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Research article

5000 Meter Run Performance is not Enhanced 24 Hrs After an Intense Exercise Bout and Cold Water Immersion

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Abstract
Cold water immersion (CWI) is used by endurance athletes to speed recovery between exercise bouts, but little evidence is available on the effects of CWI on subsequent endurance performance. The purpose of this study was to investigate the effects of CWI following an acute bout of interval training on 5000 m run performance 24 hrs after interval training, perceived muscle soreness (PMS), range of motion (ROM), thigh circumference (TC), and perceived exertion (RPE). Nine endurance-trained males completed 2 trials, each consisting of an interval training session of 8 repetitions of 1200 m at a running pace equal to 75% of VO_2peak, either a control or CWI treatment, and a timed 5000 m run 24 hrs post interval training session. CWI was performed for 12 min at 12 degrees Celsius on the legs. Recovery treatments were performed in a counterbalanced design. Run time for 5000 m was not different between the CWI and control trials (CWI = 1317.33 ± 128.33 sec, control = 1303.44 ± 105.53 sec; p = 0.48). PMS increased significantly from baseline to immediately post exercise (BL = 1.17 ± 0.22, POST = 2.81 ± 0.52; p = 0.02) and remained elevated from baseline to 24 hrs post exercise (POST24 = 2.19 ± 0.32; p = 0.02), but no difference was observed between the treatments. No differences were observed for the interaction between time and treatment for TC (λ = 0.73, p = 0.15) and ROM (λ = 0.49; p = 0.10). CWI performed immediately following an interval training exercise bout did not enhance subsequent 5000 m run performance or reduce PMS. CWI may not provide a recovery or performance advantage when athletes are accustomed to the demands of the prior exercise bout.

Key words: Cryotherapy, running, interval training, recovery, cold water immersion.

Introduction

Athletes training for endurance competitions, especially multi-sport athletes, often participate in multiple training bouts within 24 hrs leaving little time for recovery between exercise sessions. Quick and efficient recovery methods are necessary for athletes to return to physiological readiness before the next exercise bout begins (Barnett, 2006). Cold water immersion (CWI) is commonly used by endurance athletes to speed recovery and attenuate the deleterious effects of muscle damaging or fatiguing exercise (Wilcock et al., 2006b). The analgesic and vasoconstrictive effects of cold temperature combined with the hydrostatic effects of water pressure remove heat from the body, reduce edema and pain by limiting fluid movement, reduce inflammation, and decrease transport time of substrates and metabolic waste (Merrick et al., 1999; Wilcock et al., 2006a).

Despite wide use of CWI, evidence of CWI as an effective recovery technique is contradictory (Leeder et al., 2012). Conflicting findings are a result of differences in methodology. The initial degree and type of exercise insult, duration of treatment, temperature of treatment, frequency of treatment, and time between treatment and performance measure all vary in the literature (Wilcock et al., 2006a; 2006b). CWI as a recovery method is typically used to address reduced performance due to structural damage to muscles that occurs during unaccustomed, eccentric, or prolonged, fatiguing exercise. Research on the use of CWI following primarily eccentric, muscle-damaging exercise is abundant (Eston and Peters, 1999; Goodall and Howatson, 2008; Paddon-Jones and Quigley, 1997; Paschalis et al., 2005; Vaile et al., 2008a; Yanagisawa et al., 2003). Damage to muscle fibers is associated with the movement of intramuscular proteins and enzymes into extracellular spaces (Armstrong et al., 1991; Cheung et al., 2003). Damage impairs muscle structure and function, which may cause pain, swelling, inflammation, and performance limitations, all of which are theoretically improved with CWI (Armstrong et al., 1991; Cheung et al., 2003). While eccentric contractions are particularly damaging, most forms of exercise are not entirely eccentric, but contain both eccentric and concentric muscle actions. Previously, researchers have examined the effects of CWI on muscle injury from eccentric heavy exercises, specifically strength training and plyometric exercises (Jakeman et al., 2009; Paddon-Jones and Quigley, 1997). Additionally, some researchers have used CWI as a recovery method immediately prior to exercise in an attempt to reduce rating of perceived exertion, increase central blood volume, and reduce thermal strain (Dunne et al., 2013; Yeargin et al, 2006). Fewer researchers have examined the effects of CWI on fatigue from intense endurance exercise when the performance measure was 24 hrs or longer after immersion (Brophy-Williams et al., 2011; Lane and Wenger, 2004; Rowsell et al., 2014). Fast twitch, glycolytic fibers are more susceptible to muscle damage and thus, easier to quantify the effects of recovery treatments such as CWI; however, some researchers have documented muscle damage in slow-oxidative muscle fibers following marathon and half-marathon races (Linjen et al., 1988; Lippi et al., 2008; Warhol et al., 1985). While intense endurance exercise may not produce the same degree of muscle damage as eccentric or strength training exercises, muscle soreness and fatigue also necessitate recovery methods to ensure that subsequent performance is maintained.

