

REVIEW

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Effect of cold water immersion on balance and postural control in young healthy individuals: a systematic review

Omid Shahani¹ , Nahid Khoshraftar Yazdi^{2*} and Samineh Mokhtaran³

Abstract

Background Proper recovery and a faster return to activity play an important role in injury prevention and can significantly impact performance. Also, maintaining balance and postural control are prerequisites for effective performance that can be strengthened based on proper recovery. This systematic review examined the effect of cold water immersion (CWI) on balance and postural control in healthy young adults.

Methods The study was searched from inception to early March 2025. Six databases, Web of Science (WOS), Scopus, PubMed, ScienceDirect, PEDro, and Cochrane Library, were searched, and studies published in English were selected. Experimental studies and controlled clinical trials that included at least two groups, a CWI experimental group and a control group, had to use at least traditional or no-intervention retrieval methods. The mean age of participants was 16. The Rob2 and critical appraisal scales were used to assess the risk of bias and quality of studies.

Results 386 studies were found in the first stage of the search, and eight were included in this review. The effects of CWI on balance in healthy individuals are varied, with some studies suggesting a positive impact and others suggesting no effect. Duration and temperature play important roles, with shorter and more moderate immersions being more effective. Temporary neural responses cause short-term instability, but in the long term, they help improve stability and control. Due to the heterogeneity among studies, conducting a meta-analysis was impossible.

Conclusion The use of CWI can be done under different conditions, depending on the target population and their needs. Overall, its use yields more positive effects, although contradictions persist. It should be used with caution and tailored to the needs of the individual.

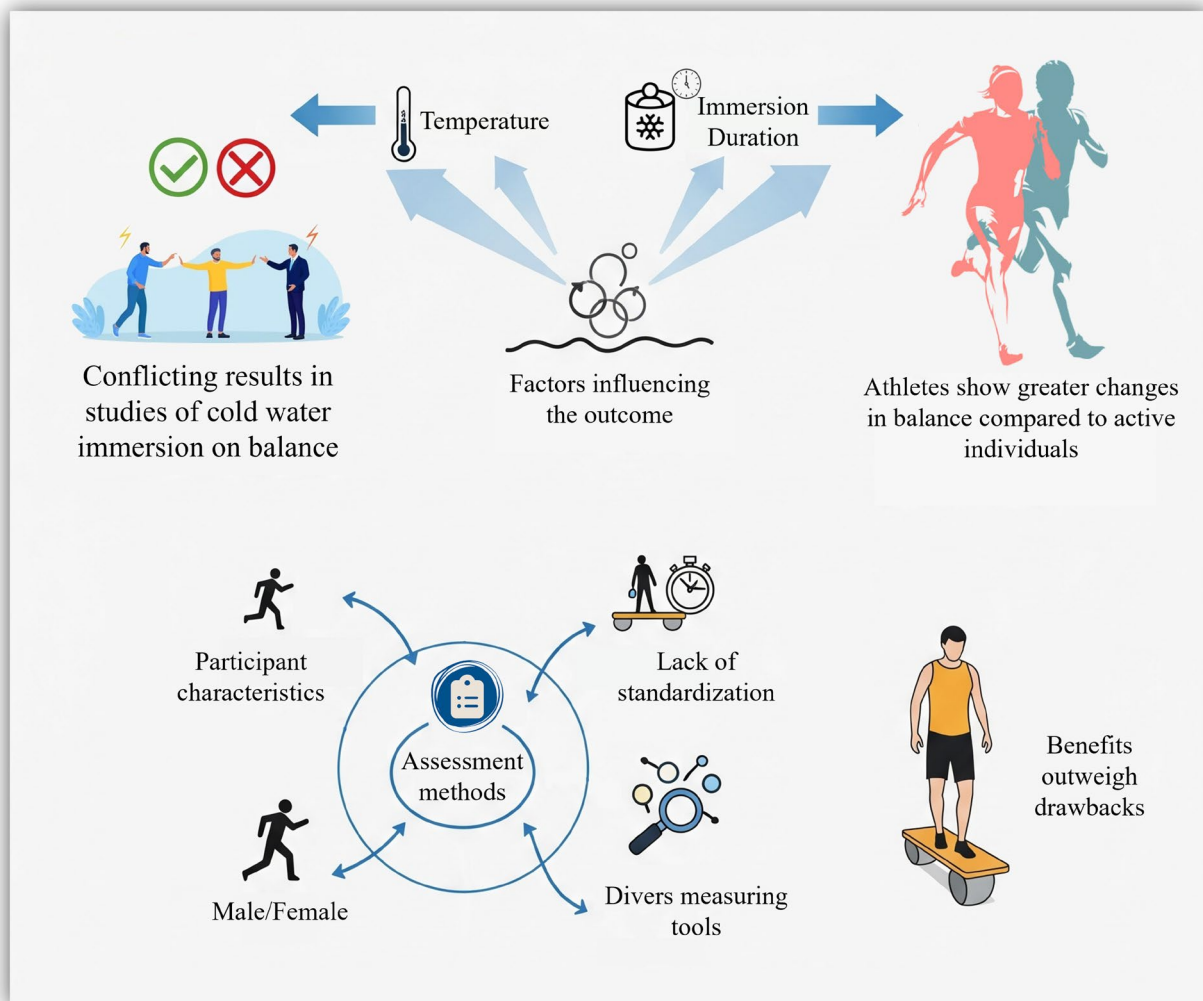
Keywords Cryotherapy, Stability, Recovery, Cold water immersion

