Original research

Cold water immersion in the management of delayed-onset muscle soreness: Is dose important? A randomised controlled trial

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Background: Cold Water Immersion (CWI) is commonly used to manage delayed onset muscle soreness (DOMS) resulting from exercise. Scientific evidence for an optimal dose of CWI is lacking and athletes continue to use a range of treatment protocols and water temperatures. 

Objectives: To compare the effectiveness of four different water immersion protocols and a passive control intervention in the management of DOMS.

Design: Randomised controlled trial with blinded outcome assessment.

Setting: University Research Laboratory.

Participants: 50 healthy participants with laboratory induced DOMS randomised to one of five groups: Short contrast immersion (1 min 38°C/1 min 10°C × 3), Short intermittent CWI (1 min × 3 at 10°C); 10 min CWI in 10°C; 10 min CWI in 6°C; or control (seated rest).

Main outcome measures: muscle soreness, active range of motion, pain on stretch, muscle strength and serum creatine kinase.

Results: 10 min of CWI in 6°C was associated with the lowest levels of muscle soreness and pain on stretch however values were not statistically different to any of the other groups. There were no statistically significant differences between groups for any other outcomes.

Conclusion: Altering the treatment duration, water temperature or dosage of post exercise water immersion had minimal effect on outcomes relating to DOMS.

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1. Introduction

Muscular pain commonly results after unaccustomed or eccentric exercise and is commonly described as delayed onset muscle soreness (DOMS) (Armstrong, 1990). Symptoms include a reduction in the ability of the muscle to generate force, decreased range of motion (Newham, 1988), DOMS is often cited by athletes and coaches as being detrimental to recovery and performance. Although the physiological mechanism underpinning DOMS has not been fully elucidated, it may relate to primary mechanical damage to muscle cells during exercise (Proske & Morgan, 2001) and a marked but transient inflammatory response (Chatzinikolaou et al., 2010). Due to its transitory nature (peak soreness 24–72 h and resolution of symptoms within 5–7 days) experimentally induced DOMS has been used as a model of myogenic pain to investigate the effects of various therapeutic modalities.

Over the past decade, cold water immersion (CWI) has become one of the most popular strategies to manage or prevent DOMS. Immediately after exercise, athletes will immerse themselves in water baths which may vary from temperature controlled spas to large containers filled with water. Contrast Water Therapy (CWT), alternating cold and warm water immersion, is also often offered to athletes as an alternative to cryotherapy and is commonly used within the sporting community. Clear physiological evidence to support these practices has not yet been fully elucidated (Bieuzen, Bleakley, & Costello, 2013; Bleakley, Glasgow, & Webb, 2012; Bleakley, McDonough, Gardner, Baxter, Hopkins, & Davison, 2012). In practice there are large variations in the CWI protocols employed, particularly in terms of the duration of immersion and water temperature (Bieuzen et al., 2013; Bleakley, Glasgow, et al., 2012; Bleakley, McDonough, et al., 2012).

One proposed mechanism is that CWI induces a pumping effect on the vasculature which stimulates blood flow, nutrient and waste
transportation through the body (Wilcock, Cronin, & Hing, 2006). This is thought to be achieved using short CWI’s repeated on either a single day (Sellwood, Brukner, Williams, Nicol, & Hinman, 2007), over a period of consecutive days (Eston & Peters, 1999; ‘Manigawasawa, Niitsu, Yoshioka, Goto, Kudo, & Itai, 2003) or with brief alternate immersions in cold and warm water (often referred to as Contrast Immersion) (Wilcock et al., 2006). Others advocate longer, continuous immersions in cold water (Bann & Melegati, 2008; Vaile, Halson, Gill, & Dawson, 2008); although this approach has traditionally been reserved for reducing pain, swelling, metabolism and inflammation associated with acute sprains and strains, it may have some rationale post exercise, particularly in sports associated with physical contact, soft tissue trauma and/or exercise induced muscle damage (EIMD). A psychological mechanism may also be possible; this may be less dependent on dose as the rationale is that CWI simply makes the body feel more ‘awake’, leading to a reduced sensation of fatigue after exercise (Cochrane, 2004; Wilcock et al., 2006).

