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original research

Use of Cold-Water Immersion to Reduce Muscle Damage and Delayed-Onset Muscle Soreness and Preserve Muscle Power in Jiu-Jitsu Athletes

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Context: Cold-water immersion (CWI) has been applied widely as a recovery method, but little evidence is available to support its effectiveness.

Objective: To investigate the effects of CWI on muscle damage, perceived muscle soreness, and muscle power recovery of the upper and lower limbs after jiu-jitsu training.

Design: Crossover study.

Setting: Laboratory and field.

Patients or Other Participants: A total of 8 highly trained male athletes (age = 24.0 ± 3.6 years, mass = 78.4 ± 2.4 kg, percentage of body fat = 13.1% ± 3.6%) completed all study phases.

Intervention(s): We randomly selected half of the sample for recovery using CWI (6.0°C ± 0.5°C) for 19 minutes; the other participants were allocated to the control condition (passive recovery). Treatments were reversed in the second session (after 1 week).

Main Outcome Measure(s): We measured serum levels of creatine phosphokinase, lactate dehydrogenase (LDH), aspartate aminotransferase, and alanine aminotransferase enzymes; perceived muscle soreness; and recovery through visual analogue scales and muscle power of the upper and lower limbs at pretraining, postrecovery, 24 hours, and 48 hours.

Results: Athletes who underwent CWI showed better posttraining recovery measures because circulating LDH levels were lower at 24 hours postrecovery in the CWI condition (441.9 ± 81.4 IU/L) than in the control condition (493.6 ± 97.4 IU/L; P = .03). Estimated muscle power was higher in the CWI than in the control condition for both upper limbs (757.9 ± 125.1 W versus 695.9 ± 56.1 W) and lower limbs (53.7 ± 3.7 cm versus 35.5 ± 8.2 cm; both P values = .001). In addition, we observed less perceived muscle soreness (1.5 ± 1.1 arbitrary units [au] versus 3.1 ± 1.0 au; P = .004) and higher perceived recovery (8.8 ± 1.9 au versus 6.9 ± 1.7 au; P = .005) in the CWI than in the control condition at 24 hours postrecovery.

Conclusions: Use of CWI can be beneficial to jiu-jitsu athletes because it reduces circulating LDH levels, results in less perceived muscle soreness, and helps muscle power recovery at 24 hours postrecovery.

Key Words: creatine kinase, cryotherapy, L-lactate dehydrogenase, martial arts, muscle power

Key Points

- Cold-water immersion may be beneficial to jiu-jitsu athletes because it decreased markers of muscle damage.
- Cold-water immersion reduced the perception of muscle pain.
- Cold-water immersion assisted in the recovery of the upper and lower limbs.
- Jiu-jitsu athletes could use cold-water immersion to improve performance and physiologic status, especially during training phases in which more intensive sessions are conducted and at the beginning of the season.

The physical preparation of high-performance combat-sport athletes requires high levels of physical effort.[1] However, strenuous exercise promotes biochemical and cellular changes that result in deterioration of the muscle structure, decreasing muscle power.[2,3] In this context, many investigators have studied muscle damage arising from high-intensity exercise because it interferes with sport performance.[3] Creatine kinase (CK), lactate dehydrogenase (LDH),[4] aspartate aminotransferase (AST), and alanine aminotransferase (ALT) are among the most studied serum muscle damage markers.[5] An increased level of exercise-induced CK is directly related to muscle pain, greater expression of cartilage injury markers,[6] and muscle disruption.[7] Furthermore, the postexercise increase in the serum concentration of CK is inversely proportional to the ability of the muscle to generate power.[8] Lactate dehydrogenase is present in large amounts in skeletal muscle because it is responsible for the anaerobic conversion of pyruvate into lactate. The association of LDH with muscle damage is linked closely to the CK concentration.[9] Aspartate aminotransferase and ALT are liver enzymes important for the catabolism of amino acids, and although they are at low concentrations in muscle, increased activity of these enzymes occurs during intense,[10] aerobic,[9] or

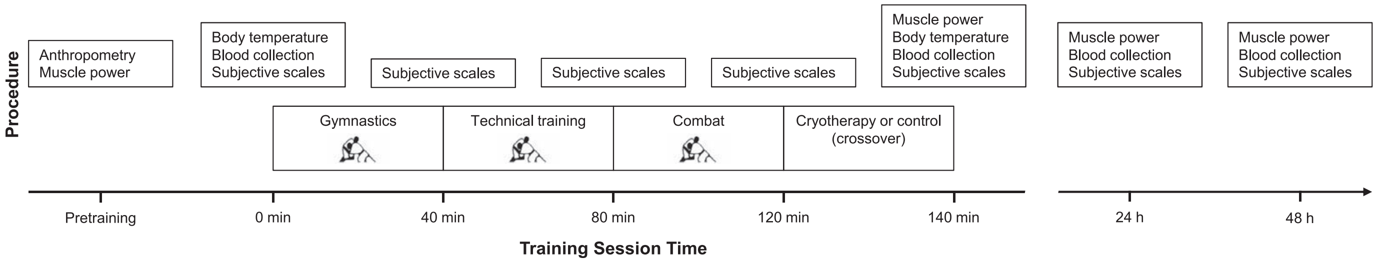

Figure 1. Organization chart of procedures used for data collection. Times on bars refer to procedures used before, during, and after training sessions.

intermittent exercise,[11] which increases protein catabolism. However, no authors, to our knowledge, have established correlations among muscle damage enzymes, perceived pain, and sport performance. Any relationship among these variables would provide some indication about variables that could be manipulated in future experiments to verify a possible causal effect.

In fact, 2.5 hours of judo training resulted in a 15% to 42% increase in the serum concentrations of these enzymes.[5] Given that training volume must be maintained for high-performance athletes, regenerative methods to reduce postexercise muscle damage have been investigated. Among these methods, cold-water immersion (CWI) has been used widely. It causes peripheral vasoconstriction, which reduces the metabolic outflow resulting from exercise, and decreases nerve conduction in the exercised muscle, resulting in decreased muscle soreness[12,13]; however, little evidence is available to support its effectiveness in improving physical performance.[13,14] In addition, Rupp et al[15] reported that CWI decreased muscle temperature faster than an ice pack, so this approach seems to be relevant to athletes conducting successive training sessions.

