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Effect of cold-water immersion at upper extremities on muscle fatigue in amateur basketball players

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Summary. Cold-water immersion (CWI) is commonly used as a post-exercise recovery strategy; however, the effects of upper-extremity CWI on perceptual, biochemical, and performance recovery following basketball-specific exercise remain unclear. Therefore, this exploratory crossover study aimed to examine the potential effects of upper-extremity CWI on fatigue-related responses, blood lactate concentration, and physical performance following a simulated basketball competition in amateur basketball players. Seventeen participants completed three experimental sessions in a randomized crossover design: 10-minute cold-water immersion (CWI10), 15-minute cold-water immersion (CWI15), and passive recovery (PAS), with a 1-week washout period between sessions. Blood lactate concentration (BLa) was assessed immediately after the simulated basketball competition (post-test) and after recovery (post-recovery). Countermovement jump (CMJ), 10-m sprint performance, and rating of perceived exertion (RPE) were evaluated at pre-test, post-test, and post-recovery. Within-condition analyses demonstrated significant reductions in BLa and RPE from post-test to post-recovery across all conditions ($p < 0.05$). CMJ performance decreased significantly from post-test to post-recovery in the CWI15 and PAS conditions ($p < 0.05$). However, no statistically significant differences were observed among CWI10, CWI15, and PAS for any outcome measures. These exploratory findings suggest that upper-extremity CWI did not confer additional recovery benefits compared with passive recovery following a simulated basketball competition. Further studies involving larger sample sizes and additional physiological measurements are warranted to clarify the potential role of upper-extremity CWI in basketball recovery strategies.

Key words. Fatigue, recovery, athletic performance, lactate, basketball.

Effetto dell'immersione in acqua fredda degli arti superiori sull'affaticamento muscolare nei giocatori di pallacanestro dilettanti

Riassunto. L'immersione in acqua fredda (CWI) è comunemente utilizzata come strategia di recupero post-esercizio; tuttavia, gli effetti della CWI degli arti superiori sul recupero percettivo, biochimico e prestazionale a seguito di un esercizio specifico per il basket rimangono poco chiari. Pertanto, questo studio esplorativo crossover mira a esaminare i potenziali effetti della CWI degli arti superiori sulle risposte legate all'affaticamento, sulla concentrazione di lattato nel sangue e sulle prestazioni fisiche a seguito di una competizione di basket simulata in giocatori di basket dilettanti. Diciassette partecipanti hanno completato tre sessioni sperimentali in un disegno crossover randomizzato: immersione in acqua fredda di 10 minuti (CWI10), immersione in acqua fredda di 15 minuti (CWI15) e recupero passivo (PAS), con un periodo di washout di 1 settimana tra le sessioni. La concentrazione di lattato nel sangue (BLa) è stata valutata immediatamente dopo la competizione di pallacanestro simulata (post-test) e dopo il recupero (post-recupero). Il salto contro movimento (CMJ), la prestazione nello sprint di 10 m e il rating di sforzo percepito (RPE) sono stati valutati al pre-test, al post-test e al post-recupero. Le analisi all'interno delle condizioni hanno dimostrato riduzioni significative della BLa e dell'RPE dal post-test al post-recupero in tutte le condizioni ($p < 0,05$). La prestazione del CMJ è diminuita significativamente dal post-test al post-recupero nelle condizioni CWI15 e PAS ($p < 0,05$). Tuttavia, non sono state osservate differenze statisticamente significative tra CWI10, CWI15 e PAS per nessuna delle misure di esito. Questi risultati esplorativi suggeriscono che la CWI degli arti superiori non ha conferito ulteriori benefici di recupero rispetto al recupero passivo a seguito di una competizione simulata di pallacanestro. Sono necessari ulteriori studi con campioni più ampi e misurazioni fisiologiche aggiuntive per chiarire il ruolo potenziale della CWI degli arti superiori nelle strategie di recupero nel basket.

Parole chiave. Affaticamento, recupero, prestazioni atletiche, lattato, pallacanestro.

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Introduction

Basketball is one of the most popular team sports in the world. Each competition requires players to perform repeated high-intensity activities, including accelerations, decelerations, sprinting, jumping, and changes of direction ability[1]. A basketball match is divided into four quarters, each lasting for ten minutes under FIBA rules and twelve minutes under NBA rules. A 15-minute halftime break and a 2-minute break between quarters are provided[2]. Because of the prolonged duration of the match and various competitive components of basketball, athletes may experience muscle fatigue during competition. Previous studies have reported that basketball players experience increased fatigue during halftime and the highest levels of fatigue following the game[3].

Muscle fatigue reduces the efficiency of muscle performance. Central and peripheral fatigue are the two primary mechanisms underlying muscle fatigue[4]. Central fatigue results from alterations in neurotransmitter concentrations within the central nervous system or upper neuromuscular junction. These alterations lead to a decline in the transmission of nerve signals from the motor cortex to the muscles, thereby reducing muscle performance[5]. Peripheral fatigue, which is associated with the accumulation of metabolites within the muscles, occurs at or below the neuromuscular junction, where several biochemical changes take place, including the glycogen depletion, and the accumulation of inorganic phosphates, calcium ions, lactate, adenosine diphosphate, magnesium, and glycogen[6]. Previous studies have reported that blood lactate levels increase during basketball competitions and peak at halftime. In addition, fatigue negatively affects physical performance[7,8].

