**Title of the article:** The effect of cold (14 °C) versus ice (5°C) water immersion on recovery from intermittent running exercise
Abstract

The purpose was to compare 14°C (CWI14°C) and 5°C (CWI5°C) cold water immersion following intermittent running. On three occasions, nine male team-sport players undertook 12 min of CWI14°C, CWI5°C or non-immersed seated recovery (CON) following 45 min of intermittent running exercise. Maximal cycling performance and markers of recovery were measured before and in the 0 – 72 h after exercise. Peak power output (PPO) was immediately reduced following all interventions ($d = 1.8$). CWI5°C was more effective at restoring PPO than CWI14°C ($d = 0.38$) and CON ($d = 0.28$) 24 h post-exercise while both CON ($d = 0.20$) and CWI5 ($d = 0.37$) were more effective than CWI14°C after 48 h. CWI was more effective than CON at restoring PPO 72 h post-exercise ($d = 0.28 – 0.30$). Mean power output (MPO) was higher in CON compared to CWI5°C ($d = 0.30$) and CWI14°C ($d = 0.21$) but there was no difference between CWI5°C and CWI14°C ($d = 0.08$). CWI5°C was more effective than CWI14°C for restoring MPO to baseline levels 24 h ($d = 0.28$) and 72 h ($d = 0.28$) post-exercise; however, CON was more, or equally, effective as CWI5°C and CWI14°C throughout. Lactate and creatine kinase concentrations were unaffected. Perceived muscle soreness remained elevated in CWI5 and CON throughout but was similar to baseline in CWI14°C after 72 h. In conclusion, repeated bouts of exercise are initially impaired following 5°C and 14°C CWI, but PPO may be improved 72 h post-exercise. CWI is not recommended for acute recovery based on these data. Athletes and coaches should use the time currently allocated to CWI for more effective, alternative recovery modalities.

Key Words: muscle damage; cryotherapy; ice bath
INTRODUCTION

Following training or competition, athletes use a range of interventions in an attempt to minimise the negative effects of demanding exercise and to optimize recovery and adaptation. One widely used intervention is post-exercise cold water immersion (CWI) (22,38). Although CWI is commonly used, the proposed mechanism(s) of benefit remain unclear (18) and data regarding the effectiveness of CWI are equivocal. Some studies report benefits (20,22,29,32,36,37,44), some suggest little or no effect (13,17,23,27,29,34), and some suggest that CWI may even impair recovery (10,26,40,42). Recent meta-analyses concluded that CWI had a moderate beneficial effect on alleviating delayed-onset muscle soreness at 24 h (Hedges’ $g = 0.4 – 0.7$), 48 h (Hedges’ $g = 0.6$), 72 h (Hedges’ $g = 0.2 – 0.6$) and 96 h (Hedges’ $g = 0.6 – 0.7$) post exercise (16,22,24) and on improving the rate of recovery of muscle power post-exercise (Hedges’ $g = 0.6$) (22). However, despite moderate benefits for these variables, these meta-analyses concluded that CWI only has a trivial or small effect on reducing the efflux of creatine kinase (Hedges’ $g < 0.1 – 0.2$) (16,22), reducing lactate (Hedges’ $g = 0.3$) (16), and improving the rate of recovery of strength (Hedges’ $g = 0.1$) following exercise (22).

Water temperatures used for CWI range from 5°C (44) to 20°C (36) with 75% of studies using 10 – 15°C (3). Recently, water temperatures of 5 – 10°C and 11 – 15°C have been termed “severe” and “moderate” respectively (24). It has been speculated that moderate CWI may be optimal (38) but mixed data have been reported for both CWI approaches (13-15,19,20,24,26-29,31,34,36,42,43). Limited studies have directly investigated the effect of CWI using different water temperatures with equivocal data reported from those that have. No difference was observed in subsequent cycling performance following immersion in water at 10, 15 or 20°C (36), yet water at 14°C has been shown to be preferable to 5°C immersion when administered.
between two bouts of running (44). Both trials were conducted in warm conditions (34°C and 27°C respectively) and so the data may not be applicable to temperate conditions. In temperate conditions (21°C) strength, maximal peak force and maximal power are immediately reduced by CWI (33,39) and the reduction in maximal peak force and power is approximately 3 – 6% per 1°C fall in muscle temperature (9,33). The impairment in maximal power production is improved more rapidly following 15°C CWI compared to 5°C CWI and control; however, strength impairments are not improved by moderate or severe CWI in the 168 h following exercise (39).

