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Effects of Recovery Method After Exercise on Performance, Immune Changes, and Psychological Outcomes

A common training model used by coaches and athletes is based on the "overload principle" or "physical stress theory."[14] An essential component of the model is that high-intensity physical exercise creates a disturbance in cellular homeostasis. This disturbance then acts as a stimulus that initiates physiological responses to restore homeostasis and induce training adaptations.[14]

• **STUDY DESIGN:** Randomized controlled trial using a repeated-measures design.

• **OBJECTIVES:** To examine the effects of commonly used recovery interventions on time trial performance, immune changes, and psychological outcomes.

• **BACKGROUND:** The use of cryotherapy is popular among athletes, but few studies have simultaneously examined physiological and psychological responses to different recovery strategies.

• **METHODS:** Nine active men performed 3 trials, consisting of three 50-kJ "all out" cycling bouts, with 20 minutes of recovery after each bout. In a randomized order, different recovery interventions were applied after each ride for a given visit: rest, active recovery (cycling at 50 W), or cryotherapy (cold tub with water at 10°C). Blood samples obtained during each session were analyzed for lactate, IL-6, total leukocyte, neutrophil, and lymphocyte cell counts. Self-assessments of pain, perceived exertion, and lower extremity sensations were also completed.

• **RESULTS:** Time trial performance averaged 118 ± 10 seconds (mean ± SEM) for bout 1 and was 8% and 14% slower during bouts 2 (128 ± 11 seconds) and 3 (134 ± 11 seconds), respectively, with no difference between interventions (time effect, $P \leq .05$). Recovery intervention did not influence lactate or IL-6, although greater mobilization of total leukocytes and neutrophils was observed with cryotherapy. Lymphopenia during recovery was greater with cryotherapy. Participants reported that their lower extremities felt better after cryotherapy (mean ± SEM, 6.0 ± 0.7 out of 10) versus active recovery (4.8 ± 0.9) or rest (2.8 ± 0.6) (trial effect, $P \leq .05$).

• **CONCLUSION:** Common recovery interventions did not influence performance, although cryotherapy created greater immune cell perturbation and the perception that the participants' lower extremities felt better.

• **LEVEL OF EVIDENCE:** Performance enhancement, level 2b. *J Orthop Sports Phys Ther 2010;40(10):656-665. doi:10.2519/jospt.2010.3224*

• **KEY WORDS:** *active recovery, cryotherapy, high-intensity exercise, hydrotherapy*

A widespread belief among many coaches and athletes is that relatively large volumes of intense training must be performed to maximize gains in performance. However, high training volumes and/or insufficient recovery has been associated with overtraining,[13] the state of which may be reflected by excessive muscular fatigue, soft tissue injury, and/or immune compromise.[20] Athletes, therefore, use many different therapeutic interventions, such as low-intensity exercise and cold therapy, in an effort to speed recovery between intense bouts of exercise and maintain sport performance.

Cold therapy is the therapeutic application of any substance to the body that results in the withdrawal of heat from the body, thereby lowering tissue temperature.[21] It is believed that, by decreasing tissue temperature, cryotherapy can diminish pain, tissue metabolism, and muscle spasm, minimizing the inflammatory and immune processes and thereby aiding recovery after soft tissue trauma.[21] The available scientific evidence related to cold therapy and exercise performance is inconclusive. Some studies show a reduced exercise performance,[9,35] while others report an improved or maintained performance,[2,18,36,40,42] when cold water immersion is used as a recovery intervention and compared with passive recovery. The major limitation of the available studies is the lack of insight into mechanisms behind potential performance benefits or detriments to the use

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of cryotherapy and how these compare to responses during active recovery or passive recovery (ie, rest).

During strenuous or high-intensity exercise, the discrepancy between the demand for energy and energy provision from oxidative metabolism means that the muscle is forced to rely heavily on nonoxidative sources of energy.[5] Intracellular acidosis associated with elevated levels of lactic acid is a popular hypothesis to explain muscular fatigue, as it is believed the excess hydrogen ions interfere with the muscle contraction process.[30] It has been demonstrated that a period of active recovery, as opposed to passive recovery, enhances the rate of metabolic recovery.[1,33] Low-intensity exercise during the recovery phase after exercise may enhance the rate of lactate uptake and oxidation by muscle[4] and facilitate performance by enhancing the aerobic contribution to total energy turnover.[11] Few studies, however, have assessed the effect of other recovery interventions, such as cryotherapy, on recovery and performance.

