

Effects of combined cold-water immersion and Swedish massage on muscle strength, fatigue, blood lactate levels, and exercise performance in male team sport athletes

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Abstract:

Background: Rapid recovery from intense training and competition with short duration between events is a crucial component for regaining maximum performance in team sport athletes. This study aimed to examine the effects of combined cold-water immersion (CWI) and Swedish massage on muscle strength, fatigue, blood lactate, and exercise performance after exercise-induced fatigue in male team sport athletes. **Materials and Methods:** A randomised crossover design was used with eight male participants. Each participant completed the exercise-induced fatigue protocol and underwent three interventions at one-week intervals: combined CWI with Swedish massage (COMB), CWI alone, and control condition (CON). Muscle strength, blood lactate, perceived fatigue, jump height, and 20-meter sprint time were measured at baseline, immediately post-exercise, and 24 h post-intervention. A handheld dynamometer and a Lactate Pro 2 with a strip were assessed for muscle strength and blood lactate levels. The statistical analysis was using the Two way-repeated measure (ANOVA). **Results:** COMB significantly decreased fatigue and blood lactate level and improved the 20-meter sprint time compared with CWI and CON 24 h post-intervention ($p < 0.05$). At 24 h post-intervention, a significant difference in quadriceps muscle strength was observed between the COMB and CON ($p < 0.001$); CWI and CON ($p < 0.001$) without a significant difference between CWI and COMB interventions. **Conclusion:** After exercise-induced fatigue, COMB promoted the recovery of all parameters to baseline levels within 24 h. This effect was particularly observed for fatigue, blood lactate levels, and the 20-meter sprint time, which were significantly better in the COMB group than in the CWI and CON groups. Therefore, team sports professionals can apply COMB after training or competition to enhance athletes' recovery.

Keywords: Swedish massage, cold-water immersion, sport performance, muscle function, recovery

Introduction

Several team sports have high-frequency training and competition schedules, and competition load requires athletes to achieve maximum performance with a short rest duration. Specifically, sports and exercise involve several sports skills such as sprinting at short distances, high jumping, agility, and movement with deceleration and acceleration which use energy sources alternately between aerobic and anaerobic energy pathways (de Araujo et al., 2014; Stojanovic et al., 2018). For instance, football, basketball, and futsal lead to fatigue and a decline in exercise performance. Moreover, high-intensity and high-frequency exercise training or sports competitions increase physical and mental stresses. These result in adverse effects such as fatigue, pain, muscle damage, decreased muscle strength, and exercise performance (de Freitas et al., 2019; Gruet et al., 2013). If fatigue is not handled properly, muscle trauma or a mild category of muscle strain can occur. Several techniques accelerate recovery from fatigue, allowing athletes to potentially return to their pre-fatigue level, such as massage, cold therapy, nutrition, and psychological techniques (Nedelec et al., 2013). Various studies have demonstrated that cold-water immersion (CWI) and massage are mainly used to restore muscle function and sports performance of athletes after intense training or competition.

CWI is popularly used as a post-exercise recovery intervention after training and competition (Xiao et al., 2023). It contributes to the recovery of performance and is associated with the effects of hydrostatic pressure and water temperature on the body. The combined effects of hydrostatic pressure and reduction in skin and intramuscular temperatures during CWI are associated with reduced local metabolism and induced vasoconstriction (Vaile et al., 2011), reduced oedema followed by an exercise that might reduce further muscle damage and maintain contractile properties of skeletal muscles (Wilcock et al., 2006a). CWI significantly decreases fatigue immediately and 24 h after intervention, reduces blood lactate levels, and facilitates the recovery of muscle strength (Ascensao et al., 2011; Delextrat et al., 2013; Himawan KMN, 2021). Moreover, an application of CWI after one and three h post high-intensity exercise could accelerate the restoration of

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maximum vertical jump and reduce muscle soreness (Chaiyakul & Chaibal, 2021). Several studies have reported that CWI accelerates performance in elite and amateur athletes (Abaidia et al., 2017; Bouzid et al., 2018; Stanley et al., 2013). Brophy-Williams et al. have reported that 15-minute CWI at 15 °C significantly improved performance based on Yoyo intermittent recovery (Brophy-Williams et al., 2011). Machado et al. have reported that CWI with a water temperature between 11 °C and 15 °C and an immersion time of 11–15 min can provide the best results and can be tolerated by athletes (Machado et al., 2016).

In addition to CWI, Swedish massage is a popular performance recovery technique commonly used by physiotherapists, sports scientists, and coaches. Swedish massage exerts physiological effects, including increased skin and muscle temperature, vasodilation of arterioles, enhanced blood circulation to the muscle, and increased lymphatic drainage (Mancinelli et al., 2006). Furthermore, massage also increases venous return, which facilitates the clearance of lactate from the contracted muscle. Rasooli et al. have reported that sports massage in swimmers after trials significantly decreases blood lactate levels compared with passive recovery (Ali Rasooli et al., 2012). Several studies have revealed that sports massage after exercise-induced fatigue can significantly restore muscle strength and sports performance, such as in isometric muscle strength test, vertical jump displacement, and vertical jump height to the pre-exercise level.

