Effect of Cold (14° C) vs. Ice (5° C) Water Immersion on Recovery From Intermittent Running Exercise

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Abstract

Anderson, D, Nunn, J, and Tyler, CJ. Effect of cold (14° C) vs. ice (5° C) water immersion on recovery from intermittent running exercise. *J Strength Cond Res* 32(3): 764–771, 2018–The purpose was to compare 14° C ($CWI_{14° C}$) and 5° C ($CWI_{5° C}$) cold water immersion after intermittent running. On 3 occasions, 9 male team-sport players undertook 12 minutes of $CWI_{14° C}$, $CWI_{5° C}$, or nonimmersed seated recovery (CON) after 45 minutes of intermittent running exercise. Maximal cycling performance and markers of recovery were measured before and in the 0–72 hours after exercise. Peak power output (PPO) was immediately reduced after all interventions ($d = 1.8$). $CWI_{5° C}$ was more effective at restoring PPO than $CWI_{14° C}$ ($d = 0.38$) and CON ($d = 0.28$) 24 hours after exercise, whereas both CON ($d = 0.20$) and CWI_5 ($d = 0.37$) were more effective than $CWI_{14° C}$ after 48 hours. Cold water immersion (CWI) was more effective than CON at restoring PPO 72 hours after exercise ($d = 0.28–0.30$). Mean power output (MPO) was higher in CON compared with $CWI_{5° C}$ ($d = 0.30$) and $CWI_{14° C}$ ($d = 0.21$), but there was no difference between $CWI_{5° C}$ and $CWI_{14° C}$ ($d = 0.08$). $CWI_{5° C}$ was more effective than $CWI_{14° C}$ for restoring MPO to baseline levels 24 hours ($d = 0.28$) and 72 hours ($d = 0.28$) after exercise; however, CON was more, or equally, effective as $CWI_{5° C}$ and $CWI_{14° C}$ throughout. Lactate and creatine kinase concentrations were unaffected. Perceived muscle soreness remained elevated in CWI_5 and CON throughout but was similar to baseline in $CWI_{14° C}$ after 72 hours. In conclusion, repeated bouts of exercise are initially impaired after 5 and 14° C CWI, but PPO may be improved 72 hours after exercise. Cold water immersion is not recommended for acute recovery based on these data. Athletes and coaches should use the time currently allocated to CWI for more effective and alternative recovery modalities.

Key Words muscle damage, cryotherapy, ice bath

Introduction

After training or competition, athletes use a range of interventions in an attempt to minimize the negative effects of demanding exercise and to optimize recovery and adaptation. One widely used intervention is postexercise 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 hours (Hedges' g = 0.4–0.7), 48 hours (Hedges' g = 0.6), 72 hours (Hedges' g = 0.2–0.6), and 96 hours (Hedges' g = 0.6–0.7) after exercise (16,22,24) and on improving the rate of recovery of muscle power after 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) after exercise (22).

Water temperatures used for CWI range from 5 (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 after 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 2 bouts of running (44). Both trials were conducted in warm conditions (34 and 27° C, respectively) and so the data may

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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 after 15° C CWI compared with 5° C CWI and control; however, strength impairments are not improved by moderate or severe CWI in the 168 hours after exercise (39).

If effective, a rapid reduction in tissue temperature during and after 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) with 2 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 and ratings of readiness for exercise, pain, and vigor were improved compared with 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 this study was to directly address this shortcoming in the literature by comparing CWI interventions using 5 and 14° C. Based on recent reviews (16,22,24,38), it was hypothesized 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) CWI after intermittent running on subsequent high-intensity exercise and markers of recovery. Nine male recreational team-sport players underwent a full familiarization trial (during which they completed a full run-through without CWI) followed by 3 experimental trials separated by at least 7 days and conducted in a randomized, counterbalanced order. Subjects completed a 45-minute intermittent running protocol on a motorized treadmill (ELG70; Woodway, Weiss, Germany) followed by one of the three 12-minute seated recovery interventions: moderate CWI (14 ± 1° C; $CWI_{14° C}$), severe CWI (5 ± 1° C; $CWI_{5° C}$), or nonimmersion (CON). Laboratory temperature and relative humidity were 18 ± 3° C and 54 ± 12%, respectively. 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 (after 10 minutes of seated rest), immediately after the intermittent exercise bout, immediately after each recovery intervention, and at 24, 48, and 72 hours after 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 hours before each trial. Water was consumed ad-libitum throughout all trials. Participants arrived >2 hours after prandial having consumed a self-standardized diet for the previous 24 hours (diet was recorded for the 24 hours before the first experimental trial and then repeated for the 24 hours before the subsequent trials) and after consuming 500 ml of water 2 hours before testing.