High-intensity training and competition also result in microtrauma to muscle and connective tissue.[7,17] It is also well established that strenuous exercise causes an increase in blood concentrations of various inflammatory cytokines.[22] After high-intensity exercise, cytokines (eg, IL-1, IL-6, TNFα) can be produced locally in the damaged muscle.[25] While changes in IL-1 and TNFα after exercise tend to be subtle, changes in systemic levels of IL-6 are most robust, being elevated shortly after strenuous exercise and tissue damage.[28] This is important because unusually high IL-6 levels during exercise imposed by IL-6 administration increase mood disturbance and reduce running performance in trained men.[31] Whether recovery strategies could improve performance by minimizing perturbations to cytokines such as IL-6, however, is unclear. Rapid migration of leukocytes into areas of damaged muscle cells and other metabolically active tissue to initiate repair has also been documented.[39] In the 15- to 60-minute period following exercise, lymphocyte counts tend to drop below resting values.[27] Wigernaes et al[46,47] found that active recovery (15 minutes at 50% VO_{2peak}), as opposed to rest, prevented the initial fall in lymphocyte count after strenuous endurance exercise. Other recovery interventions, such as cryotherapy, may also influence immune system activation. Although some evidence suggests that leukocyte mobilization can be influenced by cold exposure during intense exercise,[6,16,29,37] investigation on the impact of cryotherapy as a recovery intervention between bouts of high-intensity exercise on immune cell mobilization and IL-6 responses is lacking.[3]

While the majority of recovery studies have examined only physiological markers of recovery, physiological and psychological responses to recovery interventions are intimately linked and require adequate attention for the athlete. For example, within the massage therapy literature, it has been acknowledged that massage could improve recovery, at least, in part, through psychophysiological mechanisms such as decreased pain and fatigue.[45] Furthermore, merely expecting an intervention to have a positive effect has been shown to improve athletes' performance after receiving a placebo intervention.[19] To our knowledge, however, no study has simultaneously examined the effects of common recovery modalities between bouts of intense exercise on physiological, psychological, and performance outcome measures.

Given the identified gaps in the literature, the current study sought to understand how physiological and psychological outcomes are simultaneously affected by commonly used methods of recovery. The primary purpose of this investigation was to examine the effect of rest, active recovery, and cryotherapy on exercise performance, as measured by a time-trial cycling task. Many athletic events require athletes to complete a fixed amount of work in as short a time as possible (ie, a fixed distance race); therefore, a time-trial task was considered an ideal paradigm in which to examine recovery methods. Secondly, we examined changes in the proposed markers for muscle fatigue (plasma lactate), systemic inflammation (IL-6), and immune cell mobilization (total leukocytes, neutrophils, and lymphocytes). Finally, we studied the psychological effects of these recovery interventions by measuring pain, perceived exertion, and lower-extremity sensations. We hypothesized that, compared to rest, cryotherapy and active recovery used between bouts of high-intensity cycling would induce favorable physiological and psychological responses, such that subsequent cycling performance would be improved.

METHODS

Subjects

Nine healthy men with a mean ± SD age, height, and body mass of 29 ± 6 years, 1.80 ± 0.08 m, and 97 ± 13 kg, respectively, volunteered for the study. Participants were recruited via word of mouth and posters placed around the McMaster University campus. All were habitually active and typically engaged in recreational exercise, such as running and cycling, 3 to 4 times per week. One subject also played varsity rugby. None of the participants suffered from any illnesses or had been taking any medication for at least 4 weeks prior to, or during, the experimental period. The experimental procedure and potential risk factors were thoroughly explained prior to beginning the study, and all participants provided written, informed consent. McMaster University and The Hamilton Health Sciences Research Ethics Boards approved the experimental protocol.

Pre-experimental Procedures

To become familiarized with all testing procedures and equipment, participants performed a series of baseline performance tests prior to the main experimental protocol. All participants underwent a progressive exercise test

