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Cold Water Immersion for Recovery: Acute and Chronic Effects on Exercise Performance

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Abstract

Purpose: The purpose of this study was three-fold: 1) to quantify the acute effects of cold water immersion (CWI) during different time periods of the recovery on exercise performance, 2) to determine whether there was a dose-response relationship between CWI duration and magnitude improvement in recovery, and 3) to quantify the chronic effects of CWI during recovery on training adaptations. **Methods:** Apparently healthy men and women (n=16) were studied. To quantify the acute effects of CWI during different time periods of the recovery the following testing sessions were completed: control, 10min CWI immediately post-exercise, and 10min CWI 2hrs post-exercise. To determine whether there was a dose-response relationship between CWI duration and magnitude improvement in recovery the following testing sessions were completed: control, 10min CWI immediately post-exercise, and 20min CWI immediately post-exercise. For all testing sessions participants initially performed a running time trial bout to fatigue (TTF) at an intensity corresponding to 70% of the second ventilatory threshold (VT2) + Wingate test + chest press bout to fatigue at 80% of one-repetition maximum (1-RM). Participants then underwent one of the above-described treatments. Participants then returned exactly 24hr later to repeat the running TTF, Wingate, and chest press to fatigue tests. To compare the chronic effects of CWI on exercise performance participants were randomized to either a control group or treatment group. Both groups completed 6wk of standardized aerobic (3 days/wk) and resistance training (2 days/wk). At baseline and after 6wk training, participants performed a graded exercise test on a treadmill to determine VO_2max. Participants also performed a running time TTF bout, Wingate test, and chest press 1-RM at baseline and after 6wk training. Body composition, waist circumference, and weight were also assessed at baseline and after 6wk training. **Results:** *Effect of the timing of CWI post-exercise on performance*: Main effects for the timing of CWI post-exercise ($p<0.05$) were observed on running TTF, peak power output, and chest press to fatigue. Post hoc analyses indicated that running TTF, peak power output, and chest press to fatigue were decreased ($p<0.05$) in trial 2 with no CWI (i.e., control) when compared to trial 1. In contrast, running TTF, peak power output, and chest press to fatigue were preserved ($p>0.05$) across trials with CWI immediately post-exercise or CWI 2hr post-exercise. *Effect of CWI duration on performance*: Main effects for CWI duration ($p < 0.05$) were observed on running TTF, peak power output, and chest press to fatigue. Post hoc analyses indicated that running TTF, peak power output, and chest press to fatigue were decreased ($p<0.05$) in trial 2 with no CWI (i.e., control) when compared to trial 1. In contrast, running TTF, peak power output, and chest press to fatigue were preserved ($p>0.05$) across trials with 10min or 20min CWI. *Chronic effects of CWI during recovery on exercise performance*: At 6wk, paired t-tests revealed favorable changes ($p<0.05$) in % body fat, running TTF, peak power output, chest press to fatigue, and VO_2max in both the control and CWI groups. Changes from baseline to 6wk were similar between groups ($p>0.05$). **Conclusion:** Acute post-exercise CWI was a more effective recovery strategy when compared to no CWI (i.e., control) at maintaining endurance and power performance. All acute post-exercise CWI strategies were equally effective at preserving performance. Chronic use of CWI during recovery did not diminish long-term training adaptations.

Key Words: Aerobic Training, Resistance Training, Training Adaptations, Ventilatory Threshold

Introduction

Recovery from exercise training is a vital component of the overall exercise prescription model, and paramount for performance and continued improvement. If the rate of recovery is appropriate, higher training volumes and intensities are possible without the detrimental effects of overtraining. Over the past decade there has been considerable research focused on the topic of training recovery. One recovery strategy that has gained considerable attention is cold water immersion (CWI). The CWI strategy entails submerging either part (e.g, both legs) or the entire body within cold water (≤ 20°C) during the post-exercise time period. The physiological responses to CWI include changes in the heart rate, peripheral resistance and blood flow, as well as alterations in skin, core and muscle temperature.[1] The physiological responses of changes in blood flow and temperature may in turn have an effect on inflammation, immune function, muscle soreness and perception of fatigue.[2] The CWI procedure during recovery has been reported to benefit endurance, sprint, and muscle strength/power performance.[3] Nevertheless, there are a number of unanswered questions remaining on the topic of CWI and training recovery.[3] For example, it is unknown if CWI is more effective immediately post-exercise or a few hours after exercise cessation. Additionally, it is unclear whether there is a dose-response relationship between CWI duration and recovery benefits. Lastly, it is also unclear if regular CWI during recovery diminishes favorable training adaptations. Clearly, more research on the topic of CWI and training recovery is warranted.

