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Effects of Cold Water Immersion and Heat Exposure on Post-Exercise Recovery and Training Adaptations: A Narrative Review

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Abstract

Background: Cold water immersion (CWI) and heat exposure, including hot water immersion (HWI) and sauna bathing, are commonly used to enhance post-exercise recovery. Although both interventions are widely applied in sport, they elicit distinct physiological responses and may differently influence recovery and training adaptations.

Aim: This narrative review aimed to summarize current evidence on the effects of CWI and heat exposure on post-exercise recovery and training adaptations, focusing on physiological mechanisms and practical applications.

Materials and methods: A narrative review was conducted using publications retrieved from PubMed, Scopus, Web of Science, and Google Scholar. Original studies, randomized controlled trials, systematic reviews, and meta-analyses investigating CWI, HWI, and sauna bathing were included. Priority was given to studies published between 2023 and 2025, with earlier landmark studies providing physiological context.

Results: Current evidence indicates that CWI effectively reduces delayed-onset muscle soreness and perceived fatigue, supporting short-term recovery. However, regular post-exercise use after resistance training may attenuate hypertrophic adaptations by suppressing anabolic signaling. In contrast, HWI and sauna bathing promote thermoregulatory adaptations, increase plasma volume, and improve heat tolerance, although evidence for post-exercise recovery remains limited. Their effectiveness depends on training goals, exercise modality, timing, and treatment protocol.

Conclusions: Cold and heat exposure should be regarded as complementary rather than competing recovery strategies. CWI is primarily supported for short-term recovery, whereas HWI appears most beneficial for enhancing thermoregulatory adaptations and preparation for exercise in hot environments. Thermal therapies should be individualized according to the athlete's training goals and training phase.

Keywords: cold water immersion; hot water immersion; heat exposure; sauna; exercise recovery; exercise adaptations; sports performance.

1. Introduction

Intense physical exertion leads to fatigue, exercise-induced muscle damage, and a temporary decline in exercise capacity. Training loads may also result in delayed-onset muscle soreness (DOMS), which is often accompanied by impaired neuromuscular function and heightened perceptions of fatigue (Moore et al., 2023). Effective recovery is a fundamental component of the training process, as it helps maintain the quality of subsequent training sessions, reduces the risk of excessive fatigue and overuse, and supports the long-term development of exercise capacity. Consequently, considerable attention has been devoted to strategies that optimize post-exercise recovery, with thermal interventions attracting particular interest.

The most commonly used methods include cold water immersion (CWI), hot water immersion (HWI), and sauna bathing (Ihsan et al., 2021; Ahokas et al., 2025). Although all are intended to enhance post-exercise recovery, these interventions elicit distinct physiological responses. Cold water immersion decreases tissue temperature, alters blood flow, and modulates the inflammatory response (Ihsan et al., 2021). In contrast, heat exposure increases core body temperature, activates thermoregulatory mechanisms, and stimulates cellular responses associated with heat stress, including the expression of heat shock proteins (Normand-Gravier et al., 2025). These physiological differences suggest that the effects of cold and heat extend beyond short-term recovery and may also influence the mechanisms responsible for long-term training adaptations.

The strongest scientific evidence currently centers on cold water immersion. Systematic reviews and meta-analyses consistently show that CWI effectively reduces delayed-onset muscle soreness, decreases perceived fatigue, and may accelerate recovery of selected performance parameters after strenuous exercise (Moore et al., 2023; Wang et al., 2025). However, growing evidence indicates that regular use of CWI after resistance training may attenuate muscle hypertrophy by suppressing anabolic signaling pathways and satellite cell activity (Roberts et al., 2015; Piñero et al., 2024). These findings have reshaped perceptions of recovery interventions, emphasizing that strategies that enhance short-term recovery are not necessarily optimal for maximizing long-term training adaptations (Ihsan et al., 2021).

Recently, interest has grown in using heat exposure to aid post-exercise recovery and support training adaptations. New evidence indicates that regular use of hot water immersion (HWI) or sauna bathing may foster beneficial thermoregulatory changes, boost plasma volume, and enhance exercise tolerance in hot conditions (Zurawlew et al., 2015; Solomon and Laye, 2025). Greater focus is now on the possible effects of heat therapies on recovery, heat shock protein activation, and tissue remodeling mechanisms (Normand-Gravier et al., 2025). However, compared to cold water immersion (CWI), there are fewer studies on these effects, and their results are often inconsistent (Ahokas et al., 2025).

Despite the rapid growth of research on thermal therapies, it remains unclear how individual interventions influence the balance between post-exercise recovery and the development of training adaptations. Most available studies have focused on specific physiological outcomes, such as delayed muscle soreness, markers of muscle damage, or exercise tolerance in hot environments, whereas comparatively little attention has been paid to a comprehensive comparison of how cold and heat impact recovery and long-term adaptations (Ahokas et al., 2025; Poręba et al., 2025). Consequently, selecting the most appropriate recovery strategy in sports practice remains challenging and should consider not only the immediate benefits but also the potential long-term effects on training adaptations.

