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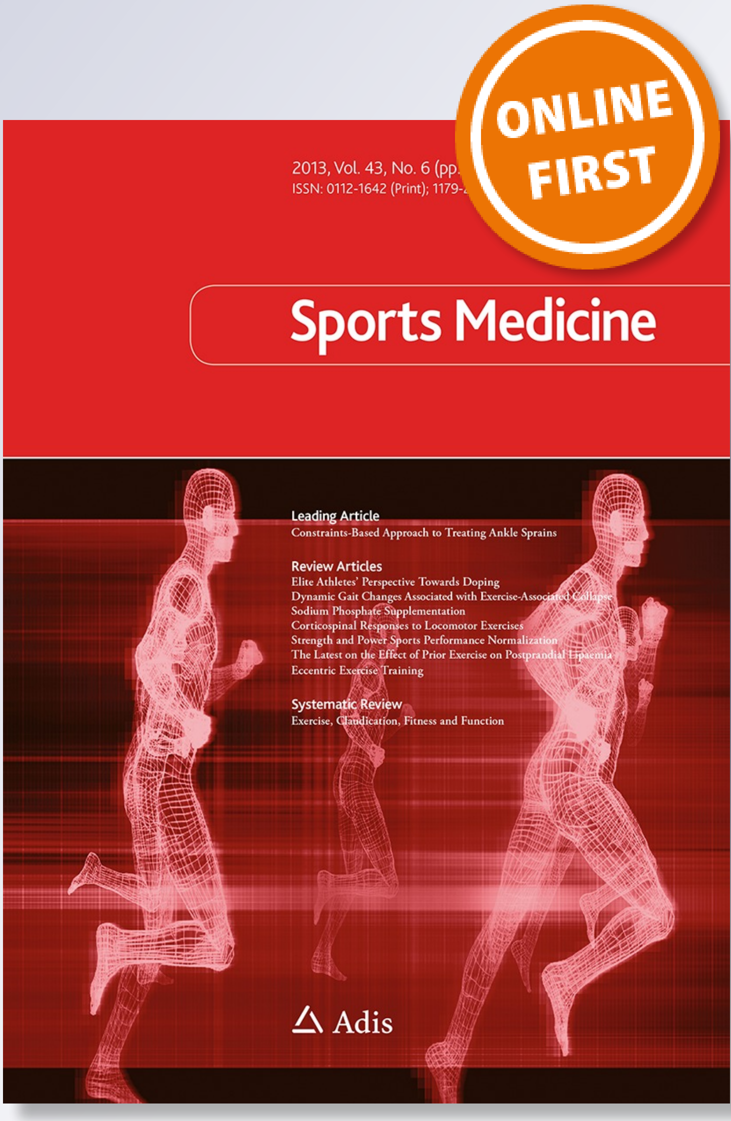

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REVIEW ARTICLE

Water Immersion Recovery for Athletes: Effect on Exercise Performance and Practical Recommendations

Nathan G. Versey · Shona L. Halson · Brian T. Dawson

Abstract Water immersion is increasingly being used by elite athletes seeking to minimize fatigue and accelerate post-exercise recovery. Accelerated short-term (hours to days) recovery may improve competition performance, allow greater training loads or enhance the effect of a given training load. However, the optimal water immersion protocols to assist short-term recovery of performance still remain unclear. This article will review the water immersion recovery protocols investigated in the literature, their effects on performance recovery, briefly outline the potential mechanisms involved and provide practical recommendations for their use by athletes. For the purposes of this review, water immersion has been divided into four techniques according to water temperature: cold water immersion (CWI; ≤20 °C), hot water immersion (HWI; ≥36 °C), contrast water therapy (CWT; alternating CWI and HWI) and thermoneutral water immersion (TWI; >20 to <36 °C). Numerous articles have reported that CWI can enhance recovery of performance in a variety of sports, with immersion in 10–15 °C water for 5–15 min duration appearing to be most effective at accelerating performance recovery. However, the optimal CWI duration may depend on the water temperature, and the time between CWI and the subsequent exercise bout appears to influence the effect on performance. The few studies examining the effect of post-exercise HWI on subsequent performance have reported conflicting findings; therefore the effect of HWI on performance recovery is unclear. CWT is most likely to enhance performance recovery when equal time is spent in hot and cold water, individual immersion durations are short (∼1 min) and the total immersion duration is up to approximately 15 min. A dose-response relationship between CWT duration and recovery of exercise performance is unlikely to exist. Some articles that have reported CWT to not enhance performance recovery have had methodological issues, such as failing to detect a decrease in performance in control trials, not performing full-body immersion, or using hot showers instead of pools. TWI has been investigated as both a control to determine the effect of water temperature on performance recovery, and as an intervention itself. However, due to conflicting findings it is uncertain whether TWI improves recovery of subsequent exercise performance. Both CWI and CWT appear likely to assist recovery of exercise performance more than HWI and TWI; however, it is unclear which technique is most effective. While the literature on the use of water immersion for recovery of exercise performance is increasing, further research is required to obtain a more complete understanding of the effects on performance.

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1 Introduction

Athletic training typically involves a progressive increase in training load to levels beyond which the body has become accustomed then, by adapting to the new stress, improvements in performance may occur provided adequate recovery is allowed [1]. However, due to the high frequency, intensity and volume of training and competition, elite athletes often experience high degrees of fatigue [1]. For the purposes of this review, fatigue is defined as the sensation of tiredness and associated decrements in

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muscular performance and function [2]. Fatigue may result from an individual session and impair athletic performance for minutes to days. Alternatively, fatigue can accumulate throughout a training block or tournament, this is often referred to as overreaching and may last days to weeks [1, 3–5]. Fatigue has been acknowledged as a complex phenomenon [2], and while the causes are not fully understood, a combination of both central and peripheral factors are likely [6].

To maximize training and competition performance, fatigue should be minimized by recovering as fast as possible. Recovery refers to the restoration of the body's physiological and psychological processes, allowing athletes to potentially return to their pre-fatigue state and performance level [7]. However, in many circumstances, only partial recovery is possible due to the short duration between successive exercise bouts and the high degrees of fatigue experienced by many athletes [3–5]. This article will focus on what has previously been referred to as 'training recovery', which is recovery between successive training sessions or competitions [8].

Elite athletes are increasingly using specific techniques to accelerate recovery and gain a competitive advantage. Accelerated recovery may allow athletes to be less fatigued in competition, sustain greater training loads or enhance the effect of a given training load [9]. Water immersion is one recovery technique that is both widely used by athletes [10] and has been examined in the scientific literature (Table 1). Following exercise, participants typically immerse all or part of their body in water; however, the optimal protocols to assist recovery of exercise performance remain unclear. The water temperature, immersion duration, timing, immersion depth and activity level can all vary.

For the purposes of this review, water immersion for recovery of athletic performance has been divided into four techniques according to water temperature: cold water immersion (CWI; ≤20 °C), hot water immersion (HWI; ≥36 °C), contrast water therapy (CWT; alternating CWI and HWI) and thermoneutral water immersion (TWI; >20 to <36 °C). All studies claiming to investigate CWI have used temperatures ≤20 °C; therefore, this cut-off has been used for CWI. Water temperatures of approximately 35 °C are considered to be thermoneutral as they do not alter core temperature during prolonged immersion [11]; however, water temperatures as low as 21 °C have been included in TWI to incorporate the use of swimming pools that are likely to cause limited body cooling [11]. In comparison, immersion in ≥36 °C water was defined as HWI as it will increase core temperature [11]. This paper aims to review the water immersion recovery protocols for each technique, their effect on recovery of performance and provide practical recommendations for use by athletes. A greater understanding of the performance effects will allow sports scientists and coaches to optimize the water immersion protocols they recommend to athletes, thereby aiding post-exercise recovery.

While many of the physiological responses to water immersion are relatively well documented [12–14], the exact mechanisms by which recovery of performance might be affected remain uncertain and may differ between modes of exercise depending on the mechanisms of fatigue involved. A brief description of the potential mechanisms has been included to assist with understanding why studies may differ in their effects on performance recovery. The potential mechanisms are likely to be associated primarily with the effects of hydrostatic pressure and water temperature on the body [15]. Hydrostatic pressure is likely to cause an elevation in cardiac output, muscle blood flow and diffusion of metabolic waste products from muscle to the blood [15–17], possibly assisting recovery by enhancing removal of metabolic waste products produced during exercise [15–17] and reducing the transport time of oxygen, nutrients and hormones to fatigued muscles [12, 15, 16]. Furthermore, hydrostatic pressure may limit formation of oedema following exercise, possibly reducing further muscle damage, maintaining oxygen delivery to muscles and maintaining contractile function [15].

Water temperature may influence these physiological responses and potential mechanisms through changes in skin temperature. During HWI superficial vasodilation and an increase in blood flow is likely to occur; conversely CWI is associated with vasoconstriction and a relative decrease in blood flow [15, 18, 19]. It is recognized that cryotherapy reduces inflammatory responses and alleviates muscle spasm and pain following acute soft tissue injuries [20–22], similar responses may occur following CWI due to a reduction in nerve conduction velocity [23, 24]. Furthermore, both CWI and CWT may promote recovery by accelerating post-exercise decreases in heat storage and core temperature to homeostasis or below [25–32], while HWI may slow decreases in core temperature [28]. Similar changes in intramuscular temperature have been shown in response to CWI [29, 33, 34] and HWI [35, 36]. If muscle temperature is elevated during subsequent exercise it may enhance muscle function and performance [37]. Conversely, performance during longer duration tests, particularly in warm to hot environmental conditions is likely to be improved by a reduction in core temperature due to a pre-cooling effect [38, 39]. More detailed explanations of these potential mechanisms are available in recent review articles [15, 40–42].