Recovery is becoming increasingly important to the performance of fitness enthusiasts and athletes alike in a bid to reduce fatigue and enhance performance. The use of CWI is one common strategy employed to augment recovery. This study will provide health and fitness professionals with important evidence for the use of CWI as an effective acute and chronic training recovery strategy. The purpose of this study was three-fold: 1) to quantify the acute effects of CWI during different time periods of the recovery on exercise performance, 2) to determine whether there was a dose-response relationship between CWI duration and magnitude improvement in recovery, and 3) to quantify the chronic effects of CWI during recovery on training adaptations. It was hypothesized that: 1) CWI immediately post-exercise when compared to a few hours post-exercise would elicit greater improvements in subsequent exercise performance, 2) there would be a dose-response relationship between CWI duration and recovery (i.e., a greater CWI duration would elicit better recovery), and 3) chronic CWI during recovery would not impair training adaptations.

Methods

Participants

Participants were recruited from the student population of a local university, as well as the surrounding community, via advertisement through the university website, local community newspaper, and word-of-mouth. Participants were eligible for inclusion into the study if they were low-to-moderate risk as defined by the ACSM[4], reported no resistance training within the previous six months, and were sedentary. Participants were considered sedentary if they reported not participating in at least 30 min of moderate intensity physical activity on at least three days of the week for at least three months[4]. Exclusionary criteria included evidence of cardiovascular pulmonary, and/or metabolic disease. This study was approved by the Human Research Committee at Western State Colorado University. Each participant signed an informed consent form prior to participation.

Acute effects of CWI during recovery on exercise performance

To quantify the acute effects of CWI during recovery on exercise performance participants completed 4 different testing session in randomized order separated by >96hr (to prevent a carryover effect). To quantify the acute effects of CWI during different time periods of the recovery the following testing sessions were completed:

- Control (testing session 1)
- 10min CWI immediately post-exercise (testing session 2)
- 10min CWI 2hrs post-exercise (testing session 3)

To determine whether there was a dose-response relationship between CWI duration and magnitude improvement in recovery the following testing sessions were completed:

- Control (testing session 1)
- 10min CWI immediately post-exercise (testing session 2)
- 20min CWI immediately post-exercise (testing session 4)

For all testing sessions participants initially performed a running time trial to fatigue (TTF) bout at an intensity corresponding to 70% of the second ventilatory threshold (VT2) + Wingate test + chest press bout to fatigue at 80% of one-repetition maximum (1-RM). The only rest in between each exercise consisted of the warm up and cool down routine for each individual exercise protocol (refer to protocol section below). The first set of tests are referred to as trial 1 in the results section. Participants then underwent one of the above-described treatments. Participants then returned exactly 24hr later to repeat the running TTF, Wingate, and chest press to fatigue tests. The second set of tests are referred to as trial 2 in the results section.

Protocols

Anthropometric measurements

Participants were weighed to the nearest 0.1 kg on a medical grade scale and measured for height to the nearest 0.5 cm using a stadiometer. Percent body fat was determined via skinfolds[4]. Skinfold thickness was measured to the nearest ± 0.5 mm using a Lange caliper (Cambridge Scientific Industries, Columbia, MD). All measurements were taken on the right side of the body using standardized anatomical sites (three-site) for men and women. These measurements were performed until two were within 10% of each other. Waist circumference measurements were obtained using a cloth tape measure with a spring loaded-handle (Creative Health Products, Ann Arbor, MI). A horizontal measurement was taken at the narrowest point of the torso (below the xiphoid process and above the umbilicus). These measurements were taken until two were within 0.5 mm of each other.

