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Original paper

Effect of water immersion methods on post-exercise recovery from simulated team sport exercise

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Abstract

This study aimed to compare the efficacy of hot/cold contrast water immersion (CWI), cold-water immersion (COLD) and no recovery treatment (control) as post-exercise recovery methods following exhaustive simulated team sports exercise. Repeated sprint ability, strength, muscle soreness and inflammatory markers were measured across the 48-h post-exercise period. Eleven male team-sport athletes completed three 3-day testing trials, each separated by 2 weeks. On day 1, baseline measures of performance (10 m × 20 m sprints and isometric strength of quadriceps, hamstrings and hip flexors) were recorded. Participants then performed 80 min of simulated team sports exercise followed by a 20-m shuttle run test to exhaustion. Upon completion of the exercise, and 24 h later, participants performed one of the post-exercise recovery procedures for 15 min. At 48 h post-exercise, the performance tests were repeated. Blood samples and muscle soreness ratings were taken before and immediately after post-exercise, and at 24 h and 48 h post-exercise. In comparison to the control and CWI treatments, COLD 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-h post-exercise period. COLD also facilitated a more rapid return to baseline repeated sprint performances. The only benefit of CWI over control was a significant reduction in muscle soreness 24 h post-exercise. This study demonstrated that COLD following exhaustive simulated team sports exercise offers greater recovery benefits than CWI or control treatments.

Keywords: Creatine kinase; c-Reactive protein; Sprints; Strength

1. Introduction

Exhaustive training and competition can potentially fatigue the musculoskeletal, nervous and metabolic systems, as well as produce delayed onset muscle soreness (DOMS). Subsequent performance may then be compromised. To maintain peak performance, coaches and athletes often use post-exercise recovery techniques to reduce recovery time. Currently, cold-water immersion (COLD) is commonly undertaken by athletes following strenuous exercise to promote recovery, diminish muscle soreness and to hasten a return to optimal performance capabilities.[1] However, despite evidence for cryotherapy/COLD to lessen the inflammatory response,[2] its effect on DOMS or performance is equivocal.[2–5]

Contrast water immersion (CWI), the repeated alternation of cryotherapy and thermotherapy, has a long history of use in sports medicine for managing oedema, and inflammation from injury.[1,6,7] However, in recent times, CWI has become popular as a post-exercise recovery method.[1,8–12] Benefits associated with CWI may be linked to changes in intra-muscular hydrostatic pressure by alternating vasoconstriction and vasodilation, which may alter blood flow in immersed musculature and improve lactate removal.[11] However, similar to COLD, evidence for CWI to reduce DOMS and to attenuate the detrimental effects of exercise on subsequent performance is equivocal. Coffey et al. [8] and Dawson et al.[9] found no performance benefits from CWI at 4 h and 48 h post-exercise after treadmill running and team game exercise, respectively. Conversely, Vaile et al. [11] and Kuligowski et al. [10] reported a more rapid return to baseline performance measures following CWI in the 24–72 h after isolated eccentric muscle exercise. Differences between studies most

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likely related to varying immersion times (15 min [8,9,11] *vs.* 24 min[10]), different exercise protocols (treadmill running[8], team game,[9] eccentric exercises of the legs[11] and elbows[10]), as well as different performance measures (noted above).

Given the potential detrimental impact that intense training and competition can have on athletic well-being, effective post-exercise recovery procedures are vital for optimal performance. While many elite sporting teams use COLD and/or CWI as post-exercise recovery modalities, there is limited data available regarding their impact on subsequent performance. Further, most studies examining post-exercise recovery modalities have induced muscle damage using eccentric exercise,[2–5,10,11] rather than exercise simulating the dynamic multi-joint patterns of movement typically used during team sports. Therefore, the aim of this study was to determine the efficacy of both COLD and CWI as recovery methods in the 48 h period following simulated team sport exercise. It was hypothesised that COLD and CWI would be superior recovery methods compared to a control condition and that there would be no significant differences between COLD and CWI.

2. Methods

Eleven male athletes (mean ± S.D. for age, height and body mass are 27.5 ± 6.0 years; 178.3 ± 6.1 cm and 76.0 ± 6.1 kg, respectively), with team games experience, volunteered for this study. All participants signed an informed consent form, and the study was approved by the Human Ethics Committee of The University of Western Australia (UWA).