Subjects

Nine male recreational team-sport players (mean ± *SD*, age:Range = 21–27 years; 24 ± 2 years; stature: 1.78 ± 0.09 m; and body mass: 77.6 ± 14.2 kg) completed a health history questionnaire (2) and provided written, informed consent before testing. Subjects were informed of the benefits and risks of the investigation before signing an institutionally approved informed consent document to participate in the study. The study was approved by the University of Roehampton's Ethical Advisory Committee. No subjects were under the age of 18 years.

Procedures

Intermittent Running Protocol. A standardized 5-minute walking warm-up (6 $km \cdot h^{-1}$) was completed before commencement of the intermittent running protocol (11). The protocol composed of 1-minute bouts of walking (6 $km \cdot h^{-1}$), jogging (12 $km \cdot h^{-1}$), cruising (15 $km \cdot h^{-1}$), and sprinting (18 $km \cdot h^{-1}$) and was performed with one alteration from the original Drust et al. (11) protocol–the sprint speed was reduced from 21 to 18 $km \cdot h^{-1}$ after issues with completion identified in pilot testing. The protocol lasted for 21 minutes and was completed twice with a 3-minute standing rest in between each 21-minute bout. Peak and mean heart rate (HR) (model S625X Heart Rate Monitor; Polar, Kempele, Finland) and ratings of perceived exertion (4) were recorded at 5-minute 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 minutes) before participants completed a randomly assigned 12-minute recovery condition (CWI_5, CWI_{14}, or CON). Each recovery condition took place in a standard bath tub (1,700 × 700 × 440 mm). Water temperature was continuously monitored using a digital thermometer (212-130; RS Products, Fort Worth, TX, USA),

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

	Mean HR ($b\cdot min^{-1}$)	HRmax ($b\cdot min^{-1}$)	Median RPE	ΔMS	ΔT_r (° C)
Main Effect (Trial)	$p = 0.87$	$p = 0.88$	$p = 0.48$	$p = 0.56$	$p = 0.37$
$CWI_{5° C}$	165 ± 10	188 ± 8	13 (12–15)	2.5 (2.0–4.0)	0.8 ± 0.2
$CWI_{14° C}$	164 ± 8	189 ± 6	14 (13–15)	2.5 (1.3–3.8)	0.8 ± 0.3
CON	165 ± 7	190 ± 8	13 (12–15)	2.5 (1.0–4.0)	0.8 ± 0.2

*HR = heart rate; RPE = rating of perceived exertion (6–20); MS = muscle soreness (1–10); T_r = rectal temperature; CWI = cold water immersion; CON = control.

and target temperatures (5 ± 1 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 ~1,013 hPa) + (gravity [9.81 $m\cdot s^{-2}$] × water density [1,000 $kg\cdot m^{-2}$] × immersion depth [0.3 m])} (41). Rectal temperature (T_{re}) was monitored and recorded at 30-second intervals during immersion using a flexible rectal thermistor (DigiTec 401; DigiTec Corporation, Lancaster, PA, USA) inserted ~10 cm beyond the anal sphincter and attached to a digital recording device (Thermistor Thermometer 5831; DigiTec Corporation).