Evidence from clinical trials on the effectiveness of CWI for sports recovery remains equivocal. A recent Cochrane review (Bleakley, McDonough, Gardner, Baxter, Hopkins, & Davison, 2012) found some evidence that CWI is superior to passive intervention at reducing muscle soreness (no intervention/rest) but found no studies comparing different treatment dosages. Further definitive conclusions were limited due to poor methodological quality relating to inadequate randomisation, allocation concealment and blinding of outcome assessor (Bleakley, Glasgow, et al., 2012; Bleakley, McDonough, et al., 2012).

The purpose of this study was to provide high quality evidence to inform post exercise recovery strategies using CWI. Continued disparity in this area and vague guidelines for its use after sport mean that athletes could risk employing more extreme temperatures or longer immersion times, before determining actual benefit or risk. Our primary objective was to compare the effectiveness of four commonly used CWI strategies and a passive control, in the management of DOMS using a randomised controlled design with blinded outcome assessment.

2. Methods

2.1. Study design

This was a randomised controlled trial using a blinded outcome assessor. There were 5 separate outcome variables (muscle soreness, active range of motion, pain on stretch, muscle strength, serum creatine kinase), with repeated measures over five time points [Baseline (0 h) and then at 24 h, 48 h, 72 h, 96 h]. All research was undertaken at the Ulster Sports Academy (University of Ulster) between January and February 2011. Approval for this study was granted by the University of Ulster Research Ethical Committee. All participants signed a letter of informed consent and were advised of their right to withdraw from the study at any time.

2.2. Participants

Healthy participants (age range: 18–35 years; height 1.79 ± 0.06 m; body mass 81.9 ± 17 kg) were recruited from the student population at the University of Ulster (N = 50; 32 male, 18 female). Participants were asked to refrain from commencing any unaccustomed physical activity during the week of the study but were advised to continue their normal levels of physical activity. Participants were excluded from the study if any of the following contraindications applied: Skin allergy, broken skin, open wounds, abnormal or altered skin sensation, epilepsy, asthma, chlorine allergy, cold allergy, Raynaud’s disease, peripheral vascular disease, cryoglobinaemia or under the influence of alcohol.

2.3. DOMS induction

At baseline (0 h), DOMS was induced to the non-dominant knee flexors using a standing hamstring curl machine (Samson Equipment, USA). Initially, the concentric one repetition maximum (1 RM) was established and this weight was used during the induction protocol. During testing, the weight was raised by an experimenter to the starting position (90° knee flexion) and participants lowered the weight eccentrically over 3 s (speed = 30 degrees·s⁻¹) by following the researcher instructions (counting ‘3,2,1’ aloud). Participants undertook three sets of eccentric hamstring contractions to fatigue (fatigue was defined as the point at which the participant could no longer control the descent of the weight), with 1 min rest between sets.

2.4. Sequence generation

We used a computer generated randomisation sequence to randomise participants. Group allocation was printed on a card, and placed in sequentially numbered opaque envelopes. After written consent had been obtained and baseline assessment, participants were randomised to one of the five groups from the numbered envelopes (n = 10 per group). Participants were not informed as to which intervention was considered therapeutic throughout the duration of the study.

1. Short contrast immersion: 1 min water immersion in 38 °C followed by 1 min CWI in 10 °C (repeated 3 times)
2. Short intermittent CWI: 1 min CWI in 10 °C followed by no immersion for 1 min (repeated 3 times)
3. 10 min CWI in 10 °C
4. 10 min CWI in 6 °C
5. Control group: seated rest, no immersion

Participants attended on five consecutive days [Baseline (0 h), 24 h, 48 h, 72 h, 96 h], during which the intervention was applied on the first three days. The first treatment was initiated within 5 min of the completion of DOMS induction. Each water immersion was completed using a CET cryotherapy spa (CET, Dromore, UK). Participants were immersed up to waist level in a standing position. For each group, the water temperature was thermostatically controlled at the relevant level, and water jets were active for the entire period of immersion.