Increasing the recovery rate is an important strategy, especially for athletes involved in training cycles. In combat sports, particularly those involving grappling (judo, wrestling, jiu-jitsu), this factor is relevant because athletes are highly predisposed to traumatic injury.[16] Reducing posttraining muscle damage could protect the health and physical integrity of athletes, increasing their chance of achieving the goals established for a given preparation cycle. However, to date, studies published on this subject have been inconclusive about the effect of cryotherapy on muscle damage in combat-sport athletes. Authors[8] have demonstrated the acute benefits of CWI in preserving muscle power and decreasing muscle soreness and damage after training[17] and simulated jiu-jitsu competition.

Given the need for new alternatives that lead to better recovery, the effectiveness of cryotherapy for reducing muscle damage, which can accelerate recovery and enhance sport performance, should be tested. Therefore, the purpose of our study was to assess the effect of CWI after jiu-jitsu training on the perceived muscle pain, inflammatory response, and muscle power of the upper and lower limbs, as well as on the relationships among these variables. We hypothesized that this intervention would reduce perceived muscle soreness and the inflammatory response and would result in better preservation of muscle power. Moreover, we hypothesized that more perceived pain and an increased inflammatory response would correlate with performance decrement.

METHODS

Design

For this crossover study, 2 training sessions separated by 1-week intervals were carried out. The data-collection procedure is provided in Figure 1.

The training protocol represented a typical session, characterized by progressive and exhaustive effort. Each training session comprised the following structure: 40 minutes each of generalized exercises (calisthenics), technical training, and combat simulation. Generalized exercises included warmup exercises involving power, speed, and endurance. Technical training focused on specific jiu-jitsu movements: guard passes, sweeps, arm locks, projections, and submissions. Combat simulations consisted of matches with varied durations: three 2-minute matches, two 5-minute matches, two 7-minute matches, and one 10-minute match. This training model was similar to that used in other studies of judo[18] and jiu-jitsu.[17] All volunteers were familiarized with the training regime and procedures.

Participants

Based on our pilot study (N = 4) and on the available literature, we performed a representative analysis to determine the appropriate sample size based on the serum CK concentration, which was the main indicator of muscle damage. To achieve 80% statistical power, a minimum sample size of 8 participants would be necessary to detect a serum CK increase of 80 IU/L throughout the experimental period and 40 IU/L to detect differences among groups (Granmo 5.2; IMIM, Barcelona, Spain). We chose this variable for the calculations because it presented the greatest variation among those variables measured in our study; a detailed description is provided in the Muscle Damage Markers subsection. Furthermore, other researchers[19,20] have found high intrasample variability for this enzyme. Given the nature of our study, we estimated a sample loss of 30%. A total of 12 highly trained male jiu-jitsu competitors were selected. This sample had trained continuously in the 10 months before the experiment and participated in all 4 phases of the state championship. Athletes were selected according to the following criteria: (1) graduation as a blue or purple belt (for technical-level equalization), (2) participation in at least 3 competitions in the year before the study, and (3) not involved in any rapid weight-loss process before competition (because this practice can negatively affect physical performance).[21] Of the sample, 4 participants did not complete all study stages:

1 had a knee injury, and 3 refused recovery by CWI. Thus, the final sample consisted of 8 athletes (age = 24.0 ± 3.6 years, mass = 78.4 ± 2.4 kg, percentage of body fat = 13.1% ± 3.6%).

All participants provided written informed consent, and the study was approved by the Federal University of Sergipe Research Ethics Committee (protocol 01723312.2.0000.0058), according to the Brazilian Health Council on experiments with humans.

Pretesting Procedures

Before data collection, we assessed the anthropometric and upper and lower limb muscle power of the athletes. Body mass was measured on a scale (Soehnle, Sao Paulo, Brazil) with maximum capacity of 200 kg and precision of 100 g. Height was measured using a stadiometer coupled to the scale (accuracy of 1 cm). Body density was estimated indirectly (Lange Skinfold Caliper; Beta Technology, Santa Cruz, CA) using the equation of Thorland et al[22] for wrestlers:

$$D(g/mL) = 1,1030 - [0.000815(SD)] + [0.00000084(SD2)],$$

where D is body density and SD is the sum of subscapular and abdominal skinfold thicknesses. Body fat percentage (BF%) was estimated using the equation of Brožek et al[23]:

$$BF\% = 457/D - 414.2.$$

Procedures

Fighters were instructed to refrain from training or any strenuous physical activity for 24 hours before the experiment. A standardized breakfast was served to all athletes 90 minutes before training. The goal of the standardized breakfast was to provide similar energy intake to all athletes, minimizing the effect of nutritional status on the effort exerted during each training session. This 880-kcal meal consisted of bread, a slice each of ham and mozzarella cheese, banana, 100 g of granola, and 200 mL of whole-milk strawberry yogurt. On the first day, half of the sample was selected randomly to receive CWI, and the other half was allocated to the control condition (passive recovery). Treatments were reversed on the second day of training. Immediately after the training session, athletes receiving the CWI condition remained immersed in the ice bath to the neck (6.0°C ± 0.5°C) for 16 minutes: 4 cycles of 4-minute immersion with a 1-minute interval between cycles, totaling a 19-minute intervention. This CWI protocol followed that applied by Santos et al.[17]

Measures

Muscle Damage Markers. Serum CK, LDH, AST, and ALT concentrations were measured as markers of muscle damage. We collected blood samples at pretraining, postrecovery, and 24 and 48 hours postrecovery. About 2 mL of blood were collected from the antecubital vein and stored in tubes containing coagulant gel (Vacuette; Greiner Bio-One, Campinas, Sao Paulo, Brazil). The blood rested for 30 minutes at room temperature to allow for coagulation and then was centrifuged at 2500 revolutions per minute for 8 minutes for serum separation. Biochemical measurements were performed in an automated analyzer (model Vitros 5600; Ortho Clinical Diagnostics, Raritan, NJ). Serum LDH (variation coefficient for same sample = 1.2%, accuracy = 1.909 IU/L), serum AST (variation coefficient for same sample = 1.8%, accuracy = 1.781 IU/L), and serum ALT (variation coefficient for same sample = 1.9%, accuracy = 1.909 IU/L) were measured using the multipoint kinetic technique. Serum CK was measured by the multipoint rate technique (variation coefficient for same sample = 1.5%, accuracy = 8.456 IU/L).