In total, 214 studies were retrieved for the present review through PubMed searches before 31 March 2012 using the keywords 'water immersion', 'hydrotherapy', 'ice bath', 'cryotherapy', 'spa', 'hot tub', 'jacuzzi', 'pool',

Table 1 Studies examining the effect of water immersion techniques on recovery of exercise performance

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Ascensão et al. [69]	Junior national league footballers (20 [M])	Randomized trials	Junior friendly football match	CWI: 10 min in 10 °C stirred water to iliac crest seated ($n = 10$) TWI: 10 min in 35 °C to iliac crest seated ($n = 10$)	Immediately post-match	20 m sprint, squat jump, CMJ, quadriceps MVIC, Mg, CK, CRP, RPE, perceived coldness, muscle soreness	<0.5, 24, 48 h	CWI: ↓ CK versus TWI at 24 and 48 h. ↓ Mg versus TWI at 0.5 h, ↓ in CRP versus TWI at 0.5 and 24 h, ↑ MVIC versus TWI at 24 h, ↓ calf and quadriceps muscle soreness versus TWI at 24 h
Bailey et al. [56]	Habitually active adults (20 [M])	Randomized control trial	LIST (90 min of intermittent simulated football activity)	CWI: 10 min in 10 °C agitated water to iliac crest, seated CON: 10 min seated rest	Immediately post-exercise	Knee extension and flexion MVIC, repeated sprint test, squat jump, HR, haemoglobin, haematocrit, change in plasma volume, CK, Mg, core temperature, body mass, muscle soreness, perceived coldness, RPE	0, 1, 24, 48, 168 h (no blood markers at 168 h). Repeat sprint test at 48 h	CWI: ↑ knee flexion MVIC at 24- and 48-h post-exercise, and perceived coldness during CWI and recovery versus CON. ↓ Mg at 1-h post-exercise, and muscle soreness for up to 48 h versus CON
Bosak et al. [73]	Trained runners (12 [9 M, 3 F])	Counter-balanced crossover control trial	5 km running performance trial. Repeated 24 h later	CWI: 12 min in 16 °C. Posture and depth not reported CON: Passive recovery	Immediately post-exercise	5 km running performance, HR, RPE, perceived fatigue, muscle soreness	24 h	CWI: ↓ 5 km running time, average HR and post-trial RPE versus CON
Brophy-Williams et al. [64]	Well trained team sport athletes (8 [M])	Counter-balanced crossover control trial	Running high-intensity interval session (8 × 3 min at 90 % v-VO_{2max}).	CWI: 15 min in 15 °C to midsternal level, posture not reported CON: 15 min seated	2 CWI trials performed immediately or 3 h post-exercise	Yoyo Intermittent Recovery test, HR, La, CRP, perceived recovery, muscle soreness	24 h	CWI: immediately post-exercise; ↑ Yoyo performance and perceived recovery, ↓ CRP versus CON. 3 h post-exercise; likely ↑ Yoyo performance and perceived recovery versus CON. Immediately post-exercise; likely ↑ Yoyo performance versus 3-h post-exercise
Buchheit et al. [58]	Adult cyclists (10 [M])	Randomized crossover control trial	1-km cycling time trial in 35 °C, 40 % humidity. Repeated 20 min later	CWI: 5 min in 14 °C to midsternal level, seated CON: seated rest in 35 °C and 40 % humidity	7.5 min post-exercise	Time-trial average power and time, HR variability, HR recovery, core temperature, perceived recovery	20 min	CWI: ↑ HR variability indexes before and after exercise bout 2, and ↑ perceived recovery versus CON

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Buchheit et al. [89]	Elite-standard youth footballers (5 [NS])	Crossover control trial	International club football match. Repeated within 48 h	CWT: 2 min in 85–90 °C sauna, 2 min in 36 ± 2 °C water to midsternal level, 2 min in 12 ± 1 °C water to iliac crest. Performed 3 times, seated CON: no treatment	12–15 h post-match	Football match low, high, and very high-intensity running, sprinting, total distance covered, peak velocity, number of sprints, number of repeated sprint sequences	Within 48 h	CWT: ↑ low-intensity running, sprinting, peak running velocity, number of sprints, and number of repeat sprint sequences during match 2 versus CON
Coffey et al. [84]	Highly active individual and team sport players (14 [M])	Randomized crossover control trial	Treadmill runs to exhaustion at 120 % and 90 % of peak running speed). Repeated ~3.5 h later	CWT: 1 min in 10 °C, 2 min in 42 °C. Repeated 3 times to iliac crest, standing ACT: 15 min run at 40 % VO_{2max} CON: 15-min standing	Immediately post-exercise	Run-to-exhaustion times, HR, La, blood pH, RPE recovery	~3.5 h	CWT: ↓ post-exercise La versus CON. ↑ perception of recovery versus ACT and CON ACT: ↓ post-exercise La versus CON
Cortis et al. [92]	Military personnel (8 [M])	Counter-balanced crossover control trial	Submaximal incremental treadmill running (4 × 5 min at 6, 8, 10, 12 km/h). Repeated ~6.5 h later	TWI: 20-min shallow water aerobic exercise at 60 % HR_{max}. Temperature not reported EMS: 20 min on quadriceps CON: 20 min seated rest	~30 min post-exercise	CMJ and repeat jump test. Submaximal incremental running HR, VO_2, VCO_2, ventilation, rectus femoris percent O_2 saturation, and La. Perception of recovery, RESTQ, muscle soreness, RPE	~6.5 h	TWI: ↑ perception of recovery versus CON EMS: ↑ perception of recovery versus CON
Crowe et al. [61]	Strength trained and team sports players (17 [13 M, 4 F)	Randomized crossover control trial	30-s maximal cycling test. Repeated 1 h later	CWI: 15 min in 13–14 °C to umbilicus level, seated CON: 15 min seated rest	1 min post-exercise	Peak power, time to peak power, total work, HR, tympanic temperature, La, blood pH, thermal discomfort, RPE	1 h	CWI: ↓ relative peak power, relative total work, exercise La, and peak exercise HR versus CON

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Dawson et al. [87]	Semi-professional Australian football players (17 [M])	Semi-randomized crossover control trial	1 WAFL game per week for 3 weeks	CWT: 2 min in 45 °C shower, 1 min in 12 °C water standing waist deep. Performed 5 hot and 4 cold immersions	15–20 min post-game for 3 games	6-s cycling sprint total work, peak power, time-to-peak power. Vertical jump, sit and reach flexibility, muscle soreness, intervention order of preference	15, 48 h	CWT: no significant effect on any measures versus CON
				TWI: 15 min of walking in 28 °C shallow swimming pool				TWI: ↑ vertical jump at 15-h post-game versus CON
				STR: 15 min of static stretching				STR: ↑ sprint performance at 15-h post-game versus CON
				CON: no treatment				Intervention order of preference: TWI, STR, CWT, CON
Eston and Peters [21]	University students (15 [F])	Randomised control trial	Elbow flexors concentric and eccentric maximal isokinetic contractions (8 sets of 5 reps)	CWI: 15 min in 15 ± 1 °C Exercised arm immersed ($n = 8$)	Post-exercise, and every 12 h for 3 days	Elbow flexor MVIC, relaxed arm angle, upper-arm girth, CK, muscle soreness	24, 48, 72 h	CWI: ↑ relaxed elbow angle and ↓ CK on days 2 and 3 post-exercise
				CON: no treatment ($n = 7$)				
French et al. [85]	Recreational- to regional-level rugby and football players (26 [M])	Pair-matched control trial	Resistance exercise challenge (6 sets of 10 squats at 100 % body mass, 1 eccentric squat at 1RM)	CWT: 1 min in 8–10 °C, 3 min in 37–40 °C. 4 colds and 3 hots performed seated in 50 cm of water ($n = 10$)	Within 10 min post-exercise	10- and 30-m sprints, CMJ, repeat CMJ, 5RM squat, multiplanar agility test, lower-limb ROM, thigh and calf girths, CK, Mg, muscle soreness	0, 24, 48 h (no blood markers at 48 h)	CWT: ↓CK (large ES) at 24- and 48-h post-exercise versus CON. ↓ Mg during the 48-h post-exercise versus CON. ↓ muscle soreness 1-h post-exercise versus CON
				COMP: wearing compression tights for 12 h overnight ($n = 10$)				COMP: ↓ thigh girth and ↑ 30 m sprint time at 48-h post-exercise versus CON
				CON: no treatment ($n = 6$)				

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Hamlin [88]	Development rugby players (20 [17 M, 3 F])	Randomized crossover trial	Repeat sprint test (10 × 40 m sprints on 30 s). Repeated 1 h later	CWT: 1 min in 8–10 °C to hip level standing, 1 min in 38 °C shower on legs. Repeated 3 times ACT: 6 min jogging on grass at 6.8 km/h	Post-exercise	Repeat sprint, La, HR	1 h	CWT: ↓ post-recovery La and exercise 2 HR versus ACT
Hamlin [67]	Development netballers (20 [F])	Randomized control trial	20-m multistage shuttle run followed by repeat sprint test (6 × 5-, 10-, and 15-m sprint shuttles on 30 s)	CWI: 1 min in 8–10 °C water seated, 1 min in air standing. Performed 3 times on legs ($n = 8$) CWT: 1 min in 8–10 °C water seated, 1 min in 38 °C shower standing. Performed 3 times on legs ($n = 7$) CON: 6 min rest ($n = 5$)	Post-exercise	Repeat sprint, POMS, La	2 h	CWI: No significant effect on any measures versus CON CWT: ↓ post-recovery La versus CON and CWI
Heyman et al. [52]	Trained climbers (13 [F])	Randomized crossover control trial	Standardized indoor rock climbing to exhaustion. Repeated 20 min later	CWI: 5 min in 15 ± 1 °C water, 2 min in air seated. Repeated 3 times with arms (excluding hands) immersed ACT: 20 min cycling at 30–40 W and 50–70 rpm EMS: 20 min on forearm flexor muscles CON: seated rest	Post-exercise	Climbing time, number of arm movements, handgrip strength, HR, mean skin temperature, La, thermal sensation, RPE	20 min	CWI: ↑ climbing performance versus EMS and CON, ↓ skin temperature and thermal sensation when in water versus CON ACT: ↑ climbing performance versus EMS and CON, largest ↓ in La during recovery, ↑ thermal sensation during recovery Versus CWI, EMS and CON

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Higgins et al. [65]	Well trained rugby union players (26 [M])	Randomized control trial	1 rugby union game and 2 trainings per week for 4 weeks	CWI: 5 min in 10–12 °C to above waistline ($n = 7$) CWT: 1 min in 10–12 °C, 1 min in 38–40 °C. Alternated cold and hot for 7 min, water depth not reported ($n = 8$) CON: passive rest ($n = 11$)	Post-games and trainings for 4 weeks	Repeat sprint, 300-m sprint. Perceived degree of rest, tightness, effectiveness of treatment	In week following the fourth game	CWI: ↓ repeated sprint performance (moderate ES) post-intervention and ↑ tightness 2-days post-games versus CON CWT: ↑ 300-m sprint performance (moderate ES) post-intervention and ↑ degree of rest versus CON
Howatson et al. [43]	Recreationally active (16 [M])	Randomized control trial	Drop jumps (5 sets of 20 jumps). Repeated 14–21 days later	CWI: 12 min in 15 ± 1 °C to iliac crest. Posture not reported ($n = 8$) CON: 12 min seated rest ($n = 8$)	Immediately, 24, 48, and 72 h post-exercise	Knee extensors MVIC, mid-thigh girth, CK, muscle soreness	0, 24, 48, 72, 96 h	CWI: no significant effect on any measures versus CON
Ingram et al. [44]	Team game experience (11 [M])	Randomized crossover control trial	Simulated team sport exercise (4 × 20 min of intermittent running), then a 20-m multistage shuttle run test	CWI: 5 min in 10 °C water, 2.5 min out of water seated, 5 min in 10 °C water. Performed to umbilicus. Posture in water not reported CWT: 2 min in 10 °C, 2 min in 40 °C. Performed 3 times to umbilicus. Posture not reported CON: 15 min seated rest	Immediately and 24 h post-exercise	Leg extension, leg flexion, and hip flexion MVIC. Repeat sprint, CK, CRP, haemoglobin, haematocrit, change in plasma volume, muscle soreness	48 h	CWI: ↑ leg extension and flexion MVIC, and ↓ muscle soreness at 48-h post-exercise versus CON and CWT. ↑ repeated sprint ability versus CON and CWT CWT: ↓ muscle soreness at 24 h post-exercise versus CON
Jakeman et al. [59]	Physically active (18 [F])	Randomized control trial	CMJ (10 sets of 10 jumps)	CWI: 10 min in 10 ± 1 °C to superior iliac crest seated CON: No treatment	Within 10 min post-exercise	Quadriceps maximal isokinetic concentric strength, CK, limb soreness	1, 24, 48, 72, 96 h	CWI: no significant effect on any measures versus CON