Chest press trial to fatigue bout

Participants initially performed a warm up consisting of 10 repetitions at a weight corresponding to 40-60% 1-RM. Participants rested for 2min and then performed the chest press trial to fatigue. The chest press trial to fatigue bout consisted of participants completing as many repetitions as possible at a weight corresponding to 80% 1-RM.

Cold water immersion (CWI)

For the cold water immersion treatment, participants sat in a bath containing water at 13 ± 0.5°C. Participants immersed their body up to their clavicle continuously for the target treatment time.

Determination of thresholds

Determination of both the first ventilatory threshold (VT1) and second ventilatory threshold (VT2) were made by visual inspection of graphs of time plotted against each relevant respiratory variable (according to 15s time-averaging). The criteria for VT1 were an increase in VE/VO_2 with no concurrent increase in VE/VCO_2 and departure from the linearity of VE. The criteria for VT2 were a simultaneous increase in both VE/VO_2 and VE/VCO_2.

Maximal exercise testing

Participants completed a modified-Balke, pseudo-ramp graded exercise test (GXT) on a power treadmill (Powerjog GX200, Maine). Participants jogged or ran at a self-selected pace. Treadmill incline was increased by 1% every minute until the participant reached volitional fatigue. Participant heart rate (HR) was continuously recorded during the GXT via a chest strap and radio-telemetric receiver (Polar Electro, Woodbury, NY, USA). Expired air and gas exchange data were recorded continuously during the GXT using a metabolic analyzer (Parvo Medics TrueOne 2.0, Salt Lake City, UT, USA). Before each exercise test, the metabolic analyzer was calibrated with gases of known concentrations (14.01 ± 0.07% O_2, 6.00 ± 0.03% CO_2) and with room air (20.93%O_2 and 0.03% CO_2) as per the instruction manual. Volume calibration of the pneumotachometer was done via a 3-Litre calibration syringe system (Hans-Rudolph, Kansas City, MO, USA). The last 15s of the GXT were averaged – this was considered the final data point. The closest neighbouring data point was calculated by averaging the data collected 15s immediately before the last 15s of the test. The mean of the two processed data points represented maximal oxygen uptake (VO_2max).

Maximal muscular fitness testing

Participants performed 1-RM testing for the following exercises: back extension, bicep curl, chest press, lateral pulldown, leg curl, leg extension, leg press, seated row, shoulder press, and tricep extension. The following protocol was used for 1-RM testing as recommended by ACSM[4]:

1. 10 repetitions of a weight the participant felt comfortable lifting (40-60% 1-RM) were performed to warm up muscles
2. RPE was recorded followed by 1 minute rest period

3. 5 repetitions of weight 60-80% 1-RM was performed as a further warm up, RPE recorded followed by a 2 minute rest period
4. First 1-RM attempt at weight of 2.5-20kg greater then warm up, weight was dependent on RPE of warm up
    a. If first 1-RM lift was deemed successful by the researcher (appropriate lifting form) weight was increased until maximum weight participant can lift was established with 3 minutes between each attempt.
    b. If first 1-RM lift deemed unsuccessful by the researcher, weight was decreased until participant successfully lifted the heaviest weight possible.

There were 3 minutes rest between 1-RM attempts and a maximum of 5 x 1-RM attempts. There were 5 minutes of rest between the 1-RM testing of each resistance exercise.

Running time trial to fatigue bout

The running TTF bout commenced with a 5min warm up performed at self-selected intensity. Participants then completed the running TTF bout at 70% of the second ventilatory threshold (VT2). A 5min cool down was performed at an intensity corresponding to VT1.

Wingate testing

Wingate testing was performed to quantify peak power output. The equipment that was used for the Wingate test was the Peak Monark Ergomedic 894 E bike (Vansbro Dalarna, Sweden). Protocol consisted of a 5min warm up performed at self-selected intensity with 10sec sprints completed at the end of each minute. The main portion of the test commenced with the participant pedaling to >150 revolution per minute (RPM), then a weight that was set to 7.5% of the participant's body weight in kg was dropped. The participant then pedaled against this weight at a maximal effort for 30sec. Once the Wingate test was completed a 5min cool down was performed at an intensity corresponding to VT1.

