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THE EFFECT OF CONTRAST WATER THERAPY ON SYMPTOMS OF DELAYED ONSET MUSCLE SORENESS

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ABSTRACT. Vaile, J.M., N.D. Gill, and A.J. Blazevich. The effect of contrast water therapy on symptoms of delayed onset muscle soreness. *J. Strength Cond. Res. 21(2):697–702. 2007.*—This study examined the effect of contrast water therapy (CWT) on the physiological and functional symptoms of delayed onset muscle soreness (DOMS) following DOMS-inducing leg press exercise. Thirteen recreational athletes performed 2 experimental trials separated by 6 weeks in a randomized crossover design. On each occasion, subjects performed a DOMS-inducing leg press protocol consisting of 5 × 10 eccentric contractions (180 seconds recovery between sets) at 140% of 1 repetition maximum (1RM). This was followed by a 15-minute recovery period incorporating either CWT or no intervention, passive recovery (PAS). Creatine kinase concentration (CK), perceived pain, thigh volume, isometric squat strength, and weighted jump squat performance were measured prior to the eccentric exercise, immediately post recovery, and 24, 48, and 72 hours post recovery. Isometric force production was not reduced below baseline measures throughout the 72-hour data collection period following CWT (≈4–10%). However, following PAS, isometric force production (mean ± *SD*) was 14.8 ± 11.4% below baseline immediately post recovery ($p < 0.05$), 20.8 ± 15.6% 24 hours post recovery ($p < 0.05$), and 22.5 ± 12.3% 48 hours post recovery ($p < 0.05$). Peak power produced during the jump squat was significantly reduced ($p < 0.05$) following both PAS (20.9 ± 13.4%) and CWT (12.8 ± 8.0%), with the mean reduction in power for PAS being marginally (not significantly) greater than for CWT (effect size = 0.76). Thigh volume measured immediately following CWT was significantly less than PAS. No significant differences in the changes in CK were found; in addition, there were no significant ($p > 0.01$) differences in perceived pain between treatments. Contrast water therapy was associated with a smaller reduction, and faster restoration, of strength and power measured by isometric force and jump squat production following DOMS-inducing leg press exercise when compared to PAS. Therefore, CWT seems to be effective in reducing and improving the recovery of functional deficiencies that result from DOMS, as opposed to passive recovery.

KEY WORDS. fatigue, swelling, pain, recovery

INTRODUCTION

Delayed onset muscle soreness (DOMS) is the sensation of discomfort that often occurs within a few days of a period of strenuous, unaccustomed exercise (14, 28). DOMS has been shown to be particularly prevalent after the performance of high-load lengthening (eccentric) contractions (10, 19). The intensity of physical symptoms, including muscle soreness/stiffness, swelling, tenderness or dull aching, peaks 48–72 hours post exercise (9) and then progressively subsides over a period of days (16). However, functional symptoms, including a prolonged loss of muscle force generating capacity, can be significant for up to 10 days (9); this loss of muscle function has significant consequences on athletic performance (5).

Numerous studies have examined the efficacy of methods to promote recovery from muscle-damaging exercise. Strategies such as the use of compression sleeves (26), light exercise (39), the ingestion (41) or dermal application (8) of nonsteroidal anti-inflammatory drugs, massage (17, 22), interferential therapy (30), hyperbaric oxygen therapy (20), and cryotherapy (35) have been used with varying degrees of success. Contrast water therapy (CWT) has become a common postexercise recovery strategy among high-performance athletes (11), despite little scientific evidence describing its benefits. During CWT, athletes periodically alternate between cold and hot water immersion after a strenuous exercise bout. While the mechanisms explaining the success of CWT in treating DOMS remain to be elucidated, it has been speculated that CWT reduces edema through a "pumping action" that is created by vasoconstriction and vasodilation; it is also thought to convey other physiological effects such as changes in tissue temperature, reduced muscle spasm, hyperemia of superficial blood vessels, reduced inflammation, and improved range of motion (11, 31). Despite these purported benefits, there is limited research examining both the effectiveness of CWT and the ideal protocol to be prescribed. Given the lack of evidence supporting the practice of CWT, the purpose of this study was to examine the effects of a commonly used CWT protocol on force loss and its subsequent recovery, muscle swelling, markers of muscle damage, and perceived pain following a muscle damage–inducing leg press exercise.

