Turkish Journal of Sports Medicine
Spor Hekimliği Dergisi

Turk J Sports Med. DOI: 10.47447/tjsm.0937

RESEARCH ARTICLE

Comparing the Acute Effects of Whole-Body Cryotherapy and Cold Water Immersion on Recovery After High-Intensity Interval Loading

Yüksek Yoğunluklu Aralıklı Yüklenme Sonrası Tüm Vücut Kriyoterapisi ve Soğuk Su Uygulamasının Toparlanma Üzerine Akut Etkilerinin Karşılaştırılması

Hasan Aytepe[1], Aysel Pehlivan[1], Emin Ergen[2], Tuba Melekoğlu[3], Emre Ak[2], Müşerref Demir[3], Kemalettin Seren[4]

[1]*Faculty of Sport Sciences, Haliç University, İstanbul, Türkiye*
[2]*Sports Medicine and Performance Center, Gloria Sports Arena, Antalya, Türkiye*
[3]*Faculty of Sport Sciences, Akdeniz University, Antalya, Türkiye*
[4]*Faculty of Sport Sciences, Atatürk University, Erzurum, Türkiye*

ABSTRACT

Objective: This study aimed to compare the acute effects of recovery methods - whole-body cryotherapy, cold water immersion, and passive rest - applied after high-intensity interval loading in trained individuals on blood lactate levels, muscle/tendon stiffness, and heart rate.

Materials and Methods: Sixteen trained male athletes completed a high-intensity interval loading protocol, consisting of 45 seconds of running at 130% of VO_2max and 45 seconds of rest at 6 km/h, repeated until voluntary exhaustion. Blood lactate, heart rate, and muscle-tendon elasticity, tone, and stiffness were measured at four time points: pre-loading, 3 minutes post-loading, immediately after recovery application, and 10 minutes after recovery. Statistical analyses were conducted using Jamovi software (v2.3.28.0). As the data showed normal distribution, parametric tests were used. Changes over time were analyzed using Repeated Measures ANOVA, and pairwise comparisons were performed when significant differences were found. Statistical significance was set at $p<0.05$.

Results: A significant decrease in blood lactate concentration and heart rate was observed in all groups ($p<0.05$). However, no statistically significant change was found in the elasticity, tone, and stiffness values of the gastrocnemius muscle and Achilles tendon ($p>0.05$). No significant differences were detected between the groups either immediately after recovery or 10 minutes later.

Conclusion: These findings suggest that cold-based recovery methods - whole-body cryotherapy and cold water immersion - produce effects similar to passive rest, offering no additional advantage in short-term recovery. This implies that such methods may not be physiologically essential in sports contexts with limited recovery windows.

Keywords: Cryotherapy, cold water immersion, high-intensity interval training, recovery of function, blood lactate

ÖZ

Amaç: Bu çalışmanın amacı, antrenmanlı bireylerde yüksek yoğunluklu aralıklı yüklenme sonrasında uygulanan toparlanma yöntemlerinden tüm vücut kriyoterapisi, soğuk su uygulaması ve pasif dinlenmenin; kan laktat düzeyi, kas/tendon sertliği ve kalp atım hızı üzerindeki akut etkilerini karşılaştırmaktır.

Gereç ve Yöntem: On altı antrenmanlı erkek sporcu, VO_2max'ın %130'unda 45 saniyelik yüklenme ve 6 km/s hızla 45 saniyelik dinlenme periyotlarından oluşan, bitkinlik noktasına kadar devam eden bir yüksek yoğunluklu aralıklı yüklenme protokolü uyguladı. Kan laktat düzeyi, kalp atım hızı ve kas-tendon elastikiyeti, tonusu ve sertliği; yüklenme öncesinde, yüklenmeden 3 dakika sonra, toparlanma uygulamaları hemen sonrasında ve toparlanmadan 10 dakika sonra ölçüldü. İstatistiksel analizler Jamovi (v2.3.28.0) programı ile gerçekleştirildi. Veriler normal dağılım gösterdiği için parametrik testler kullanıldı. Zaman içindeki değişimler Tekrarlı Ölçümler ANOVA ile analiz edildi ve anlamlı farklılık durumunda ikili karşılaştırmalar yapıldı. Anlamlılık düzeyi $p<0,05$ olarak belirlendi.

Received: 28.05.2025 · **Accepted:** 19.08.2025 · **Published:** 17.03.2026

Correspondence: Hasan Aytepe · hasanaytepe@gmail.com

Cite as: Aytepe H, Pehlivan A, Ergen E, Melekoglu T, Ak E, Demir M, et al. Comparing the Acute Effects of Whole-Body Cryotherapy and Cold Water Immersion on Recovery After High-Intensity Interval Loading. *Turk J Sports Med*. 2026; https://doi.org/10.47447/tjsm.0937

Bulgular: Tüm gruplarda kan laktat konsantrasyonu ve kalp atım hızında anlamlı düşüş gözlendi (p<0,05). Ancak gastroknemius kası ve aşil tendonu dokularının elastikiyet, tonus ve sertlik değerlerinde istatistiksel olarak anlamlı bir değişiklik tespit edilmedi (p>0,05). Toparlanma uygulamaları sonrasında ve 10 dakika sonra gruplar arasında anlamlı bir fark bulunmadı.

Sonuç: Bu bulgular, soğuk uygulamalar olan tüm vücut kriyoterapisi ve soğuk suya daldırmanın, pasif dinlenmeye benzer etkiler gösterdiğini ve bu bağlamda ek bir toparlanma avantajı sağlamadığını ortaya koymaktadır. Bu durum, sınırlı toparlanma süresi olan sporlarda soğuk uygulamaların fizyolojik olarak zorunlu olmadığını düşündürmektedir.

Anahtar Sözcükler: Kriyoterapi, soğuk su uygulaması, yüksek yoğunluklu aralıklı yüklenme, fonksiyonel toparlanma, kan laktatı

INTRODUCTION

High-intensity interval training (HIIT) is an exercise method that involves repeated high-intensity efforts, interspersed with periods of passive rest or low-intensity exercise. Originally developed for endurance athletes in the 1950s, it is now widely used due to its effectiveness in reducing body fat percentage and enhancing physiological adaptations in aerobic, anaerobic, and muscular performance [1,2]. Despite its positive effects on athletic performance and health, HIIT can lead to significant muscle damage, depending on the intensity and density of the workouts. This can result in decreased neuromuscular performance, delayed onset muscle soreness, and an increase in acute phase inflammation [3].

Recovery is crucial for athletes' subsequent training loads and overall high performance. Increasing competition, combined with intense training and congested schedules, may prevent athletes from recovering both mentally and physically. An athlete's ability to consistently maintain a high level of performance on a daily or weekly basis is directly linked to the implementation of effective recovery interventions [4]. For this reason, various active and passive recovery methods have been developed to prepare athletes for their next training load [5]. Among these methods, post-exercise cold applications have become a popular recovery strategy, frequently used by athletes and attracting the attention of researchers [6,7].

Cold applications, long used in the treatment of acute trauma, pain, and edema, are also preferred by athletes to reduce fatigue and accelerate recovery after physical exertion. It is known that athletes use methods such as ice massage, ice bags, cold sprays, cryotherapy, and cold water immersion. These applications are favored for their ability to target specific muscle groups, as well as for being practical and cost-effective. They are also popular for their whole-body effects and their potential to deliver faster recovery results. Studies have reported that local cold application can slow cell metabolism, reduce nerve conduction velocity, cause vasoconstriction, decrease muscle contractility and collagen fiber flexibility, reduce muscle spasms, and increase[M1] pain perception [8]. It has been suggested that one of the physiological mechanisms underlying cryotherapy's recovery-enhancing effects is its ability to slow cell metabolism and reduce the body's inflammatory response due to the vasoconstriction effect [9].

