

Research article

## The effects of multiple cold water immersions on indices of muscle damage

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### Abstract

The aim of this investigation was to elucidate the efficacy of repeated cold water immersions (CWI) in the recovery of exercise induced muscle damage. A randomised group consisting of eighteen males, mean  $\pm$  s age, height and body mass were  $24 \pm 5$  years,  $1.82 \pm 0.06$  m and  $85.7 \pm 16.6$  kg respectively, 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 ( $15 \pm 1$  °C;  $n = 9$ ) group who experienced immersions immediately post-exercise and every 24 h thereafter for the following 3 days, or a control group (no treatment;  $n = 9$ ). Maximal voluntary contraction (MVC) of the knee extensors, creatine kinase activity (CK), muscle soreness (DOMS), range of motion (ROM) and limb girth were measured pre-exercise and then for the following 96 h at 24 h increments. In addition MVC was also recorded immediately post-exercise. Significant time effects were seen for MVC, CK, DOMS and limb girth ( $p < 0.05$ ) indicating muscle damage was evident, however there was no group effect or interaction observed showing that CWI did not attenuate any of the dependent variables ( $p > 0.05$ ). These results suggest that repeated CWI do not enhance recovery from a bout of damaging eccentric contractions.

**Key words:** Eccentric exercise, treatment, cryotherapy.

### Introduction

Eccentric contractions, such as those elicited during plyometric exercise are an integral part of athletic training regimes. When this activity is unaccustomed or novel it is common for athletes to experience signs and symptoms of exercise-induced muscle damage (EIMD), which may last for several days post-exercise and is likely to affect athletic performance (O'Connor and Hurley, 2003). EIMD is known to result in a reduction in contractile function and cause muscle soreness (Cheung et al., 2003; Schutte and Lambert, 2001) that results from tissue microtrauma initiated by high tension produced during eccentric contractions (Enoka, 1996) and further exacerbated by the subsequent inflammatory responses (Chen and Nosaka, 2006). A fast recovery may be important for athletes involved in a training programme, or who have a competition schedule that requires one or more high intensity efforts within a short period (Chen and Nosaka, 2006; Clarkson, 1997). It is therefore important that an appropriate balance between training, competition stressors and recovery are implemented in order to maximise subsequent performances.

Cryotherapy, the lowering of tissue temperature by the withdrawal of heat from the body (Chesterton et al.,

2002), is one such intervention that may help maintain the balance between training, competition and recovery. Cryotherapy can be administered in a number of different ways and is purported to reduce inflammation, oedema and pain sensation which are all apparent following a damaging bout of exercise (Barnett, 2006). It is not known which form of cryotherapy results in the greatest oedema removal, although CWI seem to be the most frequently used during recovery (Wilcock et al., 2006). However, research examining this area is equivocal; some studies have shown no attenuation in the signs and symptoms of muscle damage following cryotherapy (Gulick and Kimura, 1996; Howatson and van Someren, 2003; Isabell et al., 1992), whereas others have (Bailey et al., 2007; Burke et al., 2000). Possibilities for these discrepancies potentially lay in methodological inconsistencies in cold temperature, frequency and immersion time (Wilcock et al., 2006).

Recently, CWI have gained increasing popularity as a means to improve recovery after strenuous training (Barnett, 2006); although most of the benefits in attenuating symptoms of EIMD are based on anecdote and lack empirical evidence (Wilcock et al., 2006). Recent studies (Burke et al., 2000; Yamane et al., 2006) have used immersions of  $<10$  °C with different treatment durations (3-10 mins), possibly explaining the inconsistency in their results regarding the recovery of strength and muscle soreness. Meeusen and Lievens (1986) suggest that a 15 min immersion at a temperature of 15°C will lower intramuscular temperature by  $\sim 10$ °C and potentially have a beneficial effect. Eston and Peters (1999) administered this type of immersion (every 12 h for a total of seven sessions) following eccentric biceps exercise and showed that muscle stiffness was reduced; however, the intervention had no impact on muscle tenderness and strength loss which are extremely important factors in athletic performance (Cheung et al., 2003). Eston and Peters (1999) demonstrated some limited value, however their model for damage (elbow flexors) lacks external validity when applying to a sport specific training regimen. More recently, Bailey et al. (2007) concluded that some indices of muscle damage (soreness and myoglobin efflux in blood) are reduced following a single CWI (10 min at 10 °C), when administered after the 90 min Loughborough Intermittent Shuttle Test (Thompson et al., 1999). Although, this investigation was not specifically designed to induce damage it suggested that a single immersion may be of value in reducing the negative effects of EIMD.