METHODS

Experimental Approach to the Problem

The study was designed to investigate whether CWT would attenuate the symptoms of muscle damage following high-intensity eccentric exercise. Thirteen recreational athletes performed 2 experimental trials, 6 weeks apart, in a randomized crossover design. Following the performance of a DOMS-inducing leg press protocol, subjects performed either CWT or passive recovery (PAS). Throughout a 72-hour follow-up period, physical and functional symptoms of DOMS were monitored and compared to pre-exercise values. After a 6-week washout period, the subjects completed the exercise task with the alternate recovery protocol.

Design Considerations. According to the literature it is possible that a single bout of eccentric exercise may have a prophylactic effect on muscle soreness, blood variables, and performance capabilities following a second bout of eccentric exercise (4, 6, 29, 34). This effect was taken into account and an attempt made to allow for it by using a crossover design as well as selecting athletes who are physically active (42). A number of studies investigating

DOMS have utilized a crossover design of varied washout durations (4, 7, 33, 37). The duration of prophylactic effects is varied with studies reporting negligible effects when exercise was separated by 4 (37), 6, and 9 weeks (7). Statistically, a crossover design offers greater power than a 2-group design with the sample size available for this study and our expected drop-out. Indeed, a 6-week washout period was deemed acceptable after considering the findings of Prou et al. (37) and Byrnes et al. (7).

Subjects

Four male and 9 female recreational athletes (approximately 3 hours of physical activity and resistance training) volunteered to participate in this study. The subjects' mean (± *SD*) age, height, and weight were 26.2 (± 5.8) years, 172.7 (± 8.5) cm, and 74.1 (± 18.4) kg, respectively. Men and women were accepted for participation to ensure the sample size was acceptable; previous investigations have utilized men and women collectively (1, 5, 27). Additionally, previous research has shown that force reduction and sarcomere disruption after damaging eccentric exercise are similar between men and women (40). Subjects were informed of all risks and provided written informed consent. The study was approved by the Waikato Institute of Technology Human Research Ethics Committee.

Procedures

The DOMS-inducing exercise protocol consisted of 5 sets of 10 eccentric bilateral leg press contractions with a load of 140% of 1 repetition maximum (1RM, concentric). This load was used as eccentric strength has been shown to be approximately 20–60% greater than concentric strength and has been used to induce DOMS previously (23). Individual 1RM was determined prior to testing on the same leg press machine using standardized procedures (33) (Fitness Works, Aukland, New Zealand). During each contraction, the load was resisted with both legs from full knee extension to a 90° knee angle with contractions lasting 2–3 seconds. After each eccentric repetition the load was raised by an electrical winch without effort from the subject, and the eccentric contraction time was monitored by an experimenter. Subjects rested for 15 seconds between repetitions and for 3 minutes between sets (33).

Recovery Strategies

Subjects performed 1 of 2 recovery strategies 45 seconds after completing the exercise protocol: (a) PAS where subjects sat with minimal movement for 15 minutes, or (b) CWT where subjects immersed their lower body to the level of the anterior superior iliac spine alternately between 2 baths—immersion for 60 seconds in cold water (8–10° C) followed immediately by immersion for 120 seconds in hot water (40–42° C); subjects alternated between the 2 baths for a total of 15 minutes.

Outcome measures

Functional and physical effects of the exercise were assessed through the measurement of isometric squat force, jump squat performance, hematic creatine kinase concentration (CK), thigh volume, and perceived muscle soreness. Measures were recorded before exercise, immediately after the 15-minute recovery, and 24, 48, and 72 hours post recovery.

Isometric Squat Force. Subjects performed an isometric squat against an immovable bar on a Smith Machine. The vertical ground reaction force was measured via a force platform (Kistler Instrumenté, Winterthur, Switzerland) positioned immediately below the bar; peak vertical force was taken as representative of the subject's isometric squat force. Feet were placed on the force platform so that there was a straight line from the temporomandibular joint to the lateral malleolus with the subject in a standing position; foot placement was recorded for each individual and maintained throughout all testing sessions (3). Prior testing in our laboratory had shown the peak force measure to be highly reliable when testing was separated by 1 week (intraclass correlation [ICC] = 0.97; technical error of measurement [TEM] = 3.1%).