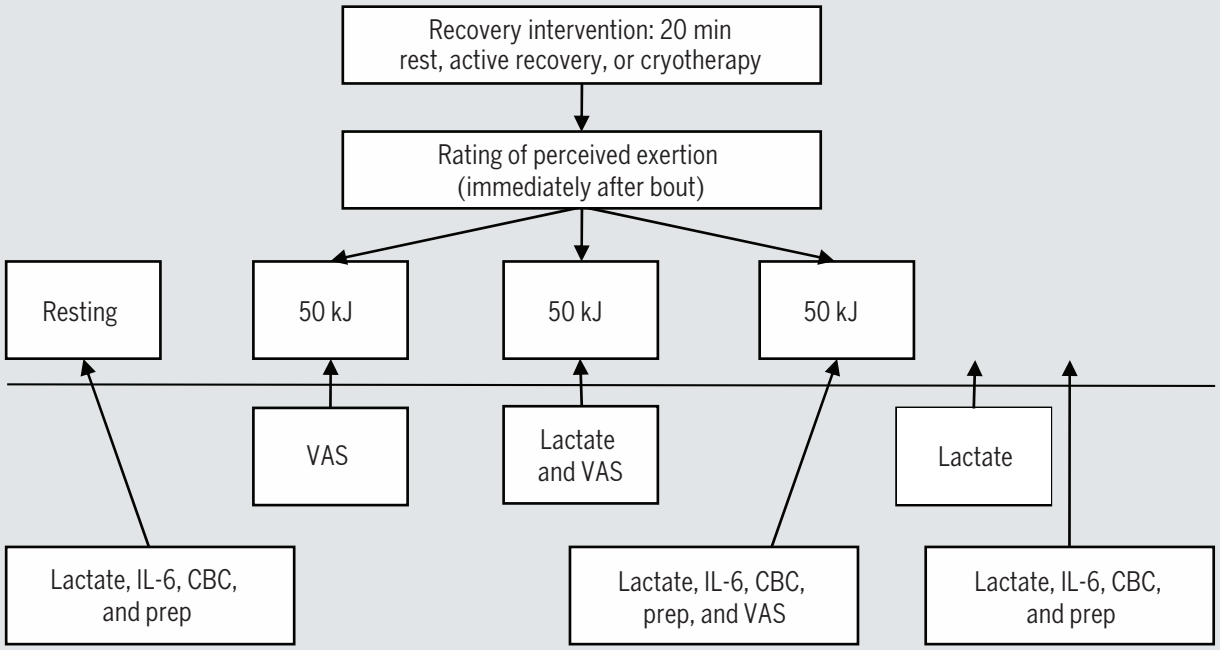

FIGURE 1. Schematic of experimental protocol. Abbreviations: CBC, complete blood count; CR, cryotherapy; IL-6, interleukin-6; prep, preparedness for exercise; VAS, visual analogue scale.

on an electronically braked cycle ergometer (Lode Excalibur Sport V2.0; Lode Medical Technology, Groningen, The Netherlands) to determine their peak aerobic power (VO_{2peak}). VO_{2peak} was determined via gas measurements taken from a mouthpiece attached to an online gas collection system (Moxus modular oxygen uptake system; AEI Technologies, Inc, Pittsburg, PA) during the incremental cycle ergometer protocol. Volitional fatigue was used to determine the end of the test. VO_{2peak} (mean ± SD) was 44 ± 8 $ml \cdot kg^{-1} \cdot min^{-1}$. Subjects also performed a familiarization test to simulate the type of exercise that was performed during the main experimental trials. Subjects were instructed to complete a 50-kJ self-paced time trial on the electronically braked cycle ergometer as quickly as possible with no temporal, verbal, and physiological feedback. The only feedback that subjects received during the test was work done, which was presented as distance covered on a computer monitor (ie, 50 kJ was equated to 2 km, such that visual feedback at any point during the ride was presented in units of distance rather than work done). Time required to complete the test and average power output were recorded on completion of the test. Participants were instructed to refrain from caffeine on test days and to avoid strenuous exercise and alcohol consumption for 24 hours prior to their testing days. They were also asked to record their diet for the day before testing so that it could be duplicated prior to each subsequent experimental visit.

Experimental Protocol

Each subject participated in 3 experimental visits separated by 1 week (**FIGURE 1**). All experimental visits were conducted in an identical manner, except for the nature of the recovery intervention applied between consecutive bouts of intense cycling exercise. Upon arrival at the laboratory, a 20-gauge catheter was inserted into an antecubital vein, and a resting blood sample was obtained. Subjects then performed a standard warm-up that consisted of 10 minutes of cycling at a workload of 50 W. Immediately after the warm-up, subjects commenced the experimental protocol, which consisted of 3 bouts of 50-kJ cycling, with 20 minutes of recovery between bouts. Similar to the familiarization trials, subjects were instructed to perform each 50-kJ cycling bout in as fast a time as possible. During a given experimental visit, the same recovery intervention was applied after each exercise bout. During each recovery period, subjects dismounted the ergometer and walked approximately 50 m to the designated recovery room (approximately 1 minute), waited until the 5-minute mark to begin the designated recovery intervention, performed the recovery intervention for 10 minutes, walked back to the laboratory, remounted the ergometer, and then waited until the 20-minute mark to begin the next 50-kJ cycling test. After the third and final recovery intervention, subjects lay supine on a bed until the final blood sample.

With regard to the specific recovery interventions, "rest" consisted of lying supine on a bed, "active" consisted of cycling on an ergometer (Model 828E;

Monark, Varberg, Sweden) at 50 W, and "cryo" consisted of sitting in a hydrotherapy tub (Model 160; Ferno Performance Pools, Ottawa, ON), submerged up to the neck with a water temperature of 10°C. All recovery interventions lasted 10 minutes. Blood samples were drawn after each recovery intervention, after subjects had returned to the laboratory and immediately prior to the subsequent bout of cycling. A final blood sample was obtained 1 hour after the third and final exercise bout. Subjects also completed several short forms designed to assess their subjective impressions of the recovery interventions. The forms were completed upon arrival at the laboratory and prior to and 1 hour after the last exercise bout. The following questions were answered based on a 10-point Likert-type scale. The items were: (1) How would you describe your legs? (1, energized; 10, dead); (2) Are you experiencing any pain in your legs related to exercise? (1, not at all; 10, extremely), and (3) Do you find the treatment postexercise makes your legs feel better? (1, not at all; 10, extremely). Participants also provided quadriceps muscle pain intensity ratings by placing a vertical mark with a pen on a 10-cm horizontal visual analogue scale (VAS). The left and right ends of the scale were anchored with the phrases "no pain" and "most intense pain imaginable," respectively. Pain intensity was scored from 0 to 100, measured in millimeters from the left end of the scale. Substantial evidence supports the validity of scores using a VAS as a measure of pain intensity.[8] Finally, participants provided a rating of perceived exertion (RPE) using Borg's 6-to-20 scale immediately after each cycling bout. The lower and upper ends of the scale were anchored with the phrases "resting, relaxing" and "can not pedal anymore," respectively.