Yanagisawa et al. [10] examined the effects of cooling skeletal muscle after exercise on blood flow and intramuscular fluid content. Their findings suggest that cooling reduces the increase in perfusion and prevents edema formation in skeletal muscle immediately after exercise. Leeder et al. [11] conducted a meta-analysis compiling various studies on the effects of cold water immersion (at temperatures between 5 and 20 degrees Celsius for 5 to 24 minutes) on delayed-onset muscle soreness following high-intensity exercise. The results show that cold water application attenuates delayed-onset muscle soreness 24 and 48 hours after high-intensity exercise. It is also known that whole-body cryotherapy reduces fatigue markers in the body post-exercise. A review by Rose et al. [12] reported improvements in recovery indicators such as a faster return to maximal voluntary contraction and lower perceived exertion.

There are studies in the literature that examine the effects of various cold applications on recovery. However, more scientific research is needed to determine which of these methods is the most effective. Our hypothesis is that there is no significant difference between the groups in terms of recovery indicators (blood lactate level, heart rate changes, muscle/tendon elasticity, tone, and stiffness) following high-intensity interval training when comparing whole-body cryotherapy and cold water immersion. Accordingly, the aim of this study was to investigate and compare the acute effects of these two recovery modalities on trained individuals.

While both whole-body cryotherapy and cold water immersion are widely used in athletic recovery, comparative studies evaluating their acute effects following HIIT under ecologically valid conditions remain limited. Moreover, previous research has predominantly focused on delayed effects (24-48 hours post-exercise), whereas immediate and short-term outcomes have received less attention. This study aims to fill this gap by directly comparing these two modalities in a controlled design using immediate and short-term recovery markers such as blood lactate, heart rate, and muscle-tendon mechanical properties. In doing so, it provides new insights into the practical equivalency - or lack thereof - of these widely adopted recovery strategies.

MATERIAL AND METHODS

Participants

The study included male university athletes aged 19 to 32 years who volunteered to participate and had no history of musculoskeletal injuries or surgeries. The participants were actively training at least three days per week and had not used any ergogenic aids in the past four weeks. The athletes represented various sports, including football, handball, cycling, tennis, taekwondo, archery, fencing, athletics, and volleyball (mean age: 22.2 ± 3.3 years; height: 176.4 ± 6.4 cm; body weight: 74.2 ± 8.6 kg and body fat percentage: 17.1 ± 5.1%). Limiting the sample to male participants avoided potential hormonal variability; however, this also restricts the generalizability of the findings to female populations and should be acknowledged as a study limitation.

The sample size was determined using G*Power version 3.1, yielding a power of 0.89 and setting the required number of participants at 18. However, due to unforeseen circumstances, two participants were unable to complete the study, resulting in a final sample size of 16. However, a repeated power analysis confirmed that this sample size remained statistically adequate.

Participants likely had different training histories due to the variety of sports disciplines involved. However, the use of a randomized three-phase crossover design ensured that each participant served as their own control. This approach minimized confounding influences related to sport-specific adaptations and interindividual differences, thereby enhancing the internal validity of the comparisons made between the recovery modalities.

Ethical Considerations

Ethical approval for the study was granted by the Ethics Committee of the Faculty of Sports Sciences at Atatürk University (Approval No: E-70400699-000-2300063387, Date: 20.02.2023). All participants provided written informed consent after receiving a detailed explanation of the study's purpose, procedures, and potential risks. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Study Design

The study followed a randomized, three-phase crossover trial design. Each phase corresponded to a specific recovery intervention (WBC, CWI, and passive recovery), with participants randomly assigned to different sequences. This randomization controlled for potential order effects, ensuring that all participants underwent each condition, with a sufficient washout period between phases. This design facilitated within-subject comparisons, reducing variability and increasing the statistical power of the analysis.

All measurements and tests were conducted between March 2024 and April 2024 in the laboratories of the Antalya Gloria Sports Arena sports complex. On the first day of testing, participants' body composition and VO_2max were assessed. Seven days later, participants returned to the testing center for the loading and recovery sessions. Blood lactate levels, heart rate, and muscle and tendon stiffness, tone, and elasticity were measured at four time points: before loading (Baseline: T0), 3 minutes after loading (Post-exercise: T1), immediately after recovery applications (Post-recovery: T2), and 10 minutes after recovery (10' Post-recovery: T3) (Figure 1).

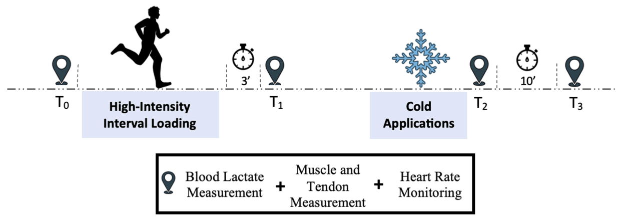

Figure 1. Timing of Measurements Taken During Loading and Recovery Process

Data Collection

Body Composition Analysis

To ensure homogeneity in body fat percentage, the body composition of all participants was assessed using air displacement plethysmography (Bod Pod; Cosmed USA). Participants were instructed to wear shorts and a Lycra swim cap during the measurements, which were conducted in accordance with the manufacturer's guidelines. They were also asked to refrain from eating or drinking for at least 3 hours prior to testing. During the measurement, participants were instructed to sit still and breathe normally. The measurement device was calibrated using a 50-liter calibration method before each test.

CPET: Cardiopulmonary Exercise Test (VO_2max)

The cardiopulmonary exercise test (Cosmed Quark CPET, Rome, Italy) was performed on a treadmill with a gas analyzer to determine individualized intensities for high-intensity interval training. Participants fasted for at least 2 hours, avoided strenuous activity for 24 hours, and refrained from smoking for 8 hours beforehand. The laboratory temperature was maintained at 20-22°C. Before starting, heart rate, blood pressure, oxygen saturation, and body temperature were recorded. The test, supervised by a physician and lab team, began with a 3-minute warm-up at 8 km/h, followed by speed increases of 1 km/h per minute starting at 10 km/h, with a 0% incline (13). Perceived exertion was monitored using the Borg Scale (6-20) and communicated verbally and visually. Heart rate and blood pressure were continuously monitored. The test ended upon voluntary exhaustion; the final treadmill speed was recorded as the reference intensity, expressed as velocity-based maximal oxygen consumption (v/VO_2max).

High-Intensity Interval Training

The high-intensity interval training protocol was conducted on a treadmill (The Technogym Wellness Company, Gambettola, Italy), similar to the VO_2max test. All sessions were supervised by a physician and physiotherapists, with the treadmill incline fixed at 0°. Participants completed a 5-minute warm-up at 50-60% of their velocity-based VO_2max (vVO_2max), followed by repeated intervals: 45 seconds of loading at 130% vVO_2max, then 45 seconds of rest at 6 km/h (approximately 50-55% vVO_2max), continuing until voluntary exhaustion (14) (Figure 2). Exhaustion was confirmed using the Borg scale, and heart rate was continuously monitored. The laboratory temperature was maintained at 20-22°C.

