when active recovery was performed compared to performing a stretching or passive recovery modality (Mika, 2007).

Stretching and contact sport

It is common routine for athletes involved in contact sports to perform static stretching following training and competition. To date no research has been conducted to provide evidence of whether a negative or positive recovery effect occurs following the use of static stretching post competition contact matches. Although it is out of the scope of this review, static stretching is usually anecdotally prescribed for the purposes of maintaining and/or enhancing range of

motion and for the prevention of injury in major muscle groups and joints affected during the match. Even though it has been suggested that stretching does not lead to injury reduction (Thacker, Gilchrist, & Stroup, 2004). The physiological recovery effect of static stretching following contact sport is yet to be investigated. Future research is needed to determine if any beneficial or harmful consequences are a result of performing static stretching following contact sport.

Stretching conclusion

There is currently no scientific evidence to suggest that stretching immediately post exercise increases the recovery of performance. However there is also no apparent short- or long-term detrimental effect from stretching. Only a few studies suggest that performing a stretching regime post eccentric exercise will reduce the sensation of muscular pain. Further research is needed to build a stronger knowledge of what kind and magnitude of effect stretching has on recovery following exercise.

Table 8: Eccentric/DOMS-Inducing & performance based interventions using stretching exercises for recovery

Author	Exercise/Fatigue Intervention	Subjects	Recovery Modes	Stretch Protocol	Outcome Measures/Timings	Summary of Main Findings
McGlynn, Laughlin & Rowe (1979)	Subjects performed 80% maximal eccentric contractions on the biceps brachii.	36 males	1. Biofeedback 2. Static stretch 3. Control	Performed at 6, 25, 30, 49 and 54 hours post exercise	EMG activity, perceived pain measured pre, immediately post and 24, 48 and 72 hours post eccentric exercise	Compared to control, auditory biofeedback and static stretching groups sign ↓ EMG muscle activity but had no effect on perceived pain. EMG and perceived pain for each subject significantly differed across observations
Buroker & Schwane (1989)	Subjects performed a 30 min step test to induce DOMS	23 Subjects	1. Stretch 2. Control	DNS	Perceived muscle pain and pain control	There was neither temporary relief or pain immediately after stretching nor a reduction in pain during the 3 day post exercise period
Wessel & Wan (1994)	Subjects underwent two experiments where stretch was performed pre (experiment 1) and post (experiment 2) a DOMS inducing protocol (3 x 20 reps of concentric/eccentric contractions of knee flexors on a KinCom isokinetic dynamometer).	10 healthy, sedentary subjects (2 women 8 men)	1. Static stretch one leg 2. Internal control	10 x 1min seated hamstring stretch on one leg	Muscle pain (VAS) measured every 12 hours for 72 hours as well as pain threshold of the hamstring and height of straight leg raise (SLR) measured at 0 and 48 hours	There was a significant difference ($p \leq 0.05$) in the VAS over time for both experiments but no between legs. Same results found in second experiment for pain threshold and SLR. Stretch either pre or post eccentric exercise does not reduce DOMS
Jayaraman (2004)	Subjects performed intense eccentric knee extension exercise (3 X MVC trials with the quadriceps femoris muscle group in the seated position (hip at 90 and the knee at 135) separated by 3 minutes each trial), followed by 2 weeks of 1 of 3 treatments (heat, stretch, heat plus stretch) or no treatment.	32 untrained males	1. Heat 2. Stretch 3. Heat + stretch 4. No treatment	Two hamstrings and two quadriceps exercises held for 20sec three times with 30sec between. Performed daily	Isometric strength, pain ratings, and multi-echo magnetic resonance imaging (MRI) of the thigh were performed before and at 2, 3, 4, 8, and 15 days following the exercise	Pain ratings and muscle volume recovered to baseline by 15 days, although muscle strength remained lower [77 (4) vs. 95 (3) kg pre exercise, mean (SE)] and T2 values higher [32.2 (0.8) vs. 28.6 (0.2) ms pre-exercise]. Results indicate that heat and/or static stretching does not consistently reduce soreness, swelling or muscle damage.
Mika et al (2007)	Subjects performed three sets of dynamic leg extension and flexion (at an angle of 20–110 degrees) at 50% of previously determined maximal voluntary contraction (MVC), with 30 secs of rest between sets. Immediately after completing the leg exercise, subjects performed one of the recovery treatments	10 healthy males	1. Active recovery (AR) 2. Passive rest (PR) 3. Stretching (ST)	Post isometric relaxation (stretching, ST). The quadriceps femoris were passively stretched to a point of onset of resistance (soft and filling). Following this, subjects performed PNF stretching (applied by certified physiotherapist) with each stretch lasting 5sec. This procedure was repeated with in 5min.	EMG, MVC at baseline and post exercise and recovery	After AR, the mean MVC was significantly ($P \leq 0.05$) higher than after PR and ST. Total time of the effort during EMG measurement was significantly lower for all three recovery modes than at baseline. During the effort after both PR and ST, there was no significant increase in motor unit activation, but a significant increase was noted after AR ($P = 0.05$). AR is a superior method for recovery following fatiguing exercise.