Cold-water immersion (CWI) is a widely used method for physical recovery. By immersing different parts of the body in cold water at a temperature of 10-15°C for 5-15 minutes, CWI has been associated with reduced perceptions of fatigue, attenuation of post-exercise muscle damage markers, and improved recovery outcomes in certain athletic settings[9,10]. These effects are hypothesized to involve cold-induced vasoconstriction and alterations in circulatory responses, which may contribute to reductions in edema, pain perception, and metabolite accumulation[11,12]. Previous research has demonstrated that 10 minutes of whole-body CWI can reduce creatine kinase (CK) levels and attenuate declines in sprint performance[12]. Similarly, lower-limb CWI performed for 12 minutes has been shown to reduce lactate dehydrogenase (LDH) concentrations and help preserve muscular power[13]. Despite these physiological benefits, both whole-body and lower-limb CWI may face practical constraints in basketball settings. The requirement for bulky equipment, such as immersion tanks, and the need for athletes to remove equipment (e.g., shoes and socks) may result in logistical delays during active competition.

Cold-water immersion of the upper extremities may represent an alternative recovery strategy for reducing muscle fatigue and effectively maintaining physical performance during competition. A recent study demonstrated that cold-water immersion from the hands to the elbows for 15 minutes significantly reduced core temperature, skin temperature, and perceived fatigue compared with a non-immersion control condition. Furthermore, this intervention helped attenuate declines in physical performance during the final 30 minutes of exercise[14]. Nevertheless, the physiological mechanisms underlying the effects of upper-extremity cold-water immersion on muscle fatigue remain unclear, particularly because previous studies have provided limited assessment of fatigue- and recovery-related biochemical markers. Therefore, further investigation is required to clarify the effects of upper-extremity cold-water immersion on muscle fatigue and related physiological responses.

This study aimed to investigate the potential effects of upper-extremity cold-water immersion during halftime on muscle fatigue in a simulated basketball game by assessing perceptual recovery, performance recovery, and biochemical markers, including blood lactate concentration. Given the limited evidence regarding the physiological responses to upper-extremity cold-water immersion in basketball settings, this study was designed to provide preliminary insights into the potential mechanisms underlying this recovery strategy and to generate hypotheses for future confirmatory research. In particular, the study explored whether upper-extremity cold-water immersion during halftime could contribute to improved perceptual recovery and the maintenance of physical performance during the second half of competition.

Material and methods

Participants

Seventeen male amateur basketball players from Mahasarakham University were voluntarily recruited using a purposive sampling technique. The sample size was calculated using G*Power (Franz Faul, Uni Kiel, Germany) (version 3.1.9.2). A statistical power of 0.95, a significance level of 0.05, and an effect size of 0.43 were used to determine the required sample size[15]. To account for a potential dropout rate of 10%, the final sample size was set at 17 participants. The inclusion criteria were as follows: having at least 1 year of continuous basketball-playing experience; being healthy and free from chronic diseases that could

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restrict physical activity; having no injuries that could interfere with participation in the study; having no cold sensitivity or sensory impairment; and not currently undergoing any form of medical treatment. The exclusion criteria were as follows: withdrawal of consent to participate in the study or the occurrence of an unexpected event that prevented continued participation in the research.

Study design

A single-blinded randomized crossover design was employed. Participants completed all experimental conditions, including passive recovery (PAS), 10-minute cold-water immersion (CWI10), and 15-minute cold-water immersion (CWI15), in a randomized counterbalanced order, as illustrated in figure 1. Participants were randomly allocated to three sequences: Sequence 1 (PAS→CWI15→CWI10, n = 6), Sequence 2 (CWI10→PAS→CWI15, n = 6), and Sequence 3 (CWI15→CWI10→PAS, n = 5), to minimize potential order effects. Intervention sequences were generated prior to data collection using an online randomization program (Stats Random Assignment Applet). Outcome assessors were blinded to the intervention conditions during data collection and statistical analysis. A 1-week washout period was implemented between trials to reduce potential carryover effects. Data were collected between October 2024 and December 2024 at Mahasarakham University. Ethical approval for this study was obtained from the Mahasarakham University Ethics Committee in Human Research (approval number: 570-405/2024).

Protocol procedures

One week prior to the experimental trials, anthropometric assessments were conducted, including height (cm), measured using a stadiometer, and body mass (kg), measured using a digital weighing scale. Body mass index (BMI) was subsequently calculated as body mass (kg) divided by height squared (m^2). In addition, body proportions required for the My Jump 2 application were assessed, including leg length, knee height at 90° flexion, and lever length. Participants were familiarized with the Basketball Exercise Simulation Test (BEST), the recovery procedures, and all outcome measurements and physical performance tests. Participants were instructed to avoid vigorous physical activity, alcohol consumption, smoking, and the use of performance-enhancing substances for at least 24 hours before each testing session and to refrain from eating for at least 2 hours prior to testing.