Peak Power Cycling Test Performance. Peak power output (PPO) and mean power output (MPO) were assessed using a 10-second peak power cycling test performed on a cycle ergometer (Monark Ergomedic 874E; Monark, Varberg, Sweden). After a 30-second bout of free pedaling and build up to maximum cadence, participants continued to pedal as fast and hard as possible for 10 seconds against a resistive load equal to 10% of body mass. Preceding all 10-second peak power cycling tests, participants completed a 5-minute 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 hours after 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 analyzed using an automated analyzer (2300 STAT plus; Yellow Springs Instruments, Inc., Yellow Springs, OH, USA) in duplicate. A 32-μl sample of blood was pipetted onto a CK Test Strip (Reflotron Plus; Roche Diagnostics, Burgess Hill, United Kingdom) and analyzed in duplicate using a commercially available Reflotron CK Assay (Reflotron Plus; Roche Diagnostics, Burgess Hill, 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 ± *SD*, whereas nonparametric 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 ($\varepsilon < 0.75$ 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 ANOVA and Wilcoxon signed-rank tests were run for nonparametric perceptual data from which effect sizes (*r*) were calculated. All analyses are $N = 9$ unless stated. Statistical significance was set at $p \leq 0.05$. Secondary analysis was performed on the performance data normalizing 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 that 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; 0.5–0.7 = large effect; and > 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 3 trials ($P > 0.05$ for all) (Table 1).

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 × time

Table 2. Peak power output, mean power output, lactate, creatine kinase, and perceived muscle soreness at baseline, postexercise, postintervention, 24-hour postexercise, 48-hour postexercise, and 72-hour postexercise.*

	Baseline	Postexercise	Postrecovery	24-h post	48-h post	72-h post
Peak power output (W)						
CON	1,063 ± 209	1,038 ± 179	964 ± 190†	967 ± 132	982 ± 142	980 ± 151
$CWI_{5°C}$	1,020 ± 152	1,016 ± 161	894 ± 201†	974 ± 161	952 ± 132	974 ± 171
$CWI_{14°C}$	1,029 ± 199	1,007 ± 168	889 ± 218†	935 ± 137	914 ± 142	998 ± 124
Mean power output (W)						
CON	905 ± 143	893 ± 133	857 ± 197	875 ± 146	869 ± 185	872 ± 144
$CWI_{5°C}$	896 ± 155	881 ± 164	749 ± 200	849 ± 140	808 ± 117	857 ± 211
$CWI_{14°C}$	882 ± 158	866 ± 169	784 ± 200	812 ± 176	791 ± 147	815 ± 144
Lactate ($mmol \cdot L^{-1}$)						
CON	0.8 ± 0.2	4.6 ± 1.2‡	3.1 ± 2.1†	1.0 ± 0.3†	1.0 ± 0.2	1.0 ± 0.1
$CWI_{5°C}$	0.9 ± 0.3	5.3 ± 1.3‡	2.6 ± 0.8†	1.1 ± 0.3†	1.1 ± 0.3	0.9 ± 0.1
$CWI_{14°C}$	0.8 ± 0.3	5.0 ± 1.3‡	2.5 ± 1.0†	1.2 ± 0.3†	1.0 ± 0.1	0.9 ± 0.1
Creatine kinase ($IU \cdot L^{-1}$)						
CON	189 ± 85	284 ± 156	281 ± 142	546 ± 294†	572 ± 172†	463 ± 97†
$CWI_{5°C}$	248 ± 165	402 ± 188	305 ± 283	486 ± 209†	624 ± 142†	426 ± 153†
$CWI_{14°C}$	274 ± 146	391 ± 177	286 ± 127	478 ± 238†	699 ± 149†	348 ± 94†
Muscle soreness (1 [not sore]–10 [very, very sore])						
CON	2 (0–3)	4 (1–6)†	3 (1–5)‡	5 (3–8)‡	6 (3–6)‡	3 (1–6)†
$CWI_{5°C}$	2 (1–5)	5 (3–7)‡	3 (1–5)†	5 (1–7)†	5 (1–8)‡	4 (1–7)†
$CWI_{14°C}$	2 (0–5)	5 (1–9)‡	3 (1–5)†	4 (1–6)†	5 (3–7)†	3 (1–6)

*CWI = cold water immersion; CON = control.
†$p \leq 0.05$.
‡$p < 0.01$ compared to baseline (output from post hoc tests for main effect time).

interaction ($F = 0.4$, $p = 0.93$), but there was a significant main effect of time ($F = 6.3$, $p < 0.01$). Peak power output was lower after recovery compared with 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 with CON immediately after the intervention. $CWI_{5°C}$ was more effective at restoring PPO than $CWI_{14°C}$ ($d = 0.38$) and CON ($d = 0.28$) 24 hours after exercise, whereas 48 hours after both CON ($d = 0.20$) and $CWI_{5°C}$ ($d = 0.37$) were more effective than $CWI_{14°C}$. Peak power output was greater after both immersion conditions compared with CON ($d = 0.28$–0.30) 72 hours after exercise.