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Graphical abstract**Introduction**

Recovery methods are divided into active and passive groups [1]. Active recovery methods include slow walking, static and dynamic stretching, etc., and passive methods CWI is one of the standard methods for recovering from sports activities [2]. Using CWI has several advantages over other recovery methods. It can be done without exceptional experience; people are more willing to use it than other methods (it is more attractive), CWI does not require special equipment, and it can be done in almost any pool [3, 4].

This method has different effects on people's bodies. Physiological effects include hormone secretion, decreased metabolic activity, decreased body temperature, etc. [5]. High-intensity exercise increases the accumulation of lactic acid in tissues. One of the primary goals of CWI is to reduce the accumulation of lactic acid

in tissues, which prevents muscle fatigue, and this plays an important role in the neuromuscular system's ability [4]. However, other parts, including psychological effects such as stress reduction, improved mood, increased relaxation, etc., and functional effects such as faster return to training, improvement, and enhancement of performance, and even injury prevention, each, in turn, represent an important part of the effects of this method [2].

This method can be used in one or more sessions, and its effects are clearly visible in one session. It also does not require expertise; anyone can use it [6]. Studies have indicated that CWI is limited to the ankle joint, CWI up to the knee joint, CWI up to half of the body, or even CWI for the whole body [7]. In addition, the temperature of the water is also an important point, with different values reported in studies [8, 9]. Immersion time also varies

from 3 to 20 min and includes one continuous immersion or multiple immersions, each lasting between 1 and 5 min, with a 1 to 2 min rest between them [3, 10].

Balance is the body's ability to maintain proper posture in the face of various forces and is particularly important in everyday activities, sports, and even therapeutic processes [11]. Reduced balance can lead to an increased risk of injury and, in addition, to a decrease in performance. CWI causes the body to respond to changes in temperature and water pressure [2]. Water temperature and pressure changes can modulate sensory-motor integration by stimulating temperature-sensitive receptors and proprioceptive pathways, which enhances neuromuscular coordination. This leads to improved body awareness, greater balance, and more precise and consistent athlete movements [12].

CWI stimulates the nervous system by modulating temperature-induced afferent input and proprioceptive processing, which enhances motor output and coordination [2].

As a result, improved neural network efficiency may lead to faster responses and more stable performance to environmental and physical stresses, and thus better results during training and competition. This faster recovery helps maintain balance and improves individual performance; when athletes feel they have a better chance of returning to normal, they will be more psychologically motivated [6]. Athletes' balance and performance directly affect competition results; every slight improvement can lead to a higher score. Improving balance and performance can also increase the enjoyment of the sport and reduce the risk of injury [13]. Feeling better during training and competition is important and motivating for any athlete. Improved balance can reduce the risk of falls or injuries during sports. Athletes with better balance face a lower risk of injury and can participate in training and competition more confidently [14].

A study by Mikel Egaña et al. stated that CWI has a better effect on athletes' performance than passive rest

[15]. Heinke et al. also compared the effects of CWI and percussive massage on post-exercise recovery and stated that there was no difference between the two methods. Neither was superior to passive rest [16].

The positive effects of CWI include reducing inflammation, improving blood circulation, strengthening the immune system, etc., and the negative impacts of this method include hypothermia, changes in heart rate, headache or dizziness, skin irritation, etc. [2, 13]. Therefore, all these aspects should be considered when applying this method for recovery to achieve the best results. However, some research suggests that CWI can temporarily reduce muscle efficiency and impair motor and balance processes. These effects are usually due to neural stimulation and physiological changes after CWI [7].

Therefore, a comprehensive study of the effect of CWI in healthy subjects on balance and postural control, which is considered a secondary outcome, seems necessary to provide a comprehensive view. To our knowledge, no systematic review has yet investigated the effects of CWI on balance and postural control in healthy adults, justifying the present study. Therefore, the present study aims to investigate the effect of CWI on balance and postural control in healthy individuals.

Method

This review was reported according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [17]. We carried out this review in accordance with Cochrane guidelines [18]. The registered ID of this review in PROSPERO: CRD420251012618.

Search strategy

Articles were selected by searching the databases of Web of Science (WOS), Scopus, PubMed, ScienceDirect, PEDro, and Cochrane Library. The search period was considered from the beginning to Early March 2025.

Studies included aimed to evaluate the effect of CWI on balance and postural control in healthy individuals. The analysis uses the Population, Intervention, Comparison, Outcome, and Study Type (PICOS) framework, which is reported in Table 1.