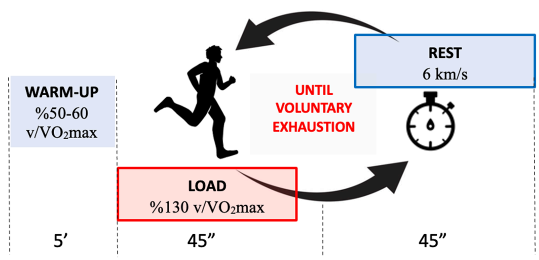

Figure 2. Intensity, Loading and Rest Periods of the High-Intensity Intermittent Loading Protocol

Blood Lactate Measurement

Blood lactate concentration measurements were conducted using a portable analyzer (Lactate Scout+, EKF Diagnostics, Cardiff, UK) along with lactate test strips (EKF Diagnostics, Germany). Capillary blood samples were collected from the earlobe using a sterile lancet by the laboratory team. The first drop of blood was discarded, and analysis was performed on the second drop. Lactate levels were measured before the HIIT session, 3 minutes post-exercise, immediately after the recovery intervention, and 10 minutes post-recovery.

Heart Rate Monitoring

Heart rate was continuously monitored throughout the exercise session using heart rate monitors (Polar Team Pro, Finland). The monitor bands, which were removed during the cold applications, were reattached immediately after the recovery session to resume measurements. The monitored heart rates were recorded at four different time points: before HIIT, immediately after HIIT, immediately after recovery, and 10 minutes after recovery.

Recovery Procedures: Whole Body Cryotherapy and Cold Water Immersion

Approximately 15 minutes after the HIIT session, participants underwent recovery interventions under physician supervision. To minimize variability, the transition period-including towel-drying, clothing changes, and equipment preparation-was standardized to approximately 15 minutes for all participants. This process was closely monitored by the research team to ensure procedural consistency across all sessions.

For whole-body cryotherapy (WBC), participants were visually and verbally monitored throughout. The WBC system consisted of three adjacent chambers set at -10°C, -60°C, and -110°C (Icelab -110°C). Before entry, participants dried sweat with a towel and wore protective equipment including cotton gloves, socks, shoes, a headband, and a mask. They wore shorts and removed all jewelry, piercings, glasses, and contact lenses. After physician clearance, they passed through the -10°C and -60°C chambers and stayed in the -110°C chamber for 3 minutes (15). During exposure, they walked slowly around the chamber.

For cold water immersion (CWI), participants wore swimsuits or shorts and sat still in a pool maintained at 10°C (±1°C) for 10 minutes, with the water level reaching the mid-sternum (16). Water temperature was controlled using a Kneipp cooling unit.

Muscle and Tendon Measurement

The measurement areas were designated as the gastrocnemius muscle and Achilles tendon of both legs. Before taking measurements, the specific areas (muscle and tendon) were marked with a permanent marker. All measurements were conducted by the same expert operator. Participants were instructed to lie face down on a Bobath bed with their feet hanging off the edge, maintaining a fully extended knee position and remaining still. The gastrocnemius muscle was measured approximately four fingers below the popliteal region, where the muscle's medial belly is located. The Achilles tendon was measured 4 cm proximal to its insertion at the calcaneal tuberosity (17).

A non-invasive digital palpation device (MyotonPRO, Myoton AS, Estonia) was used to evaluate the mechanical properties of the tissues, including:

- **Elasticity (LogD):** Tissue's ability to return to its original shape after deformation. *Higher values indicate lower elasticity.*
- **Tone (Hz):** Natural oscillation frequency at rest. *Higher values reflect increased passive tension.*
- **Dynamic stiffness (N/m):** Resistance to external mechanical force. *Higher values indicate stiffer tissue.*

The average of five consecutive measurements was recorded for each muscle and tendon measurement area; if the measurement variability exceeded 3%, the measurement was repeated. The device's probe was placed perpendicular to the tissue, and low-force (0.4 N) short-duration (15 ms) mechanical impulses were applied to the muscle. Higher stiffness and tone values may indicate increased passive muscle tension or post-exercise rigidity, whereas lower elasticity suggests reduced tissue compliance.

Statistical Analysis

All analyses were conducted using Jamovi version 2.3.28.0. Normality was assessed using the Shapiro-Wilk test, and the data met the assumptions for parametric testing. Repeated measures ANOVA was used to analyze within-subject changes across time points. Mauchly's test of sphericity was applied; when violated, the Greenhouse-Geisser correction was used. For significant main effects, pairwise comparisons between T0, T1, T2, and T3 were performed using Bonferroni-adjusted post-hoc tests. The significance level was set at p<0.05 with a confidence interval of 95%.

RESULTS

All measurements were taken at four standardized time points: T_0 (Baseline), T_1 (Post Exercise), T_2 (Post Recovery), and T_3 (10' Post Recovery).

Lactate and Heart Rate

Lactate and heart rate levels significantly changed over time in all groups, with post-hoc analyses revealed significant differences between multiple time points within each group; however, no significant differences were found between groups (lactate: p=0.768; heart rate: p=0.409) (Table 1, Figure 3).

Table 1. Lactate and eart Rate Measurements Across Different Time Points for WBC, CWI, and CON Groups

Group	T0	T1	T2	T3	p-value (Between Groups)
Lactate					
WBC	1.43 ± 0.45	10.39 ± 2.64	3.98 ± 1.52	2.46 ± 1.02	0,768
CWI	1.61 ± 0.629	10.95 ± 3.49	3.52 ± 1.31	2.20 ± 0.604	
CON	1.42 ± 0.439	10.96 ± 3.21	4.01 ± 1.45	2.38 ± 1.08	
Heart Rate					
WBC	74.9 ± 10.1	185.8 ± 18.0	94.6 ± 11.2	84.5 ± 9.65	0,409
CWI	74.6 ± 7.5	191.9 ± 7.5	90.9 ± 12.2	82.1 ± 10.9	
CON	79.8 ± 10.3	189.6 ± 9.87	96.7 ± 13.3	86.8 ± 7.12	

T0: Baseline, T1: Post-exercise, T2: Post-recovery, T3: 10' Post-recovery

Elasticity

Achilles tendon elasticity showed no statistically significant changes either within or between groups (left: p=0.811; right: p=0.413) (Figure 4, Table 2). In contrast, gastrocnemius muscle elasticity significantly changed over time in all groups, with post-hoc analyses revealed several significant within-group differences, particularly between T1 and T3 or T2 and T3; however, no significant differences were found between groups (left: p=0.472; right: p=0.947) (Figure 4, Table 2).

Table 2. Achilles Tendon and Gastrocnemius Muscles Elasticity Measurements Across Different Time Points for WBC, CWI, and CON Groups

	Group	T0	T1	T2	T3	p-value (Between Groups)
Achilles Left	WBC	0.789 ± 0.154	0.776 ± 0.115	0.803 ± 0.172	0.807 ± 0.240	0,811
	CWI	0.824 ± 0.164	0.824 ± 0.194	0.880 ± 0.238	0.825 ± 0.159	
	CON	0.718 ± 0.179	0.757 ± 0.103	0.706 ± 0.140	0.685 ± 0.160	
Achilles Right	WBC	0.851 ± 0.168	0.904 ± 0.116	0.949 ± 0.122	0.986 ± 0.136	0,413
	CWI	0.816 ± 0.164	0.858 ± 0.106	0.924 ± 0.265	0.865 ± 0.218	
	CON	0.704 ± 0.169	0.785 ± 0.135	0.723 ± 0.173	0.756 ± 0.116	
GAS Left	WBC	0.938 ± 0.120	0.959 ± 0.219	1.008 ± 0.167	0.990 ± 0.172	0,472
	CWI	0.955 ± 0.150	0.907 ± 0.103	0.946 ± 0.115	0.956 ± 0.102	
	CON	0.982 ± 0.160	0.940 ± 0.119	0.985 ± 0.134	1.005 ± 0.136	
GAS Right	WBC	0.956 ± 0.088	0.904 ± 0.116	0.949 ± 0.122	0.986 ± 0.136	0,947
	CWI	0.956 ± 0.088	0.902 ± 0.122	0.958 ± 0.126	0.986 ± 0.133	
	CON	0.941 ± 0.131	0.918 ± 0.167	0.977 ± 0.164	0.996 ± 0.166	

T0: Baseline, T1: Post-exercise, T2: Post-recovery, T3: 10' Post-recovery, GAS: Gastrocnemius.