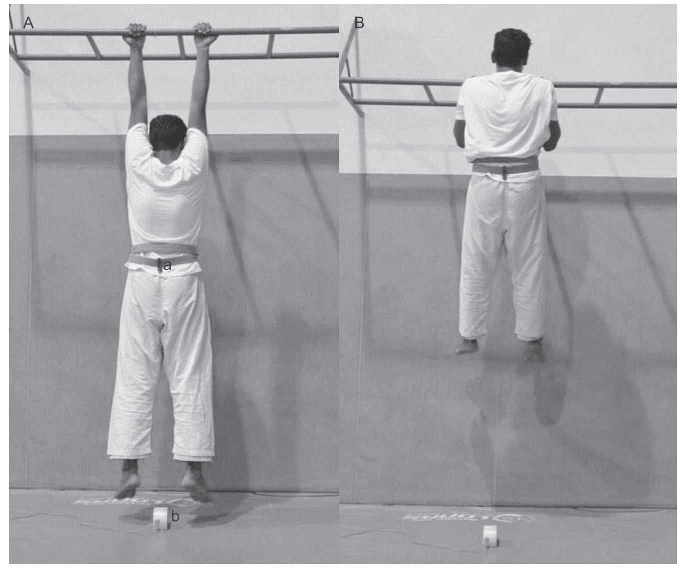

Figure 2. A, Initial and, B, final positions of upper limb power test. [a] Encoder attachment point. [b] Encoder.

Upper Limbs Power Measurement. At pretraining, postrecovery, and 24 and 48 hours postrecovery, all athletes performed a muscle power test using a bar placed in the supine position and an encoder attached to their belts (model PFMA 3010e Muscle Lab System; Ergotest, Langesund, Norway). Three repetitions were performed, and the best result was selected for analysis. We calculated reliability from the baseline repetitions and found an intraclass coefficient (ICC) of 0.97 and a standard error (SE; 95%) of 17.5 W (2.5%). The initial and final positions of the upper limbs during the power test are shown in Figure 2.

Lower Limbs Power Measurement. At pretraining, postrecovery, and 24 and 48 hours postrecovery, all participants performed a lower limb power test using the countermovement jump (CMJ) on a jumping mat (Globus, Rome, Italy) according to the methods described by Bosco et al.[24] They made 2 attempts, and the best result was used for analysis. For the lower limbs, we calculated reliability from the baseline repetitions and found an ICC of 0.96 and an SE (95%) of 1.43 cm (2.8%).

Subjective Measurements. Athletes indicated perceived muscle soreness on a visual analog scale. This measurement was obtained at pretraining, posttraining, postrecovery, and 24 and 48 hours postrecovery using the methods described by Carvalho and Kowacs[25] (ICC = 0.76; SE 95% = 0.2 au [3.5%]). Subjective perceived recovery

Table 1. Muscle Damage Markers at Different Times of Jiu-Jitsu Training in the Cryotherapy and Control Conditions

Marker, Mean ± SD, IU/L	Time			
	Pretraining	Postrecovery	24 h	48 h
Creatine phosphokinase				
Cryotherapy	164.9 ± 72.4[b]	255.3 ± 103.6[c]	381.8 ± 110.8[d]	281.5 ± 82.2
Control	166.9 ± 72.0[b]	300.1 ± 108.3[c]	465.6 ± 117.8[d]	276.0 ± 39.5
Lactate dehydrogenase				
Cryotherapy[a]	351.9 ± 30.4[e]	434.3 ± 28.2	441.9 ± 81.4[f,g]	376.4 ± 40.6
Control	353.0 ± 35.2[e]	489.3 ± 40.6	493.6 ± 97.4[f]	397.0 ± 51.5
Aspartate aminotransferase				
Cryotherapy	22.4 ± 5.1[h]	27.4 ± 6.8	24.5 ± 3.9	24.8 ± 5.1
Control	23.1 ± 7.0[h]	29.0 ± 7.5	30.3 ± 6.4	25.9 ± 4.5
Alanine aminotransferase				
Cryotherapy	23.6 ± 11.0	25.5 ± 11.4	25.5 ± 9.9	23.9 ± 8.1
Control	25.8 ± 19.0	25.5 ± 16.4	26.8 ± 14.8	26.1 ± 13.3

[a] Indicates cryotherapy condition was different from the control condition regardless of time ($P < .001$).
[b] Indicates different from the other times regardless of condition ($P < .001$).
[c] Indicates different from 24 h regardless of condition ($P < .001$).
[d] Indicates different from 48 h regardless of condition ($P < .001$).
[e] Indicates different from postrecovery and 24 h regardless of condition ($P < .001$).
[f] Indicates different from postrecovery and 48 h regardless of condition ($P < .01$).
[g] Indicates different from control condition for 24 h ($P < .001$).
[h] Indicates different from 24 h and 48 h regardless of condition ($P < .01$).

was estimated at posttraining, postrecovery, and 24 and 48 hours postrecovery using the methods described by Laurent et al[26] (ICC = 0.75; SE 95% = 0.3 au [3.0%]). The rating of perceived exertion (RPE) was measured before and every 40 minutes during training using the modified Borg[27] scale (ICC = 0.85; SE 95% = 0.2 au [2.4%]).

Body Temperature. As a complementary measure, we used a digital thermometer (G-Tech, Shenzhen, Guangdong, China) with an accuracy of ±0.2°C to measure skin temperature at 3 stages: pretraining, posttraining, and postrecovery.