Blood Analyses

All blood samples were analyzed in duplicate. To avoid interassay variation, all samples were analyzed in a single batch at the end of the study, with the exception of hematological measures, which were performed on the day of the collection. Blood samples (2 mL) for lactate determination were collected in Vacutainer tubes containing heparin and placed immediately on ice. Fifty μL of whole blood was combined with 250 μL of perchloric acid, vortexed and centrifuged (4500 rpm for 5 minutes). The perchloric acid extract was subsequently analyzed for lactate, using an enzymatic assay adapted for fluorometry (model F-2500; Hitachi, Ltd, Tokyo, Japan). Blood samples (5 mL) for IL-6 determination were collected into EDTA-treated vacutainer tubes and centrifuged (3000 rpm for 5 minutes at 4°C). Plasma was stored at −20°C until analyzed by a commercially available high-sensitivity enzyme-linked immunoassay kit (Quantikine HS600B; R&D Systems, Inc, Minneapolis, MN). The intra-assay coefficient of variation of the methods for lactate and IL-6 were less than 10%. All plasma variables were adjusted for changes in plasma volume.[10] An additional 5 mL of EDTA-treated whole blood was analyzed for total leukocytes, neutrophils, lymphocytes, Hb, and hematocrit with an automated Coulter counter, by the clinical hematology group at McMaster University.

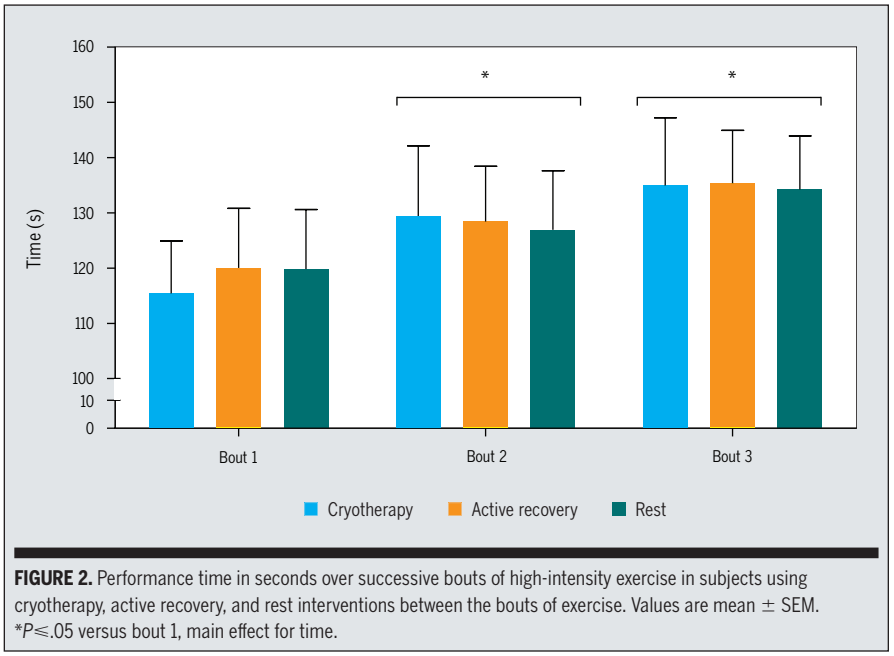

FIGURE 2. Performance time in seconds over successive bouts of high-intensity exercise in subjects using cryotherapy, active recovery, and rest interventions between the bouts of exercise. Values are mean ± SEM. *$P \leq .05$ versus bout 1, main effect for time.

Statistical Analyses

This study was performed using a randomized crossover design. The independent variable was the type of recovery intervention (rest, active, or cryo) between exercise bouts. The dependent variables involved all blood variables analyzed: lactate, IL-6, total leukocytes, and subsets (neutrophils and lymphocytes), performance (50-kJ time trials), and psychological parameters (RPE, VAS, and lower-extremity sensations). The results were analyzed using SPSS, Version 11.5, statistical software (SPSS, Inc, Chicago, IL). Blood, performance, and psychological data were analyzed using a 2-factor (trial by time) repeated-measures analysis of variance. Significant effects were further analyzed using pairwise comparisons with Bonferonni adjustments. The level of statistical significance was set at $P \leq .05$. Unless otherwise indicated, all data are presented as mean ± SEM.

RESULTS

Cycling Performance

Time trial performance was 8% and 14% slower (main effect for time, $P \leq .05$) during bouts 2 and 3, respectively, with no difference between recovery interventions (**FIGURE 2**).