Jump Squat Peak Power. The jump squat was performed on a Smith Machine; the bar, which was loaded with weights to a combined weight equivalent to 30% of their isometric squat force, rested across the subject's shoulders. Subjects performed 3 warm-up trials using the 18-kg bar with no additional weight. During maximal testing, subjects lowered the weighted bar to a 90° knee angle, paused for 2 seconds to minimize the influence of the stretch-shorten cycle, then jumped upward for maximum height (cm). Subjects performed 3 attempts separated by 2 minutes of rest. Peak power was measured using a force platform positioned under the subjects' feet. The peak power measure was acceptably reliable when assessed on 10 subjects (ICC = 0.94, TEM = 6.1%).

Creatine Kinase Concentration. A fingertip blood sample was taken using a 32 μl capillary tube and analyzed to determine CK concentration (16) using a Reflotron Plus Analyzer (Roche Diagnostics, Rotkreuz, Switzerland). Intraday reliability of CK measurements was determined on 10 individuals prior to testing (ICC = 0.99; TEM = 4.2%).

Thigh Volume Assessment. Circumference measurements were taken as an indicator of acute changes in thigh volume, which would likely occur from osmotic fluid shifts or inflammation, associated with muscle-damaging exercise (18). An anthropometric measuring tape was used to measure circumference above-the-knee, midthigh, and subgluteal. The 3 measurement sites were marked with a permanent marker to ensure measurement at exactly the same site when retested (0, 24, 48, and 72 hours). Lean thigh volume was estimated using a formula developed by Katch and Katch (24). The reliability of these measurements was high when 10 subjects were tested and retested using the identical experimental methodology as used in the present study (ICC = 1.00; TEM = 0.1%).

Perceived Soreness. Subjects completed a visual analog scale (VAS) requiring them to rank their perception of soreness on a scale of 0 to 10, with 0 being "normal" and 10 being "extremely sore." This procedure has been used previously to determine changes in perceived pain after strenuous exercise protocols (10, 20).

Statistical Analyses

A repeated-measures analysis of variance was used to examine main effects (treatment, gender, and order). There were no significant order or gender effects, but there were significant treatment effects ($p \leq 0.05$), which were further analyzed using pairwise comparisons with Bonferroni correction. Effect size was calculated using methods described by Cohen (13).

Results

Outcome Measures

Isometric Squat Force. The exercise protocol produced significant changes in peak isometric squat force over the

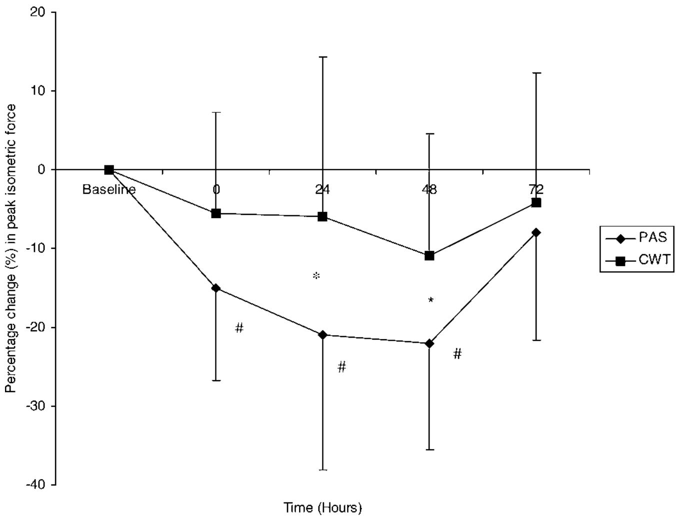

FIGURE 1. Peak isometric squat force, percentage change mean, and standard deviation (*SD*) values. Contrast water therapy (CWT) was associated with less loss of muscle force generating capacity compared to passive recovery (PAS). * Indicates a significant difference between PAS and CWT. # Indicates a significant time difference compared to baseline.

72-hour data collection period in both groups ($p < 0.05$; Figure 1, Table 1). Following PAS, peak force was significantly reduced by (mean ± *SD*) 14.8 ± 11.4% immediately post recovery, and it remained 20.8 ± 15.6% lower at 24 hours and 22.5 ± 12.3% lower at 48 hours post recovery, but it was no longer significantly reduced at 72 hours. However, following CWT, peak force did not decrease significantly relative to pre-exercise levels (≈ 4–10%). The slightly greater decrease in force immediately after PAS was not different from that after CWT although peak force produced 24 and 48 hours post recovery was significantly different between the 2 recovery strategies ($p < 0.01$). Therefore, CWT was associated with less loss of muscle force generating capacity compared to PAS.