Statistical Analysis

Exploratory data analysis was performed for identification and correction of extreme values, which was necessary only for CK. Normality and homoscedasticity were tested using the Kolmogorov-Smirnov test and the Bartlett criterion, respectively. We used analysis of variance with 2 factors (recovery × measurement time) to establish mean differences. For validation of repeated measurements, we used the Mauchly sphericity test and, when necessary, applied the Greenhouse-Geisser correction. If we observed a difference in the analysis of variance, we used a post hoc Bonferroni test. When a main effect and interaction were found, only the interaction effect was reported. The magnitude of treatment effects was calculated using the η^2 effect size. The upper and lower 95% confidence intervals (CIs) were calculated for corresponding mean variations. The standardized effect size (Cohen d)[28] analysis was used to interpret the magnitude of differences among measurements. To examine the strength of association among variables, we used the Pearson product moment correlation. The α level was set at .05 for all analyses. We used SPSS (version 15.0; SPSS Inc, Chicago, IL) to analyze the statistics.

RESULTS

Muscle Damage

The results for the serum muscle damage markers (CK, LDH, AST, ALT) in the CWI and control conditions are given in Table 1. For CK, an effect of measurement time ($F_{3,42} = 51.23$; $P < .001$; $\eta^2 = 0.785$) was found, with lower values at pretraining than at postrecovery (difference = 112.1 ± 69.3 IU/L; $P < .001$; 95% CI = 75.1, 149.0; d = 0.5), 24 hours (difference = 258.1 ± 92.5 IU/L; $P < .001$; 95% CI = 208.8, 307.4; d = 0.8), and 48 hours (difference = 113.1 ± 69.5 IU/L; $P < .001$; 95% CI = 76.1, 150.1; d = 0.6); lower values at postrecovery than at 24 hours (difference = 146.0 ± 84.4 IU/L; $P < .001$; 95% CI = 101.0, 191.0; d = 0.5); and higher values at 24 than 48 hours (difference = –144.9 ± 107.2 IU/L; $P < .001$; 95% CI = –202.0, –87.8; d = 0.6).

We observed an interaction effect for serum LDH ($F_{3,42} = 6.27$; $P = .001$; $\eta^2 = 0.309$). However, most differences were associated with the measurement time except for the lower value in the CWI than in the control condition at 24 hours (difference = 151.8 ± 136.6 IU/L; $P < .001$; 95% CI = 37.6, 265.9; d = 0.7), which was of greater interest for our study.

Serum AST showed an effect of measurement time ($F_{3,42} = 5.50$; $P = .003$; $\eta^2 = 0.282$), with lower values during pretraining than at 24 hours (difference = 5.6 ± 5.9 IU/L; $P = .009$; 95% CI = 2.4, 8.7; d = 0.7) and 48 hours (difference = 2.6 ± 6.8 IU/L; $P = .007$; 95% CI = 1.1, 6.2; d = 0.2).

We observed no effects of condition ($F_{1,14} = 0.05$; $P = .83$; $\eta^2 = 0.003$) or measurement time ($F_{3,42} = 0.44$; $P = .72$; $\eta^2 = 0.031$) for serum ALT and no interaction between condition and time ($F_{3,42} = 0.30$; $P = .82$; $\eta^2 = 0.021$).

Table 2. Upper and Lower Limb Power Performance at Different Times of Jiu-Jitsu Training in the Cryotherapy and Control Conditions

Variable	Time				
	Pretraining	Posttraining	Postrecovery	24 h	48 h
Upper limb power in the bar test, W					
Cryotherapy	692.0 ± 116.1	763.9 ± 157.6	599.3 ± 84.0[a]	757.9 ± 125.1	723.0 ± 90.8
Control	692.0 ± 116.1	762.0 ± 113.5	768.4 ± 97.0	695.9 ± 56.1[b]	729.8 ± 50.2
Countermovement jump, cm					
Cryotherapy	51.2 ± 6.5	54.5 ± 4.4	44.1 ± 8.1[c]	53.7 ± 3.7	53.5 ± 4.8
Control	51.2 ± 6.5	52.1 ± 4.6	52.5 ± 4.6[c]	35.5 ± 8.2[b,d]	55.7 ± 2.4[e]

[a] Indicates different from posttraining and 24 h in the cryotherapy condition ($P < .01$).
[b] Indicates different from 24 h in the cryotherapy condition ($P = .001$).
[c] Indicates different from posttraining, 24 h, and 48 h for the same condition ($P < .05$).
[d] Indicates different from posttraining, postrecovery, and 48 h in the control condition ($P < .001$).
[e] Indicates different from postrecovery in the cryotherapy condition ($P < .01$).

Muscle Power

The results for CMJ and upper limb power for the CWI and control conditions are provided in Table 2. For the power generated in the bar test, an effect of interaction between condition and time was observed ($F_{4,56} = 4.68$; $P = .003$; $\eta^2 = 0.251$), with lower values at postrecovery than at posttraining (difference = –5.1 ± 8.6 cm; $P = .006$; 95% CI = –9.7, –0.5; d = 0.6) and 24 hours (difference = –8.6 ± 11.0 cm; $P = .01$; 95% CI = –14.4, –2.7; d = 0.1) in the CWI condition.

We noted an interaction between condition and time for height in the CMJ ($F_{4,56} = 13.73$; $P = .001$; $\eta^2 = 0.495$). However, most differences were associated with the measurement time, except that the values in the control condition were lower at 24 hours than at postrecovery (difference = 16.3 ± 100.2 cm; $P = .01$; 95% CI = 9.5, 26.8; d = 0.8) and 48 hours (difference = 20.0 ± 8.7 cm; $P = .01$; 95% CI = 10.7, 25.1; d = 0.8), which was of greater interest for this study.