2.5. Measurements

Five outcome measurements were assessed. A single investigator was responsible for all outcome assessments; they were blinded to group allocation, and participants were advised not to reveal their group allocation to them. Subjective muscle soreness was the primary outcome with secondary outcomes of: Active range of motion (AROM), Pain on stretch (POS), Concentric peak torque (CPT) and Creatine Kinase (CK) level. The study was completed over 5 consecutive days. All outcomes were measured at baseline (0 h) and at 24 h, 48 h, 72 h, 96 h post exercise. Outcome recording at baseline was undertaken prior to any DOMS induction or treatment intervention. Outcome recording was consistently completed over a 10 min period following a standardised order (muscle soreness, AROM, POS, CPT, CK).

2.5.1. Muscle soreness

Participants were asked to rate the hamstring muscle soreness felt during everyday activity. Pain was measured using a 10 cm visual analogue scale (VAS) with terminal descriptors ‘no pain’ and ‘maximum pain.’ The distance from the ‘no pain’ descriptor was...
measured in centimetres and represented a pain score out of a maximum of 10.

2.5.2. Active range of motion (AROM): knee extension
Participants were positioned supine with a stabilisation belt around their pelvis to minimise compensatory movements. Participants started the test with their test leg in 90 degrees of hip flexion/90° knee flexion. Participants were asked to extend their knee as far as possible and AROM at the knee joint was measured using a universal goniometer.

2.5.3. Pain on stretch (POS)
Participants rated pain during the AROM test; again a 10 cm VAS was used with terminal descriptors ‘no pain’ and ‘maximum pain’.

2.5.4. Muscle strength (concentric peak torque)
Concentric peak torque (CPT) was measured using a KinCom AP2 isokinetic dynamometer (Chattanooga Group Inc, USA). Participants performed three maximum concentric contractions of the hamstring (through range from 10 to 80° knee flexion), with 10 s rest between each repetition. The highest peak torque out of the three attempts was recorded.

2.5.5. Creatine Kinase (CK)
Serum CK samples were obtained as a marker of muscle damage. A sample of blood was obtained from a finger-prick which was then analysed using a Reflotron Plus machine (Roche Diagnostics, Germany).

3. Results
Between January 2011 and February 2011, 50 participants met the inclusion criteria and provided informed consent to participate in the study. All 50 participants underwent randomisation and all received the intervention as allocated. There were no drop outs, with complete data sets for each outcome at every follow up point. There were no adverse effects reported. Table 1 summarises outcomes for each group at baseline and all follow up points. There were no significant differences between groups at baseline.

Table 1 shows a significant main effect for time for all outcomes ($p < 0.001$). Muscle soreness peaked at day 2 post exercise; POS and limitations in AROM followed the time course. Muscle strength was

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<th>Table 1</th>
<th>Muscle soreness, AKE ROM, Pain on Stretch, Peak Torque and CK.</th>
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<td>24 h</td>
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<td>Muscle soreness (10 cm VAS)</td>
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<td>10 min at 6 °C</td>
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<td>AKE ROM (degrees)</td>
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<td>Hamstring Peak Torque (N)</td>
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$N = 10$ in each group at all follow ups.

Values are mean ($\pm$ SD).

$^a$ Log transformation of data undertaken prior to analysis.

$^b$ Degrees of freedom adjusted using Greenhouse–Geisser epsilon.

2.6. Statistical analysis
We used SPSS (version 19; SPSS Inc, Chicago, IL) to conduct the analysis. Normal distribution and homogeneity of data were assessed visually (histograms; QQ plot linearity) and statistically using the Shapiro–Wilk procedure. Changes in variables over time (Baseline (0 h), 24 h, 48 h, 72 h, 96 h) were compared between groups using a Repeated Measures Analysis of Variance (ANOVA). The assumptions of homogeneity of covariance were tested by Mauchly sphericity test. When this was significant, the Greenhouse–Geisser epsilon was used to adjust the degrees of freedom to increase the critical value of the F-ratio. Effect sizes based on the absolute mean differences between groups (MD) [(+95% confidence intervals (CI)] were calculated to describe any trends in the data. The alpha level was set at $P < 0.01$ for all analyses.
lowest between day 1 and 2 post exercise, whereas CK activity peaked between day 3 and 4 post exercise.