On the testing day, rating of perceived exertion (RPE) was assessed using the Borg 6-20 scale. Baseline physical performance assessments, including the countermovement jump (CMJ) and 10-m sprint test, were subsequently performed. Participants then completed a standardized warm-up consisting of 6 minutes of dynamic stretching exercises targeting the hamstrings, quadriceps, gluteus maximus, gastrocnemius, adductors, and abductors, with each exercise performed for 1 minute.

Following the warm-up, participants completed the Basketball Exercise Simulation Test (BEST) to induce fatigue[16]. The BEST protocol consisted of walking or standing, jogging, running, sprinting, low shuffling, high shuffling, and jumping activities. Par-

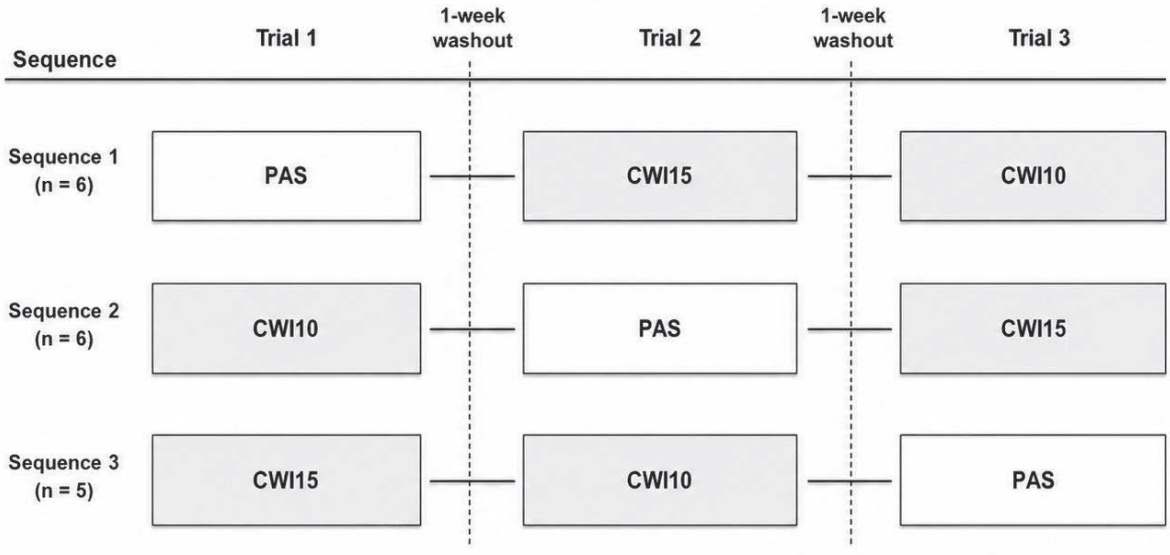

Figure 1. Randomized crossover design illustrating the sequence of recovery interventions across three experimental trials. PAS: passive recovery; CWI10: cold-water immersion for 10 min; CWI15: cold-water immersion for 15 min.

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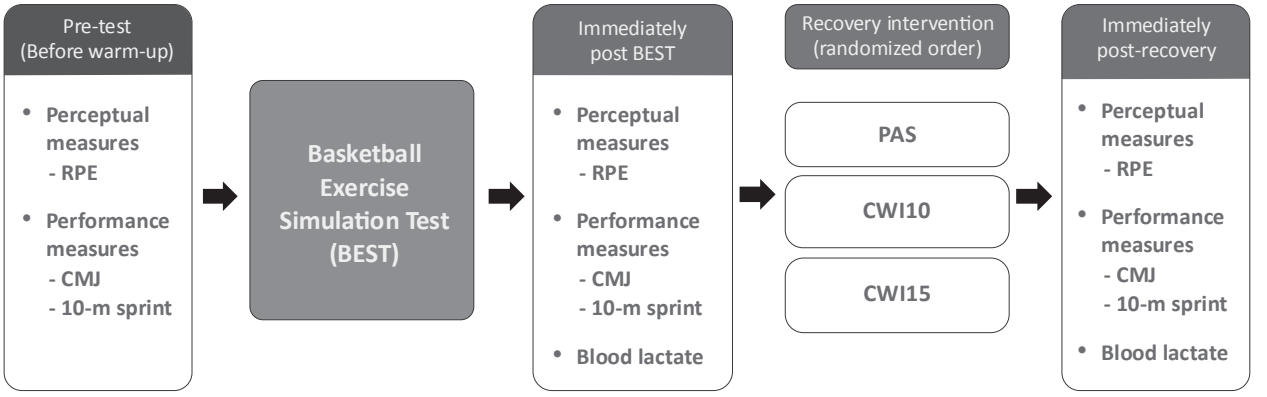

Figure 2. Trial protocol. RPE: rating of perceived exertion; CMJ: countermovement jump; PAS: passive recovery; CWI10: cold-water immersion for 10 min; CWI15: cold-water immersion for 15 min.

ticipants were required to complete one round within 30 seconds. If a participant completed the round before the allocated time, they remained standing at the starting point until the 30-second interval elapsed before commencing the next round. Participants continued the protocol until 20 rounds had been completed. If a participant was unable to complete a round within 30 s, the test continued until the 10-minute time limit was reached. Completion of either 20 rounds or 10 minutes constituted one testing period. The protocol consisted of two testing periods separated by a 2-minute recovery interval.