Contact Sport Interventions using stretching exercises for recovery

To date there has been no evidence of massage protocols under investigation prescribed independently as a recovery method following contact sports

AR- Active recovery; **DOMS**- Delayed onset muscle soreness; **DNS**- Did not specify; **EMG**- Electromyogram; **MVC**- Maximal voluntary contraction; **MRI**- Multi-echo magnetic resonance imaging; **PR**- Passive recovery; **SE**- Standard error; **SLR**- Straight leg raise; **ST**- Stretching; **VAS**- Visual analog scale; ↓- Significantly lower/worse; ↑ - Significantly higher/better

Chapter 3: The Relative Efficacy of Three Recovery Modalities Following Professional Rugby League Matches

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Abstract

This study investigated the relative efficacy of post game recovery modalities on jump height performance, subjective ratings of muscle soreness and muscle damage 1, 18, and 42 hours following professional rugby league competition games. Twenty-one professional rugby league players performed three different recovery modalities (cold water immersion {CWI}, contrast water therapy {CWT} and active recovery {ACT}). The effects of the recovery treatments were analyzed with mixed modeling with a covariate included (fatigue score) to adjust for changes in the intensity of each match on the post-match values of dependent variables. Standardization of effects was used to make magnitude-based inferences, presented as mean; $\pm 90\%$ confidence intervals. CWI and CWT clearly improved jump height performance (CWI 2.3; $\pm 3.7\%$, CWT 3.5%; $\pm 4.1\%$), reduced muscle soreness (CWI -0.95; ± 0.37 , CWT -0.55; ± 0.37), and decreased creatine kinase (CWI -11.0; $\pm 15.1\%$, CWT 18.2; $\pm 20.1\%$) by 42 hours post game compared to ACT. CWT was however clearly more effective compared to CWI on the recovery of muscle soreness and creatine kinase by 42 hours post game. We therefore recommended CWT recovery following team contact sport.

Introduction

Rugby league is a high intensity intermittent team sport played over 80 minutes. The game is combative in nature and is characterized by its forceful collisions (Duthie, Pyne, & Hooper, 2003) hence the associated muscular trauma and damage is substantial. The rate and quality of recovery from contact sports is therefore considered imperative. Athlete recovery following training and competition is multi-factorial and typically dependent on both the nature of the exercise performed and a combination of external factors (Barnett, 2006; Bishop, Jones, & Woods, 2008; Jeffreys, 2005). Optimum recovery strategies will vary among athletes depending upon the type of fatigue, current levels of training and non-training stress, and capacity to cope with the stressors (Jeffreys, 2005).

Only a handful of studies have examined the efficacy of recovery modalities and their ability to promote recovery from muscular damage and trauma following contact sport. Modalities such as the use of compression garments (CG) (Gill, Beaven, & Cook, 2006), various hydrotherapy methods such as pool recovery/deep water running (Dawson, Gow, Modra, Bishop, & Stewart, 2005), cold water immersion (CWI) (Higgins, Heazlewood, & Climstein, 2010), and contrast water therapy (CWT) (Dawson, Gow, Modra, Bishop, & Stewart, 2005; Gill, Beaven, & Cook, 2006; Higgins, Heazlewood, & Climstein, 2010; Ingram, Dawson, Goodman, Wallman, & Beilby, 2009), and active recovery (ACT) (Gill, Beaven, & Cook, 2006; Suzuki, Umeda, & Nakaji, 2004) have been used with varying degrees of success.

The implementation of ACT (light exercise) following contact sport is commonly practiced following contact sport games. While the physiological benefits of completing active recovery are well known research on the efficacy of active recovery following contact sport (rugby) is equivocal and is limited to the use of creatine kinase (CK) and perceptual muscle

soreness (MS) as post game recovery markers (Gill, Beaven, & Cook, 2006; Suzuki, Umeda, & Nakaji, 2004).

Hydrotherapy procedures are increasing in popularity and becoming a common component of athlete recovery routines following contact sport competition (Vaile, Halson, & Graham, 2010). The physiological response to immersion in varying temperatures is well investigated and understood (Bleakley & Dawson, 2010; Cochrane, 2004); however research investigating the use of hydrotherapy modalities such as CWI and CWT on the recovery of physiological and performance measures following contact sport, specifically the rugby codes, is limited and equivocal in terms of recovery efficacy.

Given the stated limitations in research to-date, the purpose of this study was to quantify the relative efficacy of ACT, CWI and CWT recovery modalities following professional rugby league matches, while accounting for relative match workloads.

Methods

Experimental Approach to the Problem

The experimental design involved all subjects being monitored across three National Rugby League (NRL) competition matches. Within one hour following each game, all subjects performed one of three selected recovery modalities (CWI, CWT or ACT {control}). Measures of neuromuscular performance (countermovement jump height), perceptual muscle soreness (MS) and muscle damage (CK) were measured at 24 hours pre match, one hour, 18 and 42 hours post match. No training, activity or other recovery modalities were scheduled or performed by subjects within the 42 hour monitoring period to assess the true recovery effect of each modality being investigated. Individual subject match statistics were analysed to produce a quantification of overall match intensity and workload.

Subjects

Twenty-one professional rugby league players from the National Rugby League (NRL) New Zealand Warriors rugby league squad volunteered to participate in this study. Their age, mass, and height were 23.5 ± 2.6 years, 97.3 ± 8.7 kg, and 183.8 ± 8.8 cm (mean \pm *SD*). The AUT University Ethics Committee (AUTECH) approved all procedures and all subjects provided signed informed consent.

Procedures

Familiarization

The subjects were given an opportunity to familiarize themselves with all testing and recovery procedures before the investigation.

Recovery Interventions

Cold Water Immersion (CWI)

Subjects immersed their lower body to the level of the anterior superior iliac spine in a water temperature range of 10-12°C for five minutes as per previously reported procedures (Higgins, Heazlewood, & Climstein, 2010) before carrying out their normal post-match routine (rehydrating, showering, media interviews, club promotions). No other recovery modalities or physical activity were performed within the 42h post game monitoring time period.

Contrast Water Therapy (CWT)

Subjects immersed their body to the level of the anterior superior iliac spine in one of two temperature controlled water baths, alternating between one minute in cold water (8–10°C) and two minutes in hot water (40–42°C) for three rotations as per previously reported procedures (Gill, Beaven, & Cook, 2006). The normal post-match routine (rehydrating, showering, media

interviews, club promotions) was completed thereafter. No other recovery modalities or physical activity were performed with in the 42h post game monitoring time period.