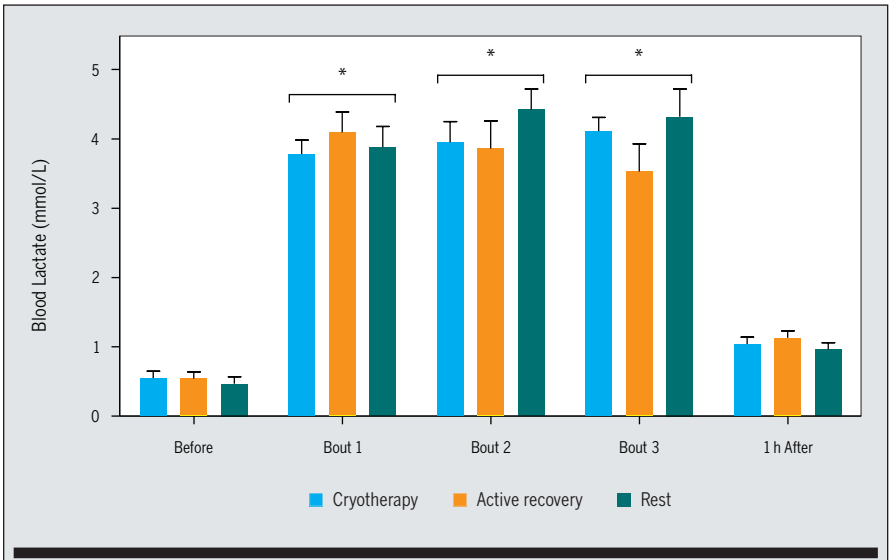

FIGURE 3. Blood lactate concentrations before, during, and 1 hour after bouts of high-intensity exercise in subjects using cryotherapy, active recovery, and rest interventions between the bouts of exercise. Values are mean ± SEM. *$P \leq .05$ versus pre-exercise, main effect for time.

TABLE 1 Plasma IL-6 Before, During, and 1 Hour After Bouts of High-Intensity Exercise in Subjects Using Cryotherapy, Active Recovery, and Rest Interventions Between the Bouts of Exercise*

	Pre-exercise	Bout 2†	1 h Postexercise†
Cryotherapy	1.6 ± 0.3	2.3 ± 0.4	4.0 ± 1.2
Active Recovery	1.5 ± 0.2	2.2 ± 0.3	3.3 ± 0.5
Rest	2.0 ± 0.6	2.6 ± 0.8	2.9 ± 0.6

** Values are mean ± SEM in pg/mL.*
† $P \leq .05$ versus pre-exercise, main effect for time.

Blood Lactate

Following each bout of exercise, lactate was increased above resting concentrations in all 3 trials, with no differences between trials (**FIGURE 3**). Lactate increased after bouts 1, 2, and 3 (main effect for time, $P \leq .05$). Although lactate values were not different between cryo and rest, values decreased by approximately 14% from bout 1 to bout 3 in active, although this did not reach statistical significance. Regardless of trial, lactate returned to near resting levels (approximately 1.0 mmol/L) by 1 hour after completing the final recovery period.

IL-6

The resting values of circulating plasma IL-6 were similar in all 3 trials. IL-6 levels increased after 2 bouts of exercise, with no difference observed between trials (main effect for time, $P \leq .05$). At 1 hour after the final recovery period, IL-6 levels were, on average, 40% higher than during exercise (main effect for time, $P \leq .05$). Although IL-6 values at 1 hour after the final recovery period during cryo were higher than during active or rest, these were not statistically significant (**TABLE 1**).

Leukocytes

Intensive exercise caused total leukocyte counts to increase. At 1 hour after the final recovery period, values during cryo were approximately 22% higher than in active or rest (interaction effect, $P \leq .05$; **FIGURE 4**). In the leukocyte subsets, a similar trend was observed. In general, we observed an exercise-induced neutrophilia in all trials (**FIGURE 4**). During cryo, circulating neutrophil counts increased by an average of approximately 93% above baseline (main effect for trial, $P \leq .05$), with the largest increase occurring at 1 hour after the final recovery period. In contrast, the average increase in neutrophil counts was lower during active (approximately 74%) and rest (approximately 55%). The immediate lymphocyte response to exercise was similar for all trials, representing an 83% increase above resting levels (main effect for time, $P \leq .05$). A significant lymphopenia occurred at 1 hour after the final recovery period, during cryo only, with values approximately 38% below pre-exercise levels (interaction effect, $P \leq .05$) (**FIGURE 4**).

Psychological Measures

Quadriceps pain as determined by the VAS increased 270% during the trials (main effect for time, $P \leq .05$). Although there was no trial effect, cryo scores were consistently lower than those for active and rest. Similar results were found for RPE; although ratings increased 6% over the 3 bouts, cryo scores were consistently lower. Finally, although participants did not report any differences in lower-extremity pain or energy across recovery methods, they did indicate that their lower extremities generally felt better during cryo than any other treatment (main effect for trial, $P \leq .05$) (**TABLE 2**).