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
King and Duffield [68]	Trained netballers (10 [F])	Randomized crossover control trial	Simulated netball circuit involving repeat sprints. Repeated 24 h later	CWI: 5 min in 9 ± 2 °C water to iliac crest, 2.5 min in air seated. Performed twice. Posture in water not reported CWT: 1 min in 10 ± 1 °C water to iliac crest, 2 min in 39 ± 2 °C shower. Performed 5 times Posture not reported ACT: 15 min exercise at 40 % v-VO_{2max}. Exercise mode not reported CON: 15 min seated rest	Post-exercise	Netball circuit time, 10-m sprint, 20-m repeat sprint, repeat CMJ, HR, body mass, skin temperature, La, bicarbonate, blood pH, muscle soreness, RPE	24 h	CWI: ↑ repeated CMJ performance (large ES) versus CON CWT: ↑ repeated sprint performance (large ES) versus CON. ↓ La post-intervention versus ACT ACT: ↑ post-intervention HR and RPE, and ↑ muscle soreness pre-exercise 2 versus CWI, CWT and CON CON: Performance returned to baseline
Kinugasa and Kilding [57]	Youth footballers (28 [NS])	Randomized crossover trial	90-min football game	CWI and ACT: 1 min in 12 °C water to midsternal level seated, 2 min cycling at 90–110 W. Performed 3 times CWT: 1 min in 12 °C water to midsternal level seated, 2 min in 38 °C shower. Performed 3 times STR: 7 min of static stretching, legs above heart for 2 min	Post-game	CMJ, resting HR, tympanic temperature, total quality recovery scale, leg heaviness, thermal sensation	0, 24 h	CWI and ACT: ↑ perceived quality of recovery post-intervention versus STR and CWI (moderate ES). Perceived lighter legs 24-h post-exercise versus STR (moderate ES). ↓ tympanic temperature (large ES) post-intervention versus STR. ↓ thermal sensation (very large ES) post-intervention versus STR CWT: ↓ tympanic temperature (large ES) post-intervention versus STR. ↓ thermal sensation (moderate ES) and leg heaviness post-intervention versus STR

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Kuligowski et al. [45]	University students (56 [28 M, 28 F])	Randomized control trial	Non-dominant arm elbow flexor eccentric contractions (5 sets of 10 reps at >1RM concentric)	CWI: 24 min in 13 °C. Exercised arm immersed to mid-deltoid level ($n = 14$) HWI: 24 min in 39 °C. Exercised arm immersed to mid-deltoid level ($n = 14$) CWT: 3 min HWI, 1 min CWI: performed 6 times ($n = 14$) CON: no treatment ($n = 14$)	Immediately, 24, 48, and 72 h post-exercise	Elbow flexor MVIC, resting elbow ROM, active elbow ROM, arm soreness	24, 48, 72, 96 h	CWI: ↑ resting elbow flexion, ↓arm soreness versus CON and HWI HWI: ↑ resting elbow flexion versus CON CWT: ↑ resting elbow flexion, ↓arm soreness versus CON and HWI
Lane and Wenger [53]	Physically active (10 [M])	Randomized crossover control trial	18 min of high-intensity intermittent sprint cycling (12 × 5 s, 6 × 10 s and 4 × 15 s sprints). Repeated 24 h later	CWI: 15 min in 15 °C, leg immersion. Posture not reported ACT: 15 min cycling at 30 % VO_{2max} MAS: 15 min leg massage CON: 15 min seated rest	Post-exercise	Cycling total work	24 h	CWI, ACT and MAS: ↑ cycling total work versus CON
Lum et al. [93]	Well trained triathletes (9 [NS])	Randomized crossover control trial	High-intensity interval running (8 × 3 min at 90 % v-VO_{2max})	TWI: 45–60 min swimming, 4 sets of 5 × 100-m freestyle at 85–90 % of 1-km time trial speed, temperature not reported CON: 45–60 min of seated rest	10 h post-exercise	Running time to fatigue at 90 % v-VO_{2max}, HR, CRP, La, perceived recovery, RPE	24 h	TWI: ↑ running time-to-fatigue 24-h post-exercise versus CON. ↓ CRP at 24 h post-exercise versus CON

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Montgomery et al. [3]	Development basketballers (29 [M])	Randomized control trial	Basketball tournament (one 48 min game per day for 3 days)	CWI: 1 min in 11 °C water to midsternal level, 2 min in air. Performed 5 times ($n = 10$) COMP: wearing lower-limb compression garments overnight for ~18 h CON: no treatment ($n = 10$)	Post-game for 3 days	20 m sprint, vertical jump, basketball line drill, basketball-specific agility, sit-and-reach flexibility, body mass, muscle soreness, perceived fatigue	Morning after tournament	CWI: ↑ 20-m sprint, vertical jump, basketball line drill, and sit and reach versus CON, ↓ muscle soreness and fatigue versus CON COMP: ↑ vertical jump and basketball line-drill versus CON. ↓ 20-m sprint, sit and reach, muscle soreness and fatigue versus CON
Paddon-Jones and Quigley [50]	6-months resistance training experience (8 [M])	Randomized control trial	64 eccentric elbow flexions per arm (8 sets of 8 reps at 110 % of concentric 1RM)	CWI: 20 min in 5 ± 1 °C water, 60 min in air. Arm (excluding hand) immersed 5 times CON: No treatment for non-immersed arm	Post-exercise	Elbow flexor MVIC and isokinetic contraction, arm volume, pressure probe muscle soreness	0, 24, 48, 72, 96, 120, 144 h	CWI: no significant effect on any measures versus CON
Parouty et al. [62]	National-level swimmers (10 [5 M, 5 F])	Randomized crossover control trial	100-m freestyle swimming time-trial. Repeated 30 min later	CWI: 5 min in 14–15 °C to shoulders seated CON: 5 min seated rest	5 min post-exercise	100-m freestyle swimming. HR peak, change and variability. La, perceived recovery, RPE	30 min	CWI: ↓ swim time, HR change and peak versus CON. ↑ perception of recovery and parasympathetic activity versus CON in the second swim
Peiffer et al. [27]	Well trained cyclists (10 [M])	Counter-balanced crossover control trial	25-min of cycling at 65 % VO_{2max}, then a 4-km time-trial in 35 °C. Repeated 15 min later	CWI: 5 min in 14 °C to midsternal level seated CON: 15 min seated rest in 35 °C	5 min post-exercise	4-km time trial time, average power, VO_2 and economy. Rectal temperature	15 min	CWI: ↑ time-trial 2 time and average power, ↓ rectal temperature pre and post-exercise bout 2 versus CON

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Peiffer et al. [29]	Trained cyclists (12 [M])	Counter-balanced crossover control trial	Cycling time to exhaustion at first ventilatory threshold power in 40 °C	CWI: 5, 10, and 20 min in 14 ± 0 °C to midsternal level seated CON: 20 min seated rest in 24 °C	25 min post-exercise	Right knee extensors MVIC and isokinetic contraction, rectal temperature, muscle temperature	55 min	CWI: ↓ rectal temperature versus CON from all immersion durations, trend for longer immersions to produce lower rectal temperatures. 10- and 20-min immersions ↓ muscle temperature more than 5 min immersion
Peiffer et al. [30]	Well trained cyclists	Counter-balanced crossover control trial	90 min of cycling at 80 % of second ventilatory threshold power, then a 16.1-km time trial in 32.2 ± 0.7 °C	CWI: 20 min in 14 ± 0 °C to midsternal level seated CON: 20 min seated rest in 24 °C	25 min post-exercise	Right knee extensors MVIC, femoral vein diameter, skin temperature, rectal temperature	0, 45, 90 min	CWI: ↓ MVIC, skin temperature, rectal temperature, and femoral vein diameter versus CON
Peiffer et al. [34]	Trained cyclists (10 [M])	Randomized crossover control trial	1-km cycling time trial in 35.0 ± 0.3 °C. Repeated 20 min later	CWI: 5 min in 14 °C to midsternal level seated CON: 5 min seated rest in 35 °C	7.5 min post-exercise	1-km cycling time, peak power, average power. Right knee extensor maximal concentric isokinetic torque, rectal temperature, muscle temperature	20 min	CWI: ↓ muscle temp after time-trial 2 versus CON
Pournot et al. [66]	Elite football, rugby and volleyball athletes (41 [M])	Randomized control trial	Exhaustive intermittent exercise protocol (2 × 10 min separated by 10 min)	CWI: 15 min in 10 °C to iliac crest seated (n = 13) CWT: 1.5 min in 10 °C, 1.5 min in 42 °C. Performed 5 times to iliac crest seated (n = 10) HWI: 15 min in 36°C to iliac crest seated (n = 9) CON: 15 min seated (n = 9)	After post-exercise measures	Knee extensor MVIC, CMJ, 30-s rowing sprint mean power, CK, LDH, leucocytes, neutrophils, lymphocytes, monocytes, eosinophils, erythrocytes, haemoglobin, haematocrit, soreness	0, 1, 24 h. Blood markers at 1 and 24 h	CWI: ↑ MVIC and ↓ in leucocytes versus CON at 1 h. ↓ in CK versus CON at 24 h CWT: ↑ 30-s rowing sprint and LDH versus CON at 1 h HWI: no significant effect on any measures versus CON

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Robey et al. [46]	Club and junior state-level rowers (20 [12 M, 8 F])	Counter-balanced crossover control trial	Stair climbing and descending running task	CWT: 2 min in 40 °C shower, 1 min in 12 °C water waist deep. Performed 5 times. Posture not reported STR: 15 min standardized static stretching CON: 15 min seated rest	Immediately, 24 and 48 h post-exercise	Rowing 2 km ergometer, maximal concentric leg extension isokinetic torque, CK, muscle soreness	CK and muscle soreness at 0, 24, 48 h. All measures at 72 h	CWT: No significant effect on any measures versus CON STR: No significant effect on any measures versus CON
Rowsell et al. [54]	Under 17 state-level footballers (13 [M])	Counter-balanced trial	Football tournament containing 1 match per day for 4 days	CWI: 1 min in 10 °C water to midsternal level, 1 min out of water seated. Performed 5 times ($n = 6$) TWI: 1 min in 34 °C to midsternal level, 1 min out of water seated. Performed 5 times ($n = 7$)	At least 10 min post-match for 4 days	Football match total and high-intensity running distance, time in HR zones. Leg soreness, perceived leg fatigue, RPE	1 match per day for 4 days	CWI: ↑ total running distance and time in moderate HR zone, ↓ leg soreness and general fatigue versus TWI
Rowsell et al. [70]	Under 17 state-level footballers (13 [M])	Counter-balanced trial	Football tournament containing 1 match per day for 4 days	CWI: 1 min in 10 °C water to midsternal level, 1 min out of water seated. Performed 5 times ($n = 6$) TWI: 1 min in 34 °C to mid-sternal level, 1 min out of water seated. Performed 5 times ($n = 7$)	At least 10 min post-match for 4 days	Repeated sprint, CMJ. 5-min submaximal runs HR and RPE. Fatty acid binding protein, CK, LDH, Mg, IL-1b, IL-6, IL-10, perceived recovery	90-min pre-match and 22-h post final match	CWI: No significant effect on any measures versus TWI