If effective, a rapid reduction in tissue temperature during and following CWI is often considered the most likely mechanism of benefit (6); however, it has been proposed that hydrostatic pressure from immersion in water of any temperature may offer a physiological and performance benefit (23,41). In addition, recent data have suggested that the benefits of CWI may actually be at least partly placebo related (5). Broatch et al. (5) compared CWI (~10°C) to two thermoneutral (~35°C) water immersion conditions, one of which involved informing the participants that the intervention was “as effective” as CWI. In the CWI trial, muscle temperature was reduced (-9.5%) and leg strength, ratings of readiness for exercise, pain, and vigour were improved compared to the control thermoneutral trial suggesting a beneficial effect of CWI; however, performance and perceptual data were similar between the CWI trial and the thermoneutral trial with the false information regarding effectiveness. These data suggest that the hypothesized benefits of CWI may actually be somewhat independent of water pressure or temperature.
Clearly the optimal water temperature for CWI remains to be established and recent reviews have highlighted the need to systematically investigate the effect of CWI using water of different temperatures on exercise performance and recovery in temperate conditions (24,38). The aim of the present study was to directly address this shortcoming in the literature by comparing CWI interventions using 5°C and 14°C. Based upon recent reviews (16,22,24,38) it was hypothesised that both CWI interventions would be more effective than no-immersion and that the 14°C CWI would be more effective than the 5°C trial.

METHODS

Experimental approach to the problem

This study was designed to compare the effect of moderate (14°C) and severe (5°C) cold water immersion following intermittent running on subsequent high-intensity exercise and markers of recovery. Nine male recreational team sport players underwent a full familiarisation trial (during which they completed a full run-through without CWI) followed by three experimental trials separated by at least 7 days and conducted in a randomised, counterbalanced order. Subjects completed a 45 min intermittent running protocol on a motorised treadmill (ELG70, Woodway, Weiss, Germany) followed by one of three 12 min seated recovery interventions; moderately cold water immersion (14 ± 1°C; CWI14°C), severely cold water immersion (5 ± 1°C; CWI5°C) or non-immersion (CON). Laboratory temperature and relative humidity were 18 ± 3°C and 54 ± 12% respectively. In order to examine the effectiveness of severe and moderate CWI on recovery, measures of muscle function, blood lactate and creatine kinase (CK), and perceived muscle soreness were measured. All variables were measured before (following 10 min of seated rest), immediately after the intermittent exercise bout, immediately after each recovery intervention, and at 24, 48, and 72 h post exercise. Participants were
required to abstain from any vigorous physical exercise and any therapeutic treatments for the
duration of testing and from any physical activity at all for the 24 h prior to each trial. Water
was consumed ad-libitum throughout all trials. Participants arrived > 2 h post-prandial having
consumed a self-standardized diet for the previous 24 h (diet was recorded for the 24 h prior to
the 1st experimental trial and then repeated for the 24 h prior to the subsequent trials) and after
consuming 500ml of water 2 h prior to testing.

Subjects

Nine male recreational team sport players (mean ± SD, age: 24 ± 2 years; stature: 1.78 ± 0.09
m; body mass: 77.6 ± 14.2 kg) completed a health history questionnaire (2) and provided
written, informed consent prior to testing. Subjects were informed of the benefits and risks of
the investigation prior to signing an institutionally approved informed consent document to
participate in the study. The study was approved by the University’s Ethical Advisory
Committee. No subjects were under the age of 18 years of age.