Furthermore, water immersions ( $>10$  mins), up to the waist provide a degree of hydrostatic pressure, which

is sufficient to displace fluid from the lower limb (Wilcock et al., 2006). A very recent addition to the literature (Sellwood et al., 2007) examined the current practice of high-level sports across Australia, whereby a 1 min immersion in ice water, followed by 1 min out of water for a total of three cycles immediately post-exercise is commonly used. Methods such as these do not allow muscle temperature to decline sufficiently (Meeusen and Lievens, 1986), or allow fluid shifts within the muscle to occur (Wilcock et al., 2006); it is therefore unsurprising that Sellwood et al. (2007) found no attenuation in markers of EIMD.

To date, the literature is equivocal with regards to the efficacy of CWI. Although investigations have shown some positive effects, there are many inconsistencies in the methods of damaging exercise and the treatment application. Most studies that demonstrate cryotherapy to be effective have used a single muscle group to model the response or a protocol designed to predict performance, both of which lack external validity when applied to a training environment. In light of the previous limitations regarding exercise specificity, immersion temperature and duration, the aim of this study was to elucidate the efficacy of repeated CWI in the recovery of EIMD elicited by plyometric exercise.

## Methods

### Subjects

Following approval from the University Ethics Committee, 18 physically active male subjects (mean  $\pm$  s age 24  $\pm$  5 years; height 1.82  $\pm$  0.06 m and body mass 85.7  $\pm$  16.6 kg) were recruited for the study after completing a medical health questionnaire and providing written informed consent. After a bout of damaging eccentric exercise on the legs, the participants were equally, but randomly allocated to either a cryotherapy treatment or control group. Dependent variables were recorded pre-exercise and at 24 h increments for 96 h. It was ensured that participants were not familiar with eccentric biased training and they were asked to refrain from any form of resistance training or any exercise that may potentially cause muscle damage and soreness for 3 weeks prior to, and for the duration of testing. In addition to this, during the testing period subjects were asked to refrain from non-steroidal anti-inflammatory drugs and nutritional supplements.

### The muscle damaging protocol

Muscle damage was induced through the use of a drop jump protocol similar to that used by Miyama and Nosaka (2004a); subjects dropped from a 0.6 m box and upon landing jumped up maximally, landing on the same surface. Five sets of twenty drop jumps were performed on a concrete based floor, in time with a set of recorded beeps allowing 10 s rest between each jump and 2 minutes rest between each set.

### Treatments

The cryotherapy group underwent a seated immersion (up to iliac crest) in an inflatable ice bath for 12 min; legs were kept apart in the cold water to ensure a maximum surface area exposure. The water was maintained at the

recommended temperature of 15  $\pm$  1°C (by adding crushed ice), Meeusen and Lievens (1986) predict this to elicit a drop in intramuscular temperature of approximately 5-8 °C. This treatment was applied immediately post-exercise and every 24 h thereafter for the following 3 days. The control group remained seated for the same amount of time as the immersions were administered for and received no treatment.