Previously, researchers reported improved perfor-

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mance on a sprint cycling task after intense exercise and CWI performed 24 hrs prior to the performance measure (Lane and Wenger, 2004). Further, researchers found improved running performance 24 hrs after CWI was used as a recovery treatment from high-intensity running in a thermoneutral environment (Brophy-Williams et al., 2011). Running and cycling performance improvements have also been documented when CWI was performed immediately or shorty prior to the performance measure (Rowsell et al., 2014; Vaile et al., 2008b; Yeargin et al., 2006). Positive effects of CWI were often found when the initial exercise and subsequent performance tests required the same or similar muscular and bioenergetics demands. The use of primarily slow oxidative muscle fibers for both the initial exercise protocol and performance measure are rarely used because of the greater susceptibility of fast, glycolytic fibers to incur damage during exercise, and the use of performance measures that consist of both slow oxidative and fast glycolytic fibers (Friden and Lieber, 1992; Paschalis et al., 2005; Warren et al., 1999). For the best indication of performance impairment or recovery efficacy, performance measurements following the initial exercise protocol and treatment should possess muscle and fiber type specificity relative to the initial exercise protocol (Warren et al., 1999).

The purpose of this study was to examine the effects of CWI on performance and recovery 24 hrs after an acute bout of intense, prolonged interval training. CWI is a popular recovery tool among endurance runners and triathletes who often complete hard training sessions separated by 24 hrs or less. With this study, we attempted to replicate a typical training schedule, which would require fast and effective recovery techniques. A randomized crossover design was used in which participants were tested under each treatment. The interval training was designed to be a prolonged, intense exercise bout, similar to an interval training session for a long- distance runner. Prolonged or intense endurance exercise can cause significant muscle fatigue and possible muscle damage, but are not as well researched as resistance or plyometric exercises which can easily produce a great deal of muscle damage (Linjen et al., 1988; Lippi et al., 2008; Warhol et al., 1985). Because there is some fiber-type specificity to muscle damage and muscular fatigue, it was important that the interval training session and the performance measure used in the present study required similar muscular and bioenergetics demands. The 5000 m run was used because it mimicked the muscular and bioenergetic demands of the interval session and because it is a common race distance. Two major hypotheses were tested. Specifically, that 5000 m run time would improve 24 hrs after an intense interval session and CWI treatment compared to a control (CON) treatment. Further, thigh circumference (TC), joint range of motion (ROM), perceived muscle soreness (PMS), and rating of perceived exertion (RPE) would improve 24 hrs post interval training when participants received the CWI treatment. TC, ROM, PMS, and RPE were measured to easily identify any potential muscle damage or muscular fatigue caused by the interval training.