From a perspective, CWI alone or Swedish massage can enhance sports performance in athletes, especially those who engage in high-intensity, immediate exercise (Ali Rasooli et al., 2012; Chaiyakul & Chaibal, 2021; Himawan KMN, 2021). Fast and efficient recovery is crucial to success in competition for athletes, especially those who compete multiple times a day or week. However, there is only one evidence that supports the effect of CWI combined with other therapies. The combination of CWI and therapeutic massage should better facilitate recovery for exercise or competition than a single therapy. Only Angelopoulos et al. investigated the effect of combined CWI with Swedish massage (COMB) on the recovery of physiological functions (Angelopoulos et al., 2022). Their results showed that CWI improved pain sensation compared to the combined application and control. The application of COMB significantly reduced pain sensation compared to the control. No significant differences in the other parameters were observed between the interventions. However, this study did not investigate the effects of COMB on the recovery of athletes' performance and their ability to remove waste products. Knowledge on the beneficial effects of COMB on muscle strength, blood lactate levels, perceived fatigue, and subsequent-day sports performance after intense exercise is limited.

Therefore, this study aimed to determine the effects of CWI, COMB and control on muscle strength, blood lactate levels, perceived fatigue, and subsequent-day sports performance in a group of team sport athletes who underwent an exercise-induced fatigue programme. Based on existing knowledge's, we hypothesized that COMB would show a higher effect in improving muscle strength and sport performance, reducing blood lactate levels and perceived fatigue in team sport athletes compared with CWI and control interventions. This study should have benefits for the team sport to select the effective intervention in order to facilitate muscle functions and athlete performance recovery in the short duration of rest after training or competition, which might reduce risks of injuries and improve the quality of training.

Materials and Methods

Participants and study design

The study had a randomised crossover design. Eight male amateurs participating in team sports at Walailak University, including basketball, futsal, and football, were included in this study. The inclusion criteria were as follows: age between 18 and 24 years; body mass index (BMI) between 18.50 and 24.90 kg/m²; skinfold thickness at the anterior thigh of <20 mm (Goodall & Howatson, 2008); experience in the university competition level for at least 1 year; and regular training more than 3 times per week and at least 1.5 h per day continuously for at least 5 years. Participants who had skin allergies, open wounds, impaired sensation, peripheral artery/venule disorders, musculoskeletal problems within 6 months before the study, cardiopulmonary diseases, or previous experience with CWI or COMB were excluded. The sample size was calculated using G*Power version 3.1.9.7, which uses a two-way repeated measures analysis of variance (ANOVA). The effect size, alpha level, and power were set at 1.13, 0.05, and 0.80, respectively (Angelopoulos et al., 2022). The sample comprised eight participants, which included 20% dropouts. The experimental procedures and potential risks were explained to the participants before they provided written informed consent. The study protocol was approved by the Ethics Committee of Human Research of Walailak University, Thailand (approval number: WUEC-24-036-01).

Procedures

This study is designed as a randomized cross-over trials. The assessors were blinded while participating in the intervention program in this research. The research setting for data collection was located at the Physical Therapy Laboratory, Walailak University. All participants underwent three recovery interventions: rest in a sitting position (CON), CWI, and COMB. The order of recovery interventions was randomised using simple random sampling by computer, with a wash-out period of at least 7 days between each intervention. All participants were prohibited from performing vigorous exercise, taking sedative medicines, and drinking coffee or alcohol 24 h before testing. Moreover, testing was performed at the same time of the day to avoid diurnal

effects. The present study assessed the fatigue numeric rating scale (the fatigue NRS), blood lactate levels, quadriceps muscle strength, vertical jump height, and the 20-meter sprint test within three time points as follows: pre-fatigue as a baseline, immediately post-fatigue, and 24 h post-intervention. Vital signs were assessed for each intervention, and dynamic stretching exercises for the lower extremity muscles and a dynamic warm-up for 3 min were performed before the baseline assessment. Subsequently, the participants were allowed to rest for 10 min in a temperature-controlled room before performing the exercise-induced fatigue protocol. They received an intervention 30 min after the exercise session. Finally, the participants repeated all the tests 24 h post-intervention.

Exercise-induced fatigue protocol

The exercise-induced fatigue protocol comprised plyometric and resistance exercises of the lower extremities. The protocol included a 30-meter single leg jump (dominant leg) for 5 sets with a 1-minute rest between sets, a 30-meter double leg jump for 3 sets with a 1-minute rest between sets, a maximum vertical jump 6 times per set for 5 sets with a 1-minute rest between sets, and leg press with a load of 70% 1RM, ten times per set for 3 sets with a 1-minute rest between sets. All participants were allowed to rest between each type of exercise for 2 min. Heart rate and the fatigue NRS scores were recorded before and after each exercise.

Three recovery interventions

After performing the exercise-induced fatigue protocol, the participants were allowed to rest for 30 min without activity in a temperature-controlled (25 °C) laboratory room.

For CON, participants rested in a sitting position in a temperature-controlled room (25 °C) for 1 h without any activity.

For CWI, the participants were immersed in cold-water set at 15 °C for 15 min with the water level at the iliac crest. The water temperature was assessed using a thermometer during immersion. Physiological responses, including heart rate, blood pressure, and percutaneous oxygen saturation 5 min before, every 5 min during, and 5 min after immersion, were recorded. Body temperature at the axillary and temperature of the anterior thigh at the midline between the hip joint and the superior border of the patella were measured using a digital thermometer (TG-100 Rossmax, Rossmax Swiss GmbH, Switzerland) and an infrared thermometer (Hubdic FS-300, HuBDIC CO., LTD, Korea), respectively. Additionally, a thermal sensation scale was used to evaluate the perception of cold during immersion. The thermal sensation scale is composed of -3, -2, -1, 0, +1, +2, and +3 for cold, cool, slightly cool, neutral, slightly warm, warm, and hot feelings, respectively. Performing any activity while receiving the recovery intervention was prohibited.