### Criterion measurements

Dependent variables to indicate damage were maximal voluntary contraction (MVC) of the knee extensors, creatine kinase activity (CK), muscle soreness (DOMS), range of motion (ROM) and swelling which have been used in previous research (Byrne et al., 2004; Howatson and van Someren, 2003; Warren et al. 1999). MVC measurements were recorded immediately pre and post-exercise and for the following 96 h at 24 h increments. All other variables were measured immediately pre-exercise and then for the following 96 h at 24 h increments. All measures were obtained before the cryotherapy treatments to avoid any potential effects such as analgesia.

**Plasma creatine kinase activity (CK):** Plasma CK was sampled from the subject's earlobe using capillary puncture. A sample of whole blood  $\sim$ 30  $\mu$ L was collected into a heparinised capillary tube and examined immediately using an automated reagent test strip analyser (Reflotron Plus Analyser, Bio Stat Ltd. Stockport, UK). The normal reference ranges of plasma CK activity for this method are 24-195 IU·L<sup>-1</sup> (according to the analyser instruction manual).

**Maximal Voluntary Contraction (MVC):** MVC was assessed using an isokinetic dynamometer (Kin-Com, Chattecx Corporation, Chattanooga Group, Tennessee, USA). The device was set up according to the manufacturer's recommendations to exercise the knee extensors of the non-dominant leg. Anatomical zero was set at a knee angle of 0° (full extension) and MVC was determined by setting the joint angle at 70° of flexion and then locked in place and marked to ensure consistency during subsequent testing sessions. Prior to the commencement of each test the limb weight and moment acting upon the dynamometer power head were corrected for gravity. Each repetition lasted 3 s interspersed with 60 s rest, the peak torque generated from three trials was recorded as the MVC.

**Delayed Onset Muscle Soreness (DOMS):** Subjects rated muscle soreness whilst standing and during a 90° squat movement (DOMS-SQ) using a 200 mm visual analogue scale (VAS) with the far-left end point representing 'no pain' (0) and the far-right end point representing 'extremely painful' (200) (Howatson et al., 2007).

**Knee Flexion - Range of Motion (ROM):** For the measurement of knee flexion ROM, subjects laid prone on a massage bed with both knees fully extended. From this position subjects were asked to fully flex their non-dominant knee. The knee joint angle was determined by using a goniometer (Bodycare Products, Warwickshire, UK) and universal landmarks (lateral epicondyle of the femur, lateral malleolus and greater trochanter) to ensure alignment (Tokmakidis et al., 2003). Landmarks were marked with a semi permanent pen to ensure consistency

on subsequent measures, 3 measurements were performed and the average was reported.

**Swelling: thigh circumference:** An anthropometric tape measure (Bodycare Products, Warwickshire, UK) was used to determine thigh circumference. Mid-thigh circumference was determined mid-way between the greater trochanter and the lateral epicondyle of the femur. The site on the subject's non-dominant leg was measured three times and the averages were reported. The skin was marked with a semi permanent marker for consistency on subsequent days.

### Statistical analysis

The CK data were log transformed and values for ROM, swelling and MVC were normalised and expressed as a percentage change relative to baseline. Difference in the measured variables among conditions and trials were analyzed with two-way ANOVA for repeated measures (Treatment, 2 x Time, 5), using treatment as the between subject factor and time as the within-subjects factors. Data were analysed using SPSS for Windows (15.0 software package) and significance was set at  $p \leq 0.05$ .

### Results

Values for CK, MVC, DOMS, DOMS-SQ and thigh circumference showed significant time effects ( $p \leq 0.01$ ), although there were no interaction or group effect ( $p \geq 0.05$ ), baseline data for both conditions are shown in Table 1.