There was a significant main effect of trial for MPO ($F = 8.8$, $p < 0.01$). Mean power output was higher in CON compared with $CWI_{5°C}$ ($p = 0.04$; $d = 0.30$) and $CWI_{14°C}$ ($p = 0.04$; $d = 0.21$), but there was no difference between $CWI_{5°C}$ and $CWI_{14°C}$ ($p = 0.47$; $d = 0.08$). There was no significant main effect for time ($F = 3.9$, $p = 0.05$) or trial × time interaction ($F = 0.9$, $p = 0.52$). Data expressed as the magnitude of change relative to baseline measures (Table 3) show that immediately after the intervention, MPO was reduced to the greatest extent in $CWI_{5°C}$ and to the least extent in CON. CON was more than, or equally, effective as $CWI_{5°C}$ and $CWI_{14°C}$ at every time point after exercise for attenuating the reduction in MPO. $CWI_{5°C}$ was more effective than $CWI_{14°C}$ at 24 hours ($d = 0.28$) and 72 hours ($d = 0.28$) after exercise for restoring MPO.

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 × 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 after exercise ($p < 0.001$; $d = 1.83$), and although there was no statistical difference after 24 hours ($p = 0.014$), concentrations were elevated at all time points compared with 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 hours ($p = 0.025$), 48 hours ($p = 0.001$), and 72 hours ($p = 0.006$) after exercise, peaking 48 hours after

TABLE 3. The magnitude of change, relative to baseline, for peak power output, and mean power output immediately, 24, 48, and 72 hours after intermittent running exercise.*†

	PPO			MPO		
Baseline vs.	$CWI_{14°C}$ vs. CON	$CWI_{5°C}$ vs. CON	$CWI_{5°C}$ vs. $CWI_{14°C}$	$CWI_{14°C}$ vs. CON	$CWI_{5°C}$ vs. CON	$CWI_{5°C}$ vs. $CWI_{14°C}$
Postrecovery						
Mean difference (W)	−42 ± 127	−27 ± 138	14 ± 90	−50 ± 88	−96 ± 96	−50 ± 91
Effect size (*d*)	−0.33	−0.20	0.16	−0.57	−1.03	−0.55
Effect magnitude	Small	Small	Trivial	Moderate	Large	Moderate
Most effective	CON	CON	–	CON	CON	$CWI_{14°C}$
24-h post						
Mean difference (W)	−2 ± 148	49 ± 138	47 ± 124	−41 ± 84	−18 ± 78	23 ± 83
Effect size (*d*)	−0.01	0.28	0.38	−0.48	−0.23	0.28
Effect magnitude	Trivial	Small	Small	Small	Small	Small
Most effective	–	$CWI_{5°C}$	$CWI_{5°C}$	CON	CON	$CWI_{5°C}$
48-h post						
Mean difference (W)	−34 ± 172	12 ± 168	47 ± 126	−56 ± 98	−53 ± 114	3 ± 98
Effect size (*d*)	−0.20	0.08	0.37	−0.57	−0.46	0.03
Effect magnitude	Small	Trivial	Small	Moderate	Small	Trivial
Most effective	CON	–	$CWI_{5°C}$	CON	CON	–
72-h post						
Mean difference (W)	47 ± 155	40 ± 144	−6 ± 116	−43 ± 88	−9 ± 116	34 ± 124
Effect size (*d*)	0.30	0.28	−0.05	−0.49	−0.08	0.28
Effect magnitude	Small	Small	Trivial	Small	Trivial	Small
Most effective	$CWI_{14°C}$	$CWI_{5°C}$	–	CON	–	$CWI_{5°C}$

*PPO = peak power output; MPO = mean power output; CWI = cold water immersion; CON = control.