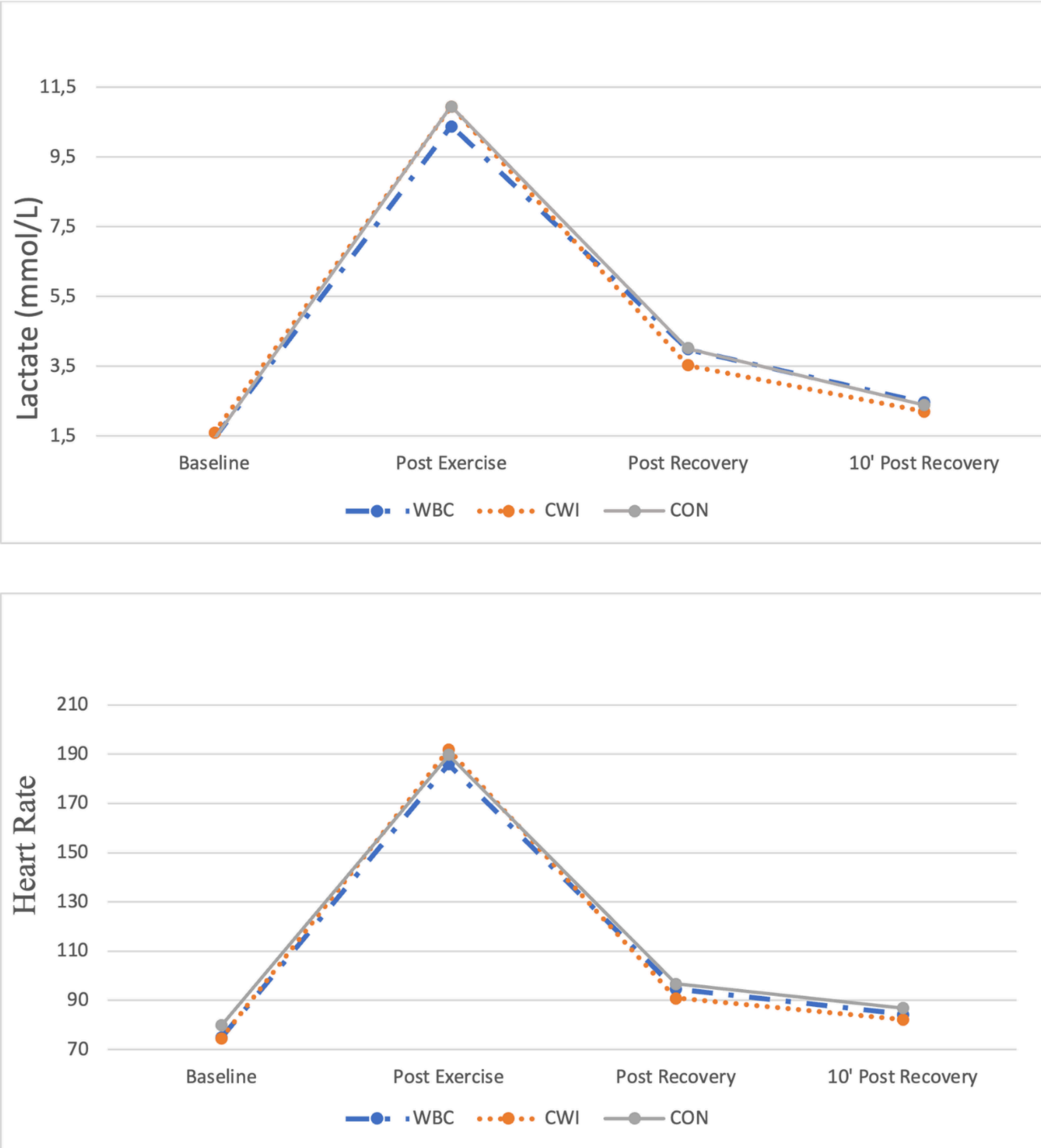

Figure 3. Effects of Whole Body Cryotherapy, Cold Water Immersion, and Control Conditions on Blood Lactate Concentration and Heart Rate Following the Loading and Recovery Sessions

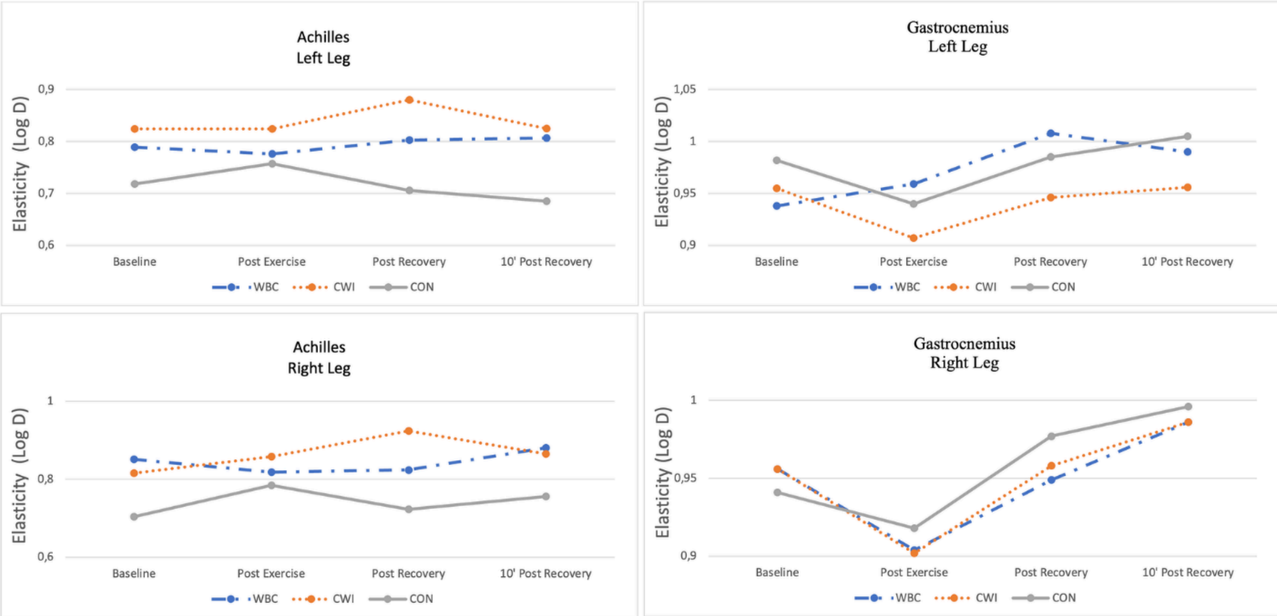

Figure 4. Effects of Whole Body Cryotherapy, Cold Water Immersion, and Control Conditions on the Elasticity of Achilles Tendon and Gastrocnemius Muscle Following the Loading and Recovery Sessions

Stiffness

Achilles tendon stiffness showed no statistically significant changes either within or between groups (left: p=0.391; right: p=0.473) (Figure 5, Table 3). In contrast, gastrocnemius muscle stiffness significantly changed over time in the CWI group, with post-hoc comparisons revealed a significant decrease from T1 to T3 in the left leg (p=0.035) and from T1 to T2 in the right leg (p=0.030); however, no significant differences were found between groups (left: p=0.460; right: p=0.164) (Figure 5, Table 3).