Relevant keywords were selected from the MeSH terms and refined to find all relevant studies. In addition to the database searches, a hand search (Reference checking and hand searching) was performed to ensure that all relevant studies were identified. Keywords used included:

“Cold water immersion” OR “Cryotherapy” OR “Cold exposure” OR “Ice bath” OR “Cold water therapy” OR “Cooling” AND “Balance” OR “Postural control” OR “Stability” OR “Balance performance” OR “Posture stability” OR “Dynamic balance” OR “Static balance” OR “Postural sway” AND “Young

Table 1 PICOS framework

P: Population	I: Intervention	C: Comparison	O: Outcome	S: Study type
Healthy individuals with no history of injury to the lower and upper limbs, athletes, men and women	Cold water immersion	Placebo, no intervention or traditional recovery methods	Static and dynamic balance, static and dynamic postural control evaluated by any valid instrument and measure	Randomized control trials (RCTs) and quasi-experimental studies

adults” OR “Healthy participants” OR “College students” OR “Young healthy adults” OR “Physically fit individuals” OR “Healthy young people”.

Eligibility criteria

Inclusion criteria include the following: Studies were published in English and were original. The average age of participants was 16 years or older. The control group had to be using traditional recovery methods or no recovery at all.

Exclusion criteria include: Reviews, Theses, case studies, studies with full text unavailable, studies using ice packs, and local cryotherapy.

Study selection

All studies found are stored in EndNote version 20, and after removing duplicates, two researchers independently review the titles and abstracts of each study and their eligibility for inclusion. Next, the full text of the remaining studies is reviewed, and a decision is made on the inclusion and exclusion criteria based on the two researchers' opinions. In the event of disagreement, a third researcher will review the results independently, and the final published report will be based on consensus and assistance from the third researcher.

Data extraction

Data extraction from studies was performed independently by two researchers. The data included the name of the first author and the country of study, year, characteristics of participants (sex, age, number), study objective, Intervention (CWI protocol), Comparison (Control group), outcome measurement, type of balance and postural control assessment, and results. Any disagreement between the two researchers was resolved by the third researcher and re-examination by consensus.

Quality assessment

A critical appraisal scale was used to assess the quality of included studies. Two researchers independently assessed included articles with assessment questions that were based on the main objectives of this systematic review, which were related to the biomechanical assessment of balance and postural control after CWI, as well as those related to the overall study design, validity, statistical analysis, and presentation of results. Each question was scored on a scale from 0 to 2. The total score on this scale ranged from 0 to 36, with higher scores indicating higher quality. In the event of disagreement between the two researchers, a third researcher independently assessed the quality of the study, and the final report was presented by consensus between the three researchers [19].

Risk of bias assessment

The Rob2 scale was a valid and up-to-date tool for assessing the risk of bias in randomized trials. The Rob2 scale was used as a standard to increase the accuracy and validity of findings. The assessment of this scale included five main domains: Randomization, Intervention, Missing Data, Outcome Measurement, and Reporting. For each of the above domains, judgments were made about whether the risk of bias was low, unclear, or high. Finally, the overall score of this scale was reported in three parts: low, moderate, and high, which indicated the overall level of bias in the study in question. In the event of disagreement between the two researchers, a third researcher independently assessed the risk of bias in the study, and the final report was presented by consensus between the three researchers[20].