†$d < 0.2$ = trivial effect; $d = 0.2–0.5$ = small effect; $d = 0.5–0.8$ = moderate effect; and $d > 0.8$ = large effect. Negative difference = a larger reduction compared with baseline in trial listed first.

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 after 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 hours ($p = 0.007$–0.027; $r = 0.74$–0.90) after exercise. Muscle soreness remained higher than baseline measurements in CWI_5 ($p = 0.03$) and CON ($p = 0.01$) throughout but was not statistically higher than baseline in CWI_{14} ($r = 0.37$; $p = 0.27$) after 72 hours.

Discussion

This study is the first to systematically investigate the effect of CWI using water of different temperatures compared with nonimmersion on recovery after intermittent running exercise in temperate conditions. Contrary to our hypotheses, compared with CON, MPO was impaired by both CWI interventions at all time points after exercise. $CWI_{5° C}$ had a small ($d = 0.28$) effect of improving PPO recovery 24 and 72 hours after exercise meaning that if an athlete is required to perform short-duration explosive actions in the 72 hours after exercise a severe CWI intervention may be beneficial. $CWI_{5° C}$ was more effective than $CWI_{14° C}$ for restoring PPO and MPO to baseline levels offering support for the use of severe, rather than moderate, CWI if such an intervention is used. Neither CWI intervention affected lactate and CK nor perceived muscle soreness in the 48 hours after exercise.

Peak power output and MPO were impaired to a greater extent in both water immersion trials compared with CON immediately after the intervention. The immediate impairment in MPO was more pronounced in the $CWI_{5° C}$ trial, and this may have been due to a greater initial reduction in muscle temperature to suboptimal physiological levels (1,9,30). Muscle temperature was not measured in this study, but previous data have shown that shorter duration (5 minutes) 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 longer (12 minutes) CWI in this 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 minutes of moderate CWI (12–14° C) can reduce power output by ~6% when exercise is performed shortly after CWI (10). As with the immediate postexercise 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 this study; however, in contrast to the immediate response, PPO was more effectively restored by $CWI_{5° C}$ than $CWI_{14° C}$ 24 and 48 hours after exercise and by $CWI_{5° C}$ than CON 24 and 72 hours after exercise. This study is the first to observe such benefits. Recently, it was reported that neither 5° C nor 15° C CWI after repeated drop-jumping improved muscle strength recovery in the 168 hours after exercise but that 15° C was more effective than 5° C CWI for the recovery of countermovement jump performance (39). The delayed benefit of CWI reported in this 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.

It has been proposed that CWI may accelerate the removal of metabolites after 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 this study, the intermittent exercise bout markedly increased blood lactate and CK concentrations in all conditions; however, CWI had no effect on postexercise 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 after 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 this study, it is likely that blood flow disturbances were greater in CWI_5 than CWI_{14} and in both CWI trials compared with 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 seems that CWI of any temperature is ineffective at altering the rate or magnitude of metabolite removal.

Peak muscle soreness is often observed in the 24- to 48-hour period after exercise (22), and in this study, peak muscle soreness was observed 48 hours 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 hours (Hedges' $g = 0.2$–0.7) after exercise (16,22,24); however, in this 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 3 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 hours after exercise. The activation of group III and IV muscle nociceptive afferent neurons (12) and TRPM8 receptors (21) is believed 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 this study. A recent review suggested that moderate CWI is preferable for the reduction of muscle soreness after 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 after exercise.

In conclusion, neither 5 nor 14° C CWI provided an additional benefit to recover 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 hours after exercise and more effective than CON 24 and 72 hours after exercise. These performance data were observed without meaningful changes in physiological or perceptual markers of recovery in the 48 hours after exercise.

Practical Applications

Effective recovery from competition or training is sought by athletes to minimize the negative effects on future performance. Postexercise CWI is a commonly used "recovery intervention"; however, data regarding the effectiveness of CWI are equivocal, and the optimal approach is unknown because of methodological differences. This study directly investigated one such variation–the temperature of the water used–and found that neither severe (5° C) nor moderate (14° C) CWI offers much of an additional benefit to nonimmersed seated rest. Mean power output is unaffected, whereas PPO may be improved by severe CWI in the 24–72 hours after exercise and by moderate CWI only 72 hours after exercise. Athletes and coaches should take note of these 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.

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