For COMB, the participants underwent CWI followed by a Swedish massage. Swedish massage was applied to both legs on the anterior and posterior sides of the thigh and calf muscles. The Swedish massage techniques included effleurage, petrissage, friction, tapotement, and vibration for 2 min for each technique. The massage duration in each area was 10 min, and the total massage lasted approximately 1 h. Swedish massage was performed by a physical therapist experienced in performing regular massages. In this recovery intervention, the participant was allowed to rest for 5 min between the CWI and Swedish massage.

Measurement

Fatigue numeric rating scale

The fatigue NRS was used to evaluate perceived fatigue before, immediately post-fatigue, and 24 h post-intervention. The fatigue NRS is a single-item, 11-point horizontal scale ranging from 0 to 10, with 0 representing “no fatigue” and 10 representing “as bad as you can imagine”. The participants were instructed to rate their fatigue (weariness and tiredness) by selecting the number that described the worst level of fatigue (Gladman et al., 2020). The fatigue NRS demonstrated excellent test-retest reliability (ICC = 0.99) and strong concurrent criterion validity of the measure with EMG recordings (ICC = 0.89–0.95) (Lampropoulou & Nowicky, 2012).

Blood lactate levels

Blood lactate levels were measured using Lactate Pro 2 with a strip (Arkray Factory Inc., Japan). Capillary blood was drawn by a finger-prick using a sterile technique. Alcohol was applied to the fingertips and allowed to air-dry. The skin was punctured with a disposable lancet, the first drop of blood was wiped, and 0.3 µL of blood was used for testing. The high accuracy, reliability, and versatility of Lactate Pro have been reported (Pyne et al., 2000).

Quadriceps muscle strength

The isometric strength of the quadriceps muscle on the dominant side was assessed using a handheld dynamometer (Commander Power Track II; JTECH Medical Industries, Inc., Utah, USA). The participant was in a sitting position with the leg hanging from the edge of a wooden chair and the knee flexed at 90°. A strap was used to stabilise the chair. The participants kept their arms crossed during testing. A handheld dynamometer pad was placed 5 cm above the lateral malleolus on the anterior part of the lower leg. The participants performed a warm-up with two maximum isometric contractions. After the warm-up, the participants completed three maximum isometric contractions, held for approximately 5 s, with a 1-minute rest between each contraction. The reliability and validity of the instrument have been reported with a test–retest reliability (intraclass coefficient) of 0.82 and validity compared with the PrimusRS system (Pearson $r = 0.65$) (Park et al., 2017).

Vertical high jump

The maximum vertical jump was measured using a Vertec Vertical Jump® device (JUMPUSA.com, Sunnyvale, CA, USA), which had cells at 1.5 cm intervals longitudinally. The participants stood with their legs shoulder-width apart and one hand extended over their head to touch the Vertec slate, and the number was recorded. Subsequently, the participants performed the maximum jump by performing as many hip and knee flexions as possible (Kargarfard et al., 2016). The vertical jump was conducted three times with a 1-minute rest between repetitions, and the maximum value was recorded. The vertical jump showed high reliability (ICC = 0.97-0.99) and high validity compared with the countermovement jump ($r = 0.81$) (Rodriguez-Rosell et al., 2017).

20-meter sprint test

The participants were encouraged to perform a maximum sprint test at 20 m. The participants stood at the starting line in a standing split-stance start position. On the “GO” signal, participants must accelerate maximally to the finish line as fast as possible. The test was repeated three times with a 1-minute rest between each repetition, and the maximum value was recorded. The 20-meter sprint test was an excellent test-retest reliability (ICC = 0.95) (Holmberg et al., 2025).

Analyses

The Statistical Package for Social Sciences version 29 for Windows was used for statistical analysis. The Shapiro–Wilk test was used to analyse the data distribution. Descriptive data of participants (age, weight, height, BMI, subcutaneous thickness at anterior of thigh, and frequency of sports training in last three months) is described as means $\pm$ standard deviations. One-way ANOVA was performed to compare physiological responses during exercise-induced fatigue, including heart rate and fatigue scale scores. Comparisons within and between the three interventions (CON, CWI and COMB) at different time points (pre-fatigue, immediately post-fatigue and 24 h post-interventions) were analysed using two-way repeated-measures ANOVA with Bonferroni correction for quadriceps muscle strength, blood lactate levels, the fatigue NRS scores, vertical high jump, 20-meter sprint, and physiological responses during water immersion. The effect size for main effects and interactions were determined by partial eta squared (η^2_p ; 0.01 (small), 0.06 (moderate) and 0.14 (large)). The effect sizes were determined for pairwise comparison using Cohen’s d . The effect sized were determined as small, moderate, and large when d was equal to 0.2-0.5, 0.5-0.8 and >0.8 , respectively. The significance level was set at $p < 0.05$ for data analysis.

Results

Eight male-team sports athletes from Walailak University with a mean age of 21.00 ± 1.30 years participated in this study. All participants had participated in competitions in university games at least once and had no underlying disease. The participants’ characteristics, including age, weight, height, BMI, subcutaneous thickness at anterior thigh, and frequency of sports training in the last three months, are listed in Table 1.