Jump Squat Peak Power. Peak power produced during the jump squat was significantly reduced ($p < 0.05$) following both PAS (20.9 ± 13.4%) and CWT (12.8 ± 8.0%), with the mean reduction in power for PAS being marginally (not significantly) greater than for CWT (effect size = 0.76). While power developed after CWT was not significantly lowered at 24 and 48 hours post recovery, power produced following PAS remained 18.0 ± 11.6% and 22.7 ± 15.8% lower after 24 and 48 hours ($p < 0.006$). Therefore, CWT was associated with a smaller reduction in, and faster recovery of, power production during the jump squat (Table 1).

Creatine Kinase Concentration. Creatine kinase concentration was found to increase in a similar manner throughout the 72-hour follow-up period following the 2 different recovery strategies (Figure 2, Table 1). However, there was a significant increase in CK following PAS 24 hours post recovery compared to baseline ($p < 0.006$). There was no significant difference in CK between treatments during the 72-hour measurement period, although CK peaked after 48 hours following PAS (183.6 ± 197.0% of pre-exercise level), and it peaked after 24 hours following CWT 82.4 ± 82.8% (Figure 3). Indeed, the difference in the area under the CK curve was approaching significance ($p = 0.09$) between CWT and PAS (4,225 ± 5,238 $U{\cdot}L^{-1}$ and 10,037 ± 9,721 $U{\cdot}L^{-1}$, respectively).

Thigh Volume. Both treatments were also associated

TABLE 1. Descriptive statistics for dependent variables for contrast water therapy (CWT) and passive recovery (PAS; control) prior to exercise (baseline), immediately post recovery (0), and 24, 48, and 72 hours post recovery.

	PAS (control)		CWT	
Variable	Mean	*SD*	Mean	*SD*
Isometric squat force (N)				
Baseline	864.8	245.7	845.1	295.3
0 h post	717.6	145.7	789.7	272.3
24 h post	683.6	244.8	723.7	216.3
48 h post	672.6	251.0	721.1	260.4
72 h post	790.2	269.1	796.5	287.9
Jump squat peak power (N)				
Baseline	1,118.4	462.2	1,054.0	471.6
0 h post	884.3	407.7	917.0	413.5
24 h post	923.3	427.4	884.0	421.2
48 h post	870.0	431.4	1,040.0	515.5
72 h post	1,020.7	419.1	1,050.0	471.2
Creatine kinase concentration ($U{\cdot}L^{-1}$)				
Baseline	108.0	68.1	109.7	35.6
0 h post	124.8	77.1	113.4	43.9
24 h post	229.6	184.1	220.7	160.3
48 h post	294.1	375.5	165.4	119.1
72 h post	243.5	371.8	178.5	219.6
Thigh volume (ml)				
Baseline	4,910.0	1,259.3	4,828.1	1,360.0
0 h post	5,123.6	1,370.9	4,934.5	1,420.6
24 h post	5,214.1	1,317.0	4,983.5	1,459.8
48 h post	5,233.2	1,367.5	4,980.0	1,508.5
72 h post	5,101.5	1,322.1	4,878.5	1,427.0
Perceived muscle soreness (0–10 scale; 0 = normal, 10 = extremely sore)				
0 h post	2.9	2.0	2.0	1.0
24 h post	6.5	2.4	4.5	2.2
48 h post	7.0	2.3	5.5	2.8
72 h post	4.0	1.9	3.3	1.9