In both groups, CK activity peaked 24 h post-exercise and returned to baseline values by 96 h post-exercise (Figure 1). Difference between the groups were approaching significance ( $F_{1,16} = 4.16$ ,  $p = 0.058$ ). No differences were found between conditions in MVC ( $F_{1,16} = 0.08$ ,  $P = 0.783$ ) and the peak percentage decrement immediately post-exercise from baseline measures for the control and cryotherapy group was 81% and 78% respec-

tively (Figure 2). Muscle soreness peaked 48 h post-exercise and returned to baseline levels by 96 h post-exercise, soreness during a 90° squat movement followed the same time course (Figure 3 and 4). Muscle soreness in a static position and muscle soreness during a squat movement did not significantly differ between groups. ROM did not significantly change over time and was not significantly different between the 2 groups. An increase was shown in thigh circumference for both groups (Figure 5) although differences between the conditions were not significant ( $p \geq 0.05$ ).

**Table 1.** Values for all normalised dependent variables prior to the damaging exercise bout. Data are means ( $\pm$ SD).

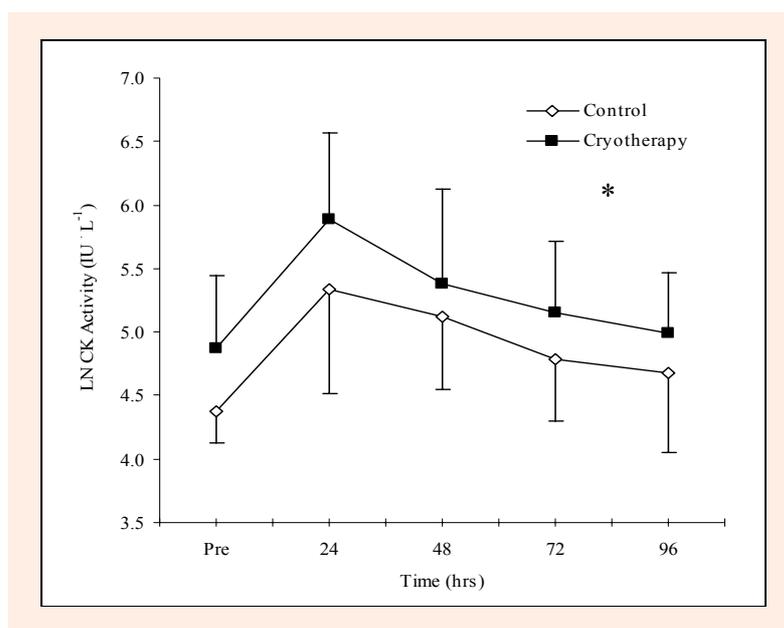
Dependent Variables	Pre-exercise values	
	Control	Cryotherapy
MVC (N·m)	806 (109)	813 (184)
CK (IU·L <sup>-1</sup> )	81.5 (21.7)	151.6 (89.3)
ROM (°)	126 (10)	129 (7)
TC (cm)	55.1 (7.1)	54.8 (3.7)

MVC, maximal voluntary contraction; CK, creatine kinase; ROM, range of motion; TC, Thigh Circumference.