Table 1. The participant’s characteristics (n=8).

Variable	(Mean $\pm$ SD)
Age (yr)	21.00 $\pm$ 1.30
Weight (kg)	69.00 $\pm$ 10.45
Height (cm)	174.50 $\pm$ 8.96
BMI (kg/m ²)	22.18 $\pm$ 2.00
Subcutaneous thickness at the anterior thigh (mm)	12.75 $\pm$ 1.67
Frequency of sport training in last 3 months (hrs/day)	2.60 $\pm$ 0.80
Frequency of sport training in last 3 months (days/week)	5.00 $\pm$ 0.00

BMI, body mass index

Effects of recovery interventions on quadriceps muscle strength

The results showed a significant interaction between time and intervention for quadriceps muscle strength ($F(4, 28975.72) = 53.84, p < 0.001, \eta^2_p = 0.843$). In addition, a significant of main effect of time and intervention were presented ($F(2, 154377.31) = 286.86, p < 0.001, \eta^2_p = 0.935$ and $F(2, 34955.43) = 4.11, p = 0.032, \eta^2_p = 0.294$ for time and intervention effects, respectively). Post-hoc analysis showed that quadriceps muscle strength was significantly reduced immediately post-exercise-induced fatigue compared with that in pre-fatigue in all groups ($p < 0.001, d = 1.827$; $p < 0.001, d = 1.587$; and $p < 0.001, d = 1.677$ for CON, CWI, and COMB, respectively). Rest in the CON group did not improve the quadriceps muscle strength to the pre-fatigue level, as shown by a statistically lower quadriceps muscle strength at 24 h post-CON intervention compared with that at pre-fatigue ($p < 0.001, d = 2.256$) and was not significantly different from immediately post-fatigue. A similar result was observed in the CWI intervention; however, in this intervention, the quadriceps muscle strength at 24 h post-intervention was significantly higher than that immediately post-fatigue ($p < 0.001, d = 1.136$). Quadriceps muscle strength at 24 h post-COMB intervention was not significantly different when compared with pre-fatigue but was significantly higher than immediately post-fatigue ($p < 0.001, d = 1.812$). The percentage of change between 24 h post-interventions and immediately post-fatigue revealed the most incredible

difference change in COMB (58.98%) and CWI (38.49%). In addition, between-intervention comparisons at 24 h post-intervention revealed that the quadriceps muscle strength in both water immersion groups was significantly higher than that in the CON group ($p < 0.001$, $d = 1.687$ and $p < 0.001$, $d = 2.458$ for CWI and COMB, respectively). However, no significant differences were observed between the CWI and COMB interventions (Table 2).

Effects of recovery interventions on blood lactate levels

There was a significant interaction between time and intervention for blood lactate levels ($F(4, 16.59) = 26.29$, $p < 0.001$, $\eta^2_p = 0.735$). In addition, a significant of main effect of time and intervention were presented ($F(2, 256.76) = 406.95$, $p < 0.001$, $\eta^2_p = 0.955$ and $F(2, 17.08) = 17.89$, $p < 0.001$, $\eta^2_p = 0.653$ for time and intervention effects, respectively). Post-hoc analysis showed that blood lactate levels significantly increased after performing the exercise-induced fatigue protocol compared to pre-fatigue ($p < 0.001$, $d = 7.689$; $p < 0.001$, $d = 6.071$; and $p < 0.001$, $d = 4.684$ for CON, CWI, and COMB, respectively). At 24 h post-intervention, blood lactate levels were significantly higher compared to pre-fatigue levels in CON and CWI ($p < 0.001$, $d = 7.166$ and $p < 0.001$, $d = 2.792$ for CON and CWI, respectively), especially the highest difference percentage change in CON showed approximately 425%. It is indicated that blood lactate level remained high in CON. COMB reduced the blood lactate concentration to a level similar to that at pre-fatigue and significantly lower than that immediately post-fatigue ($p < 0.001$, $d = 13.842$). The percentage of change between 24 h post-intervention and immediately post-fatigue revealed that blood lactate level was reduced at 86.97% in COMB. In addition, blood lactate levels at 24 h post-intervention with COMB were significantly lower than those with CON and CWI ($p < 0.001$, $d = 7.212$ and $p < 0.001$, $d = 3.485$ for CON and CWI, respectively) (Table 2).

Effects of recovery interventions on physical fatigue

The results showed a significant interaction between time and intervention for physical fatigue ($F(4, 5.86) = 16.42$, $p < 0.001$, $\eta^2_p = 0.621$). In addition, a significant of main effect of time and intervention were presented ($F(2, 352.25) = 987.12$, $p < 0.001$, $\eta^2_p = 0.980$ and $F(2, 6.23) = 10.61$, $p < 0.001$, $\eta^2_p = 0.515$ for time and intervention effects, respectively). At pre-fatigue, all participants reported no fatigue, and that the exercise protocol in this study could induce severe fatigue, without any significant difference observed between interventions. Post-hoc analysis showed that at 24 h post-intervention, fatigue in the CON and CWI groups was significantly lower compared to immediately post-fatigue values ($p < 0.001$, $d = 5.828$ and $p < 0.001$, $d = 5.651$ for CON and CWI, respectively), but remained significantly higher than pre-fatigue values ($p < 0.001$ and $p < 0.001$ for CON and CWI, respectively). A contrasting result was observed in the COMB intervention; at 24 h post-intervention, fatigue significantly decreased to pre-fatigue levels and significantly lower than immediate post-fatigue values ($p < 0.001$, $d = 9.261$). In addition, COMB had the greatest effect on decreasing fatigue when compared with CON and CWI at 24 h post-intervention ($p < 0.001$, $d = 3.224$ and $p < 0.001$, $d = 2.480$ for CON and CWI, respectively) (Table 2). The percentage of difference change in COMB was reported at approximately 90% to reduce the fatigue scale, followed by CWI (68.91%) and CON (51.56%).