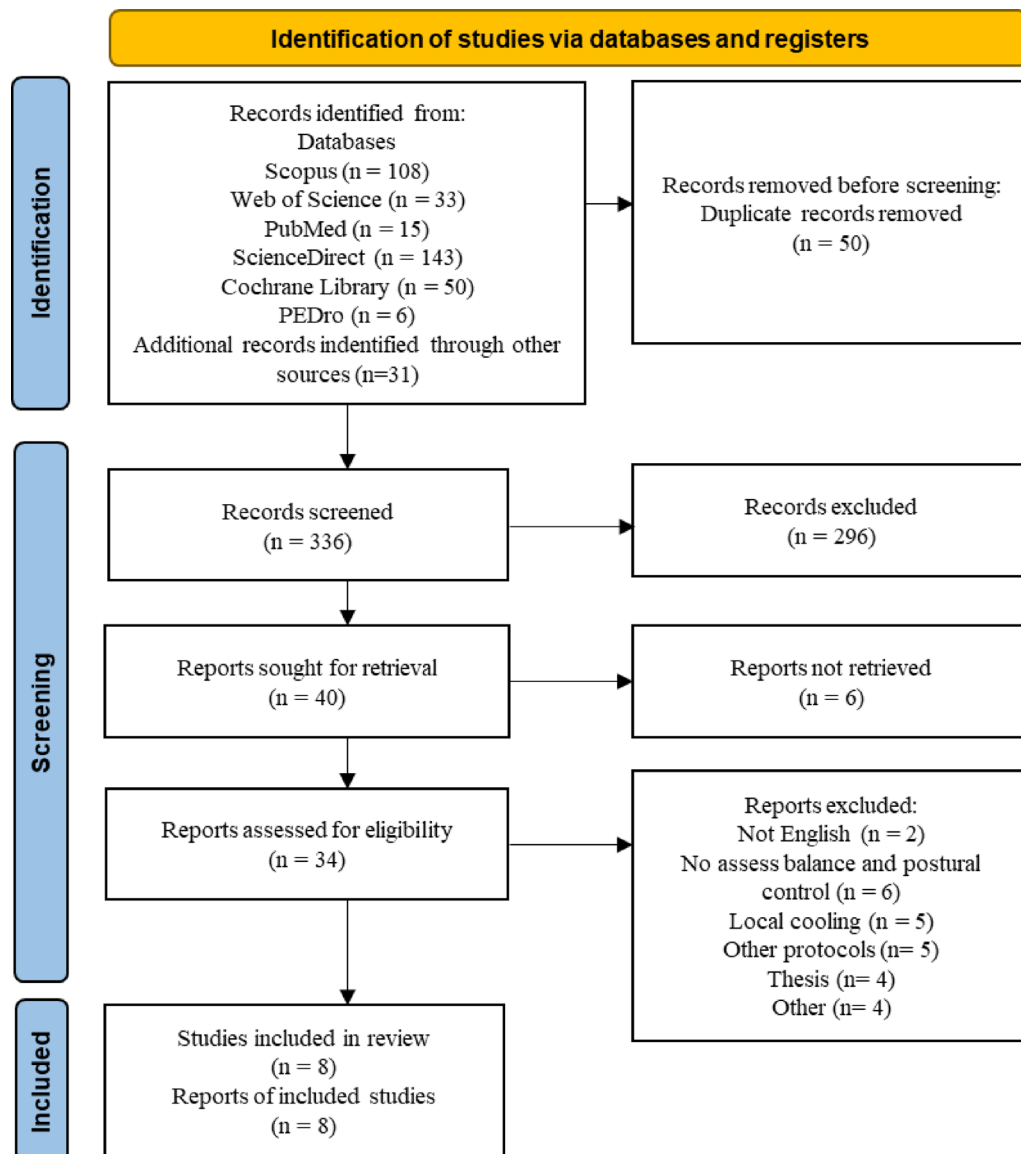
Result

Study selection

Studies were identified by searching six databases (Scopus, Web of Science, PubMed, Science Direct, Cochrane Library, and Pedro) and hand searching. 386 studies were found, of which 336 were included in the title and abstract screening stage after removing duplicate studies. In this stage, studies were filtered according to the inclusion and exclusion criteria, and finally, 34 studies were included in the full-text review stage (consistency rate = 94.64%, $\kappa = 0.76$). The 34 studies were carefully reviewed, and those eligible and relevant to the research objective were considered. Finally, after reviewing 34 studies, 26 were excluded for reasons including lack of publication in English, local cold therapy, other protocols, etc. Finally, eight studies were eligible to be included in this systematic review (consistency rate = 97.22%, $\kappa = 0.92$). Supplementary information is provided in Fig. 1. Complete information about each article is reported in detail in Table 2. Data grouping by duration, temperature, immersion level, number of participants, and gender is also reported in Additional file 1.

Study characteristics

This review included eight studies. A total of 225 participated in these studies. The participants ranged in age from 15.6 to 30.7 years. These studies were conducted between 2014 and 2023. five studies selected water temperatures between 4 and 5 degrees [6, 10, 11, 13, 21] and three studies selected water temperatures between 10 and 12 degrees [3, 22, 23]. five studies reported a immersion level at the waist [3, 11, 13, 22, 23] and three studies reported a immersion level at the ankle [6, 10, 21]. The duration of immersion in all but one study [11] ranged from 10 to 20 degrees. In five studies, the participants were athletes [3, 10, 11, 13, 22]; in three studies, active individuals [6, 21, 23] were the research participants.

**Fig. 1** PRISMA flow diagram

Temperature and duration

The studies were divided into low temperature (4–5°C) and high temperature (10–12°C). Studies conducted at low temperatures by Macedo et al. and Fengping et al. showed a significant effect on balance [10, 13]. In contrast, studies by Oliveira et al., Chow et al., and Douglas et al. did not report a significant effect [6, 11, 21]. Studies conducted at higher temperatures by Afsharnejad et al. reported a positive effect [3], and studies by Claudianeet et al. and Pesenti et al. did not report a positive effect on balance [22, 23].

Immersion level

The only studies that reported a significant effect on balance when immersion was up to the ankle joint were the

study by Macedo et al. [10]. In contrast, the studies by Oliveira et al. and Douglas et al. did not report a positive effect [6, 21]. The studies that used immersion up to the waist and reported a positive effect were the studies by Afsharnejad et al. and Fengping et al. [3, 13], and the studies by Chow et al., Claudianeet et al., and Pesenti et al. did not report a positive effect [11, 22, 23].