Muscle Soreness, Perceived Recovery, and Perceived Exertion

For subjective perceived muscle soreness (Figure 3), we observed an effect of measurement time ($F_{6,84} = 31.72$; $P < .001$; $\eta^2 = 0.694$). Values were lower at pretraining than at 120 minutes (difference = 4.8 ± 2.1 au; $P < .001$; 95% CI = 3.6, 5.8; d = 0.8), postrecovery (difference = 4.8 ± 1.4 au; $P < .001$; 95% CI = 4.0, 5.5; d = 0.9), and 24 hours (difference = 2.3 ± 1.3 au; $P < .001$; 95% CI = 1.6, 3.0; d = 0.8) but not at 48 hours (difference = 1.0 ± 1.2 au; $P = .58$; 95% CI = –2.9, 1.2; d = 0.2); lower at 40 minutes than at 80 minutes (difference = 1.6 ± 1.2 au; $P = .004$; 95% CI = 0.9, 2.2; d = 0.4), 120 minutes (difference = 2.3 ± 2.0 au; $P = .009$; 95% CI = 1.3, 3.4; d = 0.5), and postrecovery (difference = 2.4 ± 1.9 au; $P = .004$; 95% CI = 1.4, 3.4; d = 0.6); lower at 24 hours than at 120 minutes (difference = 2.4 ± 2.2 au; $P < .001$; 95% CI = 1.2, 3.5; d = 0.6) and postrecovery (difference = 2.4 ± 1.9 au; $P < .001$; 95% CI = 1.4, 3.5; d = 0.7) but not at 80 minutes (difference = 1.6

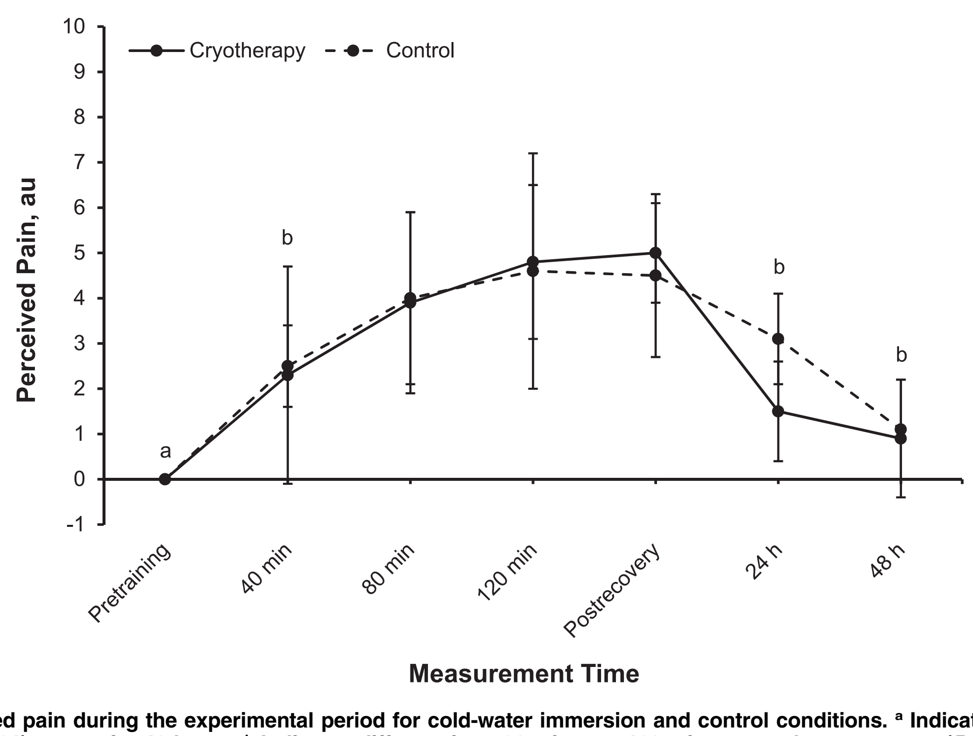

Figure 3. Perceived pain during the experimental period for cold-water immersion and control conditions. [a] Indicates different from all other times ($P < .001$) except for 48 hours. [b] Indicates different from 80 minutes, 120 minutes, and postrecovery ($P < .01$).

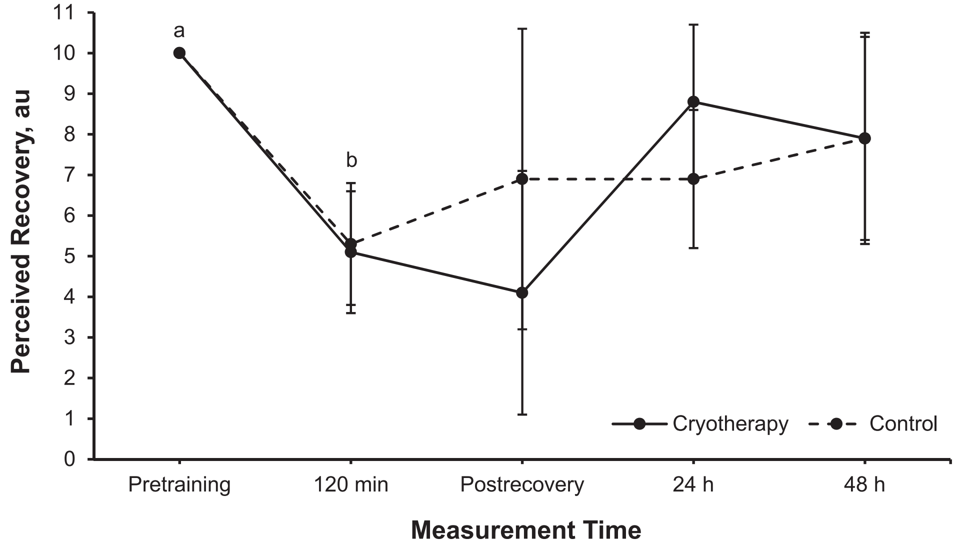

Figure 4. Perceived recovery throughout the experimental period for cold-water immersion and control conditions. [a] Indicates different from 120 minutes, postrecovery, and 24 hours ($P < .01$). [b] Indicates different from 24 hours ($P < .01$).