There were no significant interaction effects (GROUP*TIME) for AROM (P = 0.890), POS (P = 0.444), muscle strength (P = 0.620), serum CK levels (P = 0.759) and muscle soreness (P = 0.499). Fig. 1 shows the changes over time for the primary outcome, by intervention group. The largest effect sizes for muscle soreness at 48 h [MD of 2.05 cm (95% CI – 0.4 to 4.5)] based on a 10 cm VAS] and 72 h post exercise (MD of 1.06 (95% CI – 0.2 to 2.32) based on a 10 cm VAS] were in favour of the 10 min CWI in 6 °C group (vs control). There were further trends in favour of this group over the control, for POS at 48 h [MD of 1.7 cm (95% CI – 0.69 to 4.09) based on a 10 cm VAS] and 72 h post exercise [MD of 0.58 cm (95% CI – 1.68 to 2.84) based on a 10 cm VAS].

4. Discussion

Water immersions, such as CWI or CWT are commonly used as a recovery modality but there is little empirical evidence to support its use (Bieuzen et al., 2013; Bleakley, Glasgow, et al., 2012; Bleakley, McDonough, et al., 2012). To date no study has compared different WI temperatures and treatment durations in the management of delayed onset muscle soreness. This is also one of the first studies in this area to use a randomised methodology with parallel group clinical trials. The optimal duration of immersion is not clear (Bleakley, Glasgow, et al., 2012). In the current study, the largest effect size measured was for muscle soreness at 48 h post exercise. Although this is comparable to some studies (Rowsell, Coutts, Reaburn, & Hill-Haas, 2011; Yanagisawa et al., 2003), others (Bailey, Erith, Griffin, Dowson, Brewer, & Gant, 2007; Jakeman et al., 2009) have recorded earlier CK peaks at around 24 h post exercise. These variations may be due to the methods of DOMS inducement employed; early peaks seem to be associated with more moderate strengthening protocols (Sellwood et al., 2007) or single bouts of running (Bailey et al., 2007; Jakeman et al., 2009). In contrast, later peak values, such as those reported in the current study, seem to be associated with isolated eccentric loading (Yanagisawa et al., 2003) or intense game exposure (Rowsell et al., 2011).

Clinical application of CWI continues to vary dramatically depending on location, sport and personal preference. Currently the optimal duration of immersion is not clear (Bleakley, Glasgow, et al., 2012; Bleakley, McDonough, et al., 2012). In the current study, we compared a range of popular cooling durations but found no significant differences for any outcomes. In accordance with a number of recent studies (Eston & Peters, 1999; Yanagisawa et al., 2003), we employed serial treatment interventions over a period of three days. Some areas of athletics promote serial interventions as a means of inducing larger treatment dose. A subgroup analysis within a recent Cochrane review found few differences between single and serial treatments of CWI in the prevention and treatment of muscle soreness (Bleakley, Glasgow, et al., 2012; Bleakley, McDonough, et al., 2012).

The basic scientific theory underpinning cryotherapy is that it decreases metabolic activity, thereby limiting secondary hypoxic damage and facilitating recovery after soft tissue damage (Merrick, Jutte, & Smith, 2003). This theory may not translate into a clinical setting however, as tissue temperature reductions in human

![Graph of primary outcome (muscle soreness) by intervention group.](attachment:image.png)

Values are Mean (+SEM)

**Fig. 1.** Primary outcome (muscle soreness) by intervention group.
subjects are often not large enough to influence metabolic cellular activity (Bleakley, Glasgow, & Webb, 2012). Indeed many studies have shown negligible reductions in thigh muscle temperature with CWI, despite using treatment durations comparable to or longer than those used in the current study (Gregson et al., 2011; Myrer, Measom, & Fellingham, 1998). Other clinical studies have found little evidence of a duration dependent response associated with water immersion recovery, despite comparing immersion durations of 6, 12 or 18 min (Versey, Halson, & Dawson, 2011).

Water temperature may be a more important component determining clinical effectiveness. An interesting trend was that immersions in lower water temperatures (6°C) were associated with less muscle soreness throughout the entire follow up period. Indeed, at 48 h post exercise, control group scores were approximately 20% higher than the group using 10 min immersions at 6°C [MD of 2.05 cm (95% CI –0.4 to 4.5)]. Although these reductions were not statistically significant, they may be clinically relevant. A Minimal Important Difference (MID) has been defined as “the smallest difference in score in the domain of interest that patients perceive as important, either beneficial or harmful, and which would lead the clinician to consider a change in the patient’s management” (Guyatt, Osoba, Wu, Wyrwich, Norman, & Aaronson, 2006). Using recovery modalities between training sessions in elite sporting environment.