No single recovery strategy appears universally effective across all training contexts. Instead, there is growing emphasis on individualizing recovery interventions based on the type of exercise, the stage of the training cycle, and the primary training objective (Poręba et al., 2025). For example, athletes engaged in resistance training may prioritize maximizing hypertrophic and strength adaptations. In contrast, endurance athletes or those preparing for competition in hot environments may benefit more from interventions that promote thermoregulatory and endurance adaptations. Therefore, the effectiveness of thermal therapies should be evaluated not only by their effects on post-exercise recovery but also by their influence on long-term training outcomes (Zurawlew et al., 2015; Solomon and Laye, 2025).

This narrative review aimed to summarize the current state of knowledge on the effects of cold water immersion and heat exposure on post-exercise recovery and training adaptations. Particular attention was paid to the physiological mechanisms underlying thermal therapies, the comparative effectiveness of cold- and heat-based interventions on key recovery outcomes, and their potential influence on muscular, performance, and thermoregulatory adaptations. Furthermore, this review sought to discuss the practical implications of thermal therapies for training planning and to identify areas requiring further investigation.

2. Materials and Methods

This narrative review aimed to critically summarize current evidence on the effects of post-exercise thermal therapies on post-exercise recovery and training adaptations. A literature search was conducted using the PubMed, Scopus, Web of Science, and Google Scholar databases. The search was conducted between January and February 2026 using combinations of the following keywords: *cold water immersion*, *hot water immersion*, *sauna bathing*, *heat therapy*, *exercise recovery*, *exercise adaptation*, *athletic performance*, *muscle damage*, and *endurance training*.

The review primarily included original experimental studies, randomized controlled trials, systematic reviews, and meta-analyses examining the effects of cold-water immersion, hot-water immersion, and sauna bathing on post-exercise recovery and training adaptations. Particular emphasis was placed on publications from 2023 to 2025 to reflect the most recent evidence. However, landmark earlier studies that have substantially contributed to the current understanding of thermal therapies in sport were also included where appropriate.

Studies were selected for their relevance to this review's objectives. The review included publications addressing both the physiological mechanisms underlying thermal therapies and their effects on post-exercise recovery, muscular performance, and thermoregulatory adaptations. To provide a balanced overview of the available evidence, studies reporting beneficial effects as well as those with inconsistent or contrasting findings on cold- and heat-based interventions were considered.

The review focused on identifying the main directions of current research, evaluating the quality of the available evidence, and critically synthesizing findings relevant to the practical application of thermal therapies in sport. Particular attention was given to comparing the effects of cold- and heat-based interventions on post-exercise recovery and long-term training adaptations. Owing to the narrative design of this review, no formal assessment of methodological quality or risk of bias was conducted, as these procedures are characteristic of systematic reviews.

3. Mechanisms of Action of Thermal Therapies

3.1. Mechanisms of Action of Cold Water Immersion

Cold water immersion (CWI) is one of the most widely used strategies to support post-exercise recovery in both competitive and recreational sports. Despite its widespread use, the physiological mechanisms underlying its effects have not yet been fully elucidated. Recent studies suggest that the effects of CWI result from the interaction among hemodynamic, neural, and molecular responses, with the relative contributions of these responses depending on the type of exercise performed, the cooling protocol applied, and the timing of outcome assessment (Ihsan et al., 2021).

The immediate physiological response to cold water immersion is a rapid drop in skin temperature and, with sufficient exposure, a decline in muscle temperature. The extent of tissue cooling depends primarily on water temperature, immersion duration, immersion depth, and individual characteristics such as subcutaneous fat thickness. Cold exposure triggers a vascular response marked by vasoconstriction of superficial blood vessels and transient changes in blood flow. However, recent evidence suggests that these hemodynamic changes are more complex than initially assumed and do not fully account for the physiological effects observed after CWI (Ihsan et al., 2021).

One of the best-established physiological mechanisms of CWI is its effect on the nervous system. Reduced tissue temperature decreases nerve conduction velocity and lowers the excitability of peripheral nociceptors, thereby reducing pain perception. This mechanism is considered one of the most plausible explanations for the consistent reduction in delayed-onset muscle soreness (DOMS) observed after strenuous exercise. Importantly, reduced pain perception should not be interpreted as evidence of accelerated muscle repair, as analgesic effects do not necessarily reflect faster restoration of muscle tissue (Ihsan et al., 2021; Xiao et al., 2023).

For many years, attenuation of the exercise-induced inflammatory response was considered the primary mechanism underlying the effects of CWI. More recent evidence, however, suggests a more nuanced interpretation. Cold exposure appears to modulate specific components of the inflammatory response, although the magnitude and physiological significance of these changes remain uncertain. Importantly, inflammation is an essential component of tissue repair and adaptation following exercise. Consequently, available evidence does not support the view that modulation of inflammation is the sole or dominant mechanism responsible for the beneficial effects of CWI (Ihsan et al., 2021).