± 1.9 au; $P = .12$; 95% CI = –0.6, 4.8; d = 0.1); and lower at 48 hours than at 80 minutes (difference = 2.9 ± 2.2 au; $P < .001$; 95% CI = 1.8, 4.1; d = 0.7), 120 minutes (difference = 3.7 ± 2.4 au; $P < .001$; 95% CI = 2.4, 5.0; d = 0.7), and postrecovery (difference = 3.8 ± 2.0 au; $P < .001$; 95% CI = 2.7, 4.8; d = 0.8).

For the rating of perceived recovery (Figure 4), we noted an effect only of measurement time ($F_{1.92,\ 26.82} = 15.37$; $P < .001$; $\eta^2 = 0.523$), with higher recovery values at pretraining than at 120 minutes (difference = –4.8 ± 1.4 au; $P < .001$; 95% CI = –5.6, –2.1; d = 0.9), postrecovery (difference = –4.5 ± 3.6 au; $P < .001$; 95% CI = –6.4, –2.6; d = 0.7), and 24 hours (difference = –2.2 ± 2.0 au; $P = .003$; 95% CI = –3.3, –1.1; d = 0.6). The values at 48 hours were not lower than those obtained at pretraining (difference = –2.1 ± 2.5 au; $P = .054$; 95% CI = –3.5, 0.8; d = 0.5) and not higher than those obtained at 120 minutes (difference = 2.7 ± 2.2 au; $P = .056$; 95% CI = –5.6, 4.1; d = 0.6) and postrecovery (difference = 2.4 ± 3.2 au; $P = .06$; 95% CI = –2.6, 6.4; d = 0.4). In addition, the values at 120 minutes were lower than those obtained at 24 hours (difference = 2.6 ± 2.5 au; $P = .006$; 95% CI = 1.3, 4.0; d = 0.6).

Figure 5 shows the results of RPE training in the CWI and control conditions. We observed an effect of time for RPE ($F_{3,42} = 84.39$; $P < .001$; $\eta^2 = 0.858$), with lower values at pretraining than at 40 minutes (difference = 1.5 ± 1.4 au; $P < .001$; 95% CI = 0.7, 2.8; d = 0.6), 80 minutes (difference = 3.4 ± 1.7; $P = .046$; 95% CI = 2.1, 4.5; d = 0.8), and 120 minutes (difference = 5.7 ± 1.6 au; $P = .001$; 95% CI = 4.8, 6.5; d = 0.9); lower values at 40 minutes than at 80 minutes (difference = 1.9 ± 1.1 au; $P = .002$; 95% CI = 0.9, 2.2; d = 0.4) and 120 minutes (difference = 4.2 ±1.6 au; $P = .002$; 95% CI = 2.9, 5.0; d = 0.8); and lower values at 80 minutes than at 120 minutes (difference = 2.3 ± 1.3 au; $P = .012$; 95% CI = 1.5, 3.2; d = 0.6).

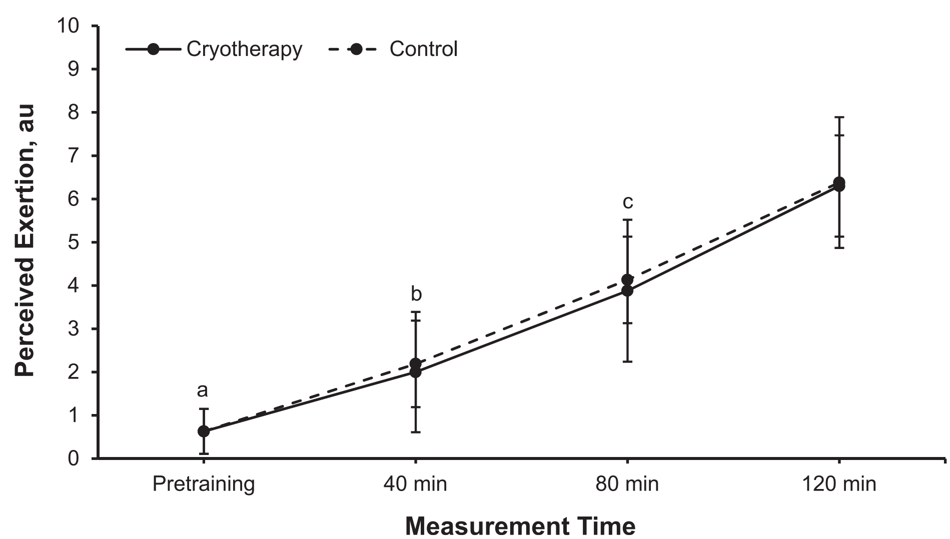

Figure 5. Ratings of perceived exertion throughout training for cold-water immersion and control conditions. [a] Indicates different from other times regardless of condition ($P < .001$). [b] Indicates different from 80 minutes and 120 minutes regardless of condition ($P < .001$). [c] Indicates different from 120 minutes regardless of condition ($P < .001$).