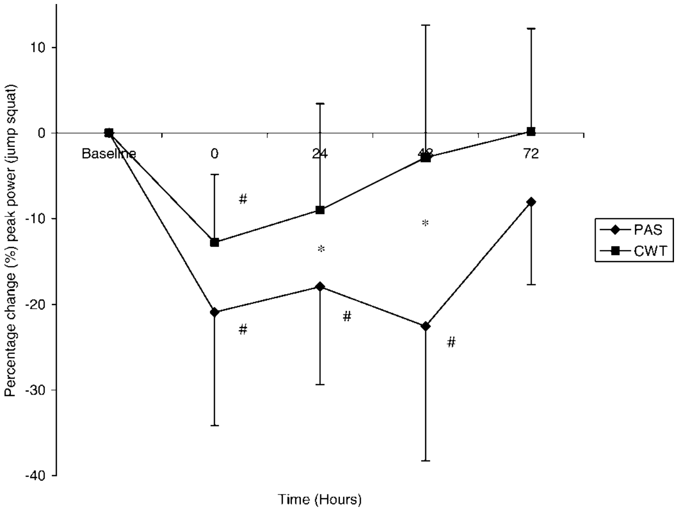

FIGURE 2. Peak power, percentage change mean, and standard deviation (*SD*) values. Contrast water therapy (CWT) was associated with a smaller reduction in, and faster recovery of, power production during the jump squat. * Indicates a significant difference between passive recovery (PAS) and CWT. # Indicates a significant time difference compared to baseline.

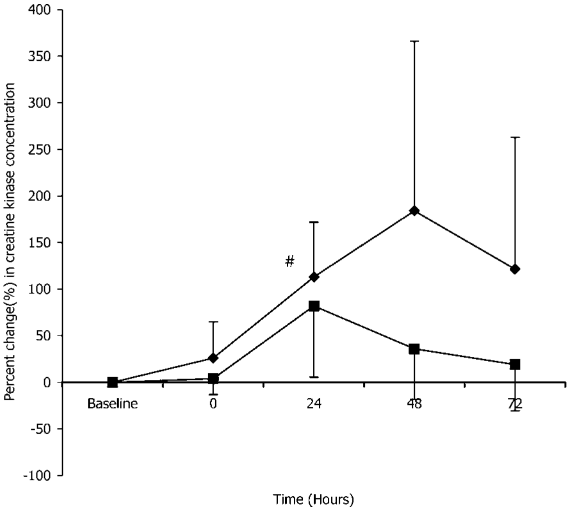

FIGURE 3. Creatine kinase (CK) concentration, percentage change mean, and standard deviation (*SD*) values. There was a significant increase in CK concentration following passive recovery (PAS) 24 hours post exercise (#, $p < 0.006$). Indeed, the difference in the area under the CK curve was approaching significance ($p = 0.09$) between contrast water therapy (CWT) and PAS.

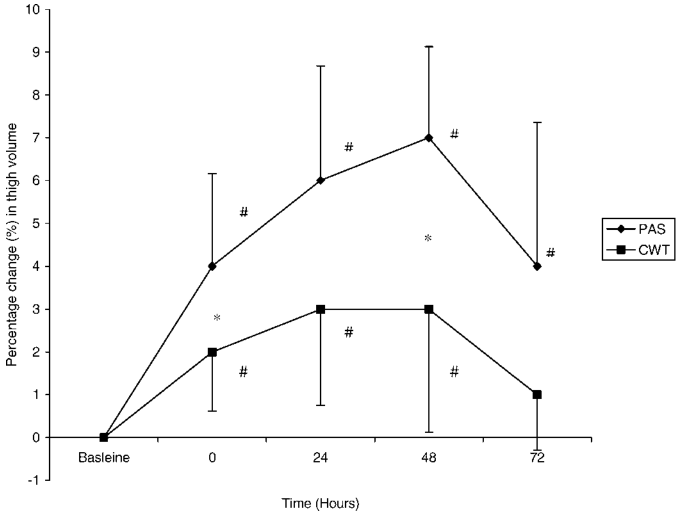

FIGURE 4. Thigh volume (estimated from subgluteal, midthigh, and above-the-knee circumference sites), percentage change mean, and standard deviation (*SD*) values. Contrast water therapy (CWT) was associated with a smaller increase and faster reduction of lean thigh volume. * Indicates a significant treatment difference between passive recovery (PAS) and CWT. # Indicates a significant difference compared to baseline.

with significant increases in midthigh and subgluteal circumference ($p < 0.006$) immediately post recovery and 24 and 48 hours post exercise. One exception was the midthigh circumference returning to baseline levels 48 and 72 hours post exercise following CWT. Above-the-knee circumference was increased significantly by 2.0 ± 1.3%, 3.4 ± 1.6%, 3.3 ± 1.4%, and 1.9 ± 1.4% immediately post recovery and at 24, 48, and 72 hours after exercise following PAS. A significant between-treatment difference after 24 and 48 hours ($p < 0.01$) was evident. Therefore, CWT was associated with a smaller increase, and faster reduction, in thigh circumferences compared to PAS. These between-group differences at midthigh and above-the-knee sites resulted in a significant difference in estimated thigh volume at 24 and 48 hours post exercise (Figure 4, Table 1). Thus, there was a significant effect of recovery strategy on thigh volume, which became significant 24 hours after exercise.