Chronic effects of CWI during recovery on exercise performance intervention

The same participants used for the acute phase of the study were also used for the chronic phase of the study. Participants were randomized to either a control group or treatment group. Both groups completed 6wk of standardized aerobic (3 days/wk) and resistance training (2 days/wk). For aerobic exercise target HR was established in the following manner:

- Wk 1-3 (HR < VT1): target HR = HR range of 10-15 bpm just below VT1
- Wk 4-6 (HR ≥ VT1 to < VT2): target HR = HR range of 10-20 bpm above VT1 and below VT2

All aerobic exercise training was performed on a treadmill. Participants performed the following exercises as part of the resistance training program: back extension, bicep curl, chest press, lateral pulldown, leg curl, leg extension, leg press, seated row, shoulder press, and tricep extension. Other details of the 6wk exercise training program are presented in Table 1. Participants randomized to the treatment group performed 10min CWI at ~15°C immediately post-exercise following all training sessions. Participants randomized to the control group did not have any intervention during the recovery period. Both groups were instructed to not change their dietary habits during the intervention. At baseline and after 6wk training, participants performed a graded exercise test on a treadmill to determine VO_2max. Participants also performed a running TTF bout, Wingate test, and chest press 1-RM bout at baseline and after 6wk training. Body composition, waist circumference, and weight were also assessed at baseline and after 6wk training. Collectively, all these measures were obtained and analyzed to determine the effectiveness of the 6wk training program, and to determine whether regular CWI during recovery mitigates favorable training adaptations.

Table 1. Aerobic and resistance exercise prescriptions throughout the intervention.

	Aerobic exercise			Resistance exercise		
Week	Days/wk	min/day	Intensity	Days/wk	Sets/Reps	Intensity
1-3	3	30	HR < VT1	2	1/10	60% 1-RM
3-6	3	30	HR ≥ VT1 to < VT2	2	2/12	70% 1-RM

Statistical analyses

All analyses were performed using SPSS Version 24.0 (Chicago, IL) and GraphPad Prism 6.0. (San Diego, CA). Measures of centrality and spread are presented as mean ± standard deviation (SD). Repeated measures ANOVA (and where appropriate Tukey's post hoc tests) were used to compare running TTF, Wingate Test, and chest press performances across CWI treatment conditions. Paired *t*-tests were used to compare mean changes from baseline to after 6wk training within each group (control and treatment) for all primary outcome measures. Independent *t*-tests were used to compare mean changes from baseline to after 6wk training between control group and treatment (CWI group) for all primary outcomes measures. The probability of making a Type I error was set at $p < 0.05$ for all statistical analyses.

Results

Effect of the timing of CWI post-exercise on performance

Main effects for the timing of CWI post-exercise ($p<0.05$) were observed on running TTF, peak power output, and chest press to fatigue (Table 2). Post hoc analyses indicated that the running TTF, peak power output, and chest press to fatigue were decreased ($p<0.05$) in trial 2 with no CWI (i.e., control) when compared to trial 1. In contrast, running TTF, peak power output, and chest press to fatigue were preserved ($p>0.05$) across trials with CWI immediately post-exercise or CWI 2hr post-exercise (Table 2).

Table 2. Effect of the timing of CWI post-exercise on performance measures (mean ± SD).

Outcome	Timing of CWI post-exercise: Control (n=16)	CWI immediately post-exercise (n=16)	CWI 2hr post-exercise (n=16)
Running TTF – trial 1 (sec)	417 ± 151	419 ± 148	417 ± 147
Running TTF – trial 2 (sec)	404 ± 146*†	417 ± 147	419 ± 147
Peak power output – trial 1 (W)	1017 ± 412	1019 ± 415	1023 ± 414
Peak power output – trial 2 (W)	969 ± 405*†	1022 ± 414	1016 ± 403
Chest press – trial 1 (reps)	5.4 ± 1.3	5.9 ± 1.1	5.6 ± 0.9
Chest press – trial 2 (reps)	4.3 ± 0.7*†	5.7 ± 1.2	5.5 ± 0.8

reps, repetitions; sec, seconds; TTF, time to fatigue; W, Watts; *change from trial 1 to trial 2 is significantly different ($p<0.05$); †decrement in performance from trial 1 to trial 2 is significantly different ($p<0.05$) when compared to CWI immediately post-exercise and CWI 2hr post-exercise trials.