Active Recovery (ACT {Control})

Subjects completed low intensity exercise on a cycle ergometer (Life Fitness, USA) for seven minutes (80–90 rpm ~150W) in an allocated recovery area after the match (Gill, Beaven, & Cook, 2006). The normal post-match routine (rehydrating, showering, media interviews, club promotions) was completed thereafter. A seven minute duration was selected as it was considered to be a sufficient time frame to increase blood flow and enhance the clearance of metabolites (Gill, Beaven, & Cook, 2006). Time and resource limitations were also factors influencing ACT duration (Gill, Beaven, & Cook, 2006). No other recovery modalities or physical activity were performed with in the 42h post game monitoring time period.

Markers

Creatine Kinase (CK) Sampling and Analysis

Trained phlebotomists collected all blood samples. Venous blood samples (5 ml) were collected from the subject's antecubital area using a heparinized plasma VacutainerTM tube and syringe set (Becton, Dickinson and Company, USA). Blood samples were immediately prepared via centrifugation in preparation for analysis of total CK activity. All blood samples were stored in -20°C and analyzed within 24 hours of the sample being taken.

Neuromuscular Performance (Countermovement jump height)

At each time point subjects performed three singular CMJ using a Ballistic Measurement System (Fitness Technology, Adelaide, Australia) contact mat and software package. The subjects started with both feet on the contact mat with their hands on their hips to eliminate the

influence of arm swing on CMJ performance (Cormack, Newton, McGuigan, & Doyle, 2008; Markovic, Dizdar, Jukic, & Cardinale, 2004). Subjects were instructed to lower as quickly as possible at a self selected depth and then jump as high as possible in the ensuing concentric phase. Subjects were also instructed to upon take off leave the contact mat with their knees and ankles extended and land in a similarly extended position (Cronin & Hansen, 2005; Young, 1995). Intraday (coefficient of variation – CV = 5.2%) and interday (CV = 5.0%) reliability has been reported for the CMJ (Cormack, Newton, McGuigan, & Doyle, 2008).

Perceived Muscle Soreness Ratings

To assess each subject's perceived state of MS, subjects were asked to provide a rating (see Table 1) ranging from one (no pain) to five (extreme pain). Subjects were also asked to identify any injuries they may have sustained during the competition match which may have an effect on any of the dependent variables.

Table 9. Muscle soreness rating

1	Extreme muscle soreness
2	
3	Moderate muscle soreness
4	
5	No muscle soreness

Fatigue Scale (Contact)

To assist in the quantification of match intensity and severity for each subject a contact fatigue scale was developed. This included the use of specific match statistics being divided into categories and allocated a number, which was representative of the amount of work and contact exposed to for each match statistic. Match statistics included in the fatigue factor (see Table 2) were total tackle contact made (tackles completed and missed), total hit-ups (an attacking tactic

where a player receives a pass at pace and runs directly at the opposition's defensive line making contact with one or more defenders) and rate of perceived exertion (RPE). RPE was included in the contact fatigue scale because the contact area of the game is considered to be the most physically demanding aspect of contact sport (Duthie, Pyne, & Hooper, 2003; Takarada, 2003).

Table 10. Contact fatigue score categories

Fatigue Factor Rating	Total tackles made (TTM)	Total hit ups made (THU)	RPE Post Game (RPE)
1	0-8 tackles	0-4	1-2 Very light
2	9-15 tackles	5-7	3-4
3	16-22 tackles	8-11	5-6 Moderately hard
4	22-30 tackles	12-15	7-8
5	30+ tackles	16+	9-10 Exhausted

TTM + THU + RPE = Final contact fatigue score

Statistical Analyses

The effects of the recovery treatments were analyzed with mixed modelling to account for any non-uniformity arising from individual responses. Separate analyses were performed for the dependent variables jump height (JH), MS and CK. JH and CK were analyzed after log transformation to reduce non-uniformity of effects and errors over the range of values of the dependent variable; effects and errors with these variables were expressed as percents via back-transformation. The mean effects of the treatments and the mean changes between treatments were estimated with a fixed effect, the interaction of treatment with time. A covariate (contact fatigue score) interacted with time was included to estimate and adjust for the effect of within-subject changes in the intensity of each match on the post-match values of the dependent variable; for this purpose the value of the covariate was rescaled to give a mean of zero for each

subject, and the within-subject standard deviation was rescaled to allow estimation and interpretation of the effect of two mean within-subject SD of the covariate. The random effects in the mixed model were the identity of the player, the residual error representing within-subject variation from time-point to time-point, and terms representing additional within-subject variation for each treatment and post-game time-point.

Mean values and standard deviations are used throughout as measures of centrality and spread of data. Standardization of effects (dividing the effects by a between-subject standard deviation) was used to make magnitude-based inferences about the outcomes. The standard deviation used for standardization was derived from the random effects in the mixed model and is effectively the standard deviation at the pre-game time-point. Standardization for effects with JH and CK was performed with the log-transformed values of these variables. Magnitude of all standardized effects was evaluated with a modification of Cohen's scale for thresholds of effects: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; >1.2, large (Hopkins, Marshall, Batterham, & Hanin, 2009). To make clinical inferences about true values of effects in the population, the uncertainties in the effects were expressed as probabilities of harm or benefit in relation to the smallest worthwhile effect (± 0.2). Effects of the treatments were unclear if there was too much risk of harm compared with the chance of benefit (odds ratio of benefit to harm less than 66, equivalent to greater than 0.5% risk of harm and greater than 25% chance of benefit). All other effects were evaluated probabilistically to communicate the chance of the effect being trivial, beneficial or harmful with the following scale; 25-75% (possibly), 75-95% (likely), 95-99.5% (very likely), >99.5% (most likely) (Hopkins, 2007).