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Sayers et al. [91]	Under 18 state-level field-hockey players (14 [M])	Randomized crossover control trial	Cycling 30-s Wingate ergometer test. Repeated 12 min later	CWT: 3.5 min in 38 °C, 0.5 min in 15 °C. Performed 3 times to jugular notch ACT: 12 min cycling at 120–130 bpm CON: 12 min seated rest	1 min post-exercise	Wingate peak power, average power, total work, and power decline. HR, blood pressure, La, perceived fatigue	13 min	CWT: trend for ↑ average power and total work versus CON, ↑ HR during recovery versus CON, ↓ La in recovery and post-exercise 2 versus CON, ↓ fatigue versus CON and ACT ACT: trend for ↑ average power and total work versus CON, ↑ HR in recovery and exercise 2 versus CON and CWT, ↓ La in recovery and post-exercise 2 versus CON
Schniepp et al. [63]	Highly trained cyclists (10 [NS])	Counter-balanced crossover control trial	0.2-mile cycling sprint. Repeated 15 min later	CWI: 15 min in 12 °C to iliac crest. Posture not reported CON: 15 min seated rest	Post-exercise	Cycling sprint average power, maximal power, time to maximal power, HR	15 min	CWI: ↓ peak power, average power and HR in sprint 2 versus CON
Sellwood et al. [49]	Untrained adults (40 [11 M, 29 F])	Randomized double-blind trial	Non-dominant eccentric leg extensions (5 sets of 10 reps at 120 % of concentric 1RM)	CWI: 1 min in 5 ± 1 °C to anterior superior iliac spine standing, 1 min out of water. Performed 3 times TWI: 1 min in 24 ± 1 °C to anterior superior iliac spine standing, 1 min out of water. Performed 3 times	Post-exercise	Quadriceps MVIC, 1-legged hop for distance, thigh circumference, CK, algometer pressure leg soreness, perceived leg soreness	24, 48, 72 h	CWI: No significant effect on any measures versus TWI

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Stacey et al. [60]	Habitually active adults (9 [M])	Randomized crossover control trial	3 × 50 kJ all out cycling bouts separated by 20 min	CWI: 10 min in 10 °C to neck level seated ACT: 10 min cycling at 50 W CON: 10 min lying supine	5 min post-exercise for 3 bouts	50 kJ cycling bout, La, IL-6, total leukocytes, neutrophils, lymphocytes, perceived leg energy, leg soreness, perceived leg recovery, RPE	20-, 40-, 100-min post-first-exercise bout	CWI: ↑ total leukocytes, neutrophils and perceived leg recovery at 1-h post-exercise versus CON and ACT. ↑ neutrophils during exercise and ↓ lymphocytes at 1-h post-exercise versus CON ACT: no significant effect on any measures versus CON
Stanley et al. [71]	Endurance trained cyclists (18 [M])	Randomized crossover control trial	60 min of high-intensity cycling session (8 × 4 min at 80 % peak power)	CWI: 5 min in 14 °C to shoulders CWT: 1 min in 14 °C, 2 min in 36 °C. Performed 4 cold and 3 hot immersions to shoulders CON: 10 min seated rest	20 min post-exercise	Work-based cycling time-trial (75 % peak power × 15 min), HR, cardiac parasympathetic activity (HR variability). Perceived fatigue, mental recovery, leg soreness, physical recovery	3.25 h	CWI: ↑ cardiac parasympathetic activity and perceived recovery versus CON. ↓ leg soreness versus CON CWT: ↑ cardiac parasympathetic activity and perceived recovery versus CON. ↓ leg soreness versus CON
Takahashi et al. [47]	Long-distance runners (10 [M])	Control trial	Downhill (−10 % gradient) treadmill running (3 × 5 min at participants 5,000 m personal best speed)	TWI: 30 min of randomly combined aqua exercises in 29 ± 1 °C ($n = 5$) CON: no treatment ($n = 5$)	Immediately, 24 and 48 h post-exercise	Maximal leg press power, whole-body reaction time, sit-and-reach flexibility, stride length, ankle ROM, muscle stiffness, CK, muscle soreness	24, 48, 72 h	TWI: ↑ leg muscle power 24-h post-exercise, ↓ calf stiffness and soreness versus CON
Tessitore et al. [94]	Junior professional elite football players (12 [NS])	Randomized crossover control trial	100 min of standardized football training	TWI: 20 min of shallow water aerobic exercises, temperature not reported ACT: 20 min of low-intensity dry aerobic exercises EMS: 20 min on quadriceps CON: 20 min seated rest	Post-exercise	Squat jump, CMJ, bounce jump, 10-m sprint, muscle soreness, RPE	4.5 h	TWI: No significant effect on any measures versus CON ACT: ↓ muscle soreness versus CON and TWI EMS: ↓ muscle soreness versus CON and TWI

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Tessitore et al. [95]	Well trained futsal players (10 [M])	Randomized crossover control trial	Friendly futsal game	TWI: 20 min of aerobic walking, jogging and running in 30 °C water. Water depth of 1.20 m ACT: 20 min low-intensity aerobic exercise EMS: 20 min on quadriceps CON: 20 min seated rest	30 min post-exercise	CMJ, bounce jump, 10-m sprint, cortisol, adrenaline, noradrenaline, sleep duration and disturbances, muscle soreness, and perceived recovery	5 h (performance tests, cortisol, soreness, and perceived recovery), 20 h (adrenaline, noradrenaline, sleep and soreness	TWI: ↑ perception of recovery versus CON and ACT EMS: ↑ perception of recovery versus CON and ACT
Vaile et al. [55]	Well trained cyclists (10 [M])	Randomized crossover trial	15 min of cycling at 75 % peak aerobic power, then a 15-min time trial in 34.0 °C. Repeated 55 min later	CWI: 1 min in 10 °C to shoulders seated, 2 min out of water. Performed 5 times CWI: 1 min in 15 °C to shoulders seated, 2 min out of water. Performed 5 times CWI: 1 min in 20 °C to shoulders seated, 2 min out of water. Performed 5 times CWI: 15 min in 20 °C to shoulders seated ACT: 15 min of cycling at 40 % VO_{2max}	Post-exercise	Cycling time-trial total work, HR, mean body temperature, La, thermal sensation, RPE	55 min	CWI: No difference between CWI conditions. ↑ time-trial performance versus ACT. ↓ HR, mean body temperature (lower with colder CWI temperatures), thermal sensation (lower with colder CWI temperatures), RPE (CWI at 10 °C, 15 °C and 20 °C continuous) following CWI versus ACT. ↑ La following CWI versus ACT

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Vaile et al. [28]	Endurance trained cyclists (12 [M])	Randomized crossover control trial	High-intensity cycling (66 maximal sprints of 5–15 s, 9 min of time trial efforts). Once per day for 5 days	CWI: 14 min in 15 °C to shoulders upright CWT: 1 min in 38 °C seated, 1 min in 15 °C upright. Performed 7 times to shoulders HWI: 14 min in 38 °C to shoulders seated CON: 14 min seated rest	Post-exercise for 4 days	Cycling total work, sprint peak power, time-trial average power, HR, rectal temperature, RPE	24, 48, 72, 96 h	CWI: ↑ sprint performance on days 4 and 5 and time-trial performance across 5 days versus CON CWT: ↑ sprint performance on days 4 and 5 and time-trial performance across 5 days versus CON, ↓ core temperature 15 min post-immersion versus CON and CWT HWI: ↑ core temperature 15-min post-immersion versus CWT and CON
Vaile et al. [48] Exp 1	Strength trained (12 [M])	Randomized crossover control trial	Eccentric leg-press protocol (5 sets of 10 reps at 120 % of concentric 1RM, 2 sets of 10 reps at 100 % of 1RM) [25, 90]	CWI: 14 min in 15 °C to shoulders upright CON: 14 min seated rest	Immediately, 24, 48 and 72 h post-exercise	Squat MVIC, loaded squat jump maximal power, thigh circumference, CK, Mg, IL-6, LDH, muscle soreness	0, 24, 48, 72 h. No Mg or IL-6 at 48, 72 h	CWI: ↑ squat MVIC and loaded squat jump peak power versus CON. ↓ post-exercise thigh circumference (swelling) and CK at 24- and 72-h post-exercise versus CON
Exp 2	Strength trained (11 [M])			HWI: 14 min in 38 °C to shoulders seated CON: 14 min seated rest				HWI: ↑ squat MVIC for 72 h, ↓ CK at 48-h post-exercise versus CON
Exp 3	Strength trained (15 [M])			CWT: 1 min in 38 °C seated, 1 min in 15 °C upright. Performed 7 times to shoulders CON: 14 min seated rest				CWT: ↑ squat MVIC and loaded squat jump peak power for 72 h versus CON, ↓ post-exercise thigh circumference (swelling) and perception of pain for 72 h versus CON

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Vaile et al. [86]	Recreationally trained (13 [4 M, 9 F])	Randomized crossover control trial	Eccentric leg-press protocol (5 sets of 10 reps at 140 % of concentric 1RM)	CWT: 1 min in 8–10 °C, 2 min in 40–42 °C. Performed 5 times to anterior superior iliac spine. Posture not reported CON: 15 min seated rest	45 s post-exercise	Squat MVIC, jump squat peak power, CK, thigh volume, muscle soreness	0.25, 24, 48, 72 h	CWT: ↑ squat MVIC and jump squat performance at 24- and 48-h post-exercise versus CON. ↓ thigh volume immediately and 48-h post-CWT versus CON
Vaile et al. [19]	Endurance trained cyclists (10 [M])	Randomized crossover trial	15 min of cycling at 75 % peak power, then 15-min time trial. Repeated 60 min later	CWI: 15 min in 15 °C to shoulders, vertical posture ACT: 15 min of cycling at 40 % peak power output	5 min post-exercise	Cycling time-trial total work, HR, rectal temperature, leg and forearm blood flow, La	1 h	CWI: ↑ cycling time-trial performance versus ACT. ↓ rectal temperature and arm blood flow until end of exercise bout 2 versus ACT. ↓ leg blood flow and HR until start of exercise bout 2 versus ACT. ↑ leg-to-arm blood flow ratio until start of exercise bout 2 versus ACT. ↑ La immediately after CWI versus ACT
Versey et al. [25]	Trained cyclists (11 [M])	Counter-balanced crossover control trial	75-min high-intensity cycling protocol (6 sets of 5 × 15 s sprints, 3 × 5 min time trials). Repeated 120 min later	CWT: 1 min in 38 °C, 1 min in 15 °C. Performed for 6, 12 and 18 min to shoulders, seated CON: 18 min seated rest	10 min post-exercise	Cycling sprints total work and peak power, cycling time-trials total work, HR, rectal temperature, thermal sensation, whole-body fatigue, muscle soreness, effort, motivation, RPE, condition order of preference	2 h	CWT: 6 min; ↑ sprints and time-trials total work versus CON. 12 min; ↑ sprints total work and peak power, and ↓ motivation versus CON. 18 min; ↑ effort versus CON. 6, 12 and 18 min; ↑ core temperature during CWT and ↓ thermal sensation, whole-body fatigue and muscle soreness versus CON. 12 and 18 min; ↓ core temperature pre-exercise 2 versus CON