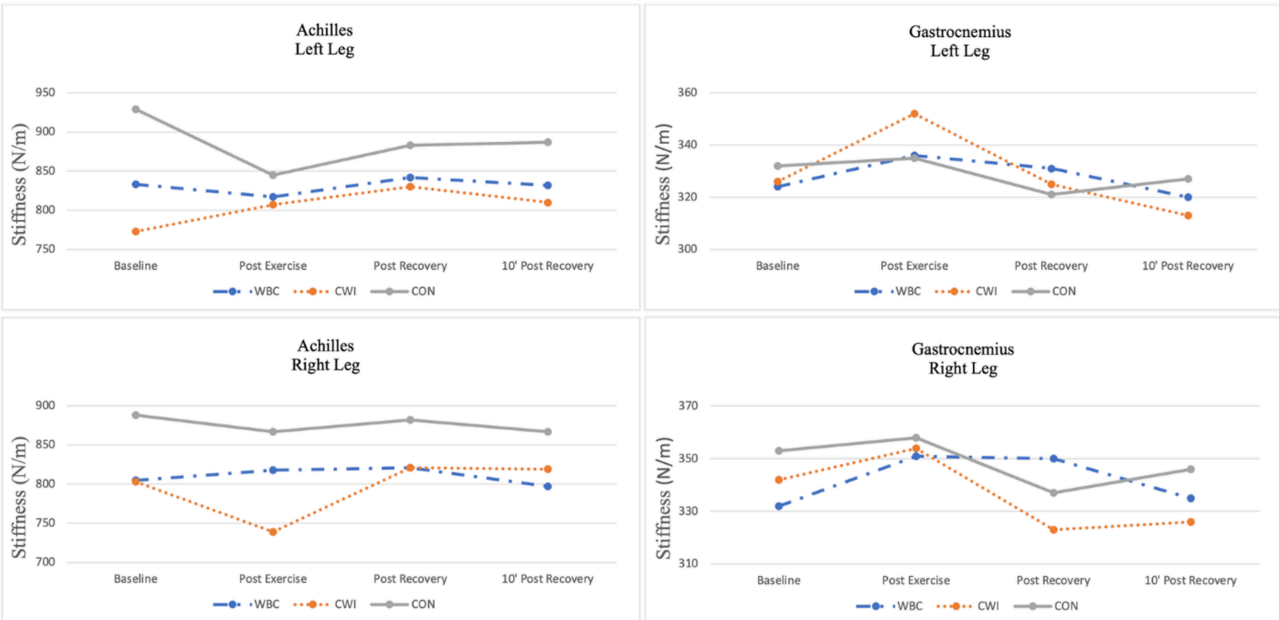

Figure 5. Effects of Whole Body Cryotherapy, Cold Water Immersion, and Control Conditions on the Stiffness of Achilles Tendon and Gastrocnemius Muscle Following the Loading and Recovery Sessions

Table 3. Achilles Tendon and Gastrocnemius Muscles Stiffness Measurements Across Different Time Points for WBC, CWI, and CON Groups

	Group	T0	T1	T2	T3	p-value (Between Groups)
Achilles Left	WBC	833 ± 79.3 N/m	817 ± 81.9 N/m	842 ± 88.4 N/m	832 ± 120 N/m	0,391
	CWI	773 ± 167 N/m	807 ± 82.1 N/m	830 ± 126 N/m	810 ± 80.4 N/m	
	CON	929 ± 173 N/m	845 ± 112 N/m	883 ± 129 N/m	887 ± 141 N/m	
Achilles Right	WBC	805 ± 86.0 N/m	818 ± 107 N/m	821 ± 91.6 N/m	797 ± 104 N/m	0,473
	CWI	803 ± 176 N/m	739 ± 119 N/m	821 ± 109 N/m	819 ± 100 N/m	
	CON	888 ± 105 N/m	867 ± 173 N/m	882 ± 166 N/m	867 ± 186 N/m	
GAS Left	WBC	324 ± 36.7 N/m	336 ± 58.0 N/m	331 ± 42.3 N/m	320 ± 51.2 N/m	0,460
	CWI	326 ± 38.7 N/m	352 ± 57.8 N/m	325 ± 44.4 N/m	313 ± 53.6 N/m	
	CON	332 ± 44.2 N/m	335 ± 34.6 N/m	321 ± 47.5 N/m	327 ± 55.9 N/m	
GAS Right	WBC	332 ± 42.0 N/m	351 ± 46.3 N/m	350 ± 60.2 N/m	335 ± 54.0 N/m	0,164
	CWI	342 ± 52.2 N/m	354 ± 66.4 N/m	323 ± 50.6 N/m	326 ± 47.5 N/m	
	CON	353 ± 49.5 N/m	358 ± 41.4 N/m	337 ± 65.8 N/m	346 ± 66.9 N/m	

T0: Baseline, T1: Post-exercise, T2: Post-recovery, T3: 10' Post-recovery, GAS: Gastrocnemius.

Tone

Achilles tendon tone showed no statistically significant changes either within or between groups (left: p=0.625; right: p=0.641) (Figure 6, Table 4). In contrast, gastrocnemius muscle tone significantly changed in the CWI group, with post-hoc analysis revealed a significant difference between T1 and T3 in the left leg (p=0.005); however, no significant differences were found between groups (left: p=0.652; right: p=0.084) (Figure 6, Table 4).

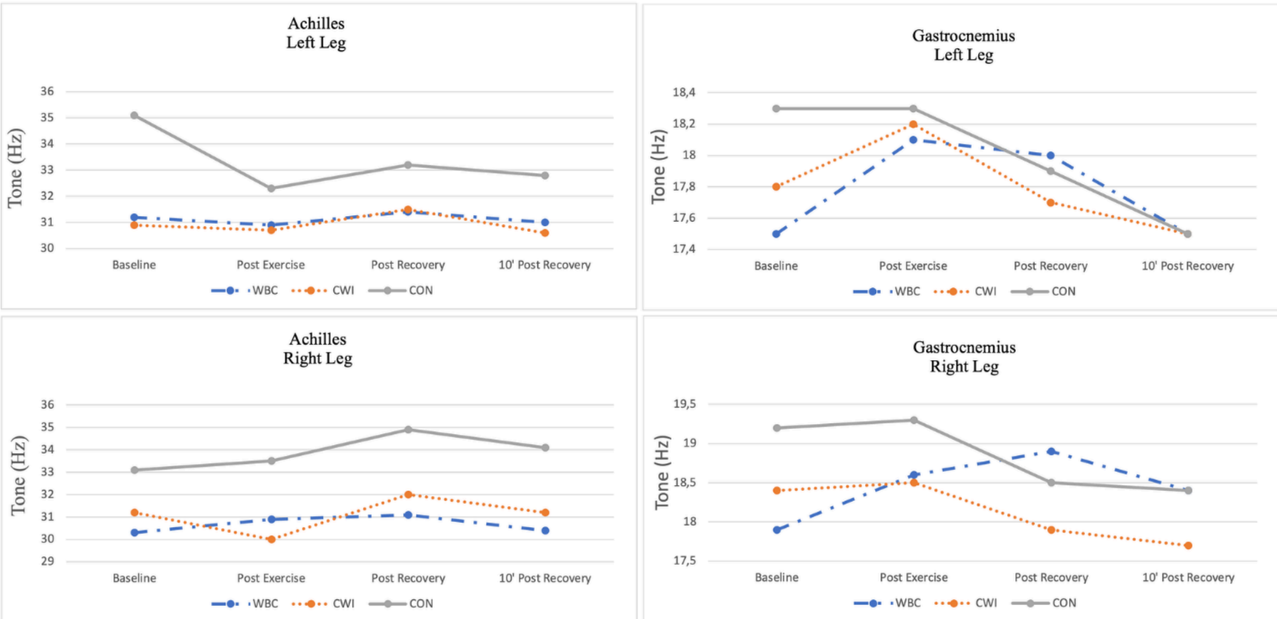

Figure 6. Effects of Whole Body Cryotherapy, Cold Water Immersion, and Control Conditions on the Tone of Achilles Tendon and Gastrocnemius Muscle Following the Loading and Recovery Sessions