Results

Percent differences in JH and CK pre to all post game time points along with raw score changes for subjective muscle soreness for all three recovery modality groups with confidence limits (\pm CL) and a qualitative inference of the magnitude of the difference are detailed in Table 3. The post game percent changes for JH performance relative to baseline at each post game time point can be observed in Figure 1, raw score changes for MS relative to baseline in Figure 2, and CK percent change relative to baseline can be observed in Figure 3 in relation to all three recovery modalities. Note that the covariate (contact fatigue score) was included to estimate and adjust for the effect of within-subject changes in the intensity of each match on the post-match values of the dependent variable of interest.

Table 11. Percent difference \pm 90%CL with magnitude based inference

	CWI-ACT	CWT-ACT	CWT-CWI
Jump Height			
1h	3.2; \pm 5.5 [?]	7.5; \pm 8.0 ^{**}	4.2; \pm 6.9 [?]
18h	-3.8; \pm 6.9 [?]	6.6; \pm 7.1 ^{**}	10.8; \pm 7.1 ^{***}
42h	2.3; \pm 3.7 [*]	3.5; \pm 4.1 [*]	1.2; \pm 4.0 [?]
Muscle Soreness			
(Raw Scores)1h	-0.43; \pm 0.52 [*]	-0.52; \pm 0.57 [*]	-0.09; \pm 0.46 ⁰
18h	-0.59; \pm 0.49 [*]	-0.04; \pm 0.51 [?]	0.55; \pm 0.47 [*]
42h	-0.95; \pm 0.37 ^{***}	-0.55; \pm 0.37 [*]	-0.41; \pm 0.37 [*]
Creatine kinase			
1h	-1.2; \pm 16.8 [?]	26.3; \pm 21.5 ^{**}	27.9; \pm 22.0 ^{**}
18h	2.9; \pm 21.2 [?]	28.8; \pm 23.9 ^{**}	25.1; \pm 24.4 ^{**}
42h	-11.0; \pm 15.1 [*]	18.2; \pm 20.1 [*]	32.8; \pm 22.8 ^{**}

Explanation of superscripts denoting probabilistic inferences:

* Possibly beneficial/positive

** Likely beneficial/positive

*** Very likely beneficial/positive

**** Almost certainly beneficial/positive

⁰ Possibly trivial

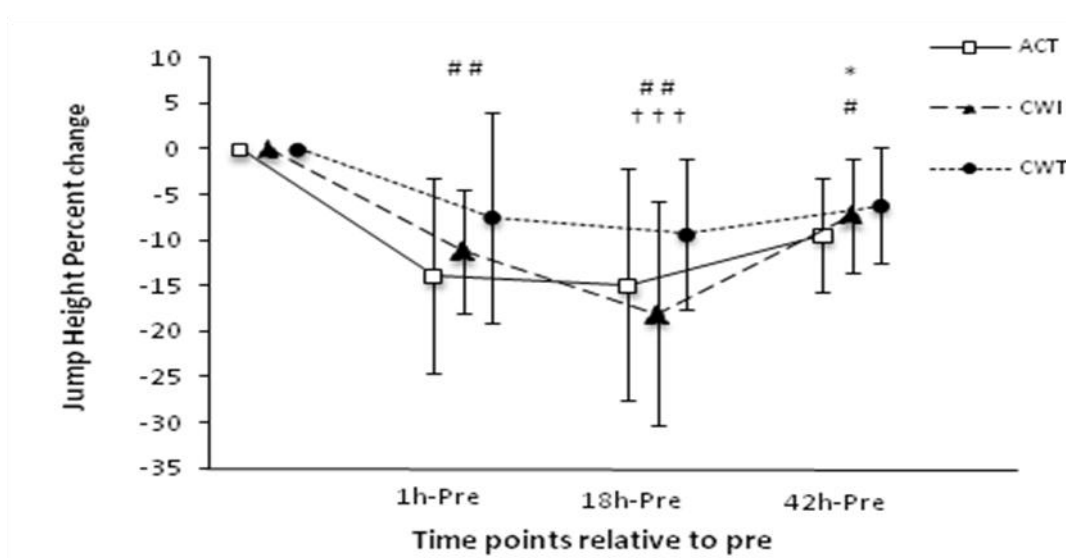
[?] Unclear

CWT is likely to have clear beneficial recovery effects on JH performance 1-18 hours and 18-42 hours post game as compared to ACT. Whereas CWI provided beneficial recovery effects at 18-42 hours post game only. CWT is very likely to be effective in regenerating JH performance at 1-18 hours post game as compared to CWI (see Table 3 and Figure 1).

Both CWI and CWT reduced MS to a meaningfully greater level than ACT at 18-42 hours post game, whereas CWI was found to be more effective than ACT at 1-18 hours post game. At 18-42 hours post game CWT is likely to have clear recovery benefits on MS as compared to CWI which was considered a possibly beneficial difference (see Table 3 and Figure 2).

CWT as compared to ACT is likely to have clear beneficial recovery effects on CK at 1-18 hours and 18-42 hours post game, whilst CWI will provide possibly beneficial recovery effects on CK at 18-42 hours post game only. The use of CWT is likely to have a more beneficial recovery effect in reducing CK compared to CWI at 1-18 hours and 18-42 hours post game (see Table 3 and Figure 3).