Immediately following completion of the BEST protocol, the dependent variables were reassessed, including RPE, CMJ performance, 10-m sprint performance, and blood lactate concentration. Participants then underwent the assigned recovery intervention according to the randomized crossover sequence. Following completion of the recovery intervention, all dependent variables were reassessed. Participants subsequently completed the remaining experimental conditions, with a 1-week washout period between trials until all three trials were completed. The overall experimental protocol is illustrated in figure 2.

Outcome measures

Countermovement jump with arm swing (CMJ) performance was assessed using a Samsung Galaxy S22 Ultra smartphone (Samsung Electronics; FHD 120 fps) in combination with the My Jump 2 mobile application, which has previously demonstrated acceptable validity and reliability[17]. Participants were instructed to place their hands on their hips, maintain full knee extension while standing, perform a rapid downward movement by flexing the knees, and subsequently jump vertically as high as possible. During the flight phase, the legs were kept fully extended, and participants were instructed to land in the same position. Each participant performed three trials with a 20-second rest interval between attempts. The highest jump height, expressed in centimeters (cm), was used for further analysis[18].

The 10-m sprint test was performed with participants standing 70 cm behind the starting line. Upon the start signal, participants sprinted maximally in a straight line over a distance of 10 m[7]. Sprint time was measured using a handheld stopwatch and recorded in seconds (s). Two trials were completed with a 2-minute recovery interval between attempts, and the best performance was used for subsequent analysis.

Rating of perceived exertion (RPE) was assessed using the Borg 6–20 scale, ranging from 6 (no exertion) to 20 (maximal exertion)[19].

Blood samples were collected via capillary puncture from the distal phalanx of the finger. Blood lactate concentration was analyzed using the EDGE Handheld Lactate Analyzer (APEXBIO) and expressed in millimoles per liter (mmol/L).

Recovery interventions

During the cold-water immersion intervention, participants were seated comfortably on a chair and immersed both hands and forearms up to the elbows in cold water using two buckets. Water temperature was continuously monitored using a digital thermometer, and ice cubes were added as necessary to maintain the temperature at 12 ± 2°C, which falls within the commonly recommended therapeutic range of 10–15°C. In the 10-minute cold-water immersion condition (CWI10), participants underwent continuous immersion for 10 minutes, followed by 5 minutes of seated rest. In the 15-minute cold-water immersion condition (CWI15), participants underwent continu-

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ous immersion for 15 minutes. During the passive recovery condition (PAS), participants remained seated comfortably on a chair for 15 minutes without any cooling intervention.

Data analysis

The collected data were presented as mean and standard deviation (SD), as appropriate. The Shapiro-Wilk test was used to assess the normality of the measured data, and the homogeneity of variance was tested. If the data did not conform to a normal distribution or if the variances were not homogeneous, the Kruskal-Wallis test was used to compare differences at different time points. If the data conformed to a normal distribution and the variances were homogeneous, a two-way analysis of variance (ANOVA) was used to analyze the main effects of group and time, as well as their interaction. Post hoc comparisons were conducted using Bonferroni multiple comparisons test. Partial eta squared (η_p^2) was used to determine effect size, with values of 0.01-0.06 considered small, 0.06-0.14 considered medium, and values ≥ 0.14 considered large effect sizes[20]. The level of statistical significance was set at $p < 0.05$. Statistical analyses were performed using IBM SPSS Statistics 29.0.

Results

The demographic characteristics of the 17 participants are presented in table 1. All datasets satisfied the assumptions of normality and homogeneity of variance.

Countermovement jump. No significant group × time interaction was observed for countermovement jump performance ($F(3.76, 90.30) = 0.96$, $p = 0.429$, $\eta_p^2 = 0.038$, 90% CI [0.00–0.08]). However, a significant main effect of time was identified ($F(1.88, 90.30) = 17.00$, $p < 0.001$, $\eta_p^2 = 0.261$, 90% CI [0.13–0.37]). Post hoc Bonferroni comparisons demonstrated significant decreases from post-test to post-recovery in the PAS and CWI15 conditions ($p < 0.001$ and $p = 0.009$, respectively). Although changes were observed at other time points, these differences did not reach statistical significance ($p > 0.05$). No significant main effect of group was found ($F(2, 48) = 0.28$, $p = 0.758$, $\eta_p^2 = 0.012$, 90% CI [0.00–0.07]). These findings suggest that temporal changes in jump performance occurred irrespective of the recovery condition, as presented in table 2.