We can only postulate the physiological mechanisms underpinning these trends. The hypoalgesic effects of cold are well reported and seem to be optimised when skin temperature is reduced to below 12°C (Alágafy & George, 2007; Kunesch, Schmidt, Nordin, Wallin, & Hagbarth, 1987). The magnitude of skin temperature reductions during immersion is strongly influenced by water temperature (Hopper, Whittington, & Davies, 1997; Kennet, Hardaker, Hobbs, & Selfe, 2007; Khannomhammad, Someh, & Ghafarinejad, 2011; Leeder, Gissane, van Someren, Gregson, & Howatson, 2012). It may be that immersion in 6°C reduces skin temperature to optimal levels fastest. Achieving more effective short term analgesia may be more conducive to higher levels of physical activity after exercise which has already been shown to attenuate painful symptoms relating to DOMS when used in isolation (Ahmaidi, Granier, Taoutaou, Mercier, Dubouchaud, & Prefaut, 1996; Reilly & Ekblom, 2005) or in combination with CWI (Kinugasa & Kilding, 2009).

Throughout the study we ensured that participants were not informed of the water temperatures employed and we did not state which intervention was deemed most therapeutic. We must however acknowledge that the nature of CWI prevents true participant blinding. Studies which are not blinded or have observational components may be vulnerable to unintended effects on intervention outcomes such as the Hawthorne effect (Fernald, Coombs, DeAlleaume, West, & Parnes, 2012). CWI is considered by many athletes as the touchstone for managing muscle soreness. In the current study, the extreme sensation associated with immersion in 6°C may have been construed as being more therapeutic and may partly explain the lower levels of muscle soreness within this group. Interestingly, we found no differences between groups based on measures of strength or active range of motion. This concurs with recent literature whereby CWI (Barnett, 2006; Bleakley, Glasgow, et al., 2012; Bleakley, McDonough, et al., 2012; Cheung, Hume, & Maxwell, 2003) seems to enhance perception of recovery over no intervention (eg. muscle pain and fatigue after exercise) but few studies report any significant effects on objective measures of function and sporting performance.

A total of 50 participants completed this study which represents one of the largest samples used within CWI research to date (Bleakley, Glasgow, et al., 2012; Bleakley, McDonough, et al., 2012).

However, as we randomised across five groups, our level of statistical significance for all tests was set at p < 0.01 a priori, to control for experiment wise error rate (Type 1 error). Although we found no statistically significant interaction effect (group*time) on our outcome variables, we have described important trends that may be clinically relevant. Another potential limitation is that our data are limited to a 96 h follow up and we cannot make conclusions on any long term effects. We also acknowledge that our research is based on a muscle damage model; CWI may have a different effect in sports associated with other physiological stresses such as: metabolic cost and energy substrate depletion, hyperthermia, oxidative stress and nervous system fatigue (Leeder et al., 2012). Indeed there is some evidence to suggest that CWI is an effective method for controlling core temperature (DeMartini et al., 2011) and optimising exercise performance in a hot environment (Schmieg, Campbell, Powell, & Pincivero, 2002; Yargin et al., 2006).

5. Conclusion

CWI remains a popular strategy for post exercise recovery; however there is little guidance on the most effective water temperature or treatment duration. We found no strong evidence to suggest an optimal treatment dosage; only trends that longer immersions (10 min) in colder water are associated with less muscle soreness. This aligns with previous studies in this area which seem to suggest that CWI has most effect on self reported recovery rather than objective measures of sporting performance (eg. increased strength). Coaches and sports practitioners should consider using CWI; however this should be undertaken as part of a structured recovery session and be tailored to the specific requirements of each athlete.

Conflict of interest

This project was part funded by CET Cryotherapy (Dromore, UK). The results of the present study do not constitute endorsement of the product by the authors.

Ethical approval

Approval for this study was granted by the University of Ulster Research Ethical Committee.

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