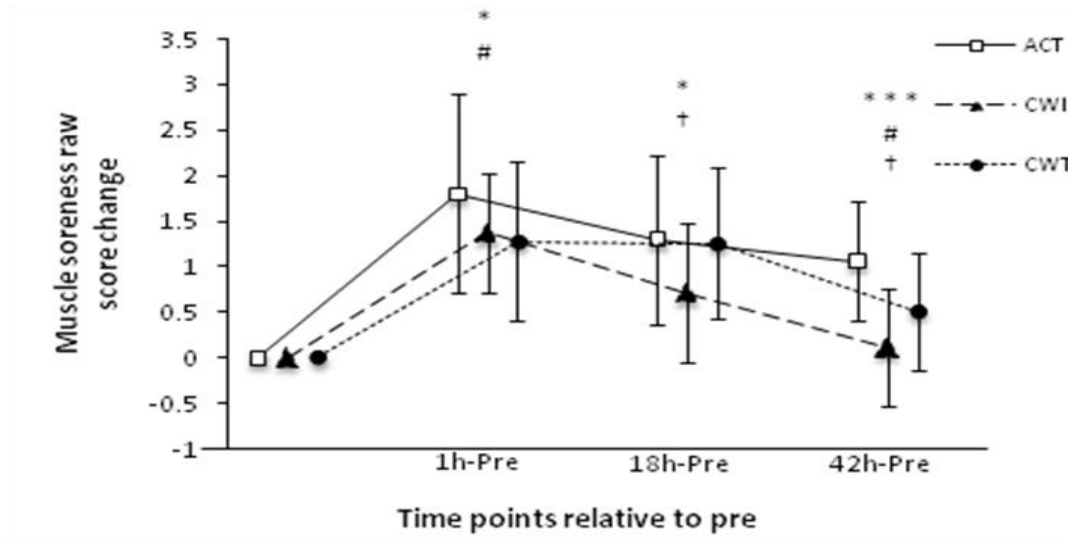
Figure 1. Post game jump height performance percent change relative to pre game measure



Explanation of superscripts denoting probabilistic inferences.

* Possibly beneficial	# Possibly beneficial	† Possibly beneficial
** Likely beneficial	## Likely beneficial	†† Likely beneficial
*** Very likely beneficial	### Very likely beneficial	††† Very likely beneficial
CWI - ACT	CWT - ACT	CWT - CWI

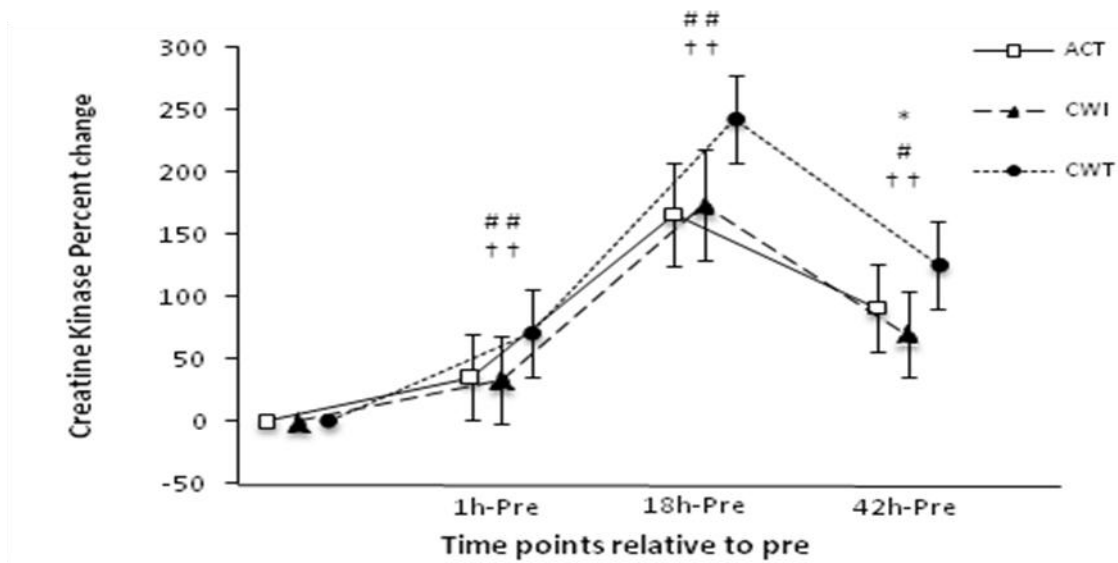
Figure 2. Post game subjective muscle soreness raw score change relative to pre game value



Explanation of superscripts denoting probabilistic inferences.

* Possibly beneficial	# Possibly beneficial	† Possibly beneficial
** Likely beneficial	## Likely beneficial	†† Likely beneficial
*** Very likely beneficial	### Very likely beneficial	††† Very likely beneficial
CWI - ACT	CWT - ACT	CWT - CWI

Figure 3. Post game creatine kinase percent change relative to pre game values



Explanation of superscripts denoting probabilistic inferences.

* Possibly beneficial	# Possibly beneficial	† Possibly beneficial
** Likely beneficial	## Likely beneficial	†† Likely beneficial
*** Very likely beneficial	### Very likely beneficial	††† Very likely beneficial
CWI - ACT	CWT - ACT	CWT - CWI

Discussion

The reader should be aware of the limitations of this study whilst reading the subsequent discussion. First, the recovery modalities were not randomly crossed over for each subject but instead each recovery modality was performed following three separate games owing to equipment and facility restrictions. Nonetheless, given the propensity of practitioners to use recovery modalities dependent on facility and equipment availability, investigation of such post game recovery modalities accounting for covariates such as game intensity is of value. Second, it should be noted that the subject group used in this study was the entire available group from the target population; that is, the top training squad of an elite rugby league team. Increasing subject numbers by including subjects other than the elite training squad with the intention of providing greater statistical power would have compromised the validity of the study in terms of

extrapolating findings to other similar athletes (Harris, Cronin, Hopkins, & Hansen, 2008). Third, the recovery modalities used in the current study were used independently from one another; therefore there is a possibility that a combination of recovery modalities both immediately and one day post game, as well as greater exposure times may further enhance the recovery response following professional team contact sport. Finally, it was considered unethical to include a passive recovery modality as a control when using professional athletes as subjects hence the active recovery was considered our control.