Ten-meter sprint. No significant group × time interaction was observed for 10-m sprint performance ($F(4, 96) = 1.77$, $p = 0.142$, $\eta_p^2 = 0.069$, 90% CI [0.00–0.13]). Similarly, neither the main effect of group ($F(2, 48) = 0.19$, $p = 0.829$, $\eta_p^2 = 0.008$, 90% CI [0.00–0.05]) nor the main effect of time ($F(2, 96) = 0.53$, $p = 0.592$, $\eta_p^2 = 0.011$, 90% CI [0.00–0.03]) reached statistical significance. Although minor fluctuations in sprint performance were observed across conditions and time points, these changes were not statistically significant, as presented in table 2.

Rating of perceived exertion. No significant group × time interaction was detected for rating of perceived exertion (RPE) ($F(3.67, 88.11) = 1.55$, $p = 0.200$, $\eta_p^2 = 0.06$, 90% CI [0.00–0.12]). A significant main effect of time was observed ($F(1.84, 88.11) = 425.97$, $p < 0.001$, $\eta_p^2 = 0.899$, 90% CI [0.86–0.92]). Pairwise comparisons revealed that RPE increased significantly from pre-test to post-test across all conditions ($p < 0.001$), followed by a significant reduction after recovery ($p < 0.001$). Interestingly, RPE in the PAS condition remained significantly elevated relative to pre-test values following recovery ($p = 0.023$). No significant main effect of group was identified ($F(2, 48) = 0.11$, $p = 0.901$, $\eta_p^2 = 0.004$, 90% CI [0.00–0.04]). Although no between-condition differences were detected, the observed temporal patterns may provide preliminary insights into perceptual recovery responses following the intervention period, as presented in table 3.

Blood lactate. No significant group × time interaction effect was observed for blood lactate concentration ($F(2, 48) = 1.61$, $p = 0.211$, $\eta_p^2 = 0.063$, 90% CI [0.00–0.17]). Likewise, the main effect of condition was not statistically significant ($F(2, 48) = 1.80$, $p = 0.176$, $\eta_p^2 = 0.07$, 90% CI [0.00–0.18]). However, a significant main effect of time was identified ($F(1, 48) = 91.12$, $p < 0.001$, $\eta_p^2 = 0.655$, 90% CI [0.51–0.74]). Blood lactate concentrations decreased significantly from post-test to post-recovery across all conditions ($p < 0.001$). Although no between-condition differences were detected, these findings may indicate a general recovery-related reduction in metabolic stress following the intervention period, as presented in table 3.

Table 1. Demographic characteristics of participants.

Variable	Value (Mean ± SD)
Age (years)	20.47±2
Height (cm)	180.82±4.49
Weight (kg)	78.03±12.29
Body mass index (kg/m2)	23.87±3.71

Discussion

The main finding of this exploratory crossover study was that upper-extremity cold-water immersion for either 10 or 15 minutes did not produce statistically significant benefits over passive recovery in terms of perceptual, biochemical, or performance recovery

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outcomes. Although reductions in RPE and blood lactate concentration were observed from post-test to post-recovery, these changes occurred across all recovery conditions, including passive recovery. Importantly, improvements in perceptual or biochemical markers did not translate into superior neuromuscular performance recovery, as countermovement jump and 10-m sprint performance remained statistically comparable between conditions. Therefore, the present findings do not support the superiority of upper-extremity cold-water immersion over passive recovery during halftime recovery in this setting.

Table 2. Comparison within groups and between groups of performance outcomes.

Performance outcomes	Mean ± SD			F(df) Sig. ES [90% CI]	Time	Group	Time X Group
	PAS	CWI10	CWI15				
CMJ (cm)							
Pre-test	38.63±6.01	39.66±5.05	38.54±4.66	F	17 (1.88,90.30)	0.28 (2,48)	0.96 (3.76,90.30)
Post-test	41.26±7.35	41.55±5.85	41±6.87	p	<0.001**	0.758	0.429
Post-recovery	37±6.18#	39.72±5.77	38.25±5.27#	η_p^2	0.261 [0.13, 0.37]	0.012 [0, 0.07]	0.038 [0, 0.08]
Ten-meter sprint (s)							
Pre-test	2.40±0.18	2.36±0.25	2.37±0.26	F	0.53 (2,96)	0.19 (2,48)	1.77 (4,96)
Post-test	2.29±0.32	2.32±0.16	2.43±0.31	p	0.592	0.829	0.142
Post-recovery	2.36±0.19	2.37±0.16	2.36±0.22	η_p^2	0.011 [0, 0.03]	0.008 [0, 0.05]	0.069 [0, 0.13]

**p<0.01; #Significantly different compared with Post-test (p<0.01). CMJ: Counter-movement jump; CWI10: cold water immersion 10 minute; CWI15: cold water immersion 15 minute; df: degrees of freedom; ES: Effect size; PAS: passive recovery; Mean: mean value; SD: standard deviation; η_p^2: Partial eta square.

Table 3. Comparison within groups and between groups of physiological outcomes.