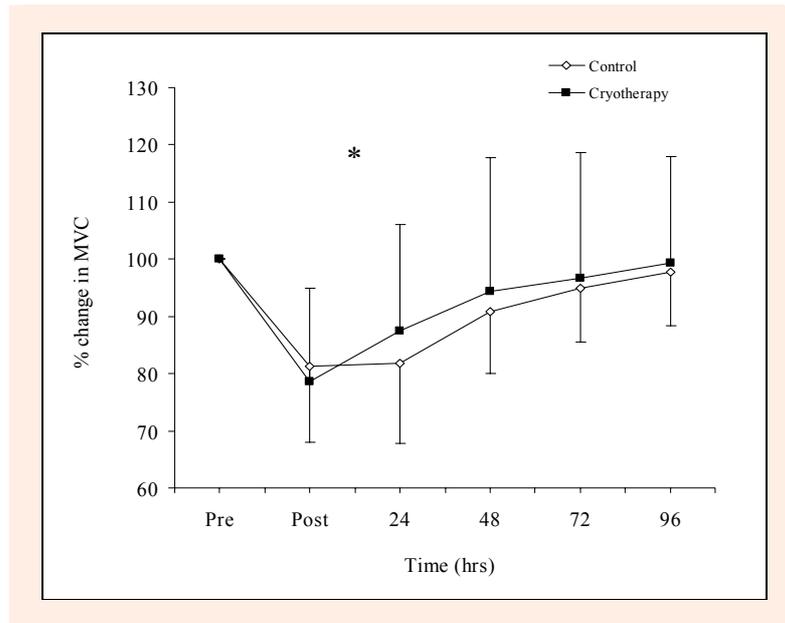
### Discussion

This investigation examined the efficacy of repeated CWI in enhancing recovery from EIMD. This is the first investigation to examine the effects of serial CWI on the recovery from a sport specific bout of heavy plyometric exercise. The results clearly demonstrate that repeated CWI did not significantly enhance the recovery process following damaging exercise to a greater extent than an experimental control. These findings add to a growing body of literature that demonstrates cryotherapy to be an ineffective strategy when recovering from EIMD (Howatson and van Someren, 2003; Howatson et al., 2005; Isabell et al., 1992; Sellwood et al., 2007).

The exercise bout was successful in inducing muscle damage, which was evident from the significant



**Figure 1.** CK activity for the control and cryotherapy groups after the damaging bout of exercise. Values are expressed in natural log and are mean  $\pm$  s. \* Indicates a significant time effect.

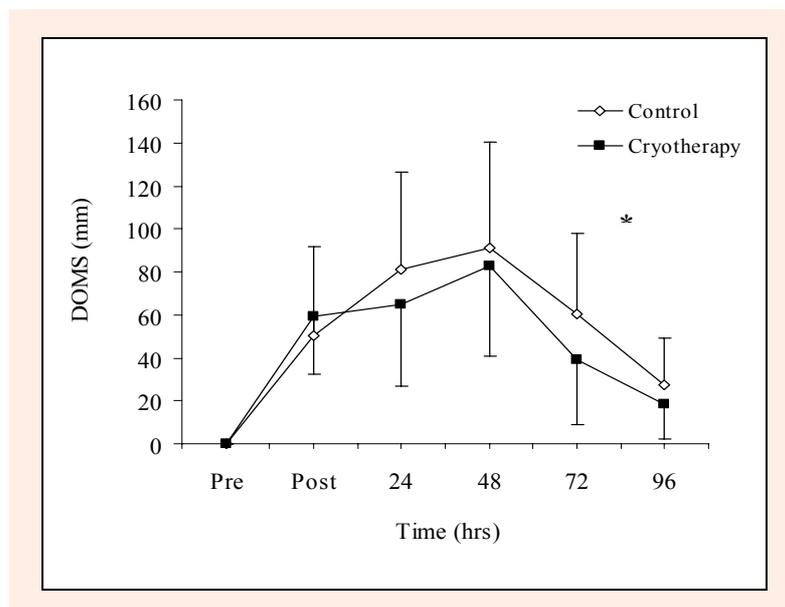


**Figure 2.** Percentage change in isometric force for the control and cryotherapy groups after the damaging bout of exercise (mean  $\pm$  s). \* Indicates a significant time effect.