3. Experimental overview

All participants performed a full familiarisation of the performance tests and exercise protocol 2 weeks prior to study commencement. Additionally, reliability trials were performed for each performance variable. Before all performance tests, a 12 min warm-up of jogging, sprinting and static stretching was performed. Subjects were given specific instructions that aimed to keep exercise intensity during this warm-up period the same, both over time and between subjects. The repeated sprint test comprised 10 m × 20 m sprints (10 m forward, then back), performed every 25 s. Sprint times were recorded using electronic timing gates (School of Human Movement and Exercise Science, UWA, Australia). Best single 20 m sprint time, total time for 10 sprints, and percent decrement from ideal total time were calculated. Typical error (TE) and coefficient of variation (CV) were 0.11 s, 2.3%; 0.90 s, 1.8%; and 1.1% and 36.1%, respectively. Three maximal voluntary isometric contractions of the quadriceps, hamstring and hip flexor muscle groups, each lasting 3 s, were also assessed (dominant leg) using a cable tensiometer. A calibration formula specific to the tensiometer was used to obtain a force output in kilograms (kgf). The best single score for each muscle group was used for analysis. Leg extension, leg flexion and hip flexion TE and CV values were 8.4 kgf, 11.4%; 4.4 kgf, 8.2%; and 3.6 kgf, 6.1%, respectively. Performance test order was kept the same throughout all testing, which was performed in an indoor gymnasium. The tests were performed immediately prior to the simulated team game exercise protocol, and again 48 h post-exercise.

Participants then completed the protocol (as described by Bishop et al. [13]) consisting of 4 min × 20 min quarters of intermittent running (each separated by 5 min of recovery) on three separate occasions, performed at the same time of the day (±1 h), with each trial separated by 2 weeks. Prior to starting, participants jogged five laps of the circuit as a further warm-up. Ratings of perceived exertion (RPE: 6–20) were taken at the end of each quarter.[14] Upon completion of this protocol, participants had a 5-min rest then commenced level 7 of the 20-m shuttle run test, continuing until unable to keep pace with the audio beeps, to ensure maximum exhaustion. The final level achieved during the first trial was used as a benchmark score and was not exceeded in later trials to ensure inter-trial consistency.

Self-ratings of muscle soreness (10-point Likert scale) of the quadriceps and blood markers of muscle damage (CK) and inflammation (c-reactive protein: CRP) were measured immediately before the performance tests, as well as immediately after the exercise protocol and 24 h and 48 h later. Resting venous blood samples were taken after 18 min of standing to control for any postural-induced changes in plasma volume. Blood was analysed for haemoglobin concentration and haematocrit using a Beckman Coulter GEN.S. system (CV < 0.8%) to determine the percentage changes in plasma volume, based on the method of Dill and Costill.[15] Creatine kinase levels were determined using a Roche Creatine Kinase assay based on the IFCC method (CV = 0.5%), while CRP levels were measured using a Roche CRPLX particle-enhanced immunoturbidimetric assay kit (CV = 1.8%).

After the exercise protocol and again 24 h post-exercise, the participants performed one of three recovery procedures (randomly assigned) for 15 min. These were CWI, COLD or a control (no treatment) condition. The experimental design was counterbalanced to minimise any impact of adaptation to the exercise protocol on the results. Immersion for both water conditions was to each participant's umbilicus. The CWI protocol consisted of alternating 2 min immersions in tanks of cold (10 °C) or warm/hot water (40 °C), repeated three times (30 s transfer time). Cold-water (10 °C) immersion consisted of 2 min × 5 min immersions, separated by 2.5 min sitting upright at room temperature (22 °C). The control condition consisted of participants sitting quietly for 15 min. No additional exercise or recovery procedures were performed in the 48-h post-exercise period.

4. Data analysis

All data were analysed using the Statistical Package for Social Sciences (SPSS) Version 13.0 (SPSS Inc., Chicago, IL) for Windows and alpha was set at $p < 0.05$. Results between recovery conditions were analysed using a one-way ANOVA with repeated measures, with Fisher's LSD being used for post hoc analysis. Paired sample *t*-tests were used to analyse pre and 48 h post-exercise performance scores within each recovery condition. Cohen's effect sizes (ES) were also calculated for all data using the control condition's S.D. Only effect sizes greater than 0.4 (moderate to large effects) are reported. Pearson product–moment correlation coefficients were also calculated between selected variables.