Gender characteristics

The only study conducted on women that reported a positive effect was by Afsharnejad et al. [3]. Studies conducted on men, by Fengping et al., and by Macedo et al. reported a positive effect [10, 13, 21]. The study by Douglas et al., the study by Claudianeet et al., and the study by

Table 2 Characteristics of included studies

Study (country/ Year)	Par- ticipants (n = M/F) Age $\pm$ SD	Objective	Intervention (Duration)		Outcome	Type of balance and pos- tural control assessment	results
			EX	CO/EX _{2,3}			
Afsharnezhad et al. [3] (Iran/2017)	(n = 15 F) 18.7 $\pm$ 1.7	Investigate the effects of CWI on anaerobic performance, balance and muscle activation of female karateka	CWI (in a standing position, set at 12 $\pm$ 1 °C for 20 min)	CO: rested passively in a comfortable position	Anaerobic Power, Dynamic Balance and Muscle Activation	Anaerobic power (30 s Wingate test), and dynamic balance (Star-Excursion test)	Dynamic balance declined in both groups; however, the reduction was least pronounced in the CWI group
Oliveira Mianutti et al. [6] (Brazil/2021)	(n = 10 M + 10 F) 21.4 $\pm$ 1.9	Compare the effects of different cryotherapy techniques (CWI, Game Ready, and ice pack) on skin surface temperature, agility, and balance	CWI 4 °C (20 min)	EX ₂ : cryotherapy + Game Ready (20 min) EX ₃ : cryotherapy using an ice pack (20 min)	Balance, Side hop, and SST	Y-balance test and SHT3 (for the analysis of dynamic balance and agility)	CWI group experienced a decline in agility performance. Dynamic balance remained unaffected by any of the treatments
Chow et al. [11] (Hong Kong/2017)	(n = 53 M) 21.6 $\pm$ 2.9	Investigate the effects of post-exercise IWI and RWI on balance control and lower limb proprioception in amateur rugby players	IWI (stood in the water tank, up to the level of the iliac crest, 5 °C) RWI (stood in the water tank, 25 °C) For 1-min	CO: sat on a chair and did not undergo water immersion, 1-Minute	Sensory organization test, Knee joint repositioning error	balance control (SOT and machine measured COG),	A one-minute immersion in either IWI or RWI after exercise did not negatively affect the sensory organization of balance control in rugby players. Additionally, RWI had a less harmful impact on knee joint proprioception compared to IWI following the intervention
Claudianeet al. [23] (Canada/2014)	(n = 26 M) CO: 22.9 $\pm$ 3.1 ICE: 26.8 $\pm$ 3.9	Determine the effects of cryotherapy (whole lower body immersion) on postural sway during bipedal and unipedal quiet standing conditions in healthy males	Set at 11 °C (cold water) sitting in a water tub for 20 min	CO: set at 26 °C (tepid water) sitting in a water tub for 20 min	Postural sway	Postural sway was measured through the COP position while they stood on a force plate during bipedal (70 s) and unipedal (40 s) conditions	Whole lower limb cryotherapy should be applied cautiously prior to performing activities that demand complex postural control
Fengping et al. [13] (China/2023)	(n = 10 M) 22.80 $\pm$ 0.84	Compare the efficacy of CWI and VFR as post-game recovery strategies in amateur basketball players	CWI: set at 5 $\pm$ 1 °C for 12 min VFR: rolling each muscle for 30 s/group $\times$ 3 groups for 12 min	CO: seated for 12 min without any recovery	Vertical Jump Height, Dynamic Balance, reaction time	Reaction time (Pavigym agility response system) dynamic balance (Y balance test)	Although CWI initially exhibited adverse effects, its recovery benefits became more pronounced and sustained over time. In contrast, VFR demonstrated the most effective immediate impact on lower limb recovery following the game
Douglas et al. [21] (United States/2013)	(n = 20 M) 23.9 $\pm$ 2.0	Determine the effect of cryotherapy applied to the ankle on static and dynamic standing balance	Received IWI 4.4 °C of the foot and ankle for 15 min immediately before balance testing	CO: condition completed at room temperature	Static and dynamic balance	BBS (measure balance during static and dynamic)	The static balance indices did not show statistically significant differences between the post-cryotherapy and control conditions; however, cryotherapy applied to the ankle negatively affected the mediolateral component of dynamic balance following IWI

Table 2 (continued)

Study (country/ Year)	Par- ticipants (n = M/F) Age $\pm$ SD	Objective	Intervention (Duration)		Outcome	Type of balance and pos- tural control assessment	results
			EX	CO/EX _{2,3}			
Macedo et al. [10] (Brazil/2015)	(n = 40 M) (20 Ath- letes + 20 Non-ath- letes) Athletes: 22.3 $\pm$ 5.43 Non-ath- letes: 20.65 $\pm$ 1.71	Evaluate the effects of CWI on the EMG response of the lower limb and balance during unipodal jump landing	All volunteers remained for 20 min with their ankle immersed in cold-water 4°C, and were re- evaluated im- mediately post and after 10, 20 and 30 min of reheating	ADL	Flight time, GRF, speed of centre of pressure oscillation muscle recruitment	The EMG analysis and force platform	CWI reduced flight time and GRF, and altered balance, particularly affecting stability in the anterior–posterior direction
Pesenti et al. [22] (Brazil/2019)	(n = 28 M) (CWI: 7, TWI: 7, AR: 7 and CO: 7) CWL: 16.5 $\pm$ 0.9 TWI: 16.8 $\pm$ 0.8 AR: 16.2 $\pm$ 0.4 CO: 17.2 $\pm$ 0.9	To analyze the effects of CWI on delayed-onset muscle soreness, muscle recruit- ment, and postural control in soccer players	CWI: set at 10°C for 10 min TWI: Water immer- sion at room temperature AR: used a tread- mill for 10 min at a light and comfortable walking pace	CO: remain seated and relax for 10 min in a comfort- able chair	Pain, Muscle recruitment, Postural stability	Force platform (measure Postural stability)	Postural control during the kicking action did not differ significantly between the various time intervals or inter- vention conditions