Table 4. Achilles Tendon and Gastrocnemius Muscles Tone Measurements Across Different Time Points for WBC, CWI, and CON Groups

	Group	T0	T1	T2	T3	p-value (Between Groups)
Achilles Left	WBC	31.2 ± 2.24	30.9 ± 2.29	31.4 ± 2.16	31.0 ± 2.95	0,625
	CWI	30.9 ± 3.21	30.7 ± 2.39	31.5 ± 3.81	30.6 ± 2.06	
	CON	35.1 ± 8.18	32.3 ± 5.71	33.2 ± 5.17	32.8 ± 5.20	
Achilles Right	WBC	30.3 ± 2.11	30.9 ± 3.28	31.1 ± 2.40	30.4 ± 2.67	0,641
	CWI	31.2 ± 3.37	30.0 ± 1.11	32.0 ± 3.12	31.2 ± 2.20	
	CON	33.1 ± 4.83	33.5 ± 6.70	34.9 ± 8.50	34.1 ± 8.93	
GAS Left	WBC	17.5 ± 2.26	18.1 ± 1.55	18.0 ± 1.41	17.5 ± 1.87	0,652
	CWI	17.8 ± 1.49	18.2 ± 1.36	17.7 ± 1.39	17.5 ± 1.64	
	CON	18.3 ± 1.67	18.3 ± 1.32	17.9 ± 1.74	17.5 ± 2.30	
GAS Right	WBC	17.9 ± 1.32	18.6 ± 1.53	18.9 ± 1.84	18.4 ± 2.33	0,084
	CWI	18.4 ± 1.60	18.5 ± 1.90	17.7 ± 1.64	17.7 ± 1.64	
	CON	19.2 ± 1.86	19.3 ± 1.51	18.5 ± 2.23	18.4 ± 2.16	

T0: Baseline, T1: Post-exercise, T2: Post-recovery, T3: 10' Post-recovery, GAS: Gastrocnemius.

DISCUSSION

In our study, we implemented a randomized, three-phase crossover design to compare the acute effects of different cold applications-whole-body cryotherapy and cold water immersion-following high-intensity interval training (HIIT). Each participant underwent all three conditions in a randomized order: WBC, CWI, and a passive recovery phase, which served as the control condition. The study assessed blood lactate levels, heart rate, and muscle/tendon elasticity, tone, and stiffness across these phases. HIIT led to significant increases in lactate concentration and heart rate ($p<0.001$), which significantly decreased during recovery. Post-HIIT recovery applications showed no significant differences in heart rate and blood lactate levels compared to the control group ($p>0.05$). No significant group differences were found in the elasticity, tone, and stiffness of the Achilles tendon and gastrocnemius muscle. However, time-dependent changes were observed in the gastrocnemius muscle.

Heart Rate

Although the physiological mechanisms of heart rate recovery are not yet fully understood, monitoring this parameter in our study aimed to provide insight into the cardiovascular autonomic recovery process following exercise [18,19]. Cold water immersion, regardless of temperature, has been shown to accelerate parasympathetic reactivation and promote a faster decrease in heart rate after exercise compared to other recovery methods [18-21].

In one study exploring the benefits of cold water immersion (CWI) following high-intensity exercise, a 15-minute protocol at 11°C revealed no significant differences in post-exercise parasympathetic reactivation between CWI and active recovery [22]. Conversely, another study conducted under similar conditions reported that cold water immersion caused a more significant decrease in maximal heart rate compared to the control condition [23].

Research on the effects of whole-body cryotherapy (WBC) on post-exercise heart rate is relatively recent and limited. Kojima et al. (2018) found that university-level male athletes who underwent WBC at -140°C exhibited significantly lower heart rate values compared to those who experienced passive rest at room temperature (22°C) [24]. Similarly, Storniolo et al. (2023) studied 28 participants using a bicycle ergometer and found that WBC led to greater reductions in heart rate during rest compared to the control group [25].

Although research on the effects of cold applications on heart rate is limited, existing studies generally indicate that such applications significantly reduce heart rate compared to control groups when administered post-exercise [24,26]. This study focuses on examining acute changes in heart rate, specifically tracking the effects of cold applications over a 10-minute recovery period. During this time, no significant differences were observed between cold water immersion (CWI), whole-body cryotherapy (WBC), and the control group. The average heart rate recorded across all groups was 76.43 ± 9.38 bpm before exercise, and following the 10-minute recovery application, it rose to 84.46 ± 9.22 bpm. This indicates that the elevated heart rate from exercise had not yet returned to baseline levels.

Thus, it is challenging to definitively conclude whether cold applications impact recovery based solely on acute heart rate measurements. Additionally, given that the applied protocol was high-intensity interval training (HIIT), it may not have exerted as profound an effect on heart rate recovery as longer-duration endurance training might have.

Based on the data presented in this study, it can be concluded that both cold water immersion and whole-body cryotherapy do not influence the heart rate decline curve during short-term recovery. However, it is important to acknowledge that heart rate is influenced by various factors, including endocrine, neurological, and respiratory responses, as well as lifestyle factors such as alcohol and tobacco use, stress, and depression [27]. Moreover, since all participants in this study were male athletes from various sports disciplines, differences in cardiovascular autonomic regulation and exercise adaptation across sex and athletic background may also have influenced heart rate responses. These demographic and training-related characteristics should be considered when interpreting or generalizing the findings. Therefore, when assessing heart rate as an indicator of recovery, it is essential to consider these influencing factors.

Blood Lactate

During anaerobic metabolism, the enzyme lactate dehydrogenase (LDH) plays a crucial role in converting lactate back to pyruvate. Its concentration increases in the blood due to muscle trauma and is widely recognized as an indicator of muscle damage in sports contexts. Research indicates that high-intensity interval training (HIIT) significantly elevates blood lactate concentrations in samples collected immediately post-exercise [28,29].

In the study conducted by Eriksson and Anttila (2023), blood lactate concentrations were measured in female participants at two consecutive time points following a Wingate anaerobic test: 10 seconds post-exercise and at the onset of cold water immersion (approximately 1 minute post-exercise) [30]. Despite the brief 50-second interval between measurements, a notable increase of 1.6 mmol/L in lactate concentration was recorded. This finding suggests that blood lactate continues to rise for a short period after exercise, rather than stabilizing immediately. Therefore, if an intervention is applied while lactate is still increasing, it becomes difficult to isolate the intervention's true physiological effect. To ensure a clearer interpretation, the timing of the application should ideally coincide with the point where lactate reaches or approaches its peak-allowing for a more distinct and measurable response to the intervention itself.