Methods

Participants

Nine male participants completed the study (mean ± SD; age: 35.89 ± 7.80 years; height: 1.81 ± 0.06 m; weight: 76.53 ± 10.30 kg; percent body fat: 11.35 ± 2.41%; peak VO_2: 67.16 ± 6.49 $ml^{-1}\cdot kg^{-1}\cdot min^{-1}$). The Institutional Review Board of Springfield College approved all procedures. All participants were briefed on the risks of the study and were given the opportunity to ask questions prior to providing written informed consent. The participants were endurance trained long distance runners and triathletes and had been training at their current level for at least 6 months. Participants reported an average of 7 ± 2 endurance training sessions per week for an average of 96 ± 19 min per session. Participants had no history of cardiovascular disease, pulmonary disease, musculoskeletal disorders, cold exposure disorders, diabetes, or other metabolic disorders. All participants were asked to report to testing normally hydrated, but were not required to report food or fluid intake prior to each testing session. Participants were asked to record and replicate dietary intake only between the interval sessions and the 5000 m time trials to control for the potential recovery benefits of dietary macronutrient compositions. Participants were asked to refrain from strenuous exercise and to abstain from caffeine, alcohol, and therapeutic treatments including cryotherapy, massage, and anti-inflammatory medications for 24 hrs prior to each testing session.

Procedures

Preliminary testing

During preliminary testing, the height, weight, and age of each participant were recorded. Body fat percentage was estimated using the sum of 7 site skinfold measurements taken using Lange calipers (Lange, Cambridge, MD) at the chest, mid-axillary, tricep, subscapular, abdomen, suprailliac, and thigh regions according to American College of Sports Medicine (ACSM) testing guidelines (ACSM, 2001). The average of 3 trials was used for each of the 7 sites. Body density was calculated from the 7 measurements, and body fat percentage was estimated from body density (ACSM, 2001). Participants then completed a $VO_{2\,peak}$ test. Participants were fitted with a Polar Heart Rate Monitor (Polar, Kempele, Finland) and a T-shaped 2-way, non-rebreathing valve system (Hans Rudolph, Shawnee, KS) attached to a metabolic testing system (Physio-dyne Max II, Quogue, NY). Participants stood on the treadmill for 5 mins after which baseline HR and VO_2 were recorded. The participants performed a graded exercise test beginning at 2.2 m/s and 0% grade. Every 3 mins, speed was increased by 0.45 m/s until the participants reached 4 m/s at which point the treadmill speed remained constant at 4 m/s and the grade was increased by 2%. Rating of perceived exertion (RPE) and VO_2 were recorded at the completion of each stage of the protocol. The VO_2 value recorded was a breath-by-breath average for the last 1 min of the 3 min stage. The exercise test was terminated if the participant reached volitional fatigue, VO_2 increased less than 150mL with an increase in workload, or if HR rose above 90% of the age predicted maximum (220-age) and the respiratory exchange ratio value was greater than 1.2. Data from the $\dot{V}O_{2peak}$ test were used to calculate the running pace that corresponded to 75% of VO_{2peak}, which was used during subsequent testing sessions.

Experimental trials

For each condition, participants were asked to take part in 2 sessions separated by 24 hrs. During the first session, participants underwent baseline testing for TC and ROM of the ankle, knee, and hip joints. TC was measured with an anthropomorphic measuring tape at 3 sites: 15 cm above the patella, halfway between the patella and the inguinal fold, and at the level of the gluteal fold. A transparent goniometer was used to measure full ROM at each joint. The average of three trials was used for analysis. Hip flexion and extension were measured from the lateral aspect of the hip joint at the greater trochanter of the femur (Norkin and White, 2009). Knee flexion was measured from the lateral epicondyle of the femur. Ankle dorsiflexion and plantarflexion were measured from the lateral aspect of the lateral malleolus of the fibula from a baseline ankle position of 90 degrees (Norkin and White, 2009). The participants were then fitted with a Polar Heart Rate Monitor (Polar, Kempele, Finland). Each participant was asked to stand quietly for 5 mins after which baseline HR was recorded. Participants were familiarized with the 0-10 RPE scale and the 7-point PMS scale used to rate the overall level of muscle soreness in both legs (Vickers, 2001). Baseline measurements were recorded for both scales prior to exercise.