Performance outcomes	Mean ± SD			F(df) Sig. ES [90% CI]	Time	Group	Time X Group
	PAS	CWI10	CWI15				
RPE							
Pre-test	7.53±1.12	7.47±1.12	7.94±1.34	F	425.97 (1.84,88.11)	0.11 (2,48)	1.55 (3.67,88.11)
Post-test	15±2.03‡	15.59±2.24‡	14.94±1.85‡	p	<0.001**	0.901	0.2
Post-recovery	8.59±1.18†#	7.71±1.36#	8.35±1.5#	η_p^2	0.899 [0.86, 0.92]	0.004 [0, 0.04]	0.06 [0, 0.12]
Lactate (mmol/L)							
Post-test	5.39±3.58	4.99±2.19	3.72±1.81	F	91.12 (1,48)	1.80 (2,48)	1.61 (2,48)
				p	<0.001**	0.176	0.211
Post-recovery	2.35±1.37#	2.19±1.04#	1.81±0.79#	η_p^2	0.655 [0.51, 0.74]	0.07 [0, 0.18]	0.063 [0, 0.17]

**p<0.01; †Significantly different compared with Pre-test (p<0.05); ‡Significantly different compared with Pre-test (p<0.01);#Significantly different compared with Post-test (p<0.01). CMJ: Counter-movement jump; CWI10: cold water immersion 10 minute; CWI15: cold water immersion 15 minute; df: degrees of freedom; ES: Effect size; PAS: passive recovery; Mean: mean value; SD: standard deviation; η_p^2: Partial eta square.

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Performance recovery

As an exploratory study, the present findings suggest that upper-extremity cold-water immersion following muscle fatigue induced by a simulated basketball competition may not enhance power performance recovery. One possible explanation is that the fatigue-inducing protocol used in the current study did not produce a meaningful decline in power performance. This observation is consistent with previous findings reported by Getto and Golden[21], who observed no recovery-related effects 24 hours after immersion in 10°C cold water when post-exercise power performance did not differ from pre-exercise values. Interestingly, 15 minutes of cold-water immersion was associated with a reduction in power performance compared with values obtained immediately after the fatigue-inducing test. Although the underlying mechanisms were not directly examined in the present study, several physiological explanations have been proposed in previous literature. Prolonged cold-water immersion may reduce muscle temperature, which can decrease nerve conduction velocity and impair neuromuscular function. Previous evidence has suggested that for every 1°C reduction in muscle temperature, jump performance may decline by approximately 4.2%[22,23]. In addition, reduced muscle temperature may increase skeletal muscle viscosity, potentially impairing elastic energy utilization and stretch-shortening cycle function, both of which are important for explosive movements such as jumping. Cold exposure may also influence Na^+ and Ca^{2+} ion exchange within nerve and muscle cells, which could delay action potential propagation and reduce force-producing capacity, thereby impairing muscle contraction performance[24]. These exploratory findings are generally consistent with the study by Li et al.[22], who reported that continuous cold-water immersion for 12 minutes at 5°C following a simulated basketball competition significantly reduced power performance compared with pre- and post-exercise values. However, in the present study, no statistically significant differences in power performance were observed among the PAS, CWI10, and CWI15 conditions at any measurement time point. This finding may further support the possibility that the exercise protocol used in the current study did not induce sufficient neuromuscular fatigue to substantially affect power performance. Nevertheless, the CWI10 condition showed no reduction in power performance after recovery compared with immediately post-exercise values. Although preliminary, these findings may suggest that shorter-duration upper-extremity cold-water immersion could help maintain power performance more effectively than longer-duration immersion or passive recovery.

In this study, the present findings suggest that upper-extremity cold-water immersion following a simulated basketball exercise test did not meaningfully enhance speed performance. One possible explanation is that the fatigue-inducing protocol used in this study may not have been sufficient to impair sprint performance, similar to the findings observed for power performance outcomes. Additionally, the 10-m sprint test may require only a short recovery period, thereby allowing participants to rapidly restore performance when adequate rest is provided[25]. In the current study, no statistically significant differences in sprint performance were observed among the PAS, CWI10, and CWI15 conditions at any time point. These findings may indicate that the combination of limited sprint-performance decrement following the fatigue protocol and the rapid recovery characteristics of short-distance sprint tasks reduced the likelihood of detecting meaningful between-condition differences. Therefore, the present results should be interpreted with caution and may be considered hypothesis-generating for future investigations examining the effects of upper-extremity cold-water immersion on sprint recovery performance.

Perceptual recovery

The current exploratory study observed a trend toward lower RPE following recovery with cold-water immersion compared with passive recovery. One possible explanation is that cold-water immersion may attenuate peripheral fatigue through reductions in blood lactate accumulation, as suggested in previous studies. Additionally, immersion of the upper extremities may contribute to reducing central fatigue by facilitating heat dissipation during exercise performed in hot environmental conditions (~30°C). The region extending from the elbows to the fingertips contains numerous arteriovenous anastomoses (AVAs)[26], which are specialized vascular structures involved in heat exchange, and this region also has a relatively high surface area-to-mass ratio[27]. These characteristics may support thermoregulatory responses during recovery. However, because core body temperature was not measured in the present study, these mechanisms remain speculative and cannot be confirmed. Despite these potential physiological explanations, no statistically significant differences in RPE were observed among the PAS, CWI10, and CWI15 conditions at any measurement time point. It is possible that the 15-minute halftime recovery period itself was sufficient to partially restore perceived fatigue after the exercise protocol. Nevertheless, only the PAS condition demonstrated significantly higher RPE values after recovery compared with pre-test values, whereas RPE in the CWI10 and CWI15 conditions returned closer to baseline levels. Although

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these findings should be interpreted with caution, they may suggest that upper-extremity cold-water immersion has the potential to support perceptual recovery during halftime.