Effects of CWI duration on performance

Main effects for CWI duration ($p < 0.05$) were observed on running TTF, peak power output, and chest press to fatigue (Table 3). Post hoc analyses indicated that running TTF, peak power output, and chest press to fatigue were decreased ($p<0.05$) in trial 2 with no CWI (i.e., control) when compared to trial 1. In contrast, running TTF, peak power output, and chest press to fatigue were preserved ($p>0.05$) across trials with 10min or 20min CWI (Table 3).

Table 3. Effect of CWI duration on performance measures (mean ± SD).

Outcome	CWI duration: Control (n =16)	10min CWI (n=16)	20min CWI (n=16)
Running TTF – trial 1 (sec)	417 ± 151	419 ± 148	416 ± 146
Running TTF – trial 2 (sec)	404 ± 146*†	417 ± 147	414 ± 145
Peak power output – trial 1 (W)	1017 ± 412	1019 ± 415	1023 ± 415
Peak power output – trial 2 (W)	969 ± 405*†	1022 ± 414	1017 ± 417
Chest press – trial 1 (reps)	5.4 ± 1.3	5.9 ± 1.1	6.0 ± 1.4
Chest press – trial 2 (reps)	4.3 ± 0.7*†	5.7 ± 1.2	5.9 ± 1.1

reps, repetitions; sec, seconds; TTF, time to fatigue; W, Watts; *change from trial 1 to trial 2 is significantly different ($p < 0.05$); †decrement in performance from trial 1 to trial 2 is significantly different ($p < 0.05$) when compared to 10min CWI and 20min CWI trials.

Chronic effects of CWI during recovery on adaptations

The physical and physiological characteristics at baseline and 6wk for both control and CWI groups are presented in Table 4. At 6wk, paired t-tests revealed favorable changes ($p<0.05$) in % body fat, running TTF, peak power output, chest press to fatigue, and VO_2max in both the control and CWI groups. Changes from baseline to 6wk were similar between groups ($p>0.05$).

Table 4. Physical and physiological characteristics at baseline and 6wk for the control and CWI treatment groups (mean ± SD).

Parameter	Control group (n=8: women= 4; men = 4)		CWI group (n=8: women= 4; men = 4)	
	Baseline	6wk	Baseline	6wk
Age (yr)	22.3 ± 2.4	____	24.5 ± 2.3	____
Height (cm)	176.4 ± 9.6	____	170.6 ± 9.7	____
Weight (kg)	61.6 ± 6.2	61.5 ± 6.2	79.4 ± 6.4	79.1 ± 6.3
Waist circumference (cm)	75.1 ± 5.5	74.6 ± 4.3	85.1 ± 4.5	84.5 ± 4.5
Body fat (%)	31.0 ± 3.6	27.9 ± 2.9*	25.5 ± 5.7	22.3 ± 5.3*
Running TTF (sec)	402 ± 106	435 ± 111*	432 ± 192	458 ± 199*
Peak power output (W)	1018 ± 489	1090 ± 494*	1016 ± 352	1080 ± 371*
Chest press (lbs)	124 ± 66	156 ± 71*	113 ± 51	134 ± 54*
VO_2max (mL/kg/min)	40.5 ± 3.8	44.6 ± 3.7*	41.2 ± 4.4	45.2 ± 4.5*

* Within-group change is significantly different from baseline, $p<0.05$.