DISCUSSION

This study examined the impact of cryotherapy, active recovery, and rest on cycling performance, along with selected physiological and perceptual markers. We found that the type of recovery intervention did not affect the decline in short-term cycling performance during repeated bouts of intense exercise. Thus, our primary hypothesis that cryotherapy would lead to improved

TABLE 2 Perceptual Data After Repeated Bouts of High-Intensity Exercise in Subjects Using Cryotherapy, Active Recovery, and Rest Interventions Between the Bouts of Exercise*

	Cryotherapy	Active	Rest
VAS†			
Bout 1	8.8 ± 1.8	10.2 ± 2.7	14.8 ± 3.8
Bout 2‡	12.5 ± 3.1	15.5 ± 4.3	18.1 ± 4.5
Bout 3‡	15.4 ± 4.3	17.6 ± 4.6	19.3 ± 4.8
RPE			
Bout 1	16.4 ± 0.4	16.9 ± 0.5	17.1 ± 0.4
Bout 2	17.1 ± 0.3	17.8 ± 0.5	17.8 ± 0.5
Bout 3	17.6 ± 0.6	17.7 ± 0.5	18.2 ± 0.6
Lower extremity sensations			
Energy	3.6 ± 0.7	3.5 ± 06	4.1 ± 0.6
Pain	1.4 ± 0.4	1.4 ± 0.4	2.0 ± 0.6
Better Feelings	6.0 ± 0.7§	4.8 ± 0.9	2.8 ± 0.6

Abbreviations: RPE, rating of perceived exertion; VAS, visual analogue scale.
** Values are mean ± SEM, with lower extremity sensations data representing the average response from each trial.*
† VAS depicting perceived quadriceps muscle pain intensity.
‡ P≤.05 versus bout 1, time effect.
§ P≤.05, trial effect.

cycling performance was not supported. However, cryotherapy induced greater immune cell perturbation and the perception that participants' lower extremities felt better.

Cycling Performance

The primary objective of this study was to study the effects of commonly used interventions between bouts of intense exercise on cycling performance, as would be experienced during typical training sessions. Although time trial performances were on average 8% and 14% slower during bouts 2 and 3, respectively, recovery intervention did not affect this decline. The results of our study are, therefore, consistent with previous literature demonstrating no benefit of cryotherapy on exercise performance.[36] However, while some studies show no benefit of cryotherapy on, for example, muscle soreness and strength performance following eccentric elbow flexor exercises,[26] other studies have reported benefits of cryotherapy in baseball pitching performance,[43] increased work, velocity, and power,[44] and the maintenance of power and performance.[12,32,34] In the context of this contradictory evidence, our results support the notion that cryotherapy has little effect on short-term cycling performance and advance this area of research by simultaneously measuring physiological and perceptual markers that are important to consider with respect to optimal recovery. It is also noteworthy that the decline in performance in our study was not exacerbated during cryo, active, or even rest, which is in contrast to other work demonstrating reductions in performance that were greater during cryotherapy.[9,35]

Metabolic Markers

Following a bout of strenuous exercise, the exercising muscles must restore acid-base balance to prepare the tissue for subsequent physical challenges. The exercise intensity that results in optimal lactate clearance varies, depending on the nature of the exercise performed and subject fitness; but light to moderate exercise at an intensity that elicits 30% to 60% of VO_{2peak} is generally recommended for active recovery.[1,4,33] In the present study, subjects cycled at a relatively low workload of 50 W, which corresponded to 15% to 20% of peak workload achieved during the baseline VO_{2peak} tests. Although lower than what is generally recommended for optimal lactate clearance, Dorado et al[11] reported that cycling at 20% VO_{2peak} during recovery improved performance during repeated high-intensity cycling efforts to exhaustion at 120% VO_{2peak} (lasting approximately 2 minutes, which is similar to the protocol used in the present study). Notably, Dorado et al[11] reported a performance improvement after active versus passive recovery, even though peak blood lactate levels were not different between conditions. Although cryotherapy is frequently used by athletes after intense exercise, only a few studies have assessed its effects on lactate recovery after intense exercise. Vaille et al[40] demonstrated that active recovery tended to improve lactate recovery over cryotherapy, whereas Crowe et al[9] found that lactate levels were lower with cryotherapy treatment compared to a control condition (passive rest). In our study, blood lactate increased 9% from exercise bout 1 to 3 during cryo, but was not different from the other interventions. It is difficult to compare these studies, as the duration of recovery times, the type of hydrotherapy, and the temperature of the water were different. That cycling performance was maintained equally during each recovery intervention (**TABLE 1**) may be the reason why blood lactate levels were similar across trials.

Immune Markers

Recent observations on skeletal muscle as an active participant in immune activation in response to exercise suggest that immune markers may play a role in recovery and adaptation. It has been suggested that the release of inflammatory cytokines represents an inflammatory reaction, presumably initiated by damage to skeletal muscle.[7] Exaggerated inflam-