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Versey et al. [90]	Trained long-distance runners (10 [M])	Counter-balanced crossover control trial	3,000-m running time-trial, 8 × 400 m running intervals	CWT: 1 min in 38 °C, 1 min in 15 °C. Performed for 6, 12 and 18 min to shoulders, seated CON: 18 min seated rest	10 min post-exercise	3,000-m running time-trial time, HR, calf and thigh girths, calf and thigh algometer pain thresholds, thermal sensation, whole-body fatigue, muscle soreness, effort, motivation, RPE, condition order of preference	2 h	CWT: 6 min; ↓ 3,000-m time, motivation and RPE versus CON. 12 min; ↑ thigh algometer pain threshold versus CON. 18 min; ↓ motivation and RPE versus CON. 6, 12 and 18 min; ↓ thermal sensation and muscle soreness versus CON
Viitasalo et al. [83]	Junior elite track and field athletes (14 [8 M, 6 F])	Randomized crossover control trial	5 track-and-field strength/power training sessions in 3 days. Repeated 2 weeks later	HWI: 20 min in 37 °C with jet massage. Water depth and posture not reported CON: no treatment	20–30 min post-evening training for 3 days	Leg extension MVCI, jump height, drop jump ground contact time. Repeat rebound jump test average power, ground contact time, jump height. CK, Mg, LDH, carbonic anhydrase-III, urine urea and creatinine, muscle soreness	2 morning and 1 afternoon post-training block	HWI: ↑ repeated rebound jump average power and ground contact time versus CON. ↑ neuromuscular performance capacity, CK, Mg, LDH, and urine urea versus CON. ↓ muscle soreness versus CON
Yamane et al. [51] Exp 1	Sedentary students (6 [M])	Counter-balanced control trial	25 min of cycling at 70 % VO_{2max}. 4 times per week for 4 weeks	CWI: 20 min in 5 ± 1 °C, 1 leg immersed (foot out). Performed a second time after 30 min out of water CON: untreated leg, 20 min rest in air	Within 3 min post-exercise, 4 times per week for 4 weeks	Cycling 1- and 2-legged VO_{2max} tests: VO_{2max}, ventilation rate, CO_2 output, ventilatory threshold	Within 3 day's post- training	CWI leg: ↓ VO_{2max} and cycling time during VO_{2max} test versus CON leg.
Exp 2	Sedentary students (6 [M])	Counter-balanced control trial	25 min of cycling at 70 % VO_{2max}. 4 times per week for 6 weeks	CWI: 20 min in 5 ± 1 °C, 1 leg immersed (foot out) CON: untreated leg, 20 min rest in air	Within 3 min post-exercise, 4 times per week for 6 weeks	Cycling 1- and 2-legged VO_{2max} tests: VO_{2max}, ventilation rate, CO_2 output, ventilatory threshold. Femoral artery diameter	Within 3 day's post-training	CWI leg: ↓ VO_{2max}, ventilatory threshold and femoral artery diameter versus CON leg
Exp 3	Sedentary students (11 [7 M, 4 F])	Counter-balanced control trial	Handgrip contraction/ relaxation exercise (3 sets of 8RM). 3 times per week for 3 weeks	CWI: 20 min in 10 ± 1 °C, 1 lower arm immersed (hand out) CON: untreated arm, 20 min rest in air	Within 3 min post-exercise, 3 times per week for 3 weeks	Maximal isometric handgrip strength and endurance	Within 3-day's post-training	CWI arm: ↓ handgrip strength and endurance versus CON arm

Table 1 continued

Study	Participants (n [sex])	Study design	Fatiguing exercise protocol	Interventions	Intervention timing	Outcome measures	Measurement timing[a]	Results
Exp 4	Sedentary students (16 [M])	Counter-balanced crossover control trial	Non-dominant handgrip contraction/relaxation exercise (3 sets of 8RM). 3 times per week for 3 weeks	CWI: 20 min in 10 ± 1 °C, non-dominant lower arm immersed (hand out, $n = 8$) CON: untreated arm, 20 min rest in air ($n = 8$)	Within 3 min post-exercise, 3 times per week for 3 weeks	Maximal isometric handgrip strength and endurance, forearm flexor muscle thickness, brachial artery diameter	Within 3- day's post-training.	CWI arm: ↓ handgrip endurance (trend) and brachial artery diameter versus CON arm
Yeargin et al. [26]	Highly trained heat-acclimatized distance runners (15 [NS])	Randomized crossover control trial	90 min moderate-intensity hilly trail run in 27 °C	CWI: 12 min in 5 ± 0 °C. Upper legs to shoulders immersed CWI: 12 min in 14 ± 0 °C. Upper legs to shoulders immersed CON: 12 min seated rest	2–4 min post-exercise	2-mile running race time, HR, rectal temperature, La, urine specific gravity, sweat rate, thermal sensation, environmental symptoms questionnaire, RPE	30 min	CWI 14 °C: ↓ race time versus CON CWI 5 and 14 °C: ↓ core temperatures post-immersion and race, and ↓ HR in first half of race versus CON

ACT active recovery, *CK* creatine kinase, *CMJ* countermovement jump, *COMP* compression, *CON* control, *CRP* C-reactive protein, *CWI* cold water immersion, *CWT* contrast water therapy, *EMS* electromyostimulation, *ES* effect size, *Exp* experiment, *F* female, *HR* heart rate, HR_{max} maximum HR, *HWI* hot water immersion, *La* lactate, *LDH* lactate dehydrogenase, *LIST* Loughborough Intermittent Shuttle Test, *M* male, *MAS* massage, *Mg* myoglobin, *MVIC* maximal voluntary isometric contraction, *NS* not specified, *POMS* Profile of Mood States assessment, *RESTQ* Recovery Stress Questionnaire for Athletes, *RM* repetition maximum, *ROM* range of motion, *RPE* rating of perceived exertion, *rpm* revolutions per minute, *STR* stretching, *TWI* thermoneutral water immersion, VO_2 oxygen consumption, VO_{2max} maximum VO_2, v-VO_{2max} velocity at VO_{2max}, VCO_2 volume of carbon dioxide production, *WAFL* Western Australian Football League, ↑ indicates higher, ↓ indicates lower

[a] Post-exercise

'recovery' and 'exercise'. In addition, other published articles known to the authors were retrieved, as well as those obtained through reference list searches of the retrieved studies. Studies were retained for inclusion in this review if they contained original research examining the effect of post-exercise water immersion on recovery of performance in humans. The 53 studies that met these criteria are summarised in Table 1.

2 Water Immersion Recovery Techniques

In all four water immersion recovery techniques, hydrostatic pressure acts on the body and its magnitude has a linear relationship with both water density and immersion depth according to the equation:

$$P_{hyd} = P_{atm} + g \times p \times h$$

where P_{hyd} = water pressure (Pa), P_{atm} = atmospheric pressure (sea level ~1,013 Pa), g = gravity (9.81 m/s^2), p = water density (1,000 kg/m^3) and h = height of the water (m) [15]. Therefore, hydrostatic pressure will be influenced primarily by immersion depth, which usually varies from waist to shoulder height with participants in a seated or upright posture (Table 1). The hydrostatic pressure at depths of 50, 100 and 150 cm would be 44, 81, and 118 mmHg, respectively, at sea level. If a consistent hydrostatic pressure is maintained across all four techniques, the key difference between techniques that may affect performance recovery is water temperature. Other factors may also vary between studies and influence the findings, but they can be kept constant between techniques. These include immersion duration, whether participants are active or passive during immersion, the nature of the fatiguing exercise and performance measures, the timing of performance measures and water immersion, and the environmental conditions (Table 1). Water immersion techniques are typically performed within 30 min post-exercise; however, some studies perform additional sessions at regular intervals post-exercise (e.g. next day) [21, 43–48].

2.1 Cold Water Immersion (≤20 °C)

2.1.1 Overview

CWI temperatures examined in the literature range from 5–20 °C; however, temperatures of either 5 °C [26, 49–51] or 10–15 °C [3, 21, 26–30, 34, 43–45, 48, 51–66] are most common. Total immersion time typically ranges from 3–20 min, consisting of either a single immersion (5–20 min) [21, 26–30, 34, 43, 45, 48, 51, 53, 56, 58–66], or multiple shorter immersions (1–5 min) separated by a period of time out of the water (1–2.5 min) [3, 44, 49, 52, 54, 55, 57, 67, 68]. The immersion depth may vary from waist [43, 49, 53, 56, 59, 61, 63, 65–69] to shoulder height [3, 19, 27–30, 48, 54, 55, 57, 58, 60, 62, 64, 70, 71]; however, a number of studies have investigated the effect of localized cooling of a body part (e.g. arm) [21, 45, 50–52]. Participants are usually passive during immersion in still water. CWI is increasingly being performed in purpose-built pools at athletic recovery facilities; but, for many athletes, the use of a bath or portable pool is more practical, particularly when travelling. Pools may be connected to portable chilling units that allow easier temperature regulation. In cold climates, the water in rivers, lakes, oceans and out of the tap may be ≤20 °C.

2.1.2 Performance Effects

The effect of post-exercise CWI on recovery of exercise performance has been investigated in numerous studies (Table 1). Most have reported that CWI can assist performance recovery [3, 26–28, 44, 48, 52–56, 64], or has no significant effect [21, 29, 34, 43, 45, 49, 50, 57–60, 66, 67, 70], while only a few have reported a detrimental effect on recovery following fatiguing exercise [30, 51, 61–63]. Performance improvements have been reported for cycling [27, 28, 53, 55], running [3, 26, 54, 64], climbing [52], vertical jump [3, 68] and leg strength tests [44, 48, 56], suggesting that the beneficial effects of CWI are not limited to specific forms of exercise. Furthermore, these performance improvements have been reported to last for minutes [26, 27, 52] to days [3, 28, 44, 48, 53–56, 64] post-CWI, probably depending on the intensity and mode of exercise [8, 72].

Most studies have compared CWI with a resting control condition [26–30, 34, 43, 44, 48, 52, 53, 56, 58, 60–68, 71, 73]; however, in attempts to isolate the effects of water temperature from those of water immersion, Sellwood et al. [49] and Rowsell et al. [54, 70] compared CWI with TWI. In Sellwood et al. [49] participants alternated 1 min in water to the anterior superior iliac spine, and 1 min out of the water, repeated three times. They found that CWI (5 °C) had no significant effect on recovery of quadriceps maximal isometric torque compared with TWI (24 °C) at 24, 48 or 72 h following eccentric leg extensions in untrained adults. In contrast, Rowsell et al. [54, 70] (both articles used the same participants) reported that CWI (10 °C) reduced the decrement in running distance (CWI: −5 %, TWI: −10 %) and heart rate across four matches of a 4-day football (soccer) tournament compared with TWI (34 °C) [54], but did not change repeated sprint test or countermovement jump performance at 22 h post-tournament [70]. The water immersion consisted of alternating 1 min in water to midsternal level, 1 min out of the water, repeated 5 times. Although Sellwood et al. [49] reported no significant effect on performance, the findings of Rowsell et al. [54, 70] suggest that water temperature may influence performance recovery in the days post-immersion. These contrasting findings could be due to the different CWI temperatures, types of exercise performed or subject populations [8, 72].