ADL: Activities of daily living, AR: Active Recovery, BBS: Biodex Balance System, CGRC: Cryotherapy + Game Ready® compression, CO: Control, COG: center of gravity, COP: center of pressure, CWI: Cold Water Immersion, EMG: electromyographic, GRF: Ground reaction force, IP: Ice Pack, IWI: Ice-water immersion, ML: Medio-Lateral, RWI: Room-temperature water immersion, SHT: Side Hop Test, SOT: sensory organization test, SST: superficial skin temperature, TWI: Thermoneutral Water Immersion, VFR: Vibration foam rolling.

Pesenti et al. did not report a positive effect on balance [21–23].

Assessment tools

Studies that reported positive results were the study by Afsharnejad et al. using the SEBT test [3], the study by Fengping et al. using the Y balance test [13], and the study by Macedo et al. using the Force plate tool [10]. While studies that had conflicting results were the study by Oliveira et al. using the Y balance [6], the study by Chow et al. using the SOT [11], the study by Douglas et al. using the BBS [21], the studies by Claudianeet et al. and Pesenti et al. using the Force plate [22, 23].

Quality assessment

The quality assessment of the studies is shown in Table 3. Overall, the studies were of good quality. The study by Afsharnejad et al. had the lowest quality among the available studies, while the study by Chow et al. had the highest quality among the studies. The average quality of the studies was 29.5 out of 36, indicating that the studies had a good quality level. In the quality assessment of the study, questions 5 and 11 (Was the sample size used justified? Were the assessors blinded? ") had the lowest scores

among the studies. In original studies, justifying sample size is important because it improves the accuracy of results and generalizability, reduces bias, and is usually suggested through power analysis or sample size estimation. On the other hand, enhancing blinding of assessors is also important: in original studies, it helps reduce measurement bias and increase data validity. Compliance with these two areas is rarely done in some studies due to reporting constraints, timing, and fewer resources.

Risk of bias

The details of the risk of bias for each study are shown in Fig. 2. 37.5% of the studies displayed a low risk of bias, with 37.5% showing some concerns, and 25% classified as having a high level of bias. The highest risk of bias was found in the randomization process, while all studies had a low level of bias concerning missing outcome data.

Discussion

This systematic review aimed to investigate the effects of CWI on balance and postural control in healthy young adults.

This systematic review reported findings from eight studies that compared the effects of CWI on postural

Table 3 Summary of quality assessment results for each study

Study	Q ₁	Q ₂	Q ₃	Q ₄	Q ₅	Q ₆	Q ₇	Q ₈	Q ₉	Q ₁₀	Q ₁₁	Q ₁₂	Q ₁₃	Q ₁₄	Q ₁₅	Q ₁₆	Q ₁₇	Q ₁₈	Total
Afsharnejad et al. [3]	2	2	2	0	1	2	1	2	2	2	0	1	2	0	2	2	0	2	25
Oliveira Mianutti et al. [6]	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	2	2	32
Chow et al. [11]	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	35
Claudianet al. [23]	2	2	2	0	0	2	2	2	2	2	0	2	2	2	2	2	0	2	28
Fengping et al. [13]	2	2	2	1	0	2	1	2	1	2	0	2	2	0	2	2	2	2	27
Douglas et al. [21]	2	2	2	1	0	1	2	2	2	1	0	1	2	2	2	2	2	2	28
Macedo et al. [10]	2	2	2	2	0	2	2	2	2	2	0	2	2	2	2	2	0	2	30
Pesenti et al. [22]	2	2	2	2	2	2	2	2	2	2	1	2	2	0	2	2	0	2	31

Questions were scored as follows: 2 = Yes; 1 = Limited detail; 0 = No. 1. Are the research objectives clearly stated? 2. Is the study design clearly described? 3. Were participant characteristics adequately described? 4. Was sampling methodology appropriately described? 5. Was sample size used justified? 6. Was equipment design and set up clearly described? 7. Were postural control assessments clearly defined? 8. Was the intervention clearly defined? 9. Was somatosensation adequately measured? 10. Were the cooling and control conditions randomized or counterbalanced? 11. Were the assessors blinded? 12. Were the analytical techniques clearly described? 13. Were appropriate statistical analysis methods used? 14. Is the actual probability value reported for main outcomes? 15. Were the main outcomes of the study clearly stated? 16. Were key findings supported by the results? 17. Were limitations of the study clearly described? 18. Were conclusions drawn from the study clearly stated?

control versus other interventions or controls. Each study reported different results, such as the study by Afsharnejad et al. (2017), Fengping et al. (2023), and Macedo et al. (2015), all of which reported positive effects of CWI interventions on balance and postural control [3, 10, 13]. On the other hand, studies by Oliveira Mianotti et al. (2021), Chow et al. (2017), Claudianit et al. (2014), Douglas et al. (2013), and Pesanti et al. (2019), reported no significant effects of CWI on balance and postural control [6, 11, 21–23].