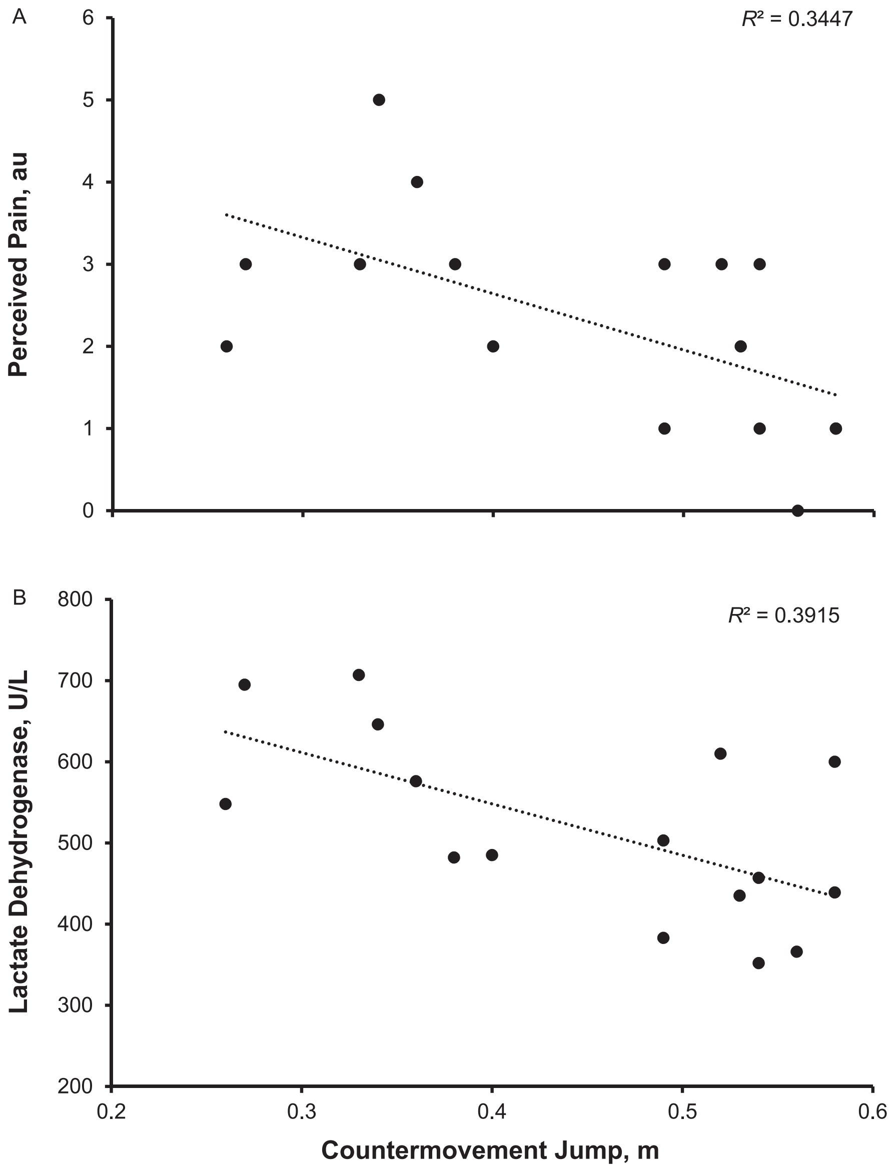

Figure 6. Countermovement jump. A, Correlation between perceived pain and power of lower limbs. B, Correlation between serum lactate dehydrogenase concentration and power of lower limbs.

The correlations between perceived muscle soreness and lower limb power ($r = -0.587$, $P = .02$) and between serum LDH levels and lower limb power ($r = -0.626$, $P = .01$) are shown in Figure 6. We observed an effect of condition for body temperature ($F_{1,14} = 22.47$; $P = .003$; $\eta^2 = 0.616$), with lower values in the CWI than control condition ($P < .001$). We also observed an interaction effect ($F_{1,14} = 13.63$; $P = .002$; $\eta^2 = 0.493$), with lower values after the CWI condition (35.3°C ± 0.5°C) than at pretraining during the CWI condition (37.9°C ± 1.1°C; $P < .001$; 95% CI = 1.6, 3.6; d = 0.8) and control condition (37.3°C ± 1.2°C; $P < .001$; 95% CI = 0.7, 3.2; d = 0.8) and in the control condition at posttraining (36.9°C ± 0.5°C; $P = .004$; 95% CI = 1.2, 2.1; d = 0.9).

DISCUSSION

Competitive jiu-jitsu requires high training volumes, and the establishment of recovery strategies can help the athlete maintain training volumes, reducing the injury risk during competitive preparation.[17] The aim of our study was to measure the effect of posttraining CWI on the recovery of jiu-jitsu athletes. Among the main results, CWI resulted in lower serum LDH concentrations at 24 hours postrecovery. It also resulted in decreased power at immediate post-recovery compared with posttraining, with restoration of values at 24 hours postrecovery. Lower limb power returned to pretraining values at 24 hours postrecovery only in the CWI condition. Perceived muscle soreness was not affected by conditions and was affected only by measurement time; the sensation of muscle soreness remained high compared with pretraining up to 24 hours after the training session, returning to baseline within 48 hours. Perceived recovery was not affected by the intervention, with a decrease at posttraining and restoration within 48 hours. These differences cannot be attributed to training efforts because the sessions were the same in both conditions and the RPE did not differ between them. Perceived muscle soreness and serum LDH levels were negatively correlated with lower limb power. In addition, CWI effectively reduced body temperature compared with the control condition. Whereas CWI is widely used in sports, its physical and physiologic effects on athletes suggest the existence of a placebo effect associated with this regenerative practice.[14] Researchers have shown that CWI may be beneficial for jiu-jitsu athletes engaged in training[17] and competition cycles[8] because it reduced the perceived muscle soreness and the serum concentration of enzymes indicative of serum muscle damage (CK and LDH).

Serum CK and LDH are enzymes important for anaerobic metabolism, and the leakage of these enzymes into the plasma has been associated with muscle damage and delayed-onset muscle soreness.[29] In contrast to our results, the meta-analysis of Leeder et al[14] showed an effect of CWI on postrecovery serum CK concentrations. Ascensão et al[30] reported lower serum CK levels 24 hours after a simulated soccer game when players underwent CWI (10 minutes at 10°C). The low temperature of the liquid medium reduces skin temperature and peripheral vasoconstriction, reducing peripheral blood flow that, in turn, reduces the release of metabolites arising from inflammation and neural signaling. These peripheral changes from the low temperature of the liquid medium result in less muscle soreness signaling.[31] Whereas the analgesic effect of CWI has not been fully explained,[12] investigators[32] believe that the smaller nerve conduction decreases the firing rate of the muscle spindle and afferent responses, thereby decreasing pain and spasm. Yanagisawa et al[33] observed that cryotherapy increases intracellular pH, delaying the onset of muscle edema, but other physiologic effects, such as the release of interleukin-6, can occur in the muscles.[34]