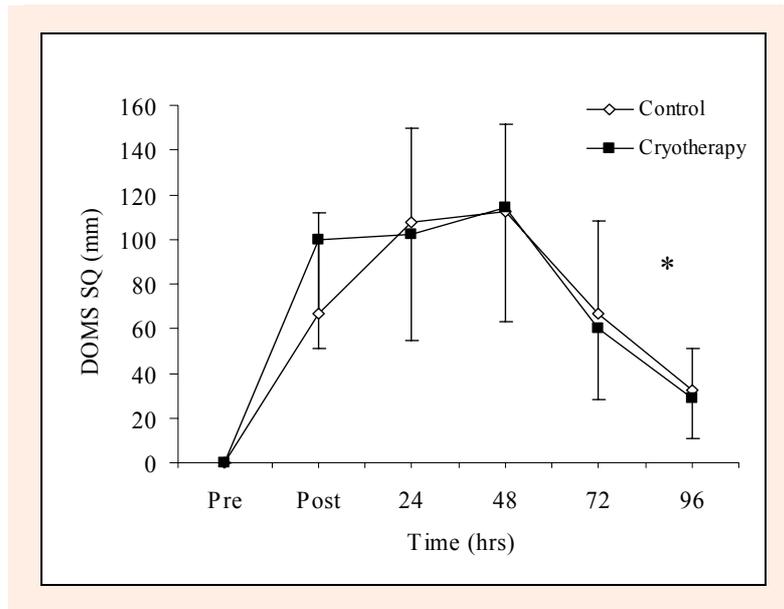
change of dependent variables and concurs with previous literature that reported similar trends following a like mode of exercise (Miyama and Nosaka, 2004b). Of particular note is muscle soreness peaking at 48h post-exercise and MVC, which showed a large decline immediately post-exercise and a general recovery towards pre-exercise levels in the subsequent 96h and concur with other previous literature (Isabell et al., 1992; Eston and Peters, 1999; Miyama and Nosaka, 2004a; 2004b; Howatson et al., 2007). Intracellular release of CK has been used as an indirect marker of EIMD for many years (Manfredi et al., 1991; Howatson et al., 2005). The CK response in this investigation peaked at 24h post-exercise, which is the same response as previous data using a similar protocol to induce damage (Miyama and Nosaka, 2004a; 2004b). It would appear that other lower limb exercise

such as downhill running (Eston et al., 1995) also follows a similar trend to this investigation. However, most CK responses following damaging eccentric exercise in the upper limb tend to be slightly more delayed and peak 24 h later (Howatson et al., 2007; Nosaka et al., 2002); although the reason for this is unclear (Miyama and Nosaka, 2004a), it may be speculated that the upper limb is more unaccustomed to eccentric loading and hence has a greater susceptibility to damage than the lower limb; consequently CK is more delayed and of a greater magnitude in the upper limb (Jamurtas et al., 2005).

Cryotherapy is documented to constrict capillaries, reduce capillary permeability and blood flow (Meeusen and Lievens, 1986) thereby attenuating swelling and the inflammatory response (Smith, 1991) which may reduce the negative effects associated with damaging exercise.



**Figure 3.** Muscle soreness for the control and cryotherapy groups after the damaging bout of exercise (mean  $\pm$  s). \* Indicates a significant time effect.



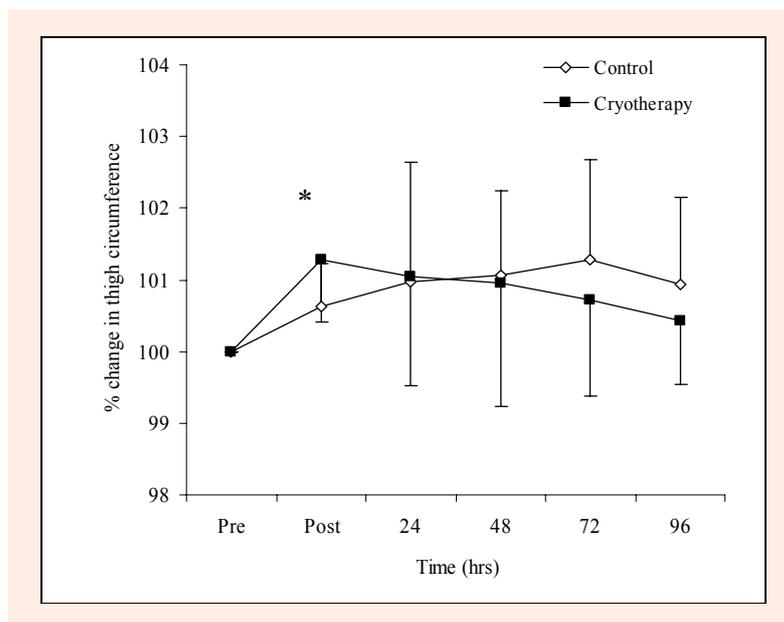
**Figure 4.** Muscle soreness during a squat for the control and cryotherapy groups after the damaging bout of exercise (mean ± s). \* Indicates a significant time effect.