CWI can have many positive effects on balance and postural control in both men and women [3, 13]. Being in a cold water environment reduces gravity and creates a feeling of lightness, which can help improve balance. This exercise also stimulates the parasympathetic nervous system and reduces muscle inflammation, which in turn relaxes muscles and improves postural control [7]. In addition, CWI increases concentration and enhances depth perception and body awareness, which are also important in improving posture and balance control. Regarding gender differences, hormones play an important role in the body's response [24]. In women, the hormone estrogen, which plays an important role in maintaining a healthy nervous system and balance, may make the effects of immersion faster and more effective. In contrast, in men, whose testosterone levels and muscle structure are dominant, differences in the intensity and speed of recovery may be observed [25].

However, it should be borne in mind that exposure to cold water can cause a physiological stress response known as the cold shock response; this reaction involves a sudden increase in heart rate, blood pressure, and breathing, and may be dangerous for some people, especially those with cardiovascular problems [26]. Also, prolonged immersion in icy water can lead to hypothermia (low body temperature), affecting muscle and nervous system function, impairing balance and postural control [27]. Different people may react differently to CWI; its effectiveness also depends on factors such as age, overall health, and a person's tolerance to cold [3, 24].

In examining the effects of CWI on balance, evidence suggests that there is no simple, linear relationship between temperature, duration, and depth of immersion and outcomes. Different studies using similar temperatures (e.g., 4 or 12°C), similar durations (e.g., 20 min), or similar immersion levels (e.g., ankle or waist) have yielded conflicting results [6, 10]. This suggests that the observed effects cannot be explained by these variables alone and are likely influenced by other factors, such as individual characteristics of the participants (e.g., training status, gender, or fitness level) and different assessment methods [3, 23]. Comparative studies have shown that athletes respond differently to CWI than active individuals and are more likely to show significant balance changes [3, 10,



Fig. 2 Risk of bias of the studies

11]. Therefore, analyzing the effects of CWI on balance requires attention to the complex interaction between variables and more careful control of intervening factors.

During immersion, body temperature gradually decreases and the skin surface cools due to heat exchange with water; the longer the immersion, the deeper the temperature drop and the colder the skin, which may reduce cutaneous blood flow and create a sensation of coldness [6]. After exit, time is required to restore temperature and skin heat levels, depending on the magnitude and duration of the immersion; prolonged immersion or icy water lengthens the recovery process and may increase energy expenditure and physiological stress [28]. Consequently, careful management of immersion time and water temperature is essential for the safe and effective use of this technique to prevent hypothermia and maintain the individual's health [28].

At lower temperatures (e.g., 5–10 °C), immersion is commonly used to reduce inflammation, muscle soreness, and accelerate recovery [11, 13, 22]. These temperatures may increase adverse effects such as nerve stimulation, decreased nerve conduction velocity (NCV), and the risk of superficial nerve damage, especially if the

duration of immersion is prolonged (greater than 10–15 min) [29, 30]. Conversely, immersion at more moderate temperatures (e.g., 11–15°C) is more effective in reducing pain and inflammation and has fewer adverse effects. At higher temperatures, although less chilling, it may be less effective in reducing inflammation. Overall, the best results are usually achieved at moderate temperatures and for limited periods of time, depending on the specific goal [3, 23].

During immersion, CWI induces a complex temporal pattern on balance: initially, rapid sympathetic activation followed by later adaptation [2]; in the short term, exposure to low temperature triggers swift sympathetic nervous system responses with elevated peripheral catecholamines (noradrenaline, dopamine), potentially impairing motor control and sensory integration and causing temporary balance instability [31]. Tissue cooling also reduces NCV, impairing proprioception and neuromuscular responsiveness [32]. Additional effects include decreased metabolic activity, hormonal changes, and altered limb blood flow. In the long term, adaptation shifts toward parasympathetic activity, stabilizing blood pressure and improving steady-state control. Through

baroreceptor feedback and reductions in inflammatory markers (IL-6, TNF- α , CK), these adaptations promote nervous and hormonal system balance and help prevent postural instability [2, 33].

Fatigue from sports training and competitions hurts physical factors (delayed muscle soreness, decreased strength and endurance, etc.) and mental factors (increased tension, mood, motivation, etc.) [34]. Choosing appropriate recovery methods can solve these issues, prevent injuries, reduce the gap between training and competitions, and improve performance [35, 36]. One of the hydrotherapy methods is immersion in cold water, a common and popular method used by the general public for faster healing and recovery after exercise [9].