Effects of recovery interventions on physical performance

This study evaluated physical performance using the maximum vertical jump and 20-meter sprint test to assess power and speed, respectively. There was a significant interaction between time and intervention for vertical jumps and sprints ($F(4, 26.19) = 15.21$, $p < 0.001$, $\eta^2_p = 0.603$ and $F(4, 0.11) = 15.30$, $p < 0.001$, $\eta^2_p = 0.605$ for vertical jumps and sprints, respectively). In addition, a significant of main effect of time and intervention were presented ($F(2, 274.95) = 159.61$, $p < 0.001$, $\eta^2_p = 0.889$ for time effects of vertical jumps, and $F(2, 2.18) = 297.42$, $p < 0.001$, $\eta^2_p = 0.937$ and $F(2, 3.29) = 9.92$, $p = 0.007$, $\eta^2_p = 0.208$ for time and intervention effects of sprint, respectively). An ability to perform vertical jumps and sprints significantly decreased immediately post-fatigue compared to pre-fatigue ($p < 0.001$, $d = 1.000$; $p < 0.001$, $d = 1.219$; and $p < 0.001$, $d = 0.974$ for the maximum vertical jump in the CON, CWI, and COMB groups, respectively; $p < 0.001$, $d = 2.965$; $p < 0.001$, $d = 3.626$; and $p < 0.001$, $d = 3.568$ for the 20-meter sprint in the CON, CWI, and COMB groups, respectively). At 24 h post-CWI and CON intervention, the vertical jump and 20-meter sprint performance significantly improved compared to immediately post-fatigue ($p < 0.001$, $d = 0.994$ and $p = 0.041$, $d = 0.295$ for vertical jump in the CWI and CON groups, respectively; $p < 0.001$, $d = 2.647$ and $p < 0.001$, $d = 0.998$ for the 20-meter sprint in the CWI and CON groups, respectively). However, the values in the CWI and CON groups remained significantly lower than the pre-fatigue values ($p = 0.013$, $d = 0.314$ and $p < 0.01$, $d = 0.660$ for the maximum vertical jump and $p < 0.001$, $d = 1.025$ and $p < 0.001$, $d = 2.053$ for the 20-meter sprint in the CWI and CON groups, respectively). In contrast, the COMB intervention significantly increased the vertical high jump ($p < 0.001$, $d = 1.304$) and 20-meter sprint time ($p < 0.001$, $d = 3.700$) at 24 h post-intervention compared to immediately post-fatigue. The difference in percentage change of the vertical high jump and 20-meter sprint time in COMB was better than immediately post-fatigue 18.14% and 14.94%, respectively. However, no significant difference in vertical jump height was observed between the groups at 24 h post-intervention. In contrast, at 24 h post-COMB, the 20-meter sprint time in these recovery interventions significantly improved compared with the performance with CON and CWI ($p < 0.001$, $d = 3.700$ and $p = 0.046$, $d = 0.732$, compared to CON and CWI, respectively) (Table 2). Moreover, CON and CWI showed an increase in the percentage of difference change between 24 h post-intervention compared to pre-fatigue, at 12.14% and 7.29%.

Table 2. Effects of interventions on quadriceps muscle strength, blood lactate levels, maximum vertical jump height, 20-meter sprint and fatigue at pre-fatigue, immediately post-fatigue and 24 h post-interventions (Mean±SD).

Variable	Interventions	Two-way repeated measures ANOVA			Percentage of change (%)	
		Pre-fatigue	Immediately post-fatigue	24 h post-interventions	24 h post-interventions and immediately post-fatigue	24 h post-intervention and pre-fatigue
Quadriceps muscle strength (N/kgBW)	CON	7.34±1.64	4.62±1.32*	4.25±1.03*	-6.52±7.99	-41.72±6.71
	CWI	7.11±1.48	4.80±1.43*	6.53±1.61 ^{#a}	38.49±9.79	-9.58±7.56
	COMB	7.31±1.57	4.83±1.38*	7.50±1.56 ^{#a}	58.98±19.94	2.72±3.45
Blood lactate levels (mmol/L)	CON	1.24±0.27	8.14±1.24*	6.44±0.99 [#]	-22.78±14.71	425.65±185.16
	CWI	1.44±0.38	8.00±1.48*	3.1±0.75 ^{#a}	-58.41±5.26	152.80±97.73
	COMB	1.35±1.90	7.95±0.60*	1.05±0.37 ^{#ab}	-86.97±3.74	-23.25±16.44
Maximum vertical jump height (cm)	CON	53.75±6.54	47.25±6.45*	49.25±7.07 [#]	4.25±4.62	-8.56±4.13
	CWI	54.00±5.10	47.63±5.34*	52.50±4.41 [#]	10.93±4.50	-3.34±2.00
	COMB	53.75±6.56	47.25±6.78*	55.50±5.83 [#]	18.14±6.84	3.46±2.76
20 meter sprint (s)	CON	3.16±0.18	3.74±0.21*	3.54±0.19 [#]	-5.15±1.82	12.14±5.14
	CWI	3.13±0.20	3.82±0.18*	3.33±0.19 [#]	-12.51±2.17	7.29±4.06
	COMB	3.17±0.13	3.71±0.17*	3.15±0.13 ^{#ab}	-14.94±3.77	-0.63±3.07
Fatigue scale	CON	0.00±0.00	7.25±0.45*	3.25±0.86 [#]	-51.56±7.95	
	CWI	0.00±0.00	8.25±1.24*	2.50±0.73 [#]	-68.91±7.77	
	COMB	0.00±0.00	7.38±0.75*	0.75±0.68 ^{#ab}	-90.18±9.06	