5. Results

All results are expressed as mean ± S.D. Dry bulb temperature and relative humidity recorded for each exercise session were 19.8 ± 1.5 °C and 41 ± 12%, respectively.

During the simulated team game protocol, RPE scores revealed a significant main effect for time ($p = 0.000$). Values increased from 15 ± 1 after the first quarter of the exercise protocol to 19 ± 1 after the shuttle run, indicating near maximal exhaustion.

Muscle soreness ratings were significantly higher than baseline immediately after exercise, as well as 24 h and 48 h post-exercise (Table 1). While no significant differences existed between any of the recovery conditions immediately after and 48 h post-exercise, 24 h post-exercise values were lowest after COLD, being significantly different ($p < 0.05$) from both CWI and control conditions. Muscle soreness scores 24 h after CWI were also significantly lower ($p < 0.05$) compared to control. Large effect sizes were calculated 24 h post-exercise between control and CWI (0.81) and control and COLD (1.48), while a moderate effect size was recorded between the CWI and COLD conditions (0.60), with COLD recording the lowest ratings. At 48 h post-exercise, moderate effect sizes were recorded between control and CWI (0.63) and CWI and COLD (0.48), with COLD again recording the lowest ratings.

Pre-exercise total sprint times were not different between the three conditions. At 48 h post-exercise, these times were significantly slower ($p < 0.05$) than baseline values after control and CWI (Table 2), while conversely, total sprint time was slightly, but not significantly faster after COLD (0.23 s). Differences in total sprint times recorded prior to exercise and 48 h post-exercise, as well as percentage differences, were also significantly less after COLD compared to CWI and control (Table 2). Large effect sizes were calculated for the differences in performance decrement between control and COLD (−1.49) and COLD and CWI (−1.56). Best sprint times recorded 48 h post-exercise were significantly slower ($p < 0.05$) than baseline after control, and differences between pre and 48 h post-exercise scores, as well as percentage differences, were significantly smaller after COLD compared to control (Table 2). Moderate effect sizes were observed for the differences in best sprint time recorded pre-exercise and 48 h post-exercise for the control (−0.50) and the CWI conditions (−0.41), as well as for the percentage differences between control and COLD (−0.65), and between CWI and COLD (−0.61).

There were no significant differences between recovery conditions for any of the isometric strength measures. However, significant ($p < 0.05$) strength losses were recorded 48 h post-exercise for leg extension and flexion after the control and CWI conditions, but not after COLD (Table 2). Moderate to strong effect sizes existed for the differences in leg extension and flexion strength recorded pre-exercise and 48 h post-exercise between control and COLD (−0.55 and 0.70, respectively), as well as between CWI and COLD

Table 1
Muscle soreness rated on a 10-point Likert scale, serum creatine kinase and serum c-reactive protein concentrations recorded prior to and immediately after exercise and 24 h and 48 h post-exercise ($n = 11$) (mean ± S.D.)

	Pre-exercise	Post-exercise	24 h post-exercise	48 h post-exercise
Muscle soreness				
Control	1 ± 0	7 ± 2[a]	5 ± 1[a]	5 ± 1[a]
CWI	1 ± 0	7 ± 2[a]	4 ± 1[a,b]	4 ± 1[a]
COLD	1 ± 0	7 ± 2[a]	3 ± 1[a,b,c]	3 ± 1[a,b]
Serum CK ($U L^{-1}$)				
Control	166 ± 75	410 ± 200[a]	681 ± 720[a]	391 ± 436[a]
CWI	172 ± 108	344 ± 161[a]	582 ± 357[a]	332 ± 168[a]
COLD	158 ± 59	315 ± 135[a]	571 ± 375[a]	337 ± 218[a]
Serum CRP ($mg L^{-1}$)				
Control	0.5 ± 0.3	0.6 ± .03	2.9 ± 1.7[a]	1.6 ± 1.0[a]
CWI	0.6 ± 0.4	0.6 ± 0.4	3.3 ± 3.8[a]	2.6 ± 2.6[a]
COLD	0.6 ± 0.4	0.7 ± 0.8	2.5 ± 1.7[a]	1.4 ± 0.8[a]

CWI = contrast temperature water immersion. COLD = cold-water immersion.
[a] Values are significantly different from pre values ($p < 0.05$).
[b] Values are significantly different from control values ($p < 0.05$).
[c] Values are significantly different from CWI values ($p < 0.05$).