In contrast, applying specific protocols such as walking or fatigue before immersion helps to focus and target the training and allows for a more accurate comparison of results [3, 11]. Previous training, such as walking, can prepare the nervous system and muscles and create the best state for assessing balance and posture. In contrast, applying specific protocols such as walking or fatigue before immersion helps to focus and target the training and allows for a more accurate comparison of results [3, 11]. Previous training, such as walking, can prepare the nervous system and muscles and create the best state for assessing balance and posture. At the same time, fatigue can reduce muscle control and affect the ability of an individual to stabilize posture [6].

In the study by Fengping et al., the duration of CWI was 12 min, and in the other two studies, the immersion time was 20 min. Various studies suggest that short-term immersions and, conversely, moderate immersions (11–15 min) have less effect [11]. In contrast, longer immersions, for which definitive results are still limited, may have adverse and positive effects. In addition, very long immersions at low temperatures, for 20 min, can cause superficial nerve irritation and damage and negatively affect neural function [27]. Evidence also suggests that faster cooling in cooling processes provides the best results, although there are limitations in determining the optimal limit and size [10].

The lack of effectiveness in the Claudianit et al. (2014) and Douglas et al. (2013) studies may be because a pre-immersion protocol was not provided, and the desired variables were examined before and after immersion, unlike in other studies [21, 23]. In Oliveira Mianotti et al. (2021) and Pesanti et al. (2019), the protocol volume was smaller than in other studies [6, 22]. Additionally, although a fatigue protocol was applied by Chow et al. (2017), the immersion duration was very short [11]. This variability across studies may have led to such inconsistent results. Differences in the number of participants and the characteristics of the population under study are also important factors influencing the results. In the

absence of a specific protocol, CWI is performed freely and without specific planning, which makes the results of the assessment of posture and balance of an individual variable unpredictable [21]. In this case, individual differences are more influential, and it is impossible to easily assess the effect of an individual's previous training or condition on balance and postural control. Also, the individual's stress and reactions to immersion may be different each time, which complicates the assessment process and may affect performance and postural control ability [2, 7].

In the study by Bezoglov et al., recovery methods such as sauna baths, massage, and sleep were most commonly used among professional athletes, often accompanied by napping, while CWI and compression garments were less common. These methods were more commonly used by high-level endurance athletes [37]. In the study by Stella et al., results showed that sports massage performed in a cold environment after uphill-downhill running may reduce the effects of fatigue on balance and perceived pain and may be helpful for improving recovery after intense exercise [38]. With these considerations in mind, the choice between CWI and other recovery methods should be based on the type of training, individual needs, and exercise preferences of each individual. However, overall, both methods can play an important role in recovery and fitness programs [2, 3, 11].

Limitations of this review include the lack of blinding of the assessors, which may have biased the reporting of the final results and created differences that were not real, and the small sample size reduces the generalizability of the results, as well as increasing the randomization error and reducing the statistical power. The variety in the types of assessments and different tools and devices used to assess the generalizability of the findings limited the study and prevented a meta-analysis. One of the key points that can lead to inconsistent results among studies is the lack of blinding of the assessors and the small sample size. Variability in the type of immersion can confound decisions regarding the best method. Water temperature and immersion duration are also important factors that play an important role in the final decision. These studies used different methods. The studies did not examine the protocols over a long period, and only the acute effect of this factor was assessed. Therefore, investigating the impact of continuous and long-term use followed by a follow-up period could provide a clearer view for trainers and specialists.

It is suggested that future studies consider the hypothesis that the dose–response to CWI, in combination with temperature and duration, differs significantly among different populations (e.g., by gender, fitness level, or age). These differences could narrow the optimal region, thereby limiting or enhancing the interpretation

of between-group effects. Therefore, these hypotheses should be considered in future studies.

Conclusion

This review suggests that cold-water immersion (CWI) can improve balance and postural control in healthy young adults, particularly when carefully following temperature, duration, and protocol. The available evidence indicates a positive potential for reducing inflammation, increasing focus, and enhancing body awareness; however, some studies have not found significant effects, likely due to differences in methodology and protocols. Systematic and planned sampling in study design plays a crucial role in drawing reliable conclusions, and larger studies with more extended follow-up periods are needed to assess the efficacy and sustainability of the effects definitively. Considering the discussed benefits and limitations, CWI can be regarded as an effective adjunct to exercise recovery programs. However, its use should be approached with caution, and individual factors and medical conditions should be taken into account.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13018-025-06398-4>.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Acknowledgements

Not applicable

Author contributions

All authors contributed equally to the preparation of this manuscript. All authors read and approved the final manuscript.

Funding

No funding was acquired for this research.

Data availability

All data generated or analysed during this review are included in this published article [and its supplementary information files].

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Received: 7 August 2025 / Accepted: 5 October 2025

Published online: 03 November 2025

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