Grappling sports, such as jiu-jitsu, require high power demand,[35] and highly trained athletes possibly have neuromuscular adaptations that increase efficiency in the energy supply from anaerobic pathways.[36] Athletes who demand energy from the glycolytic pathway potentially recruit alanine and glutamine for the synthesis of adenosine triphosphate, thereby increasing the activity of serum AST and ALT enzymes.[37] In fact, increased serum ALT after a single 7-minute jiu-jitsu match has been reported.[38] In addition, during prolonged exercise, these enzymes catabolize amino acids for use as energy in the Krebs cycle.[10] Between the starting and post-CWI times, serum AST increased approximately 22% and 25.5% in the CWI and control conditions, respectively; however, at 24 hours postrecovery, it remained high only in the control condition. An increase in the posttraining serum AST concentration was observed in Japanese judo athletes who performed 120 minutes of training. According to Andreato et al,[35] a jiu-jitsu match requires a moderate energy supply from the glycolytic pathway, which explains the increased demand for this enzyme during training, but other energy sources are also used. According to Andreato et al,[38] glycogen is not the only source of energy used during a jiu-jitsu match, and proteolytic and lipolytic activation also occur. Among the enzymes used to estimate muscle damage in our study, only serum LDH showed an interaction, and the CWI condition showed advantages over the control condition. In fact, the effect of CWI on these enzymes is not completely understood in the literature. The authors[13,14] of meta-analyses affirmed that the main physiologic effect found in cryotherapy studies was the reduction of pain.

At immediate postrecovery, we observed less lower and upper limb power in the CWI condition. Nazari et al[10] also noted less muscle stress and elasticity after the application of ice packs to the quadriceps. However, at 24 hours postrecovery, lower limb power in the CWI condition returned to baseline, corroborating the results of Glasgow et al.[39] In rugby players, CWI resulted in recovery of the maximal voluntary isometric contraction at 24 hours postrecovery.[40] Whereas the mechanisms explaining recovery are not completely elucidated, Ihsan et al[41] suggested that CWI decreases intramuscular infusion and the metabolism of fibers; however, this process does not affect muscle recovery. Accordingly, Gregson et al[42] observed that CWI does not affect the recovery of muscle glycogen. Although it delays some muscle regeneration, power recovery is greater when individuals undergo cryotherapy, and further studies are needed to clarify how postcryotherapy muscle strength is restored.[43] We observed varied responses to the 4 muscle damage enzymes measured. We measured the effect of CWI on AST and ALT enzymes in combat-sport athletes. Despite the increases that we observed and that Umeda et al[44] observed after a typical judo training session, Yamamoto et al[45] measured lower serum levels of AST, LDH, and CK posttraining in judokas engaged in a long-term training period (6 months), suggesting that one important adaptation of long-term training is less or no muscle damage. Whereas few investigators have measured the AST and ALT enzymes, Yamamoto et al[45] reported increased values in judo athletes at immediate posttraining but not at 24 hours postrecovery. We did not measure several factors that modulate the CK response, including changes in plasma volume, the difference between the rate of release of CK into and its removal from the blood,[20] and polymorphisms of the actinin-3 and myosin light chain kinase genes.[19]

In our study, serum LDH was inversely associated with lower limb power. Pinho Júnior et al[8] observed an inverse correlation between serum LDH and perceived muscle soreness ($r = -0.53$) and upper limb power ($r = -0.32$) in jiu-jitsu athletes who underwent CWI after simulated competition. Detanico et al[1] reported an increase in serum LDH levels and less lower limb power in judo athletes after 3 successive matches. According to Warren et al,[46] strenuous exercise caused structural disruption of sarcomeres, resulting in membrane damage and failures in the coupling process triggering muscle contraction. The lower serum LDH level and less perceived muscle soreness are possibly associated with faster recovery of muscle homeostasis. Gregson et al[31] noted that CWI decreased peripheral temperature and resulted in less muscle osmotic pressure, which affected the release of metabolites resulting from exercise (eg, muscle enzymes), propagating lower pain afferent signaling.

A possible bias in our study was the absence of direct measures of exercise intensity, which is a variable that is difficult to monitor in studies involving combat-sport athletes.[47] However, the RPE did not differ in our athletes when training before the different recovery protocols. Future researchers could focus on the effect of CWI or other forms of cryotherapy on the specific performance of combat-sport athletes.

The recovery process after training and competition is paramount in athletic preparation. Combat-sport athletes normally perform 2 training sessions per day, 6 days per week.[14] Thus, improving athletes' physiologic state and performance potential is important to ensuring that training goals will be achieved more efficiently. Among the recovery interventions recommended and used by athletes is cryotherapy. We demonstrated that intermittent exposure (four 4-minute immersions interspersed by 1-minute intervals) to cold water (6.0°C ± 0.5°C) improved the posttraining recovery of jiu-jitsu athletes. Specifically, CWI resulted in a lower level of a muscle damage marker (serum LDH) and improved both upper and lower limb muscle power performance at 24 hours postrecovery compared with the control condition. These changes were accompanied by decreased perceived muscle soreness and a higher rating of perceived recovery. Thus, coaches and athletic trainers could apply this recovery intervention to improve physiologic status and performance, especially during training phases in which more intensive sessions are conducted and at the beginning of the season. We emphasize that our results were obtained after a single training session; future researchers should focus on the long-term results of cryotherapy on performance and on injury prevalence during the competitive season. We studied highly trained athletes; however, the effects of CWI can last longer in athletes who train at lower levels. In healthy individuals, Selkow et al[12] observed less perceived pain 48 hours after CWI. Given that our results provided evidence of a positive effect of CWI on serum LDH levels, muscle soreness, and upper and lower body performance until 24 hours, this approach can be useful when athletes are submitted to periods of intensified training.

CONCLUSIONS

Considering the objectives established and the results obtained with the methods applied, we conclude that CWI (at approximately 6°C) may be beneficial to jiu-jitsu athletes because it decreases serum LDH levels, reduces the perception of muscle soreness, and assists in the recovery of upper and lower limb power 24 hours after a training session.

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