Metabolic recovery

This exploratory study observed that both 10- and 15-minute cold-water immersion following the basketball simulation exercise were associated with reductions in blood lactate concentration. One possible explanation is that cold-water immersion stimulates cutaneous vasoconstriction, a thermoregulatory response that occurs in both immersed and non-immersed regions to preserve body heat[28]. This response may reduce peripheral blood flow and increase central blood volume, thereby facilitating the transport of lactate from the blood and skeletal muscles for further metabolic clearance[11].

However, no statistically significant differences in blood lactate concentration were observed among the CWI10, CWI15, and PAS groups at any measurement time point. This finding differs from the study by Panyakham and Pariwat[12], who reported that 10-minute cold-water immersion at 10°C during halftime in football reduced blood lactate levels more effectively than passive rest. The discrepancy may be related to the recovery protocol used in the present study, as the 15-minute rest interval may have been sufficient to promote recovery of blood lactate concentration following the basketball simulation exercise[29]. Moreover, although reductions in blood lactate concentration were observed following recovery, these changes were not accompanied by improvements in sprint or jump performance. This finding suggests that reductions in blood lactate concentration may not necessarily translate into enhanced speed or power performance and that metabolic recovery and neuromuscular performance recovery may represent distinct physiological domains. Contemporary exercise physiology also recognizes blood lactate primarily as a marker of metabolic stress and substrate turnover rather than a direct cause of impaired athletic performance[30]. Therefore, the present findings should be interpreted with caution and considered hypothesis-generating for future investigations.

Limitations

This study has several limitations that should be acknowledged. First, the simulated basketball exercise protocol may not have induced sufficient neuromuscular fatigue to meaningfully evaluate recovery-related changes in physical performance. CMJ and 10-m sprint performance showed minimal reductions following exercise, which may have limited the ability to detect recovery effects between conditions. Second, sprint performance was measured using a hand-held stopwatch, which may have lower reliability compared with electronic timing systems. Third, although the My Jump 2 application has demonstrated acceptable validity for assessing jump height in athletic populations, it remains an indirect measure compared with the gold-standard force platform. Fourth, blood lactate concentration was the only physiological marker assessed, while additional markers of muscle damage, inflammation, thermoregulation, or neuromuscular fatigue were not measured. In particular, core temperature and skin temperature were not evaluated, thereby limiting mechanistic interpretation regarding heat dissipation and AVA-mediated cooling responses. Finally, the relatively small sample size and variability in physiological responses may have limited the statistical power to detect small-to-moderate effects. Therefore, the findings should be considered exploratory and hypothesis-generating. Future studies should include larger and more diverse samples to improve statistical power and external validity. More demanding and basketball-specific fatigue protocols should also be used to induce greater neuromuscular fatigue and better evaluate recovery responses. Additional physiological measurements, such as core temperature, skin temperature, heart rate variability, creatine kinase, inflammatory markers, and neuromuscular function, are needed to clarify the mechanisms underlying upper-extremity cold-water immersion. Future research should also use more precise performance assessments, including electronic timing systems and force platforms. In addition, different immersion temperatures, durations, and halftime recovery strategies should be compared to identify optimal recovery protocols. Finally, confirmatory studies conducted during real basketball competition are warranted to determine whether perceptual recovery benefits translate into meaningful improvements in athletic performance.

In conclusion, upper-extremity cold-water immersion for 10 or 15 minutes did not provide additional recovery benefits over passive recovery in amateur basketball players following a simulated basketball exercise protocol. Although RPE and blood lactate concentration decreased after the recovery period, these changes occurred across all conditions and should not be interpreted as evidence supporting the superiority of cold-water immersion. Therefore, these findings should be considered exploratory and hypothesis-generating.

Conflicts of interest. The authors declare there is no conflict of interest.