Studies that have found CWI to assist recovery of exercise performance have typically examined immersion in 10–15 °C water (Table 1) [3, 26–28, 44, 48, 52–56, 64]; however, only two studies have attempted to determine the ideal temperature by directly comparing different CWI temperatures [26, 55]. In Yeargin et al. [26] participants performed a 90-min moderate-intensity hilly trail run, followed immediately by water immersion and then a 2-mile running race 15 min later. They reported no significant difference in race performance following 12 min CWI of the upper legs to shoulders in 14 °C (2 % faster) compared with 5 °C; however, only performance following immersion in 14 °C water was faster than control [6 %, 0.41 effect size (ES)], suggesting that CWI in 14 °C is preferable to 5 °C for recovery of running performance. In a more recent attempt to determine the ideal CWI temperature, Vaile et al. [55] compared intermittent immersions to shoulder level in 10, 15 and 20 °C water for 5 min and continuous immersion in 20 °C for 15 min following cycling. Although all CWI conditions helped maintain subsequent (1 h later) cycling time-trial performance (10 °C: −0.6 %, 15 °C: 0.4 %, 20 °C: −1.0 %, 20 °C continuous: −0.6 %) compared with active recovery (−4.1 ± 1.8 %), there were no significant differences in performance between CWI conditions.

However, it is notable that the studies by both Yeargin et al. [26] and Vaile et al. [55] were performed in warm-to-hot environmental conditions (27 and 34 °C, respectively) and the subsequent performance tests were conducted within about 30-min post-CWI. Therefore, the findings may not transfer to exercise in other environmental conditions because CWI may have assisted subsequent performance due to pre-cooling, as opposed to enhanced recovery [38]. This suggestion is supported by the decreases in body temperatures observed following CWI and during subsequent exercise in both studies [26, 55]. Interestingly, Yeargin et al. [26] suggested that CWI in 5 °C may have cooled participants too much to allow optimum performance 15 min later as they reported feeling ‘stiff and cold’. Furthermore, the performance effects in the subsequent hours and days remain unknown and may differ from the initial 30-min post-immersion. Based on the combined findings of the scientific literature (Table 1), CWI in 10–15 °C water appears most likely to assist recovery of exercise performance; nevertheless, the findings of Vaile et al. [55] suggest that CWI in temperatures as warm as 20 °C might be as effective for recovery of exercise performance in hot conditions.

In addition to water temperature, immersion duration may influence the effect of CWI on recovery of performance. Peiffer et al. [29] is the only study to have examined different CWI durations, comparing 5, 10 and 15 min in 14 °C water to midsternal level on recovery of knee extensor maximal isometric and isokinetic torque. However, none of the CWI durations accelerated performance recovery, probably because testing was performed 10–25 min after CWI and therefore participants were still too cold to perform anaerobic tests optimally. If participants had more time to adequately warm-up prior to testing [37], or a prolonged aerobic test had been performed, the results may have been different [38]. This point will be discussed in more detail later in this section. Studies that have found CWI can assist recovery of exercise performance have typically used immersion durations of 5–15 min [3, 26–28, 44, 48, 52–56, 64], but these durations are also common in studies not reporting a performance benefit (Table 1) [21, 29, 34, 43, 58–63, 66, 70]. When considering immersion duration, thought should also be given to the practicality of performing CWI due to the thermal discomfort experienced during immersion [25, 52, 55, 56]. Shorter immersion durations are probably more tolerable for athletes, therefore increasing compliance; although, this may not be optimal for recovery of performance. Whether longer immersion durations provide greater recovery benefits remains unknown at this stage.

The optimal CWI duration for recovery of performance may also differ depending on the circumstances. It would seem logical that immersion durations should be shorter in colder water (within the previously discussed range of 10–15 °C) as less time would be required to have the same cooling effect on the body [26, 55]. In addition, until recently it was thought that athletes with higher subcutaneous adipose tissue levels experienced a slower decrease in core temperature during CWI [74, 75], possibly due to poor vascularization and thermal conductivity of adipose tissue [76]. However, this understanding was based on the responses of normothermic individuals during CWI [74, 75]. In contrast, athletes may commence water immersion with elevated body temperatures due to prior exercise. More recently, it has been found that subcutaneous adipose tissue levels (12.9 ± 1.9 % vs. 22.3 ± 4.3 %) have no significant effect on core body temperature cooling rates in habitually active, hyperthermic individuals performing post-exercise CWI (full body immersion in 8 °C) [77]. Lemire et al. [77] suggested this was due to any differences in muscle insulation being reduced by a high residual muscle blood flow and blood pooling post-exercise, and exercise in the heat causing an increase in skin blood flow and therefore a decrease in the effect of greater adipose tissue insulation. These findings suggest that CWI duration may be positively related to subcutaneous adipose tissue levels when athletes are normothermic, but not when they are hyperthermic, and immersion duration should be altered accordingly.

The timing of CWI post-exercise may also influence any effects on performance recovery; however, most studies have commenced water immersion within 30-min post-exercise (Table 1). To our knowledge, Brophy-Williams et al. [64] is the only study to have compared the effect of immediate, versus delayed CWI on recovery of exercise performance. It was reported that 15 min in 15 °C water to midsternal level provided greater recovery benefits in team sport athletes when undertaken immediately compared with 3 h post-exercise, but performing CWI 3 h post-exercise was still likely to assist recovery. Performance changes were measured 24 h after fatiguing exercise by the Yoyo Intermittent Recovery test. Furthermore, some studies have investigated the effect of multiple CWI sessions in the days following a single exercise bout [21, 43–45, 48] probably because it was thought that multiple sessions would be more likely to stimulate a physiological response and therefore promote recovery than a single session [26, 27, 29, 30, 34, 50, 52, 53, 55–63, 67, 68]. It remains uncertain whether this is the case as no study has conducted a direct comparison, and the proportion of studies that find performance benefits using each methodology is similar (∼40 %).

Conversely, most athletes train or compete once or twice per day for many days in succession; therefore, studies examining repeated post-exercise CWI use are likely to be more sports-specific in design [3, 28, 51, 54, 65]. Vaile et al. [28] used such a design and found that CWI for 14 min in 15 °C water to shoulder level following a high-intensity cycling protocol performed daily for 4 days in succession enhanced recovery compared with control. Similar findings were also observed by Montgomery et al. [3] and Rowsell et al. [54] during multiday team sport tournaments, in which repeated post-exercise CWI enhanced performance recovery. These combined findings suggest that repeated post-exercise CWI are likely to enhance performance recovery, possibly due to accumulated fatigue from multiple exercise bouts [5, 28]. Contrasting findings were reported by Yamane et al. [51] in four experiments summarized in Table 1; however, their results should be interpreted with caution as the study used a low number of sedentary adult participants and therefore their findings may not transfer to trained athletes. It is generally recognized that sports science research should be performed on highly trained participants to increase applicability to athletic populations [9, 78], as trained athletes have been shown to have a reduced capacity for adaptation and some different physiological responses during and following training, compared with sedentary adults [79–82]. Furthermore, the exercise protocols used by Yamane et al. [51] were unlikely to have produced accumulated fatigue, in some cases were not sports specific and, additionally, only the exercised portion of the body was immersed.

Studies investigating the use of CWI to accelerate recovery have measured exercise performance at times ranging from immediately post, to up to 7 days after the completion of CWI (Table 1). The timing of performance tests is likely to depend largely on the practical situation being replicated, the time-course of the fatigue experienced by participants and the time available to conduct the research. Most studies that report CWI as having a detrimental effect on recovery of performance have performed high-intensity, explosive exercise tests within 45 min of completing CWI [30, 61–63]. However, CWI has been shown to decrease internal body temperatures following immersion [30], and it is recognized that elevated internal body temperatures can improve sports performance [37]. Therefore, to perform optimally, athletes should not undertake CWI shortly before (<45 min) high-intensity, explosive exercise unless an adequate warm-up is completed to increase internal body temperatures. The CWI is effectively acting as pre-cooling for the subsequent exercise, therefore longer duration performance tests or tests performed in a warm-to-hot environment may benefit more from the lower internal body temperatures that can result from CWI [38, 39]. This reduction in core temperature is the likely mechanism behind studies, which have found that CWI can assist recovery of performance in the heat, despite undertaking exercise tests within 35 min of water immersion [26, 27, 55].

2.2 Hot Water Immersion (≥36 °C)

2.2.1 Overview

HWI is typically performed in temperatures ≥36 °C, with immersion times examined in the literature ranging from 10–24 min [28, 45, 48, 66, 83]. A single full-body immersion is usually performed; however, similar to CWI, one study has examined the effect of localized heating of a body part (arm) [45]. Participants are usually passive during immersion, although underwater jets are often available for massage [15, 83]. Hot pools may be more widely available than cold pools as they might be part of a swimming pool complex, and hot temperatures are easier to achieve than cold temperatures in a home or hotel bath. Similar to CWI, a bath or portable pool attached to a heating unit may be more practical at some competition or training venues.

2.2.2 *Performance Effects*

Few studies have investigated the effect of HWI on recovery of exercise performance [28, 45, 48, 66, 83], and none have provided substantial evidence that HWI may assist performance recovery. The first study was performed by Viitasalo et al. [83] and found that 20 min of warm (37 °C) underwater jet massage performed daily for 3 days by junior elite track-and-field athletes, improved maintenance of repeated jump test mean power (0 %, $p > 0.05$) compared with control (−10 %, $p < 0.001$), but had no significant effect on leg extension maximal isometric strength or jump height across the training block. A subsequent study by Kuligowski et al. [45] found that following elbow flexor eccentric contractions, immersion for 24 min in 39 °C water had no significant effect on elbow flexor maximal isometric contractions compared with control for up to 96 h [45]. While HWI was performed daily for 4 days, Kuligowski et al. [45] only exercised and performed HWI on the non-dominant arm elbow flexors of untrained participants; therefore (as discussed earlier), the applicability of their findings to athletes performing sport-specific tasks may be limited.

More recently, Vaile et al. [28] reported that daily post-exercise immersion for 14 min in 38 °C water to the shoulders had no significant effect on subsequent cycling sprint or time-trial ability over 5 days compared with control. However, in another study [48], the same authors found that an identical HWI protocol improved recovery of isometric squat force for 72-h post-exercise (24 h: −12.8 %, 48 h: −10.1 %, 72 h: −3.2 %) compared with control (24 h: −17.0 %, 48 h: −16.0 %, 72 h: −9.8 %), but did not significantly affect loaded squat jump maximal power, following an eccentric leg-press protocol designed to induce muscle damage. Based on the small number of studies in the area, it is unlikely that post-exercise HWI has a significant effect on recovery of subsequent exercise performance, despite a range of fatiguing exercise protocols, and performance tests having been examined in the literature. Therefore, HWI is currently not recommended as a recovery technique for athletes. However, there is some suggestion that HWI may improve recovery of isometric squat force [48] and repeat rebound jump average power (without improving jump height) [83] following muscle-damaging exercise. While the investigated HWI protocols appear unlikely to have a detrimental effect on performance, if HWI causes an elevation in core temperature during subsequent prolonged exercise (particularly in hot environmental conditions), performance may be compromised [39].

2.3 Contrast Water Therapy (Alternating ≥36 and ≤20 °C)

2.3.1 *Overview*

CWT is performed by alternating regularly between HWI and CWI. Most published CWT protocols alternate 3–7 times between 1 min CWI and 1–2 min HWI, accumulating 6–15 min in the water [28, 48, 65, 66, 68, 84–86]. In some studies, a hot shower is used instead of a hot pool [46, 57, 67, 87, 88], possibly to simulate a situation in which athletes do not have access to this facility. In the literature, there appears to be no consensus on whether CWT should finish with HWI [44, 57, 66–68, 84, 86, 88] or CWI [28, 45, 46, 48, 65, 85, 87, 89], with roughly half of the protocols finishing with either temperature. Participants are usually passive during the water immersion; however, they are still required to move between pools. The equipment or facilities required to perform CWT may be relatively difficult to obtain because both hot and cold water are required.