All participants completed a prescribed warm up, which lasted between 15 and 30 mins. After 15 mins of easy running at a self-selected pace, participants completed five 50 m runs with progressively increasing self-selected speeds. The remaining warm up time was used to stretch or perform additional warm up exercises as necessary. The participants then completed eight repetitions of 1200 m at a pace corresponding to 75% of VO_{2peak}. (pace: 307.56 ± 25.97s) The participants performed the intervals on a 200 m indoor track and alternated running direction on the track after each repetition to prevent injury. A recovery period equal to run time was allowed after each repetition, during which time the participants performed light jogging or walking. During the exercise task, HR was monitored continuously and recorded every 800 m and at the end of each interval. RPE was also recorded every 800 m during exercise and at the end of each interval. Immediately following the exercise bout, measurements were taken for TC, ROM, and PMS. Participants then underwent either a CWI or CON treatment.

Participants were instructed to refrain from exercise during the 24 hrs between sessions. Post treatment, participants were given a 24 hr diet record and verbal and written instructions for completing the record. Participants were asked to record all food and fluid intake for the 24 hrs between sessions. The participants were asked to replicate the diet between sessions during trial two to control for macronutrient intake that may affect the recovery process. Paired samples *t*- tests were computed to compare total caloric and macronutrient consumption for 24 hrs following the interval session for both treatments. No significant differences were found between carbohydrates (CON = 490 ± 320 g, CWI = 347 ± 137 g; t = 1.47, p = 0.13), fat (CON = 88 ± 34 g, CWI = 99 ± 42 g; t = 1.29, p = 0.23), protein (CON = 140 ± 47 g, CWI = 150 ± 70 g; t = 0.59, p = 0.57), and total caloric intake (CON = 3244 ± 1312 kcal, CWI = 2840 ± 1020 kcal; t = 1.47, p = 0.18) between the two treatments. Diets for the 24 hrs between testing sessions for each trial were similar.

Participants reported back to testing exactly 24 hrs after the interval session. Baseline measurements were taken for resting HR, RPE, TC, ROM, and PMS and participants individually completed a 5000 m time trial on the same 200 m indoor track. Warm up procedures prior to the 5000 m time trial were standardized from the warm up performed prior to the interval session and replicated for the following trial. During the time trial, HR and RPE were recorded every 800 m as well as at the completion of the run. Split times were recorded every 400 m. The procedures for both sessions were repeated at the same time of day with the opposite treatment condition. A minimum of seven days and a maximum of 14 days separated the two trials to prevent carry over effect of the treatment and to avoid adaptations associated with the repeated bout effect (Proske and Morgan, 2001).

Treatment procedures

The 2 treatments included a CWI treatment and a passive recovery treatment (CON). During the CWI treatment, participants sat passively in agitated cold water up to the level of the umbilicus. The water was maintained at a temperature of 12 degrees Celsius and participants were immersed for 12 mins. Immersion of the affected muscle groups in water temperatures between 10 and 15 degrees Celsius for 10 to 15 mins should elicit a drop in intramuscular temperature of up to 10 degrees Celsius (Meeusen and Lievens, 1986) The midpoints of the ideal range for time and temperature were chosen for the treatment. During the CON treatment, participants sat passively for 12 mins in a thermoneutral environment. No stretching or cool down routine was permitted during this time.

Statistical analyses

Paired samples t-tests were used to determine differences between 5000 m run times and to compare total caloric intake, carbohydrate, fat, and protein intake between the 2 treatments. HR and RPE during the 5000 m time trials were each analyzed with 2x8 repeated measures analysis of variance (ANOVA). For each dependent variable, the independent variables were treatment and time. Bonferroni adjustment was used for post hoc analyses for both ANOVAs. A 2x3 repeated measures ANOVA was used to examine differences or interactions that existed for PMS over time. The dependent variable was observed over 3 time periods for each of two treatments. A 2x3 multivariate analysis of variance (MANOVA) was used to examine differences among ROM variables for the 2 treatments. The dependent variables included hip, knee, and ankle ROM, with the independent variables of treatment and time. A similar 2x3 MANOVA was also used to examine differences in TC for the 2 treatments. The dependent variables were 3 locations of TC, with the independent variables of treatment and time. The alpha level for all analyses was set at 0.05.