Our key finding was that both CWT and CWI were clearly effective recovery modalities 42 hours following a game of rugby league as compared to ACT alone; however the trend was for CWT to be the most effective recovery modality of the two. Gill et al (2006) and Higgins et al (2010) also found CWT to be an effective recovery modality following contact sport, however Dawson et al (2005) concluded that recovery of muscle soreness, vertical jump and power at 48 hours post game was not significantly enhanced by performing an immediate CWT post game recovery. The contrasting results between our study and Dawson et al (2005) may be owing to the different technique used to expose subjects to alternating water temperatures. Dawson et al (2005) employed the use of showers as the means for heat exposure compared to the use of baths for CWT in our study. It may be that the effect of hydrostatic pressure from actual water immersion versus superficial localized water contact is of influence. Gill et al's (2006) protocol was similar to this study incorporating water immersion to the level of the anterior superior iliac spine. Higgins et al (2010) also applied waist deep immersion (using a different protocol) following a rugby match, further supporting that water immersion in conjunction with alternating temperatures is of benefit to enhancing recovery following contact sport. It is possible that the relative superiority of CWT compared to CWI was owing to total hydrostatic time exposure

(CWT 9 minutes; CWI 5 minutes). Future studies may benefit from equating hydrostatic time exposure between CWT and CWI modalities in order to quantify such an effect.

The results of this study showed that CWI had a positive impact on JH performance, MS and muscle damage by 42 hours post game when compared to ACT in our study. Higgins et al (2010) also implemented a five-minute CWI protocol, however small and medium negative effects on anaerobic performance following a rugby competition match were reported. It was also concluded that CWI increased perceived feeling of muscular tightness and elicited a generally negative response compared to CWT. Notably, only anaerobic performance measures were used; no direct physiological or functional performance (e.g. jumps) markers were investigated to identify the underlying mechanisms associated with this particular protocol. Studies by Rowsell, Coutts, Reaburn, and Hill-Haas (2009) and Rowsell, Coutts, Reaburn, and Hill-Haas (2011) investigated the effect of CWI and thermo-neutral water immersion during and following a four day soccer tournament (one game each day) and reported a reduction in leg soreness perception which were similar to our findings. However, Rowsell et al (2009) also reported no significant improvement in JH or reduction in muscle damage following the use of CWI, in contrast to our findings. In our study CWI was performed once only following the match with all recovery markers being monitored up to 42 hours following one game. Rowsell et al (2009) used CWI after each game and monitored recovery markers 22 hours post game over four consecutive games in as many days, and observed no difference in markers from day one to five. It may be that allowing only 22 hours post game for CWI to be effective on the recovery markers was of insufficient duration. Although the current literature on the efficacy of CWI following team contact sport is unclear (Higgins et al., 2010; Ingram et al., 2009), the current study provides evidence that CWI assists in the recovery of JH performance, MS and damage within a

timeframe typically associated with commencement of structured training sessions following a competition game.

In the present study ACT was not clearly effective in recovering JH, MS, and CK by 42 hours following professional rugby league games compared to CWI and CWT. In contrast, Gill et al (2006) found that ACT elicited a similar CK recovery rate to CWT at 36 and 84 hours following a competitive rugby game. Suzuki et al (2004) also reported no difference in CK activity as a result of ACT or passive recovery modalities, although an increase in perceptual psychological state was observed following an 80-minute rugby match. However, the study by Suzuki et al (2004) incorporated a different means of ACT (multi-directional movements and swimming in water) and was performed for an hour each day for two days post game, whereas in the current study ACT was performed for only seven minutes and immediately post game only. Previous literature has suggested that the increased energy demands of higher volume or intensity ACT may compromise its efficacy (King & Duffield, 2009). Hence, the high volume of each ACT session employed by Suzuki et al (2004) may explain why no physiological benefit was observed. In the present study the ACT modality was not as effective in enhancing any of our recovery markers when compared to CWT. Gill et al (2006) incorporated the same ACT protocol as ours following professional rugby union games, finding that ACT post game was as effective on recovery as CWT and CG modalities at any post game time point, a result difficult to explain when compared to our findings. While it has been contested that the implementation of ACT provides theoretically similar physiological benefits to CWT (Wilcock, 2005), according to our study CWT is superior to ACT as a recovery modality.

It is common in professional team contact sport that the first training session of a training week during the competitive season is conducted within a 36-42 hour post game time period.

Both CWI and CWT were clearly effective in improving JH performance, MS and CK by 42 hours compared to ACT. Allowing sufficient time for the body to recover following a game characterized by a high number of collisions is critical. It is understood that if we used time points longer than 42 hours post game a greater recovery effect may have been observed.

Practical Applications

Practically available resources often limit the choice of recovery modality implemented in the field. Specifically, when traveling away from home, resources and space restrictions may limit the ability to implement the procedures and protocols compared to home recovery procedures. Practical implementation of CWT is possible using accessible resources such as portable baths or bins filled with ice. Even though CWT was clearly more effective by 42 hours post game than CWI in the current study, the use of CWI was still effective in reducing muscular damage and soreness, and improving muscular performance. If circumstances arise where CWT is not practically available rather than neglecting recovery, CWI (arguably a simpler modality to implement) will provide a similar recovery effect following contact sport. However we recommend the use of the current CWT protocol used in this study in order to improve JH performance, reduce muscle damage and improve perception of MS leading into the first structured training session following team contact sport: hot water immersion for two minutes (40-42°C) followed by one minute of cold water immersion (10-12°C) to the level of the anterior superior iliac spine repeated three times consecutively.

Chapter 4: Conclusions

Literature concerning the post exercise use of various recovery modalities and their subsequent recovery effect on physiological markers is well documented, but very few studies have examined the efficacy of recovery modalities and their ability to promote recovery following contact sport. No studies have attempted to incorporate match statistics to quantify match intensity and severity and its subsequent recovery effect on performance and physiological markers. The relative efficacy of CWI, CWT and ACT on JH performance, MS, and CK following professional rugby league matches, including a match intensity and severity scale, was investigated in the experimental study within this thesis.