Perceived Muscle Soreness. Both treatment groups reported significant increases ($p < 0.01$) in pain immediately post recovery, and 24, 48, and 72 hours post exercise, as measured on the VAS. However, there were no statistically significant differences between treatments (Figure 5, Table 1).

DISCUSSION

The present study examined the effects of postexercise CWT on recovery from muscle-damaging eccentric exercise. Following the PAS condition, the exercise protocol caused significant losses of isometric force generating capacity in a squat test (15, 21, 23, and 8% at 0, 24, 48, and 72 hours post exercise), which are similar in magnitude to those reported by previous researchers (24–50%, 19–46%, 9–19%, and 10–14% at 0, 24, 48, and 72 hours post exercise) (1, 10, 16, 39). These reductions in isometric force were mirrored by reductions in dynamic force capacity (jump squat; Figure 1), strong feelings of pain (Figure 5), and significant swelling (Figure 4) of the thigh. Thus, the exercise protocol caused significant DOMS and a functional deficit in the subjects. Compared to PAS, CWT was associated with a smaller loss of isometric and dynamic force generating capacity, a smaller increase in thigh volume (swelling), and slightly lower levels of perceived pain immediately after the 15-minute recovery period. The present research is the first to show that CWT can effectively minimize the loss of muscular force and promote its recovery after muscle-damaging exercise.

The mechanism by which alternating immersion in hot and cold water affects recovery from muscle damage is yet to be determined. However, there are 4 main candidates that deserve consideration. First, the hydrostatic pressure associated with the immersion process could have lead to both muscular and vascular compression and

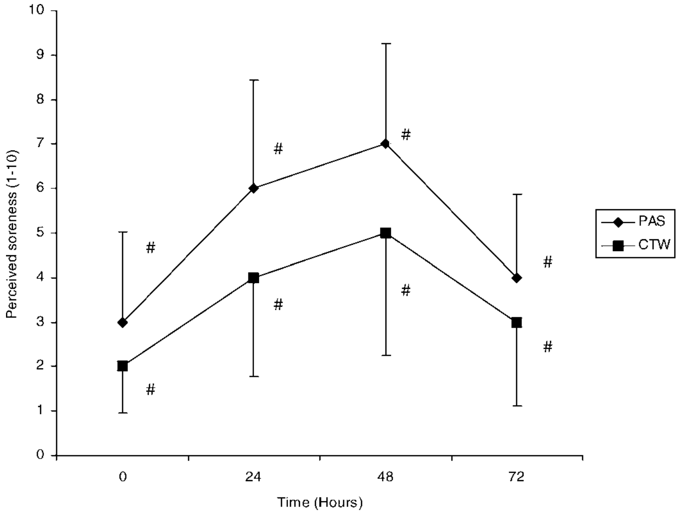

FIGURE 5. Rating of perceived soreness using the visual analog scale (0–10; 0 = normal, 10 = extreme soreness). There were no statistically significant differences between treatments, although the mean perceived soreness was lower following contrast water therapy (CWT) than passive recovery (PAS) at all time points during recovery. # Indicates a significant time difference (compared to baseline).

therefore reduced the early onset of swelling. Indeed, Kraemer et al. (26) recently showed that compression bandages were effective for relieving the symptoms of DOMS. Minimization of early swelling would reduce pain and pressure receptor activity, and therefore attenuate the immune response. This is consistent with the present findings that local swelling was significantly reduced at later time periods (as well as immediately post recovery) following the CWT treatment.

Second, the warm water treatment, which formed a significant part of the CWT protocol, may have promoted vasodilation to improve the supply of oxygen and antibodies while also improving metabolite clearance (36). It is likely that this occurred to some degree in the present study because alterations in sympathetic drive are mediated by both skin and core body temperature changes (28), both of which may have been affected by immersion in hot (40–42°C) water for 2-minute periods. Also, similar to the up-regulation seen during fever (25), heating would also have increased the immune response to muscle damage and, therefore, contributed to increases in myocellular necrosis as the recovery process progressed. Given that force recovery was enhanced following CWT at all time points, and swelling subsided after 48 hours, it is unlikely that the warm water treatment alone was the major factor affecting force recovery.