Results

No significant difference was found between treatments for 5000 m run time (CWI = 1317.33 ± 128.33 sec, CON = 1303.44 ± 105.53 sec; $t = 0.74$; $p = 0.48$). The interaction between treatment and time was not significant for HR ($F_{(2.71, 21.65)} = 0.34$, $p = 0.78$) or RPE ($F_{(2.54, 20.34)} = 1.28$, $p = 0.31$) during the 5000 m run; however, the main effect for time was significant for both HR ($F_{(1.66, 13.30)} = 294.1$, $p < 0.01$) and RPE ($F_{(1.95, 15.57)} = 172.26$, $p < 0.01$). Pairwise comparisons of main effects for time for both HR and RPE indicated that HR and RPE were significantly lower at baseline than any other time point. While there was no significant difference between treatments, RPE following CWI was lower than CON at each time point between the beginning and end of the 5000 m run (Figure 1).

No significant interaction was found between treatment and time for PMS ($F_{(2,16)} = 0.66$, $p = 0.53$). We observed a significant main effect for time ($F_{(2,16)} = 9.65$, $p < 0.01$) and examined pairwise comparisons. PMS measured immediately after the interval training session (2.81 ± 0.52) was significantly higher than baseline (1.17 ± 0.22; p = 0.02) and remained elevated from baseline to 24 hrs post exercise (2.19 ± 0.32; p = 0.02). We found no significant difference between post interval values and 24 hrs post interval values (p = 0.49) (Figure 2).

The interaction between treatment and time was not significant for the 3 ROM variables ($\lambda = 0.49$; $p = 0.10$) (Table 1). The mean vectors for hip, knee, and ankle joint ROM between the 2 treatments were not significantly different ($\lambda = 0.79$, $p = 0.21$). Additionally, the mean vectors for hip, knee, and ankle joint ROM over 3 time periods were not significantly different ($\lambda = 0.81$, $p = 0.80$). We found no significant differences in TC on 3 areas of the leg between treatments and over time ($\lambda = 0.73$, $p = 0.15$) (Table 2), and the mean vectors for TC between treatments were not significantly different ($\lambda = 0.65$, $p = 0.42$). Also, the mean vectors for TC over 3 time periods were not significantly different ($\lambda = 0.47$, $p = 0.08$).

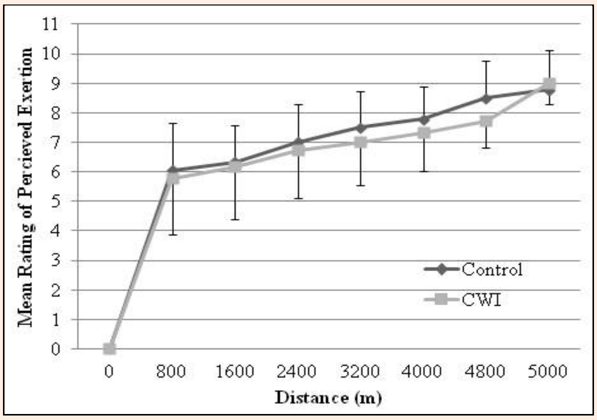

Figure 1. Rating of perceived exertion (RPE) during the 5000m run trials 24 hrs after an interval training session and either a cold water immersion (CWI) or control (CON) treatment (n = 9).