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References

1. Ramirez-Campillo R, García-Hermoso A, Moran J, Chaabene H, Negra Y, Scanlan AT. The effects of plyometric jump training on physical fitness attributes in basketball players: A meta-analysis. J Sport Health Sci 2022; 11: 656-70.
2. Cuzzolin F. Training and performance differences between the NBA and FIBA rules and major competition aspects (Euro, WC, and Olympics). In: Laver L, Kocaoglu B, Cole B, Arundale AJH, Bytomski J, Amendola A, eds. Basketball Sports Medicine and Science. Berlin, Heidelberg: Springer Berlin Heidelberg, 2020; 791-7.
3. Izquierdo J. Quantitative assessment of the effects of official match on physical performance factors on under-16 and under-18 female basketball players at national league level. Eur J Hum Mov 2021; 46.
4. Pajoutan M, Ghesmaty Sangachin M, Cavuoto LA. Central and peripheral fatigue development in the shoulder muscle with obesity during an isometric endurance task. BMC Musculoskelet Disord 2017; 18: 314.
5. Périard JD, Caillaud C, Thompson MW. Central and Peripheral Fatigue during Passive and Exercise-Induced Hyperthermia. Med Sci Sports Exerc 2011; 43.
6. Tornero-Aguilera JF, Jimenez-Morcillo J, Rubio-Zarapuz A, Clemente-Suárez VJ. Central and Peripheral Fatigue in Physical Exercise Explained: A Narrative Review. Int J Environ Res Public Health 2022; 19.
7. Pliauga V, Kamandulis S, Dargevičiūtė G, et al. The Effect of a simulated basketball game on players' sprint and jump performance, temperature and muscle damage. J Hum Kinet 2015; 46: 167-75.
8. Pociūnas R, Pliauga V, Lukonaitiene I, et al. Effects of Different Half-Time Re-Warm Up on Vertical Jump During Simulated Basketball Game. Balt J Sport Health Sci 2018; 2: 35-40.
9. Versey NG, Halson SL, Dawson BT. Water immersion recovery for athletes: effect on exercise performance and practical recommendations. Sports Med 2013; 43: 1101-30.
10. Xiao F, Kabachkova AV, Jiao L, Zhao H, Kapilevich LV. Effects of cold water immersion after exercise on fatigue recovery and exercise performance: meta-analysis. Front Physiol 2023; 14.
11. Wilcock IM, Cronin JB, Hing WA. Physiological response to water immersion: a method for sport recovery? Sports Med 2006; 36: 747-65.
12. Panyakham A, Pariwat P. The effect of cold-water immersion at half-time on the physical fitness of soccer players of Loei Rajabhat University after competition. J Faculty Phys Educ 2021; 24: 38-47.
13. Bouchiba M, Bragazzi NL, Zarzissi S, et al. Cold water immersion improves the recovery of both central and peripheral fatigue following simulated soccer match-play. Front Physiol 2022;13.
14. Iwahashi M, Chaen Y, Yanaoka T, Kurokawa Y, Hasegawa H. Cold water immersion of the hand and forearm during half-time improves intermittent exercise performance in the heat. Front Physiol 2023; 14.
15. Salaohom A, Benjapalakorn B. Acute effects of cold water immersion durations on performance and lactate recovery in 100 meter front crawl swimming. Academic Journal of Thailand National Sports University 2021; 13: 107-16.
16. Scanlan AT, Fox JL, Borges NR, Tucker PS, Dalbo VJ. Temporal changes in physiological and performance responses across game-specific simulated basketball activity. J Sport Health Sci 2018; 7: 176-82.
17. Bogataj Š, Pajek M, Andrašić S, Trajković N. Concurrent validity and reliability of my jump 2 app for measuring vertical jump height in recreationally active adults. Appl Sci 2020; 10.
18. Kamandulis S, Venckūnas T, Masiulis N, et al. Relationship between general and specific coordination in 8- to 17-year-old male basketball players. Percept Mot Skills 2013; 117: 821-36.
19. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982; 14: 377-81.
20. Cohen J. Statistical power analysis for the behavioral sciences. Lawrence Erlbaum, 1988.
21. 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.
22. Li F, Song Y, Cen X, et al. Comparative Efficacy of vibration foam rolling and cold water immersion in amateur basketball players after a simulated load of basketball game. Healthcare 2023; 11.
23. Bergh U, Ekblom B. Influence of muscle temperature on maximal muscle strength and power output in human skeletal muscles. Acta Physiol Scand 1979; 107: 33-7.
24. Machado AF, Ferreira PH, Micheletti JK, et al. Can water temperature and immersion time influence the effect of cold water immersion on muscle soreness? A systematic review and meta-analysis. Sports Med 2016; 46: 503-14.
25. Abt G, Siegler JC, Akubat I, Castagna C. The effects of a constant sprint-to-rest ratio and recovery mode on repeated sprint performance. J Strength Cond Res 2011; 25.
26. Walløe L. Arterio-venous anastomoses in the human skin and their role in temperature control. Temperature 2016; 3: 92-103.
27. DeGroot DW, Gallimore RP, Thompson SM, Kenefick RW. Extremity cooling for heat stress mitigation in military and occupational settings. J Therm Biol 2013; 38: 305-10.
28. Isii Y, Matsukawa K, Tsuchimochi H, Nakamoto T. Ice-water hand immersion causes a reflex decrease in skin temperature in the contralateral hand. J Physiol Sci 2007; 57: 241-8.
29. Chopra S, Needham-Beck S, Ambegaonkar JP. Blood lactate and heart rate responses between active and passive recovery modes over a 15-minute recovery period in female dancers after kathak dance. J Dance Med Sci 2023; 28: 75-82.
30. Wan JJ, Qin Z, Wang PY, Sun Y, Liu X. Muscle fatigue: general understanding and treatment. Exp Mol Med 2017; 49: e384.

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