Limb girth showed no discernable difference between groups and consequently provided indirect evidence that the intervention was unsuccessful in bringing about these vascular changes, a result that has been demonstrated elsewhere (Sellwood et al., 2007). In addition, cryotherapy has been speculated to reduce membrane permeability, thereby reducing CK efflux (Eston and Peters, 1999) and alter nerve conduction velocity and hence pain tolerance (Algaflly and George, 2007), however, these changes were not observed in this investigation.

Contrary to the positive effects that have been found in some studies (summarised by Wilcock et al., 2006), the repeated applications of cryotherapy that were administered in the present study did not enhance the recovery of any dependent variable. These findings concur with a number of other cryotherapy investigations

(Isabell et al., 1992; Howatson et al., 2005). Perhaps a positive point is that the immersions do not seem to have a detrimental effect on recovery, although the impact on adaptation or repeated bout effect has yet to be elucidated. It is important to note that some aspects of fatigue, not measured in this study, may have improved as an effect of the CWI, which may include psychological benefits.

Another factor that has the ability to affect the intramuscular cooling from cryotherapy is the amount of adipose tissue (particularly subcutaneous) in the area being cooled (Merrick et al., 1999). Myrer et al. (2001) found a significant inverse relationship between overlying adipose tissue and intramuscular temperature changes during and after cryotherapy treatment of the calf muscle at different skin fold thicknesses (<8 mm, 10-18 mm and >20 mm). Myrer and colleagues (2001) concluded that the



**Figure 5.** Percentage change in thigh circumference for the control and cryotherapy groups after the damaging bout of exercise (mean ± s). \* Indicates a significant time effect.

greater amount of adipose thickness lead to a greater amount of time for maximum cooling to be obtained. This is further emphasised by the results of Otte et al. (2002), who displayed dramatic effects of skin fold thickness on cooling rates of the anterior thigh. Skin fold thickness of 20 mm or less required 20 min cooling, whereas skinfolds of 20-30 mm required 38 min and skinfolds of 30-40 mm required 59 min to decrease intramuscular temperature 7 °C from baseline. Although these skin fold thicknesses are quite large in comparison to active populations, like those used in this investigation, the observations of Otte et al. (2002) and Myrer et al. (2001) highlight the importance of determining skin fold thickness when administering cryotherapy treatments, something future investigations might like to consider.

## Conclusion

In conclusion, this investigation addressed limitations associated with previous research, such as exercise external validity and CWI frequency. Despite this, CWI did not enhance recovery from EIMD; athletes who use CWI as a recovery strategy after heavy eccentric exercise should be aware of the growing body of research demonstrating no effect. It could be speculated that a more aggressive regimen should be employed, whereby the frequency, duration or temperature of the immersions could be altered, however there is then a danger of making such an intervention of limited value to athletic populations if the treatment is too time consuming or logistically difficult to carry out. Further research should examine the influence of manipulating the aforementioned variables to examine the potential value of CWI.

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### Key points

- Cryotherapy, particularly cold water immersions are one of the most common interventions used in order to enhance recovery post-exercise.
- There is little empirical evidence demonstrating benefits from cold water immersions. Research evidence is equivocal, probably due to methodological inconsistencies.
- Our results show that the cryotherapy administered did not attenuate any markers of EIMD or enhance the recovery of function.
- We conclude that repeated cold water immersions are ineffective in the recovery from heavy plyometric exercise and suggest athletes and coaches should use caution before using this intervention as a recovery strategy

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