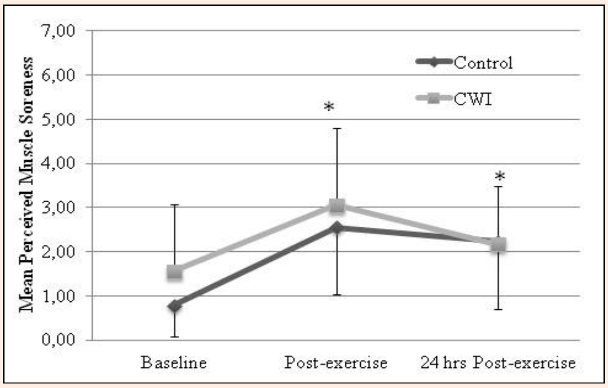

Figure 2. Perceived muscle soreness (PMS) at baseline, immediately post interval training, and 24 hrs post interval training (n = 9). * indicates time point significantly different from baseline.

Table 1. Range of motion (ROM, degrees) of the hip, knee, and ankle joints at baseline, immediately post interval training, and 24 hrs post interval training (n = 9). Data reported as mean (±standard deviation).

		Baseline	Post Exercise	24 hrs Post Exercise
Ankle	**CON**	63.89 (15.83)	63.11 (18.09)	60.78 (15.79)
	CWI	61.00 (15.16	64.11 (15.62)	65.11 (13.72)
Knee	**CON**	45.33 (5.92)	46.44 (5.77)	47.67 (6.48)
	CWI	51.89 (8.59)	50.89 (7.32)	46.44 (6.37)
Hip	**CON**	142.67 (11.87)	142.89 (9.73)	141.89 (11.78)
	CWI	139.33 (8.34)	141.44 (11.66))	142.89 (7.94)

CON = control; CWI = cold water immersion.

Table 2. Thigh circumference (TC, cm) of three areas of the upper leg at baseline, immediately post interval training, and 24 hrs post interval training (n = 9). Data reported as mean (±standard deviation).

		Baseline	Post Exercise	24 hrs Post Exercise
TC 1	**CON**	41.72 (2.81)	42.72 (3.40)	42.89 (2.61)
	CWI	42.28 (3.54)	43.00 (3.56)	43.50 (3.19)
TC 2	**CON**	50.67 (4.15)	51.11 (4.44)	50.83 (3.64)
	CWI	50.11 (4.67)	50.39 (4.67)	51.00 (3.97)
TC 3	**CON**	56.33 (3.42)	56.56 (3.18))	56.28 (3.29)
	CWI	55.28 (3.29)	55.39 (3.96)	56.24 (3.36)

CON = control; CWI = cold water immersion.

Discussion

The main finding of the present study was that performance in a 5000 m running time trial 24 hrs after a running interval training session and a CWI treatment was not different from performance in a 5000 m time trial 24 hrs after an interval training session and no recovery treatment. RPE and HR were also not significantly different between the two 5000 m time trials. PMS increased significantly after the interval sessions, but no significant difference was found between the two treatments. Further, ROM and TC were not affected by the interval session or either the CWI or CON treatments.

Our participants were well-trained marathon runners and triathletes who were accustomed to prolonged, intense exercise. Based on the lack of significant changes in PMS, TC, and ROM, the interval session did not induce measureable muscle damage. The intent of the interval training session was not to induce muscle damage, but to induce fatigue similar to that experienced after a hard interval workout performed by an endurance athlete. During normal endurance training, athletes may not experience the same degree of muscle damage induced by heavy strength training or eccentric exercise. Previously, researchers examined the efficacy of CWI after exercise induced muscle damage when the damaging protocols used primarily eccentric strength and power exercises which would likely recruit fast, glycolytic fibers not heavily recruited during endurance exercise (Eston and Peters, 1999; Goodall and Howatson, 2008; Jakeman et al., 2009; Paddon-Jones and Quigley, 1997; Yanagisawa et al., 2003). Fast, glycolytic muscle fibers are more susceptible to exercise induced damage (Cheung et al., 2003; Friden and Lieber, 1992; Howatson and vanSomeren, 2008); however, runners competing in half-marathon, marathon, and other long-distance events, which recruit primarily slow oxidative muscle fibers, also experience some muscle damage (Linjen et al., 1988; Lippi et al., 2008; Warhol et al., 1985). Warhol and colleagues (1985) reported mitochondrial damage, myofibrillar lysis and damage to the sarcoplasmic reticulum in gastrocnemius samples of trained male runners after a marathon. Lippi and colleagues (2008), found increased levels of creatine kinase, myoglobin, and lactate dehydrogenase in the blood after a half-marathon run in endurance-trained males. The researchers suggested that changes in sarcolema permeability caused the release of intracellular proteins into the intravascular space. Similar finding have been reported in first time male marathon runners (Linjen et al., 1988).