A study by Adamczyk et al. (2014) investigated the relationship between blood lactate concentration and body temperature following high-intensity exercise [31]. Participants remained seated while blood lactate levels were measured at 1, 3, 6, 9, 12, 15, 20, 25, and 30 minutes post-exercise. Each measurement showed a statistically significant difference compared to the previous time point, with the highest lactate level recorded at the 3rd minute (11.73 mmol/L). Goodwin et al. (2007) also reported that peak lactate values typically occur between 3 and 8 minutes after intense exercise [32]. Based on these findings, the 3rd minute was chosen in this study as the most appropriate time point to assess the onset of lactate decline following high-intensity interval exercise and to evaluate the potential accelerating effect of cold applications.

Given the rapid fluctuations in lactate levels within 30 minutes post-exercise, measurement timing is critical. In our study, delays caused by stiffness measurements and clothing changes before recovery applications may have reduced the visible impact of cold applications. The interval between the end of exercise and the initiation of recovery modalities extended to approximately 15 minutes. This duration likely allowed for partial normalization of lactate levels through endogenous clearance mechanisms, diminishing the potential impact window for the applied cold interventions. This could explain the similar outcomes between cold application groups and the control group. Additionally, the physiological responses to lactate clearance may differ depending on sex and sport-specific conditioning, which were not controlled for in this study.

Muscle and Tendon Stiffness

Exercise-induced muscle stiffness is closely linked to muscle fatigue in athletes [33]. High-intensity loads can increase stiffness immediately after exercise and maintain this effect for up to a week [33]. Post-exercise stiffness elevates muscle tone, increases intramuscular pressure, and delays recovery [34]. Cold applications have been shown to alleviate post-exercise muscle stiffness; however, there is no clear consensus regarding the optimal temperature, duration, or timing of application. Accordingly, they are generally believed to reduce muscle stiffness by decreasing intramuscular fluid accumulation and edema [35-37].

Pinto et al. (2020) studied sedentary men by applying cold water immersion to one randomly selected leg following plyometric exercise [36]. Muscle stiffness was measured at several time points using a digital palpation device on both the soleus and gastrocnemius. Their results showed that cold water immersion did not produce a statistically significant reduction.

Similarly, another study with 30 athletes examined the effects of 15-minute cold water immersion at 12°C following 20 minutes of cycling at 70% Wattmax. Using ultrasound elastography, they also found no significant changes in muscle stiffness before and after exercise [37].

These findings raise questions about the intensity and type of exercise required to induce measurable stiffness. It is well known that eccentric contractions cause more muscle damage than other contraction types [38]. However, more research is needed to determine the extent to which aerobic loading contributes to muscle stiffness. This study faced a similar challenge. Although the loading protocol was set at a high intensity (130% vVO_2max), it may not have been sufficient to induce measurable muscle damage. Consequently, the impact of cold applications on the tissues was not adequately observed. Possible reasons include the minimal presence of eccentric contractions and the well-trained status of the participants, which may have limited muscle and tendon responsiveness. Moreover, individual differences in muscle-tendon characteristics arising from sport discipline and sex may have also influenced these outcomes, yet were not accounted for in this study. Additionally, the duration of loading may have led to early exhaustion, with both central and peripheral fatigue potentially occurring before sufficient muscular deformation took place.

Comparison of the Effects of Whole Body Cryotherapy and Cold Water Immersion on Recovery

The results of our study confirmed that both whole-body cryotherapy (WBC) and cold water immersion (CWI) produced similar effects on heart rate, blood lactate concentration, and muscle/tendon stiffness. No statistically significant differences were found between the two experimental groups or compared to the passive recovery phase, which functioned as the control condition. It is important to emphasize that all participants completed each recovery method as part of a randomized, three-phase crossover design. However, these findings should be interpreted in the context of the high-intensity interval training (HIIT) protocol used. It is known that different loading methods affect the rate at which heart rate returns to pre-exercise levels. For instance, Kaikkonen et al. (2008) found that heart rate decreased more slowly following higher-intensity loads and that continuous loading caused a more prolonged elevation compared to intermittent loading at the same intensity [39]. Had we employed a more sustained loading protocol, the recovery effects of WBC and CWI might have been evaluated more comprehensively.

The study also identified several perceived advantages and disadvantages of both methods. Most athletes found initial immersion in cold water difficult but adapted within approximately three minutes. In contrast, athletes generally found WBC easier to tolerate and more pleasant. This may be due to the shorter exposure time in WBC, which likely reduced psychological resistance. Additionally, since the thermal conductivity of water is twenty times higher than air, cold water can decrease body temperature three times faster than air at the same temperature-potentially explaining differences in athletes' experiences [40].

CWI was recognized for its practical setup and lower cost; however, several limitations were noted. Maintaining hygiene in shared pools was difficult, and drawbacks included longer session durations, the need to dry off afterward, temperature fluctuations, and the inability for multiple athletes to use the pool simultaneously. In contrast, WBC cabins-despite their higher cost-allow multiple users at once, maintain stable temperature, and eliminate drying needs. These factors suggest that WBC may offer a more practical and hygienic solution for sports clubs with the financial means to support it. Overall, since both methods had comparable effects on recovery, clubs seeking efficiency and convenience might prefer whole-body cryotherapy.

CONCLUSION

In this study, HIIT based on VO_2max intensity elevated blood lactate and heart rate to anaerobic levels in all groups (WBC, CWI, Control), and Borg scale ratings confirmed a high level of exertion. Although significant within-group decreases in lactate and heart rate were observed post-recovery, no between-group differences emerged. Similarly, muscle-tendon elasticity, tone, and stiffness did not differ significantly. Future studies should minimize inter-individual fitness disparities and consider psychological dimensions of recovery, which may influence outcomes even in the absence of measurable physiological change.

Additionally, future research should consider extending the recovery monitoring period until heart rate returns to pre-exercise levels, and investigate the comparative effects of cold applications following more prolonged or anaerobic chronic loading. Studies incorporating cellular-level analyses may also provide more detailed insights into recovery mechanisms.

From a practical perspective, while both cold applications had similar physiological effects, athletes found WBC easier to tolerate and more hygienic, suggesting it may be a more feasible option for sports teams with access to the necessary infrastructure.

Ethics Committee Approval

The approval for this study was obtained from Atatürk University Clinical Research Ethics Committee, Erzurum, Türkiye (Approval No: E-70400699-000-2300063387, Date: 20.02.2023).

Conflict of Interest

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

Financial Disclosure

The authors received no financial support for the research and/or publication of this article.

Author Contributions

Concept: HA, AP, EE, TM; Design: HA, AP, EE, TM; Supervision: AP; Materials: EA, KS; Data collection and/or processing: HA, AP, EE, TM, EA, MD; Analysis and interpretation: HA; Literature review: HA, EE; Writing manuscript: HA, EE; Critical reviews: AP, EE. All authors contributed to the final version of the manuscript and discussed the results and contributed to the final manuscript.