Both CWT and CWI were clearly effective recovery modalities 42 hours following a game of rugby league as compared to ACT alone; however the trend was for CWT to be the most effective recovery modality of the two. Therefore the use of the CWT protocol used in this study in order to improve JH performance, reduce muscle damage and improve perception of MS leading into the first structured training session following team contact sport was recommended: hot water immersion for two minutes (40-42°C) followed by one minute of cold water immersion (10-12°C) to the level of the anterior superior iliac spine repeated three times consecutively.

It may be of benefit that future research further examines the relative efficacy of recovery modalities by quantifying match intensity and severity to determine recovery effects on post-match physiological and performance markers. Investigations examining the recovery benefit of different exposure times, number of rotations (CWT), equated hydrostatic pressure exposure, and the use of a combination of recovery modalities following contact sport would give coaches and practitioners the ability to make more informed decisions regarding recovery modality prescription.

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Appendices

Appendix A: Participant consent form

<h1>Consent Form</h1> <p>For use when laboratory or field testing is involved.</p>	
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Project title: **The relative efficacy of three recovery modalities following professional rugby league competition matches**

Project Supervisor: **Nigel Harris**

Researcher: **Nick Webb**

- I have read and understood the information provided about this research project in the Information Sheet dated 26.05.2010.
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- I am not suffering from heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or injury that impairs my physical performance, or any infection
- I agree to provide blood samples from a vein in my arm using venipuncture
- I agree to permit the giving of data to the coach(es) of the NZ Warriors NRL rugby league squad
- I agree to take part in this research.
- I wish to receive a copy of the report from the research (please tick one):
Yes No
- I wish to have my blood samples returned to me in accordance with right 7 (9) of the *Code of Health and Disability Services Consumers' Rights* (please tick one):
Yes No
- I consent to the researcher storing a sample(s) of my blood for its later use as a part of this study. Yes No
- I consent to any remaining blood sample(s) being disposed of using standard disposal methods at the end of the study. Yes No
- I wish to have any remaining blood sample(s) disposed of with appropriate karakia at the end of the study. Yes No
- I wish to have any blood sample(s) returned to me at the end of the study.
Yes No

Participants`signature:.....

Participants`Name:.....

Participants Contact Details (if appropriate):

.....
.....
.....
.....

Date:

*Approved by the Auckland University of Technology Ethics Committee on **type the date on which the final approval was granted** AUTEK Reference number **type the AUTEK reference number***

Note: The Participant should retain a copy of this form.

Participant Information Sheet



Date Information Sheet Produced:

26.05.2010

Project Title The relative efficacy of three recovery modalities following professional rugby league competition matches

An Invitation

I Nick Webb invite you to participate in this study which will benefit you, as well as the coaches involved in the Vodafone NZ Warriors 2010 season campaign. The proposed research will contribute to the completion of a Masters in Health Science. Your participation in the proposed research is purely voluntary and you may withdraw at any time prior to the completion of data collection without any adverse consequences.

What is the purpose of this research?

It is the purpose of this study to examine the relative efficacy of three recovery modalities on the rate and magnitude of muscle damage recovery, as measured by creatine kinase, subjective muscle soreness and ballistic jump measures following professional rugby league competition matches. The results obtained from this research will be used towards the qualification of a Masters in Health Science and may result in publication into a research journal.

How was I identified and why am I being invited to participate in this research?

Team administration and coaches of the NZ Warriors rugby league club provided a list (pool) of potential participants, from whom I (the researcher) invited potential participants to take part in the study. You have been specifically chosen to be invited to take part in this research due to your selection in the NZ Warriors NRL squad. Your contact details were obtained through the NZ Warriors NRL squad administration staff.

What will happen in this research?

24 hours prior to kick off all players will be required to complete the following testing procedure.

1. Weigh in and record body weight (please note, the players that do not like to weigh in before games due to psychological reasons the screen will be covered and weight recorded without them seeing).
2. Fill out a muscle soreness question on a piece of paper which will be provided.
3. Under go creatine kinase testing which involves extraction of blood via the brachial vein using a venipuncture system
4. Performing a set of three countermovement jumps on a force platform/jump mat.

Thirty minutes prior to kick off all players will be required to complete the following:

1. Put on a GPS unit

Within 45 minutes following the full time whistle all players will be required to complete the following testing procedure.

1. Take off GPS unit
2. Weigh in and record body weight (please note, the players that do not like to weigh in before games due to psychological reasons the screen will be covered and weight recorded without them seeing).
3. Fill out a muscle soreness question on a piece of paper which will be provided
4. Fill out a RPE scale on a piece of paper which will be provided
5. Performing a set of three countermovement jumps on a force platform/jump mat.
6. Under go creatine kinase testing which involves extraction of blood via the brachial vein using a venipuncture system
7. Perform recovery intervention (Explained below)

24 hours post match all players will be required to complete the following testing procedure.

1. Fill out a muscle soreness question on a piece of paper which will be provided
2. Performing a set of three countermovement jumps on a force platform/jump mat.
3. Under go creatine kinase testing which involves extraction of blood via the brachial vein using a venipuncture system

48 hours post match all players will be required to complete the following testing procedure.

1. Fill out a muscle soreness question on a piece of paper which will be provided
2. Performing a set of three countermovement jumps on a force platform/jump mat.
3. Under go creatine kinase testing which involves extraction of blood via the brachial vein using a venipuncture system

Blood collection procedure

Participants will be asked to lie down on a medical bed where blood will be extracted from their arm via a BD Vacutainer needle and blood tube. Blood tubes will then be labelled and stored appropriately ready for analysis. Participant safety will be ensured throughout the extraction and all samples will be taken in the NZ Warriors medical staff room. This procedure will occur at four time points during an intervention (pre game, immediately

post game, 18 and 42 hours post game). A total of 16 blood samples each participant will be required over a time period of four games spread throughout the season.