Table 2
Best sprint time over 20 m, total time taken to complete 10 m × 20 m sprints and isometric force output for leg extension, leg flexion and hip flexion prior to and immediately after exercise, as well as 48 h post-exercise ($n = 11$) (mean ± S.D.)

Measure	Treatment	Pre-exercise	48 h Post-exercise	Pre–post difference	Pre–post % difference
Total sprint time (s)	Control	47.93 ± 1.39	48.29 ± 1.25	0.36 ± 0.54	0.75 ± 1.14
	CWI	47.31 ± 1.57	47.80 ± 1.38	0.49 ± 0.43	1.02 ± 0.91
	COLD	48.45 ± 1.92	48.22 ± 1.82	−0.23 ± 0.78[b,c]	−0.50 ± 1.14[b,c]
Best sprint time (s)	Control	4.59 ± 0.17	4.67 ± 0.14[a]	0.08 ± 0.10	1.69 ± 2.26
	CWI	4.57 ± 0.17	4.64 ± 0.16	0.07 ± 0.12	1.33 ± 2.89
	COLD	4.67 ± 0.21	4.67 ± 0.19	−0.00 ± 0.10[b]	−0.03 ± 2.26[b]
Leg extension (kgf)	Control	76.4 ± 13.9	72.2 ± 10.7[a]	−4.2 ± 5.8	−5.2 ± 8.6
	CWI	76.4 ± 13.6	70.9 ± 13.1[a]	−6.3 ± 5.3	−9.5 ± 8.1
	COLD	74.6 ± 19.1	73.4 ± 18.5	−1.2 ± 8.4	−2.3 ± 10.0
Leg flexion (kgf)	Control	56.8 ± 11.8	52.7 ± 10.7[a]	−4.3 ± 4.8	−8.4 ± 8.1
	CWI	57.4 ± 8.5	52.4 ± 8.5[a]	−4.7 ± 3.0	−9.5 ± 6.6
	COLD	55.9 ± 13.6	55.3 ± 15.9	−0.5 ± 6.0	−.20 ± 8.2
Hip flexion (kgf)	Control	66.7 ± 7.4	60.7 ± 9.0[a]	−6.2 ± 4.7	−11.3 ± 8.1
	CWI	69.7 ± 9.6	60.8 ± 11.0[a]	−7.0 ± 9.1	−11.8 ± 9.6
	COLD	69.6 ± 10.6	63.7 ± 9.9[a]	−5.9 ± 5.3	−9.6 ± 8.8

CWI = contrast temperature water immersion. COLD = cold-water immersion.
[a] Values are significantly different from pre values ($p < 0.05$).
[b] Values are significantly different from control values ($p < 0.05$).
[c] Values are significantly different from CWI values ($p < 0.05$).

(0.90 and 1.02, respectively). In addition, a strong effect size was recorded between control and CWI for leg extension strength (1.00). In all cases, COLD resulted in lower decrements. Hip flexion strength recorded pre-exercise and 48 h post-exercise showed significant decrements after all three recovery conditions (Table 2). Moderate to strong effect sizes were recorded for differences in scores recorded pre-exercise and 48 h post-exercise for control (0.82), CWI (0.92) and COLD (0.55).

Serum CK and CRP increased significantly in the 48-h post-exercise period in all recovery conditions, peaking at 24 h post-exercise (Table 1). No significant differences were found in CK or CRP between the three recovery conditions at any time point (Table 1).

Finally, using pooled recovery data ($n = 32$), no significant relationships immediately after exercise or 24 h and 48 h post-exercise were found between CK and muscle soreness ($r = 0.12$, 0.07 and 0.04, respectively), or between CRP and muscle soreness ($r = -0.14$, −0.21 and 0.30, respectively).