2.3.2 *Performance Effects*

To our knowledge, 20 studies have investigated the effect of post-exercise CWT on recovery of exercise performance (Table 1) [25, 28, 44–46, 48, 57, 65–68, 71, 84–91], with only nine reporting beneficial effects [25, 28, 48, 65, 66, 68, 86, 89, 90]. Nonetheless, many of the studies reporting beneficial effects on performance recovery have contained similar CWT protocols [25, 28, 48, 65, 66, 86, 89, 90] that differ notably from the protocols used in studies that do not find a performance benefit [44–46, 57, 67, 71, 84, 85, 87, 88, 91], suggesting that certain protocols might be more likely to enhance performance recovery. These protocols typically alternate regularly between hot and cold water (1–2 min immersions), contain a similar ratio of hot-to-cold water immersion, involve full-body immersion and do not use hot showers instead of a pool. Two of the studies that found performance benefits were conducted by Vaile et al. [28, 48] who used different modes of exercise, but identical water immersions that led to the CWT protocol suggestions above (alternating 1 min in 38 °C, and 1 min in 15 °C, for 14 min immersed to shoulder level). Vaile et al. [28] found that CWT performed daily for 4 consecutive days post-exercise enhanced recovery of cycling time-trial performance on days 2–5 (0.0–1.7 %) compared with control (−2.6 to −3.8 %), but did not improve recovery of sprint performance (0.5–2.2 %) until days 4 and 5 compared with control (−1.7 to −4.9 %). Their results indicated that the benefits of CWT may be greater when athletes have cumulative fatigue from multiple daily training sessions. Vaile et al. [48] reported that daily CWT for 4 days enhanced recovery of squat-jump performance (24 h: −6.7 %, 48 h: −3.4 %, 72 h: 0.0 %) compared with control (24 h: −14.6 %, 48 h: −12.5 %, 72 h: −7.8 %) and isometric squat performance (24 h: −10.3 %, 48 h: −7.4 %, 72 h: −2.8 %) compared with control (24 h: −17.3 %, 48 h: −14.0 %, 72 h: −11.5 %), at 24, 48 and 72 h after participants undertook a delayed onset-muscle-soreness-inducing leg-press protocol.

Other studies have used similar CWT protocols to Vaile et al. [28, 48] and found improvements in recovery of exercise performance. An earlier study by Vaile et al. [86] also used a delayed onset-muscle-soreness-inducing leg-press protocol and found that CWT (alternating 1 min in 8–10 °C, and 2 min in 40–42 °C, for 15 min) enhanced recovery of isometric squat force (mean ± SD 24 h: ∼− 6 ± 21 %, 48 h: ∼− 11 ± 16 %) compared with control (24 h: −20.8 ± 15.6 %, 48 h: −22.5 ± 12.3 %), and jump-squat peak power (24 h: ∼− 9 ± 12 %, 48 h: ∼− 3 ± 16 %) compared with control (24 h: −18.0 ± 11.6 %, 48 h: −22.7 ± 15.8 %), despite participants only immersing in the water to the level of the anterior superior iliac crest, using 8–10 °C instead of 15 °C CWI, and spending twice as much time in the hot than the cold water. Higgins et al. [65] reported that post-exercise CWT (alternating 1 min in 10–12 °C, and 1 min in 38–40 °C, for 7 min) performed 3 times per week for 4 weeks enhanced recovery of 300 m sprint performance (0.72 ES), but had no significant effect on repeat sprint performance in well trained rugby union players.

Furthermore, Buchheit et al. [89] reported that CWT (2 min in an 85–90 °C sauna, 2 min in 36 ± 2 °C water to midsternal level, 2 min in 12 ± 1 °C water to iliac crest level, repeated 3 times) performed 12–15 h post-match can enhance recovery of football match running performance (sprinting distance 30 ± 67 %, peak match speed 6 ± 3 %) over two consecutive games within 48 h in highly trained youth footballers. However, their results should be interpreted with care as the study was conducted retrospectively by analysing data from a competitive season that met criteria for inclusion in their study. Data from only five participants were included and, due to the retrospective nature of the study, there appeared to be little control over other recovery practices performed by the footballers between consecutive games.

The duration of CWT may influence its effect on recovery of exercise performance. Versey et al. [25, 90] conducted two studies investigating whether post-exercise CWT (alternating 1 min in 38 °C, and 1 min in 15 °C for 6, 12 or 18 min to the shoulders) had a dose-response effect on recovery of exercise performance. Both studies found that a dose-response relationship did not exist, but CWT for 6 and 12 min accelerated recovery of sprint and time-trial cycling performances 2 h later, while CWT for 6 min assisted recovery of 3,000 m running performance. These findings suggest that CWT for 6–12 min duration is more effective at accelerating recovery of exercise performance than longer durations such as 18 min. While these findings may also imply that CWT for 12 min is only effective for recovery following concentric-only exercise, it should be noted that the original authors suggested that CWT for 12 and 18 min may have failed to assist recovery of running performance because their cooling effects were too large for the cold environmental conditions experienced by participants [90]. Therefore, the different findings could be due to the environmental conditions experienced during each study, and further research is required to determine whether CWT affects recovery from running and cycling performance differently. In addition, it has been suggested that the stimulus for benefits from CWT is the movement between extreme temperatures [40], therefore it would seem logical for CWT protocols to consist of short immersions (∼1 min) and alternate frequently between the hot and cold water.

Eleven studies have found little or no enhancement in recovery of exercise performance after undertaking post-exercise CWT [44–46, 57, 67, 71, 84, 85, 87, 88, 91]; however, some have had methodological issues, possibly compromising their ability to observe an improvement in performance [46, 57, 68, 84, 88]. Coffey et al. [84], King and Duffield [68] and Robey et al. [46] used methodology that failed to detect a decrease in performance in their control trials. Therefore, either the exercise protocols did not induce sufficient fatigue, or the performance tests used were inappropriate to detect the fatigue. An improvement in exercise performance compared with baseline would have been required for CWT to assist recovery. This is unlikely to occur and would bring into question the validity of the baseline performance. Hamlin [88] and Kinugasa and Kilding [57] compared CWT with active recovery (6 min jogging at 6.8 km/h) and stretching (7 min of static stretching and 2 min with legs above the heart), respectively, rather than a resting control condition. If active recovery or stretching assisted recovery of exercise performance it would decrease the possibility of finding a significantly beneficial effect from CWT.

The remaining studies that found CWT had no significant effect on performance recovery [44, 45, 67, 71, 85, 87] all used CWT protocols that differed from the relatively similar protocols used in studies that reported recovery benefits, therefore it appears that certain CWT protocols are less likely to assist recovery than others. Vaile et al. [28, 48] compared different water immersion recovery interventions and reported that CWI assisted recovery of exercise performance, while HWI did not have the same benefits. Consequently, CWT protocols containing 2–3 times more HWI than CWI seem counterintuitive and have generally failed to assist recovery of exercise performance [45, 46, 57, 68, 84, 85, 87, 91]. In addition, it appears reasonable that increasing the amount of the body immersed during CWT would increase the possibility of a physiological response to either the water immersion or the extreme temperatures [35]. Several studies have only immersed the lower part of the body during CWT [44, 46, 66–68, 84, 86–88], thereby potentially decreasing the magnitude of any physiological response. Most of these studies have been unsuccessful at accelerating recovery of exercise performance [44, 46, 67, 84, 87, 88]. Some studies have used a hot shower instead of pool immersion, decreasing the body surface area in contact with hot water and removing any potential benefits from hydrostatic pressure on the body while in the shower [46, 57, 67, 68, 87, 88]. Likewise, these studies have typically failed to assist recovery of subsequent exercise performance.

Finishing CWT in either hot or cold water does not appear to influence the likelihood of subsequent performance benefits. Of the nine studies to find a benefit, four finished in hot [65, 68, 86] and five in cold water [25, 28, 48, 89, 90]. Studies that did not report an improvement in exercise performance were split six to four for finishing in hot [44, 57, 67, 84, 87, 88] and cold water [45, 46, 71, 85, 91], respectively.

2.4 Thermoneutral Water Immersion (>20 to <36 °C)

2.4.1 Overview

Water temperatures of approximately 35 °C are considered to be thermoneutral as they do not alter core temperature during prolonged immersion [11]. Consequently, some studies have used immersion in approximately 35 °C as a control condition to isolate the effects of water temperature from those of water immersion on post-exercise recovery. These studies are discussed in the section on CWI as they do not contain a control condition without immersion [49, 54, 69, 70]. For the purposes of this review, water immersion performed in swimming pools has been included in TWI [47, 87, 92–95]. Consequently, TWI temperatures in the literature range from 24 to <36 °C [47, 49, 54, 69, 70, 87, 95]; however, some studies have failed to report water temperature [92–94]. Typical immersion durations range from 15 to 30 min [47, 87, 92, 94, 95]. Unlike the other water immersion techniques, published TWI protocols often contain swimming, walking and other aerobic exercises [47, 87, 92–95], while, anecdotally, athletes may also perform stretching during immersion. The water temperature required for TWI is relatively easy to obtain as swimming pools are usually more readily available than cold or hot pools, and tap water may be used to achieve the desired temperature in a bath without cooling or heating the water.

2.4.2 Performance Effects

To our knowledge, six studies have examined the effect of TWI on recovery of exercise performance compared with a control condition [47, 87, 92–95]. In five studies [47, 87, 92, 94, 95], participants performed TWI containing low-intensity exercise that appeared to be designed to enhance recovery, adding active recovery as a new mechanism in addition to water immersion by which performance recovery might be affected. Despite the inclusion of low-intensity aerobic exercise in the five studies [47, 87, 92, 94, 95], contrasting findings were reported. Dawson et al. [87] found that TWI (15 min walking in 28 °C shallow water) improved recovery of vertical jump, but not cycling sprint performance 15 h after Australian football games (1.02 ES). Meanwhile, Takahashi et al. [47] reported that TWI (30 min of aqua exercise in 29 °C water) helped maintain leg muscle peak power 24 h after downhill running (−4.1 %) compared with control (−16.5 %). In contrast, Cortis et al. [92] and Tessitore et al. [94, 95] found that 20 min of shallow water aerobic exercise had no significant effect on recovery of explosive exercise performance after 6.5 h and about 5 h, respectively. In Tessitore et al. [95] TWI was performed in 30 °C water; however while neither of the other two studies reported water temperature [92, 94], it is likely that they were performed in swimming pools of 25–30 °C. While the fatiguing exercise bouts differed between these four studies, both the performance measures and TWI protocols were similar [47, 87, 92, 94, 95]. It is possible that the different fatiguing exercise bouts or timing of the post-exercise performance measures (5–24 h) could explain the contrasting findings [8, 72]. Cortis et al. [92] and Tessitore et al. [94, 95] may have found different outcomes if the performance measures had been performed the day after TWI.

Another study [93] examined the effect of a 45–60 min high-intensity swimming interval training session 10 h after a high-intensity interval running session on recovery of running performance in triathletes. Despite the high-intensity of the swimming session, Lum et al. [93] reported that running time to fatigue was greater (830 ± 198 s) compared with control (728 ± 183 s) at 24 h post-exercise. Based on the available literature, there is a possibility that TWI combined with aerobic exercise may improve recovery of explosive exercise performance; however, due to the contrasting findings and lack of available literature, this is uncertain.