Procedures

Intermittent running protocol

A standardised 5 min walking warm-up (6 km h⁻¹) was completed before commencement of
the intermittent running protocol (11). The protocol comprised of 1 min bouts of walking (6
km h⁻¹), jogging (12 km h⁻¹), cruising (15 km h⁻¹) and sprinting (18 km h⁻¹) and was performed
with one alteration from the original Drust et al. (11) protocol - the sprint speed was reduced
from 21 km h⁻¹ to 18 km h⁻¹ following issues with completion identified in pilot testing. The
protocol lasted 21 minutes and was completed twice with a 3 min standing rest in between each
21 min bout. Peak and mean heart rate (HR) (model S625X Heart Rate Monitor, Polar,
Kempele, Finland) and ratings of perceived exertion (RPE) (4) were recorded at 5 min intervals throughout the exercise protocol.

**Water Immersion**

On completion of the intermittent running protocol, exercise performance, blood sampling and perceptual measures were immediately recorded (total assessment duration < 5 min) before participants completed a randomly assigned 12 min recovery condition (CWI5, CWI14 or CON). Each recovery condition took place in a standard bath tub (1700 x 700 x 440 mm). Water temperature was continuously monitored using a digital thermometer (212-130, RS Products, Texas, USA) and target temperatures (5 ± 1°C and 14 ± 1°C) were achieved by the addition of ice to cold tap water. Participants remained seated and motionless ensuring that the iliac crest was fully submerged during immersion trials. Both immersion conditions provided hydrostatic pressure of approximately 39.56 hPa (hydrostatic pressure = ambient pressure [standard sea level ~ 1013 hPa] + (gravity [9.81 m/s^2] x water density [1000 kg/m^2] * immersion depth [0.3 m])) (41). Rectal temperature (T_{re}) was monitored and recorded at 30 s intervals during immersion using a flexible rectal thermistor (DigiTec 401, DigiTec Corporation, Lancaster, USA) inserted ~10 cm beyond the anal sphincter and attached to a digital recording device (Thermistor Thermometer 5831, DigiTec corporation, Lancaster, USA).

**Peak power cycling test performance**

Peak and mean power output (PPO and MPO respectively) were assessed using a 10 s peak power cycling test performed on a cycle ergometer (Monark Ergomedic 874E, Varberg,
Sweden). Following a 30 s bout of free pedalling and build up to maximum cadence, participants continued to pedal as fast and hard as possible for 10 s against a resistive load equal to 10% of body mass. Preceding all 10 s peak power cycling tests, participants completed a 5 min submaximal (50 – 100 W) cycling warm-up. The cycling test was performed before, and immediately after the intermittent exercise bout, immediately after each recovery intervention, and at 24, 48, and 72 h post-exercise.

Lactate, creatine kinase, and perceived muscle soreness

To determine blood lactate and CK concentrations, aliquots of blood were obtained from a finger-prick sample. Blood lactate was directly analysed using an automated analyser (2300 STAT plus, Yellow Springs Instruments Inc., Ohio, USA) in duplicate. A 32 µl sample of blood was pipetted onto a CK Test Strip (Reflotron® Plus, Roche Diagnostics, UK) and analysed in duplicate using a commercially available Reflotron CK Assay (Reflotron® Plus, Roche Diagnostics, UK). Self-ratings of perceived quadriceps muscle soreness were assessed using a 10 point scale ranging from 1 (not sore) to 10 (very, very sore) (35) while the participants stood.