CON, control; CWI, cold-water immersion; COMB, combined cold-water immersion with Swedish massage. * denotes a significant difference from pre-fatigue, # denotes a significant difference from Immediately post-fatigue, ^a denotes a significant difference from CON, ^b denotes a significant difference from CWI. Two-way repeated measures ANOVA was analysed.

Heart rate and the fatigue NRS were measured immediately post-single leg jump, double leg jump, maximum vertical jump, and leg press before administering each intervention. No significant differences in heart rate and the fatigue NRS scores were observed for all sessions of exercise-induced fatigue protocols (Table 3). The results indicated a similar intensity of exercise in each session. Additionally, this study measured physiological responses including heart rate, blood pressure, body temperature, anterior thigh temperature, thermal sensation scale, and percutaneous oxygen saturation 5 min before (-5^{th}), during (5^{th} , 10^{th} , and 15^{th}), and 5 min after (20^{th}) the session of CWI in COMB and CWI (Table 4). The heart rate was significantly lower at 10 and 15 min of immersion than before immersion ($p=0.043$, $d=1.243$ and $p=0.041$, $d=1.054$ for CWI, and COMB, respectively), without significant differences between the interventions. Skin temperature of the anterior thigh at both interventions at the 15^{th} minute of immersion was significantly reduced compared to before immersion ($p<0.001$, $d=3.214$ and $p<0.001$, $d=3.156$ for CWI, and COMB, respectively). However, no significant differences were observed in other physiological parameters, including blood pressure, body temperature, and percutaneous oxygen saturation, either within or between recovery techniques.

Table 3. Physiological responses including heart rate and fatigue scale during exercise -induced fatigue before obtain each interventions (Mean±SD).

Interventions	Exercise induced fatigue			
	S-leg jump	D-leg jump	MVJ	Leg press
Heart rate (beat/min)				
CON	129.00±13.55	141.63±11.76	118.88±19.85	138.50±11.48
CWI	136.43±21.42	150.29±13.06	123.43±16.77	137.86±13.93
COMB	134.00±8.28	150.88±12.51	119.88±15.07	130.50±15.60
Fatigue numeric rating scale				
CON	4.00±1.03	5.25±1.00	5.63±0.72	7.25±0.45
CWI	4.50±1.37	5.75±1.13	6.13±1.41	8.25±1.24
COMB	3.63±0.72	88.4±0.96	5.25±0.68	7.38±0.72

CON, control; CWI, cold-water immersion; COMB, combined cold-water immersion with Swedish massage; S-leg jump, single leg jump; D-leg jump, double leg jump; MVJ, maximum vertical jump. Statistical analysis was using One-way ANOVA.

Table 4. Physiological responses at 5 min before (5th), during (5th, 10th, and 15th), and 5 min after (20th) the session of cold water immersion in cold-water immersion combined with Swedish massage and cold-water immersion (Mean±SD).

Parameters/ interventions	Minute -5 th	5 th	10 th	15 th	20 th
HR (beats/min)					
<i>CWI</i>	82.00±13.84	73.14±15.24	71.43±12.16*	71.71±10.70*	73.71±20.43
<i>COMB</i>	84.38±14.34	75.12±15.72	70.25±16.68*	71.75±10.34*	73.41±15.38
SBP (mmHg)					
<i>CWI</i>	124.00±19.53	119.86±14.25	120.57±16.24	123.86±15.18	127.43±15.76
<i>COMB</i>	121.75±13.58	127.75±12.50	126.00±11.93	126.50±17.44	125.88±9.70
DBP (mmHg)					
<i>CWI</i>	77.86±11.22	76.86±9.23	75.86±13.70	76.00±11.31	73.71±13.15
<i>COMB</i>	80.50±13.35	80.38±13.08	81.63±12.18	81.13±10.34	81.88±13.89
Body temperature (°C)					
<i>CWI</i>	35.65±0.88	35.34±1.08	35.56±0.98	35.61±1.02	35.03±1.35
<i>COMB</i>	35.70±0.78	34.73±0.91	35.13±0.75	35.50±0.37	35.25±0.88
Anterior thigh temperature (°C)					
<i>CWI</i>	34.89±0.68			17.24±0.81*	24.90±0.81*
<i>COMB</i>	34.58±0.74			16.98±0.59*	25.19±0.71*
Thermal sensation scale					
<i>CWI</i>	-0.12±0.29	-1.50±0.89*	-65.1±0.61*	-1.38±0.89*	-0.75±0.46
<i>COMB</i>	-0.13±0.34	-1.50±0.73*	-1.75±0.68*	-1.38±0.42*	-1.25±0.98
SpO₂ (%)					
<i>CWI</i>	98.63±1.02	99.50±0.89	99.38±1.15	98.88±0.96	99.63±0.50
<i>COMB</i>	99.00±1.03	99.50±0.52	99.63±0.50	98.94±0.65	99.25±1.13

CWI, cold-water immersion; COMB, combined cold-water immersion with massage; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; SpO₂, percutaneous oxygen saturation. * denotes significant time different from Pre-immersion.