2.5 Comparison of Water Immersion Recovery Techniques Performance Effects

To optimize the recovery of exercise performance, athletes need to know which water immersion technique will provide them with the greatest recovery benefits. Furthermore, it is possible that the optimal immersion technique may differ between sports, because certain recovery techniques may assist recovery from some forms of exercise more than others [8, 72]. Vaile et al. conducted two important studies [28, 48] that aimed to answer these questions by comparing the effect of full-body CWI (15 °C), HWI (38 °C), CWT (alternating 1 min in 38 °C, and 1 min in 15 °C) and control for 14 min on recovery of sprint and time-trial cycling performance [28], and the functional deficits associated with delayed onset muscle soreness [48]. Both studies used the same water immersion protocols and suggested that daily CWI and CWT assisted recovery of performance by similar amounts, and more so than HWI or control during the 3–4 days post-exercise. Moreover, both CWI and CWT assisted recovery by a greater percentage compared with control following muscle damaging exercise (2–10 %) [48], compared with cycling performance (0–2 %) [28]. While it should be remembered that the performance tests differed between the two studies, these findings not only suggest that CWI and CWT are likely to provide athletes with the greatest recovery benefits, but also that the recovery benefits may be greater following muscle-damaging exercise than cycling.

The findings of Vaile et al. [28, 48] contradict those of an earlier study by Kuligowski et al. [45] that also compared CWI (13 °C), HWI (39 °C), CWT (alternating 3-min HWI, and 1-min CWI) and control for 24 min performed daily for 3 days following eccentric elbow flexor contractions. It was found that none of the water immersion techniques affected recovery of elbow flexor maximal voluntary isometric contraction during the next 4 days. The lack of significant findings could have been because the participants were untrained and they did not perform whole-body sports-specific exercise, as only one arm was exercised and immersed [9, 78].

Other studies have compared CWI and CWT in team sport athletes, but their findings have been inconsistent and inconclusive [44, 45, 57, 65, 67, 87]. Higgins et al. [65] suggested that CWT (alternating 1 min in 10–12 °C, and 1 min in 38–40 °C, for 7 min) assisted recovery of anaerobic exercise performance in rugby players by a greater amount (repeat sprint test: 0.99 ES, 300 m sprint: 0.53 ES) than CWI (5 min in 10–12 °C to above waistline) when performed 3 times per week for 4 weeks. In contrast, Ingram et al. [44] found that CWI (5 min in 10 °C, 2.5 min out of the water, 5 min in 10 °C to umbilicus) helped maintain repeat sprint ability by a greater amount (1.56 ES) than CWT (alternating 2 min in 10 °C, and 2 min 40 °C, for 12 min to umbilicus) in team sport athletes when performed immediately and 24 h after simulated team sport exercise; however, fastest sprint time and maximal isometric leg strength was not significantly affected. Furthermore, Hamlin [67] reported that neither post-exercise CWI (alternating 1 min in 8–10 °C, and 1 min air, for 6 min) nor CWT (alternating 1 min in 8–10 °C, and 1 min in a 38 °C shower for 6 min) accelerated recovery of repeat sprint-test performance in developmental netballers 2 h after high-intensity running. This could have been because participants only spent 3 min with just their legs immersed in water during each intervention; the stimulus may have been insufficient to accelerate recovery. While Kinugasa and Kilding [57] also investigated both CWI and CWT, a comparison between their effects on performance recovery is not appropriate as the CWI was confounded by the inclusion of active recovery that was not included in the CWT. The reasons for these inconsistent findings are unclear at this stage; however, it may be related to the differences in exercise and water immersion protocols between studies [8, 72].

Based on the available literature, it appears likely that CWI and CWT assist recovery of exercise performance more than HWI and TWI, but it is unclear which technique is most effective. It is possible that the optimal water immersion technique and protocol for recovery of performance may depend on the type of exercise performed [8, 72], but insufficient evidence is available to determine whether this notion is correct.

3 Effect of Water Immersion on Training Adaptations

The water immersion recovery literature primarily examines the short-term effects on recovery of exercise performance and physiological markers of recovery. While this literature suggests that some water immersion techniques may assist in acute recovery of performance in the days following fatiguing exercise, concern exists as to whether these techniques, in particular CWI, affect long-term adaptation to training [43, 51, 65]. One theory suggests that water immersion techniques could assist acute recovery, therefore allowing athletes to perform a larger training load (increased frequency, intensity or duration) in subsequent sessions, in turn producing a greater stimulus for adaptation [8, 9, 96]. Alternatively, by disrupting the mechanisms of fatigue, recovery techniques may blunt chronic adaptations to training [43, 51]. This ‘adaptation’ issue is important to all athletes; although, it is likely to be of greatest importance to sports in which physical condition is the primary influence on the outcome, and sports that only have a few important competitions per season. In highly skilled or team sports, the benefits of the potential for an increase in training load, and therefore time practising skills or developing understanding with team-mates may offset any potential detrimental effects on physical conditioning.

Three studies have attempted to address this issue by examining the effect of regular CWI over 3–6 weeks of training [43, 51, 65]. Three of the four experiments conducted by Yamane et al. [51] found that regular CWI attenuated training-induced improvements in cycling ability or handgrip strength compared with control (Table 1). However, their results should be interpreted with caution because participant numbers were low, they were sedentary adults rather than trained athletes and only one limb was immersed in water (the other was the control) rather than half- to full-body immersion. In addition, Higgins et al. [65] reported that regular CWI decreased repeat sprint test performance (−0.62 ES), but had no significant effect on 300 m sprint test performance (0.17 ES) when compared with a control condition in rugby union players. However, there appeared to be potential for substantial human error in their test results due to visual observation of the distance covered during the repeat sprint test and hand timing of the 300 m sprint test. Howatson et al. [43] reported that CWI (12 min in 15 ± 1 °C to iliac crest) performed daily for 3 days following muscle-damaging exercise neither inhibited nor promoted the repeated bout effect during the subsequent 4 days. The current literature suggests that CWI may attenuate adaptations to training; however, due to the methodology employed in existing studies, further research investigating the effects on adaptation for athletic performance is required.

4 Future Research

Insufficient literature is available to conclusively answer numerous questions regarding the use of water immersion for post-exercise recovery. Future research should compare CWI and CWT to determine the optimal water immersion technique and examine the effects of regular post-exercise water immersion on long-term adaptations to training. In addition, research is needed to confirm the optimal water temperatures, immersion durations, immersion depths, timing post-exercise and time before subsequent exercise for CWI, HWI, CWT and TWI. The timing post-exercise would be of particular interest to athletes that do not have access to pools at their training facility, or do not have time to undertake water immersion until the end of the day or the following morning. To our knowledge, no studies have directly compared full-body immersion to half-body immersion using CWI, HWI, CWT or TWI to determine whether immersion depth influences recovery of performance. In addition, further research is required to determine whether using showers instead of water immersion influences the effect on subsequent exercise performance. It should be noted that for many of these questions the outcomes may differ depending on the mode of exercise and the environmental conditions involved.

Questions relating to specific water immersion techniques also remain unanswered. Further research is necessary to determine whether post-exercise HWI influences recovery of performance and it is unknown whether CWT should conclude in hot or cold water. Insufficient literature is available to conclusively determine whether TWI combined with aerobic exercise accelerates recovery of exercise performance. In addition, to date no studies have examined the effect of performing TWI without concurrent exercise on recovery of performance compared with a control condition; therefore it is unknown whether exercise plays a critical role in the ability of TWI to enhance recovery of performance.

5 Practical Recommendations

This section provides practical recommendations on the use of water immersion for recovery of athletic performance. The recommendations are primarily based on the literature discussed in this review. However, some topics have not been adequately investigated in the literature; therefore recommendations on these topics are based on current theoretical best practices. The authors acknowledge that further research is required to confirm these recommendations.

5.1 Water Immersion Techniques

CWI and CWT should assist recovery of exercise performance more than HWI and TWI when performed appropriately. Greater scientific and anecdotal support exists for the use of CWI compared with CWT; however, further direct comparisons are needed between the two techniques to conclusively determine which is more effective. Insufficient literature is available to determine whether the use of either CWI or CWT is more effective at accelerating recovery from different forms of fatigue (e.g. neural fatigue vs. muscle damage). Therefore, it is not possible to recommend a particular water immersion technique for recovery from specific modes of exercise. Athletes with an elevated core temperature (often caused by sustained high-intensity exercise in hot conditions) should perform CWI as first preference, as it is likely to cause the greatest rate of decrease in core temperature, but CWT may be preferable for athletes with a lower core temperature to limit further decline. Athletes with an injury should follow medical advice when considering the use of HWI, CWI or CWT.

5.2 Water Temperatures and Immersion Durations

The optimal temperature for CWI appears to be in the range of 10–15 °C. When performing CWT, the same temperature CWI should be used in conjunction to HWI in about 38 °C. The ideal CWI duration is likely to be in the range of 5–15 min; however, this probably depends on the water temperature (the lower the water temperature, the shorter the immersion duration). The ideal CWT duration is uncertain; although the available data suggests it is up to 15 min in total.

5.3 Water Immersion Depth and Whether to be Activity or Passive

To our knowledge, no studies have compared the influence of immersion depth on the effectiveness of water immersion for recovery of exercise performance. Nonetheless, it appears logical that the greater the immersion depth, the greater the physiological effect on the body and therefore the potential performance benefits. In addition, it is unknown whether participants should be active or passive during immersion.

5.4 Timing of Water Immersion Post-Exercise

It is recommended that athletes perform water immersion techniques as soon as practical post-exercise to obtain the greatest recovery benefits. Any recovery effects may be reduced when water immersion is performed some hours after exercise or the following day. Most studies that report recovery benefits have commenced water immersion within 30-min post-exercise.

5.5 Time to Subsequent Exercise

When selecting a water immersion recovery technique, the time to the subsequent exercise bout should be considered due to the cooling effects of CWI and CWT. Following CWI and CWT, athletes should allow sufficient time for internal body temperatures to increase so subsequent exercise performance is not compromised. If exercise is performed soon after (≤45 min) water immersion, CWI and CWT may decrease exercise performance, particularly if the exercise is high-intensity or explosive in nature. However, when exercising in a warm-to-hot environment, pre-cooling might enhance subsequent exercise performance and therefore be desired, principally for prolonged exercise. In this case, athletes should perform an appropriate sports-specific warm-up so subsequent exercise performance is not compromised.

5.6 Effect of Water Immersion on Training Adaptations

The effect of water immersion on adaptation to training is not known. If immersion does not alter adaptation processes, it can be used to accelerate recovery in the daily training environment. However, if water immersion attenuates adaptations to training, then it should primarily be used between competitions when limited recovery time exists. Furthermore, if immersion impairs adaptation processes, its use may still be beneficial for highly skilled or team sports athletes through the potential for an increase in skill development and teamwork.

6 Conclusions

Most of the literature investigating post-exercise water immersion for recovery of exercise performance has focused on CWI and CWT, with few studies examining HWI and TWI. Based on the current literature, both CWI and CWT can assist recovery of exercise performance when conducted appropriately; however, it is unclear which technique is more effective. Due to the lack of literature and contrasting findings, it is uncertain whether HWI and TWI assist performance recovery. Future research should aim to determine whether water immersion techniques are more effective at assisting recovery from some forms of fatigue than others, and should answer key practical questions that have yet to be resolved.

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