TC and ROM were measured in the present study to determine if the interval session did produce any muscle damage. Eston and Peters (1999) reported increased arm circumference for up to 72 hrs following maximal contractions of the elbow flexors. Muscle swelling may be a result of protein rich fluid movement into the damaged muscle (Cheung et al., 2005). Swelling in damaged muscle causes subsequent muscle soreness (Friden and Lieber, 1992). Researchers found that CWI attenuates muscle swelling and soreness (Eston and Peters, 1999; Vaile et al., 2008a). The lack of increase in TC in the present study indicates that the interval session did not produce edema associated with significant muscle damage.

Similarly, hip, knee, and ankle joint ROM did not change over time and were not different between treatments in our study. Previously, researchers observed a significant decrease in ROM of the knee 24 hrs after muscle damaging eccentric exercise (Paschalis et al., 2005). Eston and Peters (1999) suggested that muscles and connective tissue may be shortened following damage inducing exercise, and that CWI would attenuate changes in muscle stiffness. Consistent with the results of the present study, Goodall and Howatson (2008) reported that neither muscle damaging plyometric exercise nor a CWI recovery protocol affected knee flexion. Further, neither calf raise exercises nor CWI affected ankle joint ROM (Yanagisawa et al., 2003). The interval session in the present study was not a sufficient stimulus to increase muscle and tendon stiffness and thus, no differences were found over time or between treatments.

We chose the interval training session used in this study because the intensity and duration are typical of workouts performed by endurance runners who train and compete at high levels multiple times per day or across consecutive days. It was also imperative that the interval protocol and the performance measure were similar in terms of muscular and bioenergetic demands (Warren et al., 1999). While the interval training session did not produce muscle damage, it did significantly increase PMS. Muscle soreness is typically due to swelling induced by muscle damage (Friden and Lieber, 1992). Muscle soreness increases immediately after exercise, but typically peaks 24 hrs post exercise (Cheung et al., 2003). In the present study, PMS immediately after the interval session was higher than PMS 24 hrs following the interval session, suggesting that the interval session did not induce the symptoms commonly experienced with delayed onset muscle soreness due to muscle damage. Because the increase in PMS was not accompanied by an increase in TC in this study, PMS was also not likely a result of swelling induced by muscle damage. Mean PMS 24 hrs after the interval session was only slightly higher than baseline and was not different between the CWI and CON treatments. Contradictory to the findings of previous researchers, CWI used in the present study was not more effective than CON in alleviating PMS (Leeder et al., 2012).

The significant increase in PMS following the interval session during both trials of the present study may have resulted from a lack of understanding of the scale by participants. Because the interval session did not produce muscle damage, fatigue and pain could have been misinterpreted as soreness immediately following the interval training session. A visual analog scale for perceived fatigue used in conjunction with the PMS scale could have provided further insight into the effectiveness of the interval training session to induce muscular fatigue and helped the participants distinguish between the constructs of muscle fatigue and muscle soreness.

Previously, researchers noted positive performance effects after CWI was used as a recovery technique after sprint and endurance exercise. Rowsell and colleagues (2014) found that CWI positively affected power output during cycling intervals when CWI was used immediately after 7, 5 min running intervals at 105% of anaerobic threshold in elite triathletes. The triathletes were able to maintain a higher power output 9 hrs after CWI than thermoneutral water immersion. While similar in design to the present study, the use of different exercises for the fatigue inducing exercise and performance test and the shorter time period between CWI and the performance measure account for contradictory results. Lane and Wenger (2004) reported improved performance on an intermittent cycling protocol 24 hrs after CWI treatment. The cycling interval protocol was the same before and after the recovery treatments, but was different from the present study in that the cycling intervals were near maximal effort and of very short duration (between 5 sec and 15 sec).