Third, the cold water immersion component of the CWT may have attenuated the immune response to muscle damage by either reducing tissue temperature, reducing skin temperature (38) and up-regulating sympathetic nervous system activity (38). While Biggar et al. (2) have shown that neutrophil migration is impaired in vivo and in vitro at reduced temperatures, this is unlikely to have occurred given the short (60 seconds) cold-water immersion periods used in the present study. Indeed, muscle temperature appears to be well maintained during cold-water immersion provided core temperature is not compromised (15). It has previously been shown that immersion of the right leg in hot (40.6° C) water for 4 minutes and then cold (15.6° C) water for 1 minute was not sufficient to reduce muscle temperature measured 1 cm below the muscle surface (31). Alternating hot and cold pack treatment at 5-minute intervals also produced no physiological effect (32). More likely is the decrease in skin temperature resulting in an increase in sympathetic drive causing a significant shift of blood from the extremities/periphery. The mechanism explaining our findings from the data collected can only be speculated upon. While the aforementioned could all occur following CWT, the exact mechanisms cannot be known until further research is completed. Nonetheless, changes in immune response and blood flow are consistent with our findings of rapid recovery of strength and power within 72 hours and the minimization of swelling in the CWT treatment. Direct comparison of CWT and cold-water immersion recovery strategies would more clearly show the effects of the cold-water component of CWT.

Finally, alternating between cold and hot water might have produced rapid changes in muscle perfusion, due to a combination of effects previously discussed. This is sometimes referred to as a "pumping" effect (11). As mentioned above, the significant drop in skin temperature would have up-regulated sympathetic activity, while the subsequent warming of the skin would likely have reduced it. The present results indicate that CWT can significantly reduce swelling. It is hypothesized that CWT also causes alterations in the perfusion of the muscle via alternating vasodilation and vasoconstriction, which might attenuate the immune response and therefore reduce myocellular damage. Our results showing a trend toward decreased CK after CWT are consistent with this hypothesis.

To our knowledge, no previous research has specifically examined the effects of CWT on recovery from muscle-damaging exercise. Furthermore, limited research has been conducted investigating warm and cold hydrotherapy techniques in isolation (16, 42). The effects of warm underwater jet-massage have provided promising implications for the use of CWT. Viitasalo et al. (42) incorporated three 20-minute warm (~37° C) underwater water-jet massages into the training week of 14 junior track and field athletes. The results indicated an enhanced maintenance of performance following the warm water therapy compared to the control. While an enhanced maintenance of neuromuscular ability occurred, increased levels of CK and myoglobin were observed. The authors suggest that the warm water treatment may have increased release of proteins from the muscle to the blood and that this increased release of proteins may have reduced the proportion of muscle components degraded in the extra cellular space (42). In addition, cold water immersion has been investigated as a postexercise recovery procedure, with results indicating decreases in the amount of muscle or connective tissue shortening following eccentric exercise, suggesting a possible reduction in muscle tissue damage (16). However, in addition to these findings Eston and Peters (16) found cold water immersion to have no effect on the perception of tenderness or isometric strength loss. Despite the fact that CWT has rarely been investigated as a recovery strategy, a recent study found both CWT and active recovery to reduce lactate accumulation after high intensity running and that CWT was associated with an increased perception of recovery (12).

The results of the present study are the first to provide positive scientific support for the practice of CWT. While CWT has been acknowledged in sports medicine as a recovery strategy for the treatment of postacute soft-tissue injury (21), there is an apparent lack of knowledge surrounding its use as a recovery strategy to alleviate muscle soreness and enhance the recovery of various physiological factors. Although the results of the present study support the use of CWT, further research into its use is required to develop knowledge and information in the area of this recovery strategy, with an emphasis on gaining understanding into the possible physiological mechanisms of CWT. Given that the CWT protocol used in the present study was successful in minimizing force loss and promoting recovery, it could be used as a template for future studies. Despite its positive affect on muscle force generation, the long-term effects of CWT are not known. Some caution should therefore be exercised with its prolonged use until its effects on long-term muscle adaptation are fully understood.

PRACTICAL APPLICATIONS

The findings of this study indicate that strength, power, and symptoms of DOMS are improved following CWT compared to passive recovery. These improvements in the recovery profile support CWT as a practical and low-cost recovery strategy. Therefore, CWT appears to be a recovery strategy that could easily be adopted and integrated into athletes' recovery programs.

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