Discussion

There are three key 'take-home messages' based on findings from the present study:

1. Acute post-exercise CWI was a more effective recovery strategy when compared to no CWI (i.e., control) at maintaining endurance and power performance. Indeed, in a second series of tests (running TTF, peak power output, and chest press to fatigue) completed 24hr later, performances were maintained with CWI during recovery when compared to no CWI (refer to Tables 2 and 3).
2. All acute post-exercise CWI strategies were equally effective at preserving performance (refer to Tables 2 and 3). From a time efficient perspective, health and fitness professionals may recommend 10min CWI immediately post-exercise as the optimal acute CWI strategy for recovery.
3. Chronic use of CWI during recovery did not diminish long-term training adaptations. Indeed, improvements in various physical and physiological measures were comparable between CWI and no-CWI groups following 6wk of standardized aerobic and resistance exercise training (see Table 4).

CWI and recovery – what are the potential mechanisms?

In recent years there has been considerable research focused on numerous alternative recovery strategies, including CWI. The use of CWI has been adopted as a viable method to recover from an exercise training session or competitive performance because it is believed to aid in lessening muscle fatigue and soreness[3] and, ultimately, reducing the overall time needed for recovery. The exact mechanisms involved in aiding in recovery are not well understood, since the use of CWI in investigations is a relatively newer topic of concern. However, in a recent review to outline the possible physiological mechanisms associated with CWI, it was found that the major factors are the effects from the *cold* water and the added hydrostatic pressure.[5] The coolness of the water helps to decrease the core and skin temperature, which increases the heat-storage capacity, causes peripheral vasoconstriction and increases central blood volume. The increased vasoconstriction may also aid in mitigating the inflammatory response in the tissue effected from the training bout or performance. The added hydrostatic pressure to the body is thought to aid in increasing the osmotic gradient and allows for a better "flushing" of metabolic by-products.

In a previous study, a group of Belgian researchers[6] investigated the effects of passive recovery, active recovery, electromyostimulation and CWI of the arms (three sessions of five minutes in the water (15° C) and two minutes out of the water) after a rock climbing test (completion of a 6b route, on the French grading system, at an indoor climbing gym) to volitional exhaustion. Once the recovery methods were implemented, the athletes completed the same rock climbing test to volitional fatigue. Indeed, it was found that CWI allowed for the climbing performance to be preserved, indicating CWI may be effective for recovery when repeating intense exercises. The authors suggested that CWI was successful in helping to maintain performance due to an analgesic effect and reduced inflammation in the forearms. These findings and the application of CWI are comparable to those observed in the present study.

Acute vs. Chronic CWI

Even though there have been a plethora of studies indicating the effectiveness of CWI, there are just as many indicating CWI may have no effect or a negative effect on performance. In particular, there is some evidence to suggest that that chronic CWI may be counterproductive to long-term performance adaptations. For instance, Fröhlich and colleagues[7] examined the long-term effects of CWI after resistance training. In this study, the researchers investigated five weeks of the leg curl exercise with one leg undergoing CWI after training bouts. At the end of the study, it was found that the cooled leg exhibited a 1 to 2 percent reduction in training effects compared to the non-cooled leg. While these effects may be small, this could play a critical role in decreasing adaptations in a high-performance setting. Similarly, Roberts et al.[8] found that after a 12wk strength training program, participants that utilized CWI had less strength and muscle mass gains than those who participated in active recovery. A subset of this study also found that CWI reduced the acute anabolic signaling pathways that regulate muscle hypertrophy. Accordingly, it was suggested that if CWI immersion were to be employed chronically, there may be smaller muscle strength and hypertrophy adaptations after strength training. Nevertheless, findings from the present study indicated that chronic CWI elicited similar improvements in performance when compared to no CWI during post-exercise recovery. A variety of factors may explain the different findings across studies, including CWI protocol, performance outcome measures, and the population studied.

Conclusions

Health and fitness professionals should recognize that current and future clients will spend more time throughout the week in training recovery compared to actual exercise training. The use of CWI is one common strategy employed to augment recovery. This study provided fitness professionals with important evidence in terms of 'dose' and 'timing' for the use of CWI as an effective acute and chronic training recovery strategy

Competing interests

This investigation was supported financially by the American Council on Exercise (ACE). The American Council on Exercise (ACE) was not involved in development of the study design, data collection and analysis, or preparation of the manuscript. There are no other potential conflicts of interest related to this article.

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