6. Discussion

This study assessed the effects of CWI and COLD on recovery of athletic performance and indicators of exercise-induced muscle damage following exhaustive simulated team game exercise. Importantly, the intensity and duration of the exercise used here induced acute muscle soreness and damage, as evidenced by significantly greater muscle soreness (7 ± 2), and plasma CK levels (131% increase) immediately and 24 h post-exercise.

The results demonstrated COLD to be a superior recovery modality when compared to CWI and control conditions. Significantly lower muscle soreness ratings for COLD, than either control or CWI conditions, were found at 24 h ($p < 0.05$) and 48 h post-exercise (control only). Additionally, only after COLD were best sprint and total sprint times at 48 h similar to baseline values. Further, leg strength recorded 48 h post-exercise was similar to baseline values for leg extension and flexion after COLD, whereas significant decrements were recorded for control and CWI conditions. However, COLD had little influence on hip flexion strength with all recovery conditions recording significant decrements at 48 h post-exercise.

Although no significant differences between recovery conditions for markers of muscle damage (CK) and inflammation (CRP) were found, results did demonstrate smaller elevations in these measures after COLD. This most likely reflects COLD's ability to reduce the inflammatory response and consequent secondary muscle damage. Of interest, the CK efflux here was similar to that reported in previous studies examining muscle damage following simulated or actual team sports exercise.[16,17] Further, plasma concentrations of CK and CRP were not significantly correlated to either muscle soreness or performance capabilities in this study. This outcome supports recent literature which has questioned whether CK levels accurately quantify the severity of DOMS.[3,17,18] In fact, Warren et al. [18] suggested that maximal voluntary force generating capacity is a more relevant marker of muscle damage than CK concentrations, a contention also supported by Morton et al. [19] The results of the present study support this finding, with COLD facilitating a more rapid return to baseline isometric leg extension and flexion force values than CWI or control treatments, despite no significant differences occurring in CK or CRP levels between the three recovery conditions.

Currently, there is substantial evidence supporting COLD as a means of ameliorating the inflammatory response.[3,5,20,21] Cryotherapy has been shown to reduce cell necrosis, oedema and neutrophil migration, as well as slow cell metabolism and nerve conduction velocity, which in turn reduces secondary muscle damage.[3,5,12,20,21] As COLD is widely accepted as an effective treatment for acute soft tissue injury,[7,21] it has some logical value as a recovery technique in field settings where players experience direct contact muscle trauma, as well as contraction-induced trauma that typically results in DOMS. Further, the recovery benefits of COLD found here are most likely due to water temperature rather than pressure, as CWI involved a slightly longer hydrostatic pressure stimulus.

In comparison to COLD, CWI demonstrated little recovery benefit other than a slight reduction in muscle soreness 24 h post-exercise. In fact, for some performance measures, the decrement in scores recorded 48 h post-exercise was greater after CWI than after control. The inability of CWI to facilitate a more rapid return to baseline performance here is consistent with previous studies that also found no significant post-exercise recovery benefits to be associated with CWI.[8,9] Conversely, Vaile et al. [11] reported CWI being associated with smaller strength losses, decreased muscle soreness and reduced muscle swelling following muscle damaging (eccentric) exercise. They proposed that the benefits observed may have been mediated by warm water promoting vasodilation, which improved immune function by increasing antioxidant and antibody supply, while cold water promoted vasoconstriction, reducing swelling and myocellular necrosis. It was also suggested that varying water temperatures could induce rapid changes in muscle perfusion (a 'pumping effect'), which could enhance recovery by promoting lactate and waste removal. However, for any of these physiological benefits to take place, substantial changes in muscle tissue temperature must occur,[7] with previous research into CWI being unable to elicit any significant changes in deep tissue temperature.[6,7] Muscle temperature was not assessed during any of the recovery protocols in this study. Another limitation to this study was that variables were only assessed over a 48-h period rather than a longer period where differences in some measures may have become more evident.

7. Conclusion

It was concluded that COLD was superior to both CWI and control treatments as a post-exercise recovery procedure following exhaustive team game exercise.

Practical implications

For the 48 h recovery of muscle soreness, repeat sprint ability and leg strength, COLD may be more effective than CWI or no recovery treatment following exhaustive team sport exercise.

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