Evidence of improved running performance 24 hrs after high intensity intervals and CWI has also been demonstrated (Brophy-Williams et al., 2011). Brophy-Williams and colleagues (2011) found improvements in YoYo Intermittent Recovery Test performance after high intensity running intervals and CWI. Participants performed 8, 3 min intervals at 90% VO_{2max} with 1 min rest. Because Brophy-Williams' (2011) interval protocol was higher intensity and allowed for less recovery between intervals, the protocol likely caused greater fatigue and muscle damage than the interval protocol used in the present study. In contrast, Rupp and colleagues (2012) noted that CWI did not affect performance on the YoYo Intermittent Recovery Test when the tests were separated by 48 hrs. The researchers stated that 48 hrs of rest is likely enough time to recover from the test without additional recovery techniques. Given the positive effects of CWI on performance demonstrated by previous researchers, the interval session used in the present study may not have been a challenging enough exercise task to warrant specialized recovery techniques.

The present study has several limitations. The participants had been training at current levels for more than 6 months and may have been protected by the repeated bout effect, a phenomenon that describes adaptations that occur after a session of severe or muscle damaging exercise (Proske and Morgan, 2001). Additionally, the participants in this study were highly trained and were more accustomed to the demands of interval training than we expected. The high training levels of the participants may have provided protection against fatigue and muscle soreness (Ebbeling and Clarkson, 1989). Because of the similarities in mechanical stress and metabolic cost between our study and others using marathon and half-marathon distances, we assumed that a small degree of muscle damage, and certainly a significant amount of fatigue, would have resulted from the interval training (Linjen et al., 1988; Lippi et al., 2008; Warhol et al., 1985). The interval session used in the present study was not sufficient to induce significant muscular fatigue or muscle damage necessary to observe recovery treatment differences. Future researchers should measure both muscle soreness and muscular fatigue and use an exercise task sufficient to induce a measurable degree of muscular fatigue.

Results of the present study were also limited by some deviation in the warm up procedures. Our participants all completed the same warm up with the exception of stretching during a 5-10 min period during which the participants were allowed to prepare themselves for testing. Participants were asked to repeat their individualized warm up procedures between testing days, but techniques varied slightly between individuals and may have affected the results. Additionally, we instructed participants not to perform strenuous exercise for 24 hrs preceding testing; however, the effects of fatiguing, prolonged, or muscle damaging exercise may persist for up to 72 hrs following exercise (Cheung et al., 2003). It is possible that the participants experienced residual effects of other exercise bouts prior to the interval training sessions, which can be seen by the slightly greater than zero baseline PMS in both conditions.

Conclusion

Competitive endurance athletes typically train or compete multiple times within 24 hrs and seek quick recovery between exercise bouts. The results of our study indicate that 12 mins of water immersion at 12 degrees Celsius up to the level of the umbilicus immediately following an intense interval training session does not affect performance in a 5000 m time trial when performed 24 hrs after immersion in endurance trained males. As athletes become more accustomed to prolonged or intense exercise, CWI may not provide a recovery or subsequent performance advantage. Although a single CWI bout did not improve 5000 m run performance, performance was not impeded. Recently, researchers have noted that excessive use of recovery techniques which block the inflammatory response to muscle injury, such as CWI, may be detrimental to muscle repair and recovery (Butterfield et al., 2006). Athletes should be cautious in their use of CWI as a recovery technique.

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Key points

- CWI is a popular recovery technique among endurance athletes, but the effect of CWI on subsequent performance is unclear.
- CWI does not enhance 5000 m run performance 24 hrs after a hard interval run session.
- As athletes become more accustomed to prolonged or intense exercise, CWI may not provide a recovery or subsequent performance advantage
- CWI was not more effective than a control at reducing perceived muscle soreness after an interval training session.
- Muscle soreness and muscle fatigue are independent constructs.

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