Statistical Analyses

Parametric data are reported as mean ± standard deviation (SD) whereas non-parametric data are reported as median (range). Repeated-measures analysis of variance (ANOVA) and Cohen’s $d$ effect sizes were used to compare changes in blood lactate, CK and exercise performance over time and between conditions. Post hoc analyses were conducted on significant $F$-ratios with Bonferonni corrections applied for multiple comparisons. Greenhouse-Geisser corrections were applied when the assumption of sphericity had been
violated (ε < 0.75 for all such instances). One-way repeated measures ANOVA tests and Cohen’s $d$ effect sizes were used to evaluate differences in mean and peak HR. Friedman’s ANOVA and Wilcoxon signed-rank tests were run for non-parametric perceptual data from which effect sizes ($r$) were calculated. All analyses are $N = 9$ unless stated. Statistical significance was set at $P < 0.05$. Secondary analysis was performed on the performance data normalising the change in PPO and MPO to baseline (smaller difference = faster recovery) and these data were compared using Cohen’s d effect sizes. The likelihood that the true value of the effect represents a worthwhile change was assessed using the following thresholds: $d < 0.2$ = trivial effect; 0.2 - 0.5 = small effect; 0.5 - 0.8 = moderate effect and $> 0.8$ = large effect, and $r = < 0.1$ = trivial effect; 0.1 - 0.3 = small effect; 0.3 - 0.5 = moderate effect and 0.5 - 0.7 = large effect, $> 0.7$ = very large effect (8).

RESULTS

Responses to the intermittent running protocol and immersion

By design, the intermittent running protocol elicited similar physiological and perceptual responses in all three trials ($P > 0.05$ for all) (Table 1).

Table 1 about here

Peak power cycling test performance

Power output data are shown in Table 2. There was no significant difference between conditions ($F = 1.3, P = 0.31$) for PPO nor was there a significant condition x time interaction
(F = 0.4, P = 0.93) but there was a significant main effect of time (F = 6.3, P < 0.01). PPO was lower post-recovery compared to baseline (P = 0.02, d = 1.75) but there were no other differences at any time-point. Table 3 contains data comparing the magnitude of change relative to baseline as an index of recovery for each trial. Performance was impaired in both immersion trials compared to CON immediately following the intervention. CWI5°C was more effective at restoring PPO than CWI14°C (d = 0.38) and CON (d = 0.28) 24 h post exercise while 48 h post both CON (d = 0.20) and CWI5°C (d = 0.37) were more effective than CWI14°C. PPO was greater following both immersion conditions compared to CON (d = 0.28 – 0.30) 72 h after exercise.

There was a significant main effect of trial for MPO (F = 8.8, P < 0.01). MPO was higher in CON compared to CWI5°C (P = 0.04; d = 0.30) and CWI14°C (P = 0.04; d = 0.21) but there was no difference between CWI5°C and CWI14°C (P = 0.47; d = 0.08). There was no significant main effect for time (F = 3.9, P = 0.05) or trial x time interaction (F = 0.9, P = 0.52). Data expressed as the magnitude of change relative to baseline measures (Table 3) shows that immediately following the intervention MPO was reduced to the greatest extent in CWI5°C and to the least extent in CON. CON was more than, or equally effective as CWI5°C and CWI14°C at every time point post-exercise for attenuating the reduction in MPO. CWI5°C was more effective than CWI14°C at 24 h (d = 0.28) and 72 h (d = 0.28) post-exercise for restoring MPO.

Table 2 and 3 about here

**Blood lactate, creatine kinase, and muscle soreness**
There was no main effect of trial for lactate ($F = 0.2, P = 0.84$) or creatine kinase data ($F = 0.2, P = 0.82$) nor was there a trial x time interaction for either variable (Lactate: $F = 1.0, P = 0.44$; Creatine kinase: $F = 0.9, P = 0.51$). There was a significant main effect for time for both variables ($P < 0.01$). Lactate concentrations peaked post-exercise ($P < 0.001; d = 1.83$) and although there was no statistical difference after 24 h ($P = 0.014$), concentrations were elevated at all time-points compared to baseline ($P = 0.23 – 0.99; d = 0.59 – 1.83$). Creatine kinase concentrations were higher than baseline at all time-points ($d = 0.30 – 1.58$), although only statistically 24 h ($P = 0.025$), 48 h ($P = 0.001$), and 72 h ($P = 0.006$) post exercise, peaking 48 h post-exercise ($d = 1.58$) (Table 2). There was no main effect of trial for muscle soreness ($P = 0.89$), but soreness changed over time ($P < 0.01$). Muscle soreness was elevated above baseline following exercise in all trials ($P = 0.007 – 0.017; r = 0.80 – 0.89$;) and it remained elevated in all trials 24 ($P = 0.007 – 0.034; r = 0.65 – 0.90$) and 48 h ($P = 0.007 – 0.027; r = 0.74 – 0.90$) post-exercise. Muscle soreness remained higher than baseline measurements in CWI5 ($P = 0.03$) and CON ($P = 0.01$) throughout but was not statistically higher than baseline in CWI14 ($r = 0.37; P = 0.27$) after 72 h.