What are the discomforts and risks?

For some participants the extraction of blood from the brachial vein may create some discomfort. There is a risk that the research protocol may get in the way (prevent) of a good game.

How will these discomforts and risks be alleviated?

If a circumstance may arise that you (the participant) refuse or do not want the extraction of blood to occur, the extraction of blood will not be forced upon you and will not be completed.

What are the benefits?

As a participant of this research project and a member of the NZ Warriors rugby league club you will benefit from such a study as the area in which the research is concentrating on (recovery) will allow the associated trainers and coaches to prescribe specific recovery protocols in order to optimise your recovery following matches and therefore assist you in performing at you best following a match. The benefits to me (the researcher) is that I am able to identify trends from the results of the research and able to give evidential advice on the most efficient recovery modality to optimise post match recovery. Additionally, I (the researcher) will also gain a qualification of Masters in Health Science upon completion of this research.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Everything that you will fill out on paper will only be seen by my supervisors and I. Everything will be stored in a secure area and/or on a restricted computer system. It is my obligation to advise you that all data from this research will be shared with the coaching staff of the NZ Warriors NRL rugby league club.

What are the costs of participating in this research?

A maximum of 10 minutes every testing time point which occurs two hours before a competition match, immediately after (within 45 minutes), 24 hours and 48 hours after a competition match. No payment on your behalf will be required.

Disposal of body fluids (blood)

Following analysis of the bloods supplied, you as the participant have the choice of two methods of disposal, and may choose to have your remaining blood sample(s) disposed at the end of the study by:

1. Using the standard disposal methods (as approved by AUTEK)
2. Or, with an appropriate karakia (Maori prayer).

You as the participant also have the option of having your blood sample(s) returned to you at the end of the study. If you chose to have them returned you must advise the primary researcher (Nick Webb) on the first instance.

What opportunity do I have to consider this invitation?

You have an opportunity window of one month from the date stated on this information sheet to consider this invitation and advise the primary researcher of your acceptance or declination of this invitation.

How do I agree to participate in this research?

If you agree to participate in this research you must then contact me (primary researcher) and advise me of this decision. After doing so I will instruct you to fill out and sign an informed consent form to take part in the research.

Will I receive feedback on the results of this research?

Upon completion and this study interventions and analysis of all results you will (along with all other participants) receive feedback on the results obtained from the research.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Nigel Harris, *nigel.harris@aut.ac.nz*, 921 9999 extension 7301

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEK, Madeline Banda, *madeline.banda@aut.ac.nz*, 921 9999 ext 8044.

Whom do I contact for further information about this research?

Researcher Contact Details:

Nick Webb, Nick@warriors.co.nz, 021 288 8069

Project Supervisor Contact Details:

Nigel Harris, *nigel.harris@aut.ac.nz*, 921 9999 extension 7301

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEK
Reference number *type the reference number*.

Appendix C: Ethics approval



MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Nigel Harris
From: **Madeline Banda** Executive Secretary, AUTEC
Date: 15 June 2010
Subject: Ethics Application Number 10/103 **The relative efficacy of three recovery modalities following professional rugby league competition matches.**

Dear Nigel

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 10 May 2010 and that I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 12 July 2010. Your ethics application is approved for a period of three years until 15 June 2013. I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/research/research-ethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 15 June 2013;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/research/research-ethics>. This report is to be submitted either when the approval expires on 15 June 2013 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEK grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

Also, if your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEK and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely



Madeline Banda

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Nicholas Paul Webb nick@warriors.co.nz

Appendix D: Post game questionnaire



Intervention RPE and Perceived Muscle Soreness Scores

Participant Name: _____

Participant ID: _____

Recovery modality used (Coordinator to tick)

CGT CWI AR(control)

Round ____

Vodafone NZ Warriors vs. _____

Pre game measures

- How would you rate your muscle soreness at this point in time? (Please circle)

1. Extreme	2.	3. Moderate	4.	5. Nothing
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Please indicate the location of your muscle soreness:

- Pre game body weight: _____ kg

Immediately (within 45min) after competition match

- How would you rate your muscle soreness at this point in time? (Please circle)

1. Extreme	2.	3. Moderate	4.	5. Nothing
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Please indicate the location of your muscle soreness:

- Please specify your current rate of perceived exertion

1. Not tired/fatigued at all	2.	3. Fairly tired/fatigued	4.	5. Moderately tired/fatigued	6.	7. Very tired/fatigued	8.	9. Near Exhaustion	10. Exhausted
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- Post game body weight: _____ kg

18 hours after competition match

- How would you rate your muscle soreness at this point in time? (Please circle)

1. Extreme	2.	3. Moderate	4.	5. Nothing
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Please indicate the location of your muscle soreness:

42 hours after competition match

- How would you rate your muscle soreness at this point in time? (Please circle)

1. Extreme	2.	3. Moderate	4.	5. Nothing
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Please indicate the location of your muscle soreness:

Appendix E: Countermovement jump protocol and procedure

Counter Movement Jump (CMJ) Set up and Protocol



Intervention Countermovement jump (CMJ) protocol

Set Up

Equipment Needed:

- Indoor facility
- Fitness Technology force platform
- Ballistic Measurement System computer software and platform attachments
- Lap top and associated equipment to go with it

Ensure you have all the required equipment booked the day before testing

Protocol:

1. Participants are to stand on the force platform with feet positioned shoulder width apart.
2. Hands are to be placed on the hips throughout the jump.
3. Participants are to perform three separate countermovement jumps.
4. Players are instructed to jump as high and as quickly as they can in each jump.

Measurements recorded:

- Jump height
- Flight time
- Peak power
- Mean Power
- Peak force
- Mean force
- Contraction time