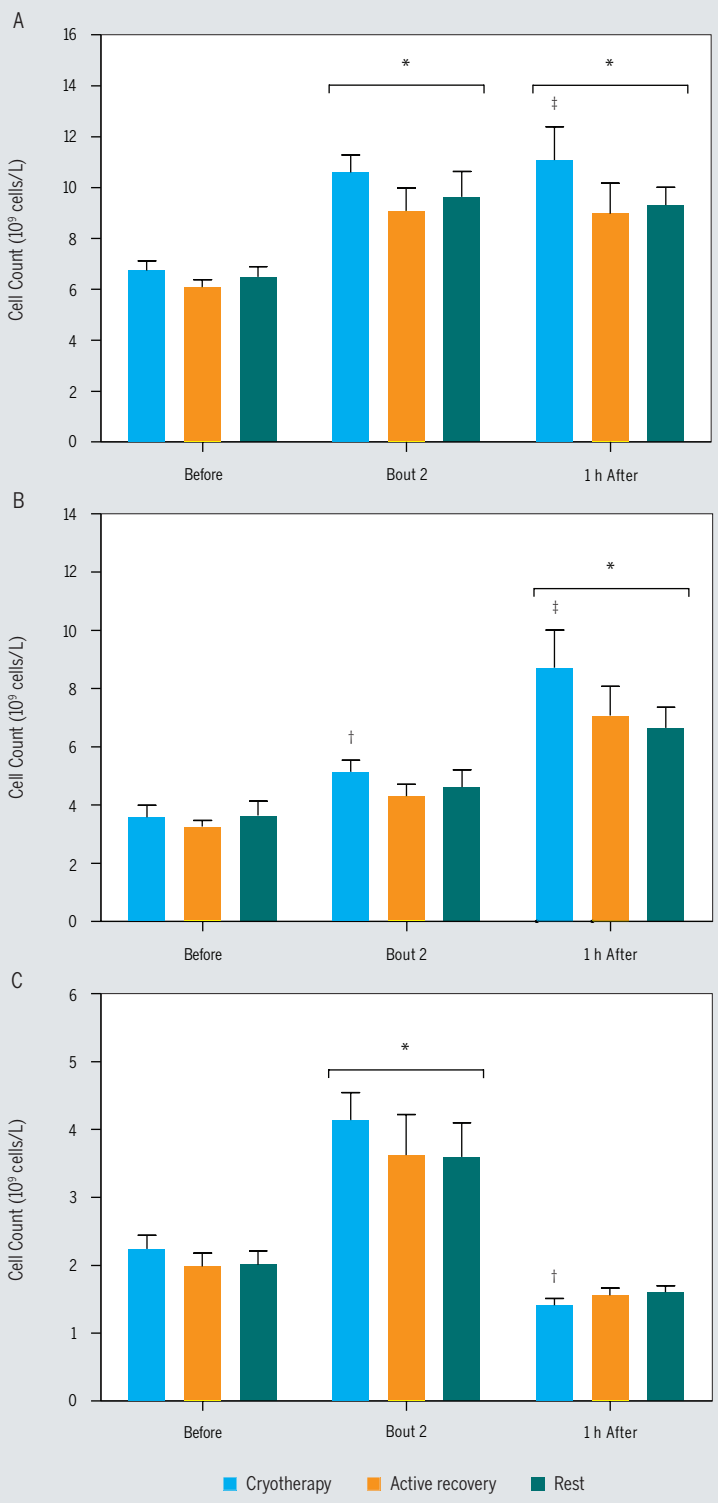

FIGURE 4. Total leukocyte (A), neutrophil (B), and lymphocyte (C) counts before, during, and 1 hour after bouts of high-intensity exercise in subjects using cryotherapy, active recovery, and rest interventions between the bouts of exercise. Values are mean ± SEM in cells × 10^9/L. Abbreviation: pre, pre-exercise. *$P \leq .05$ versus pre, main effect for time. †$P \leq .05$ versus rest for cryotherapy at that time point. ‡$P \leq .05$ versus active and rest for cryotherapy at that time point.

matory responses with exercise, however, may influence exercise performance through central mechanisms of mood and fatigue. For example, Robson-Ansley et al[31] found that infusion of IL-6 during exercise in trained individuals increased mood disturbance and reduced running performance. To date, the majority of studies have investigated immune perturbations in response to prolonged exercise or eccentrically biased exercise tasks. Few have looked at changes in responses to short bursts of high-intensity exercise, and the effects of recovery modalities on the immune system are not well documented. Although the need to study inflammation in the context of recovery interventions has been proposed,[3] we are aware of only 1 such study that measured inflammatory markers in the context of various recovery interventions.[41] This study measured IL-6 in strength trained athletes for up to 72 hours following an eccentrically biased workout. IL-6 was not influenced by any of the water immersion recovery interventions when compared to values taken during a control (passive rest) condition. In our study, which used a more acute time line for measuring IL-6 responses, we found IL-6 concentrations to be on average 30% higher during cryo than active and rest, but this did not achieve statistical significance.