**DISCUSSION**

The present study is the first to systematically investigate the effect of CWI using water of different temperatures compared to non-immersion on recovery following intermittent running exercise in temperate conditions. Contrary to our hypotheses, compared to CON, MPO was impaired by both CWI interventions at all time-points following exercise. CWI5°C had a small ($d = 0.28$) effect of improving PPO recovery 24 and 72 h post-exercise meaning that if an athlete is required to perform short-duration explosive actions in the 72 h post-exercise a severe CWI intervention may be beneficial. CWI5°C was more effective than CWI14°C for restoring
PPO and MPO to baseline levels offering support for the use of severe, rather than moderate, CWI if such an intervention is utilised. Neither CWI intervention affected lactate, CK, or perceived muscle soreness in the 48 h after exercise.

The effect of CWI on subsequent exercise performance

Peak and mean power output were impaired to a greater extent in both water immersion trials compared to CON immediately following the intervention. The immediate impairment in MPO was more pronounced in the CWI5°C trial and this may have been due to a greater initial reduction in muscle temperature to sub-optimal physiological levels (1,9,30). Muscle temperature was not measured in the present study, but previous data have shown that shorter-duration (5 min) immersion in cold water (14°C) can lower muscle temperature by ~1.3°C (29). Muscle temperature may have been reduced to a greater extent by the colder (5°C) and/or longer (12 min) CWI in the present study although the warm-up may have prevented such reductions from occurring. Reductions in muscle temperature can lower nerve velocity conduction (1) and delay action potential generation (30) and a negative relationship between muscle temperature and explosive exercise performance is well-documented. There is a 3 – 6% reduction in contractile force for every 1°C reduction in muscle temperature (9,33) and 15 min of moderate CWI (12 – 14°C) can reduce power output by ~6% when exercise is performed shortly after CWI (10). As with the immediate post-exercise data, no immersion (CON) was equally or more effective than CWI in attenuating reductions in PPO and MPO at most time-points (Table 3) in the present study; however, in contrast to the immediate response, PPO was more effectively restored by CWI5°C than CWI14°C 24 and 48 h post-exercise and by CWI5°C than CON 24 and 72 h post-exercise. The present study is the first to observe such benefits. Recently, it was reported that neither 5°C nor 15°C CWI following repeated drop-jumping
improved muscle strength recovery in the 168 h following exercise but that 15°C was more effective than 5°C CWI for the recovery of counter-movement jump performance (39). The delayed benefit of CWI reported in the present study and elsewhere (39) suggests that the benefits of CWI might only be observed ~1 – 3 days after exercise. Such a delay may limit the practical application of the intervention and the data highlight that it is vital to consider timing, duration and temperature of water immersion to avoid impairing subsequent high-intensity exercise performance.