REFERENCES

1. Boullosa D, Dragutinovic B, Feuerbacher JF, Benítez-Flores S, Coyle EF, Schumann M. Effects of short sprint interval training on aerobic and anaerobic indices: A systematic review and meta-analysis. Scand J Med Sci Sports. 2022;*32*:810-20
2. Khodadadi F, Bagheri R, Negaresh R, Moradi S, Nordvall M, Camera DM et al. The effect of high-intensity interval training type on body fat percentage, fat and fat-free mass: a systematic review and meta-analysis of randomized clinical trials*. J Clin Med.* 2023;12:2291
3. Alves JW, Farias-Junior LF, Alves CPL, Mortatti AL, Costa EC. Low-volume high-intensity interval training sessions with different work-recovery durations and muscle damage in trained men. Res Q Exerc Sport. 2023;94:73-81
4. Cochrane DJ. Alternating hot and cold water immersion for athlete recovery: a review. Phys Ther Sport. 2004;5:26-32
5. Kellmann M, Bertollo M, Bosquet L, Brink M, Coutts AJ, Duffield R et al. Recovery and performance in sport: consensus statement. Int J Sports Physiol Perform. 2018;13:240-45
6. Sautillet B, Leprêtre PM, Schmitt L, Ahmaidi S, Costalat G. Post-exercise heart rate variability: whole-body cryotherapy vs. contrast water therapy. Int J Sports Med. 2021;42:979-84
7. Ihsan M, Abbiss CR, Allan R. Editorial: the use of post-exercise cooling as a recovery strategy: unraveling the controversies. Front Sports Act Living, 2022;4:825016
8. Douris P, McKenna R, Madigan K, Cesarski B, Lu M. Recovery of maximal isometric grip strength following cold immersion. J Strength Cond Res. 2003;17:509-13
9. White GE, Wells GD. Cold-water immersion and other forms of cryotherapy: physiological changes potentially affecting recovery from high-intensity exercise. Extrem Physiol Med. 2013;2:1-11
10. Yanagisawa O, Kudo H, Takahashi N, Yoshioka H. Magnetic resonance imaging evaluation of cooling on blood flow and oedema in skeletal muscles after exercise. Eur J Appl Physiol. 2004;91:737-40
11. Leeder J, Gissane C, Van Someren K, Gregson W, Howatson G. Cold water immersion and recovery from strenuous exercise: a meta-analysis. Br J Sports Med. 2012;46:233-40
12. Rose C, Edwards KM, Siegler J, Graham K, Caillaud C. Whole-body cryotherapy as a recovery technique after exercise: a review of the literature. Int J Sports Med. 2017;38:1049-60
13. Riboli A, Coratella G, Rampichini S, Limonta E, Esposito F. Testing protocol affects the velocity at VO2max in semi-professional soccer players. Res Sports Med (Print). 2022;30:182-92
14. Gojanovic B, Shultz R, Feihl F, Matheson G. Overspeed HIIT in lower-body positive pressure treadmill improves running performance. Med Sci Sports Exerc. 2015;47:2571-78
15. Broatch JR, Poignard M, Hausswirth C, Bishop DJ, Bieuzen F. Whole-body cryotherapy does not augment adaptations to high-intensity interval training. Sci Rep. 2019;9:12013
16. Getto CN, Golden G. Comparison of active recovery in water and cold-water immersion after exhaustive exercise. Athl Train Sports Health Care. 2013;5:169-76
17. Cristi-Sánchez I, Danes-Daetz C, Neira A, Ferrada W, Yáñez Díaz R, Silvestre Aguirre R. Patellar and achilles tendon stiffness in elite soccer players assessed using myotonometric measurements. Sports health. 2019;11:157-62
18. Choo HC, Nosaka KJ, Peiffer J, Ihsan MC, Yeo C, Abbiss C. Effect of water immersion temperature on heart rate variability following exercise in the heat. Kinesiology. 2018;50:67-74
19. Oliveira Ottone V, Castro Magalhães F, Paula F, Avelar NCP, Aguiar PF, Matta Sampaio PF et al. The effect of different water immersion temperatures on post-exercise parasympathetic reactivation. Plos One. 2014;9:e113730
20. Al Haddad H, Laursen PB, Chollet D, Lemaitre F, Ahmaidi S, Buchheit M. Effect of cold or thermoneutral water immersion on post-exercise heart rate recovery and heart rate variability indices. Auton Neurosci. 2010;156:111-16
21. Stanley J, Buchheit M, Peake JM. The effect of post-exercise hydrotherapy on subsequent exercise performance and heart rate variability. Eur J Appl Physiol. 2012;112:951-61
22. Bastos FN, Vanderlei LC, Nakamura FY, Bertollo M, Godoy MF, Hoshi RA et al. Effects of cold water immersion and active recovery on post-exercise heart rate variability. Int J Sports Med. 2012;33:873-79
23. Schniepp J, Campbell TS, Powell KL, Pincivero DM. The effects of cold-water immersion on power output and heart rate in elite cyclists. J Strength Cond Res. 2002;16:561-66
24. Kojima C, Kasai N, Kondo C, Ebi K, Goto K. Post-exercise whole body cryotherapy (− 140° c) increases energy intake in athletes. Nutrients. 2018;10:893
25. Storniolo JL, Chaulan M, Esposti R, Cavallari P. Effects of whole-body cryotherapy on exercise performance and subsequent fast recovery. Sport Sci Health. 2023;19:S75
26. Krüger M, de Marees M, Dittmar KH, Sperlich B, Mester J. Whole-body cryotherapy's enhancement of acute recovery of running performance in well-trained athletes. Int J Sports Physiol Perform. 2015;10:605-12
27. Fatisson J, Oswald V, Lalonde F. Influence diagram of physiological and environmental factors affecting heart rate variability: an extended literature overview. Heart int. 2016;11:e32-e40

28. Rahmanian K, Hooshmand F, Shakeri M, Rahmanian V, Jahromi FS, Jahromi AS et al. Creatine kinase and lactate dehydrogenase enzymes response to lactate tolerance exercise test. Exercise Science. 2022;31:168-72
29. Rhibi F, Abderrahman AB, Prioux J, Clark CC, Bideau B, Besbes S et al. Effects of different training intensities in high-intensity interval training (HIIT) on maximal aerobic velocity, hematological and muscle-damage markers in healthy young adults. BMC Sports Sci Med Rehabil. 2022;14:1-12
30. Eriksson L, Anttila A. Cold water immersion improves muscular recovery after an anaerobic test in healthy women [Bachelor's thesis]. Halmstad (Sweden): Halmstad University, School of Business, Innovation and Sustainability; 2023.
31. Adamczyk JG, Boguszewski D, Siewierski M. Thermographic evaluation of lactate level in capillary blood during post-exercise recovery. Kinesiology. 2014;46:186-93
32. Goodwin ML, Harris JE, Hernández A, Gladden LB. Blood lactate measurements and analysis during exercise: a guide for clinicians. J Diabetes Sci Technol. 2007;1:558-69
33. Dankel SJ, Razzano BM. The impact of acute and chronic resistance exercise on muscle stiffness: a systematic review and meta-analysis. J Ultrasound. 2020;23:473-80
34. Alaca N, Kablan N. Acute effects of cold spray application on mechanical properties of the rectus femoris muscle in athletes. J Bodyw Mov Ther. 2022;30:100-04
35. Jo HD, Kim CS, Kim MK. Effects of hydrotherapy on muscle damage and recovery profile after eccentric exercise in arm. Exercise Science. 2021;30:336-45
36. Pinto J, Rocha P, Torres R. Cold-water immersion has no effect on muscle stiffness after exercise-ınduced muscle damage. Clin J Sport Med. 2020;30:533-38
37. Hüttel M, Golditz T, Mayer I, Heiss R, Lutter C, Hoppe MW et al. Effects of pre-and post-exercise cold-water immersion therapy on passive muscle stiffness. Sportverletz Sportschaden. 2020;34:72-78
38. Hedayatpour N, Falla D. Physiological and neural adaptations to eccentric exercise: mechanisms and considerations for training. Biomed Res Int. 2015, 193741
39. Kaikkonen P, Rusko H, Martinmäki K. Post-exercise heart rate variability of endurance athletes after different high-intensity exercise interventions. Scand J Med Sci Sports. 2008;18:511-19
40. Tipton MJ, Collier N, Massey H, Corbett J, Harper M. Cold water immersion: kill or cure?. Exp Physiol. 2017;102:1335-55