It is well established that high-intensity exercise (>75% VO_{2peak}) is associated with larger increases in circulating neutrophils and greater falls in lymphocytes during recovery, compared with the same duration of moderate-intensity exercise.[24] In the present study, neutrophils increased an average of 114% from resting levels and lymphocytes fell an average of 27% below resting levels in the hour following the last recovery period. While these findings are consistent with the vast exercise immunology literature, we have advanced understanding in this area by studying the effect of recovery interventions on immune activation. In our study, total leukocyte counts during active (10 minutes of cycling at

50 W) were not significantly different than during rest. Recovery levels of total leukocytes and subsets were higher during cryo than during active or rest. Specifically, neutrophil counts increased by 143% above pre-exercise levels during cryo but were increased only 100% during active and rest. Consistent with prolonged, endurance exercise, the lymphocyte subset was also found to be most responsive to exercise, but experienced a significant drop below resting values by 1 hour following the final recovery period. This effect was driven mainly by the response during cryo. In 2 separate studies by Wigernaes et al,[46,47] active recovery (15 minutes at 50% VO_{2peak}) during the first 15 minutes after high-intensity (80% VO_{2peak}) and moderate-duration exercise (60 minutes) counteracted the postexercise fall in leukocytes as compared to rest. The discrepancy between the studies of Wigernaes et al[46,47] and the current study is likely due to the nature of the exercise task. Our findings are consistent with those of Jansky et al,[16] however, who found that a single cold-water immersion (14°C for 1 hour) created a small but significant increase in monocytes and lymphocytes. The authors concluded that it was the stress-inducing effect of cold-water immersion that activated the immune system. Brenner et al[6] examined immunological responses to cold exposure with and without exercise and found that cold exposure and exercise exerted an additive effect on leukocyte mobilization. The biological significance of immune changes on adaptations to training, however, remains to be determined.

Psychological Outcomes

Given the interest in optimal recovery interventions among competitive athletes, it is surprising that most studies have not examined psychological effects. A strength of our study is that we simultaneously assessed psychological outcomes along with physiological and performance variables. We found that over successive bouts of intense exercise, VAS scores for pain and RPE increased, regardless of recovery method, and participants' lower extremities generally felt better during cryo. Hudson et al[15] found RPE scores to be lower with active recovery in water. We have previously reported[38] that the use of contrast baths (ie, alternating hot and cold water exposure) during recovery from intense exercise resulted in participants feeling that their lower extremities felt better prepared for subsequent bouts of exercise. Here we confirm this finding with cold water exposure only. Although Myrer et al[23] found no physiological effect of contrast therapy on intramuscular tissue 1 cm below the skin, they did report an influence on the superficial layer of fat and skin. At lower temperatures, the rate of firing of pain and temperature sensory receptors located in the skin—the superficial tissue most affected by cryotherapy—is diminished, thus reducing the sensation of pain.[21] With less feeling of pain and heightened perceptions of well-being, athletes may feel greater self-efficacy when commencing subsequent bouts of exercise. However, our findings raise the interesting possibility that cryotherapy may provide the athlete with a false sense of well-being. All our blood measures and the cycling performance results would suggest that physiological recovery was not improved with cryotherapy, yet the individual perceived that he felt better. In this scenario, an athlete may be inclined to train harder before his body is fully recovered. Whether this scenario increases the risk of injury or even overtraining is unknown. However, it is interesting to note a recent study that found the percent improvement in exercise performance (1-legged incremental cycling test to exhaustion) following training when cryotherapy was applied to 1 lower extremity after each training session was only half of the improvement in the other leg that did not receive cryotherapy.[48] Future studies should, therefore, evaluate the long-term consequences of acute recovery interventions on athletic performance and the mediating effects of psychological variables.

Limitations

In this study, a small sample size could have precluded confirmation of trends as statistically significant findings. Notwithstanding the strength of the repeated-measures design of this study, we acknowledge that sample size is a limitation. For our primary outcome measure—50-kJ cycling performance—we made post hoc estimations to determine how many participants would have been needed to observe a statistically significant difference in the reduction in performance from bout 1 to bout 3 between cryo and rest. We would have needed to test 97 participants, albeit based on independent samples. It is, therefore, probable that the recovery strategy truly does not influence performance, at least under the conditions that we tested it.

CONCLUSION

The use of commonly used recovery interventions of rest, active, and cryo did not affect the decline in cycling performance during repeated bouts of intense exercise. The use of cryotherapy, however, did induce a greater perturbation to blood immune markers (neutrophils and lymphocytes) than either active or passive recovery, and increased the perception that the lower extremities felt better, even though subsequent cycling performance was not affected. Despite the limited evidence supporting recovery interventions from a physiological perspective, the use of cryotherapy is effective in creating the perception of better preparedness for subsequent exercise, and this feel-better phenomenon may allow athletes to train harder. Other physiological variables (lactate, IL-6,) were not influenced by cryo. Whether this scenario of enhanced perceptual recovery in the face of limited physiological benefit would eventually lead to injury

or a syndrome of overtraining should be examined. ◉

KEY POINTS

FINDINGS: Cryotherapy did not improve performance but did make participants feel that their lower extremities felt better before the next exercise task. This effect was observed without major changes in physiological responses and even a greater mobilization of immune cells.

IMPLICATION: Cryotherapy may give athletes a false sense of recovery of their lower extremities.

CAUTION: Our participants were only recreationally active, so our study needs to be replicated in hard-training athletes. We used a very specific laboratory-based performance test, which may limit applicability to many team sports or endurance events.

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