**The effect of CWI on physiological markers of recovery**

It has been proposed that CWI may accelerate the removal of metabolites following exercise with the hydrostatic pressure and cold-induced peripheral vasoconstriction working symbiotically to increase the central blood pressure and osmotic gradient facilitating metabolite efflux (18). Although these symbiotic responses may improve metabolite removal (which may or may not be beneficial (25)), muscle blood flow is reduced by CWI (7) and this is likely to be detrimental to recovery. In the present study, the intermittent exercise bout markedly increased blood lactate and CK concentrations in all conditions; however, CWI had no effect on post-exercise clearance. Similar results have been reported previously (15,44) and align with recent meta-analyses which reported that CWI has a trivial-small effect on reducing lactate (Hedges’ $g < 0.3$) (16) and CK (Hedges’ $g < 0.1 – 0.2$) (16,22) efflux in to the blood post-exercise. It has been proposed that efflux rates may be sensitive to blood flow changes (22) and although regional blood flow was not measured in the present study it is likely that blood flow disturbances were greater in CWI$_5$ than CWI$_{14}$ and in both CWI trials compared to CON (7). Despite the likelihood that blood flow was reduced to the greatest extent in CWI$_5$ there were
no differences in CK concentrations between trials and so it appears that CWI of any
temperature is ineffective at altering the rate or magnitude of metabolite removal.

The effect of CWI on perceived muscle soreness

Peak muscle soreness is often observed in the 24 – 48 h period after exercise (22) and in the
present study peak muscle soreness was observed 48 h after exercise in all groups. Recent meta-
analyses reported that CWI has a small to moderate beneficial effect on alleviating delayed-
onset muscle soreness at 24, 48, 72 and 96 h (Hedges’ $g = 0.2 – 0.7$) post exercise (16,22,24);
however, in the present study CWI had a negligible effect on perceived muscle soreness.
Perceived muscle soreness remained higher than baseline in CWI$_{5°C}$ and CON throughout and
did not return to baseline in any of the three trials - data similar to that recently reported by
Vieira et al. (39) - but returned to values similar to those observed at baseline in CWI$_{14°C}$ 72 h
after exercise. The activation of group III and IV muscle nociceptive afferent neurons (12) and
TRPM8 receptors (21) is thought to explain the cold-induced reductions in perceived pain;
however, despite both CWI trials being sufficiently cold to activate these receptors an
improvement in perceived muscle soreness was not observed in the present study. A recent
review suggested that moderate CWI is preferable for the reduction of muscle soreness
following exercise (24) but the current study does not support the use of either severe or
moderate CWI for the reduction in perceived muscle soreness in the first 72 hours following
exercise.

PRACTICAL APPLICATIONS
Effective recovery from competition or training is sought by athletes to minimise the negative effects on future performance. Post-exercise CWI is a commonly used “recovery intervention”; however, data regarding the effectiveness of CWI are equivocal and the optimal approach is unknown due to methodological differences. The present study directly investigated one such variation - the temperature of the water used – and found that neither severe (5°C) nor moderate (14°C) cold water immersion offer much of an additional benefit to non-immersed seated rest. MPO is unaffected while PPO may be improved by severe CWI in the 24 – 72 h post-exercise and by moderate CWI only 72 h post-exercise. Athletes and coaches should take note of the present data when deciding on the most effective use of their recovery time and may wish to use the time currently allocated to CWI for more effective alternative recovery modalities.

Conclusion

In conclusion, neither 5°C nor 14°C CWI provided an additional benefit to recovery from a bout of intermittent running exercise compared with passive, seated rest (CON) for MPO. CWI_{5°C} was better than CWI_{14°C} at restoring PPO 24 and 48 h post-exercise and more effective than CON 24 and 72 h post exercise. These performance data were observed without meaningful changes in physiological or perceptual markers of recovery in the 48 h following exercise.

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Table headings

Table 1. Physiological and perceptual responses to the intermittent running protocol.

Table 2. Peak power output, mean power output, lactate, creatine kinase, and perceived muscle soreness at baseline, post-exercise, post-intervention, 24 h post-exercise, 48 h post exercise, and 72 h post-exercise.

Table 3. The magnitude of change, relative to baseline, for peak power output and mean power output immediately, 24 h, 48 h, and 72 h post intermittent running exercise.