Discussion

The primary finding revealed that the COMB intervention facilitated the recovery of muscle strength, maximum vertical jump height, and 20-meter sprint, and decreased perceived fatigue and blood lactate levels to the pre-fatigue level. Notably, at 24 h post-intervention, COMB significantly improved the 20-meter sprint, blood lactate levels, and perceived fatigue compared to CWI and CON intervention alone. However, CWI alone could not restore muscle strength, maximum vertical jump height, 20-meter sprint, perceived fatigue, and blood lactate levels to pre-fatigue levels. Nevertheless, this intervention significantly improved muscle strength and decreased blood lactate levels compared with the CON intervention.

To the best of our knowledge, this is the first study to investigate the effects of COMB after intense exercise on the recovery of muscle function, lactic clearance, perceived fatigue, and sports performance 24 h after exercise-induced fatigue. The COMB significantly restored all parameters after exercise to baseline levels, the 20-meter sprint, blood lactate levels, and perceived fatigue were significantly greater after COMB than after CWI and CON alone. By contrast, Angelopoulos et al. have reported no significant difference in muscle fatigue, pain, knee flexion range of motion, maximum isometric strength of the knee flexor muscle, and creatine kinase level between combined cold water immersion and control intervention (Angelopoulos et al., 2022). The difference in these results might be attributable to the differences in the total area of massage and the sequence of CWI and massage in COMB. The previous study applied massage to the quadriceps muscle on both sides, whereas the present study applied massage therapy to the anterior and posterior thigh and calf areas on both sides which covered most of the muscles used during the fatigue protocol. This may have promoted a greater effect of massage on performance, lactate clearance, and perceived fatigue in the present study.

CWI alone significantly improved muscle strength and decreased blood lactate levels compared to CON intervention at 24 h post-intervention. These results support the findings of Ascensao et al., and Himawan et al. (Ascensao et al., 2011; Himawan KMN, 2021). In the present study, CWI at 15 °C for 15 min revealed significantly lower skin temperature at the anterior thigh than before immersion value. The reduction of skin and muscular temperature leads to reduced local metabolism and vasoconstriction of arterioles (Vaile et al., 2011). Combining it with the compressive hydrostatic force during immersion will enhance the vasoconstriction of the peripheral vessels. Subsequently, more blood will return to the central circulation, resulting in increased clearance of waste products such as lactic acid from the muscle (Ihsan et al., 2016; Yanagisawa et al., 2010). In addition, CWI can reduce oedema following exercise according to vasoconstriction, which might further reduce muscle damage and maintain the contractile properties of skeletal muscles (Wilcock et al., 2006b). CWI reduced lymphatic and capillary permeability and fluid diffusion into the interstitial space, leading to decreased cell inflammation after exercise (Xiao et al., 2023). In contrast with Dantas and Vieira, CWI revealed no significant correlation between plasma creatine kinase concentration and neuromuscular performance, or functional

performance in 10-km runners within 24 h. The load of the 10-km street run is insufficient to induce muscle damage (Dantas & Vieira, 2024). Chaiyakul and Chaibal recommended that after high-intensity interval exercise (HIIE), CWI rapidly recovered maximum vertical jump capacity and muscle pain soreness within 24 h (Chaiyakul & Chaibal, 2021). This mechanism may be related to the ability to improve muscle function to a greater extent than the CON intervention in high-magnitude athletes. However, muscle strength and blood lactate levels did not return to pre-fatigue levels, as observed in the COMB group. This indicates that massage exerted an additional effect in enhancing the positive effects of CWI alone. After the CWI session, arteriole responses increased vascular vasodilation, which promoted blood circulation to the muscle. Simultaneously, Swedish massage increases skin and muscle temperature, leading to increased blood circulation to muscles (Best et al., 2008). In addition, COMB might have a physiological mechanism similar to that of a contrast bath, which promotes vasoconstriction and vasodilation, thereby increasing blood circulation and facilitating the clearance of lactic acid. In addition, the direction of massage used in this study was applied from the distal to the proximal part which facilitated the removal of waste products produced during exercise, such as lactic acid and other forms of hydrogen ions. Massage also activates vasomotor nerves to stimulate the dilation of venules and lymph (Ali Rasooli et al., 2012). Therefore, massage may improve muscle function and decrease blood lactate in combined intervention.

The perceived fatigue at 24 h post-COMB was significantly lower than that of the CWI and CON interventions and returned to the pre-fatigue level. However, CWI alone did not alter perceived fatigue. To the best of our knowledge, this is the first study to investigate the effect of COMB on fatigue after an exercise-induced fatigue protocol. However, two studies compared the effects of separate CWI and massage on perceived of fatigue, and controversial results have been reported. Delextrat et al. have reported a significant decrease in fatigue immediately and 24 h after both CWI and massage compared to after CON intervention (Delextrat et al., 2013). Meanwhile, Stella et al. have reported that both CWI at 10 °C for 12 min and massage did not affect the perceived of fatigue immediately after administering an intervention. However, this study did not evaluate the effects of the intervention at 24 h (Buoite Stella et al., 2024). The difference in the results might be caused by the varying cold temperatures and durations applied during the immersion. Moreover, the production of fatigue depends on the nervous, ion, vascular, and energy systems (Wan et al., 2017). Specifically, metabolic factors and fatigue reactants during the process of contraction, including hydrogen ions (H^+), induce intramuscular acidosis, lactate acid, inorganic phosphate, adenosine triphosphate energy, and intracellular calcium (Allen & Trajanovska, 2012; Ortenblad et al., 2011). During high-intensity short-duration physical exercise, muscles contract mostly through anaerobic energy pathways. Therefore, synthesis occurs via anaerobic glycolysis, which results in increased blood and muscle lactic acid levels. In the present study, lactate levels were significantly lower in the COMB group than in the CWI and CON groups, similar to the perceived fatigue results. Therefore, fatigue was reduced in the present study owing to the reduction in blood lactate levels after COMB intervention.

This study aimed to compare the effects of COMB, CWI alone and CON interventions on sports performance, specifically power and speed. These two performance categories play essential roles in football, basketball, and futsal. Our finding was that the 20-meter sprint time at 24 h after COMB was significantly reduced to the baseline level and significantly shorter time than that of the CWI and CON groups. CWI alone did not affect the 20-meter sprint time compared with the baseline and CON groups. For power performance, as tested by the maximum vertical jump height, no significant difference was observed between the groups 24 h after the interventions. However, the maximum vertical jump height in the combined intervention returned to the baseline value. This indicates that massage had an additive effect on CWI but was not sufficient to show a significant difference between the two groups. The difference in the 20-meter sprint time and maximum vertical jump height in the present study might have been caused by the difference in the duration needed to recover each performance. Andersson and colleagues reported that complete recovery of performance after a match was quickest for sprint performance (5 h), followed by strength (27 h for quadriceps and 51 h for hamstrings), and finally jump performance (>69 h) (Andersson et al., 2008). Therefore, the recovery protocol showed the highest effect on sprint performance than jump performance because sprint performance quickly recovered within 24 h. The current study demonstrated that the reduction in lactate levels and feeling of fatigue possibly explains the greatest improvement in 20-meter sprint time in the COMB group compared to the other groups. Romero and colleagues revealed that fatigue affected the kinetics during repeated sprint ability protocols, such as decreased maximum power output and less efficiency in horizontally orienting the ground reaction force (Romero et al., 2022). In addition, a piece of evidence shows a reduction in maximum velocity and force output during sprint affected by fatigue (Jimenez-Reyes et al., 2019).

To determine the minimal clinically important difference, effect sizes in the form of Cohen's *d* was presented in case of there were significant differences for the pairwise comparison at 3 time points and intervention. As shown in the results, Cohen's *d* for all parameters were higher than 0.8. It is indicated a large effect size which means that the research finding has practical or clinical significance and is meaningful in the real-world application. Cold water immersion combined with Swedish massage has a strong positive effect on the restoration of muscle strength, improves 20-meter sprint, decreases blood lactate levels, and perceived fatigue. While cold water immersion alone has a strong positive effect on the improvement of muscle strength

and reducing blood lactate levels. The professionals in team sports can apply cold water immersion followed by Swedish massage immediately after a real situation of training or competition especially for an intense plyometric and resisted training causing of severe fatigue. However, the water temperature, duration, and level of immersion should be controlled at 15 °C for 15 minutes and immersion at the iliac crest level. It should improve muscle strength, blood lactic clearance, anaerobic performance, and reduce fatigue in athletes within 24 h. Therefore, team sports athletes who have received this combined intervention can perform a maximum sports performance and be ready to train or compete in the next match. This is the first study to investigate the effects of combined cold-water immersion with Swedish massage on several factors related to the ability of sports performance in athletes, including muscle function, blood biomarkers and perceived fatigue, as well as anaerobic performance in the same study. However, this study has two limitations. Firstly, the research's parameters did not cover the sports performance related to aerobic capacity, the key component of team sports performance. Secondly, the long-term effect of combined cold-water immersion with Swedish massage did not investigate. Based on the different recovery periods for each sport performance is necessary for the sports team as shown by the study of Anderson and colleagues (2008). Therefore, further studies are required to investigate the long-term effects of COMB on sports performances necessary for team sports athletes including both anaerobic and aerobic-related performances.

Conclusion

COMB significantly improved the 20-meter sprint time and decreased perceived fatigue and blood lactate levels 24 h post-intervention compared to CWI and CON. In addition, it facilitated the recovery of all parameters to baseline levels. CWI alone had a significant effect on muscle strength and blood lactate levels compared to the control group. It indicated that COMB had a higher benefit in restoring muscle function and sports performance in team sport athletes. Therefore, physical therapists, sports scientists, coaches, and athletes should apply COMB after plyometric and resistance exercises of the lower extremities to achieve faster recovery of muscle strength, blood lactate levels, perceived fatigue, and anaerobic performance, specifically for training or competition that requires recovery within 24 h. However, the study to find effective recovery programs remains an important aspect for improving performance and accelerating the recovery processes in team sport athletes.

Conflicts of interest

All authors declared that they have reported no financial interests or potential conflicts of interest.

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