Increasing attention has been directed toward the molecular responses induced by CWI. Experimental studies suggest that post-exercise muscle cooling may influence the expression of genes associated with metabolic adaptations, including increased expression of peroxisome proliferator-activated receptor gamma coactivator-1 alpha (PGC-1α), a key regulator of mitochondrial biogenesis (Ihsan et al., 2014). Conversely, studies involving resistance-trained individuals have demonstrated that regular use of CWI following resistance exercise may attenuate activation of the mammalian target of rapamycin (mTOR) signaling pathway and reduce satellite cell activity, both of which play central roles in skeletal muscle hypertrophy. These findings indicate that the influence of CWI on training adaptations depends largely on the type of exercise performed and should not be evaluated solely on its short-term recovery effects (Roberts et al., 2015; Fyfe et al., 2019).

3.2. Mechanisms of Action of Heat Exposure

Heat exposure, primarily through hot water immersion (HWI) and sauna bathing, elicits a complex physiological response involving thermoregulatory, cardiovascular, and cellular mechanisms. Unlike cold water immersion, which primarily lowers tissue temperature and modulates recovery-related physiological responses, heat-based interventions raise core body temperature and induce controlled heat stress. This stimulus activates multiple physiological pathways that maintain thermal homeostasis and, with repeated application, promotes adaptations that enhance tolerance to exercise in hot environments (Hussain and Cohen, 2018; Zurawlew et al., 2015; Solomon and Laye, 2025).

The initial response to elevated core temperature is activation of thermoregulatory mechanisms controlled by the hypothalamus. Increased body temperature induces cutaneous vasodilation, increases skin blood flow, and stimulates sweating, thereby promoting heat dissipation. Simultaneously, heart rate and cardiovascular strain rise, allowing the body to maintain adequate perfusion of the skin and exercising muscles despite elevated thermal stress. These responses constitute the fundamental physiological mechanisms that maintain thermal balance during heat exposure (Hussain and Cohen, 2018).

Repeated heat exposure induces adaptations characteristic of heat acclimation. The most consistently reported changes include increased plasma volume, an earlier onset of sweating, a lower core temperature threshold for initiating sweating, and a lower core temperature during exercise in hot environments. Together, these adaptations reduce physiological strain and improve exercise tolerance under heat stress. Zurawlew et al. (2015) demonstrated that several consecutive days of post-exercise hot water immersion can induce physiological adaptations comparable to those observed with conventional heat acclimation protocols. Subsequent studies have confirmed similar responses in both recreationally active individuals and competitive athletes (Zurawlew et al., 2015; Zurawlew et al., 2018; Solomon and Laye, 2025).

Systemic adaptations are accompanied by cellular responses that are a key component of the body's adaptation to heat stress. One of the best-characterized mechanisms is the increased expression of heat shock proteins (HSPs). These proteins function as molecular chaperones by stabilizing protein structure, preventing denaturation, and facilitating the repair and refolding of damaged proteins. Their expression increases in response to various forms of cellular stress, including heat stress, and is considered a fundamental mechanism underlying cellular adaptation to repeated heat exposure (Hussain and Cohen, 2018; Normand-Gravier et al., 2025).

Activation of HSPs is part of a broader cellular response that enhances resistance to subsequent stressors. Recent evidence suggests that heat exposure may also modulate cellular homeostasis, inflammatory signaling, and mechanisms involved in tissue protection and repair. Nevertheless, most evidence describing these mechanisms comes from experimental and preclinical studies, and their relevance to post-exercise recovery and athletic performance requires further confirmation in well-designed human studies (Normand-Gravier et al., 2025).

Cardiovascular adaptations also substantially contribute to the physiological effects of repeated heat exposure. Plasma volume expansion helps maintain stroke volume, improves heat transfer from the body's core to the skin, and reduces cardiovascular strain during exercise in hot environments. Similar adaptations have been observed after repeated sauna bathing and post-exercise HWI protocols, suggesting that different forms of passive heat exposure elicit comparable physiological responses (Scoon et al., 2007; Zurawlew et al., 2015; Solomon and Laye, 2025).

4. Effects of Thermal Therapies

4.1. Cold Water Immersion (CWI)

Cold water immersion (CWI) is among the most extensively studied post-exercise recovery interventions and has been widely used in both competitive and recreational sports for many years. Its popularity stems largely from its potential to reduce post-exercise fatigue and support recovery between successive training sessions or competitions. Over the past decade, the evidence base supporting CWI has grown substantially, with numerous randomized controlled trials, systematic reviews, and meta-analyses evaluating its effectiveness (Moore et al., 2023; Xiao et al., 2023; Wang et al., 2025). Current evidence indicates that the effectiveness of CWI depends on several factors, including the type of exercise performed, the recovery outcomes assessed, and the characteristics of the cooling protocol.

4.1.1. Effects on Delayed Onset Muscle Soreness and Markers of Muscle Damage

The most consistent and well-established effect of CWI is reduced delayed-onset muscle soreness (DOMS). Recent meta-analyses show that cold-water immersion after strenuous exercise significantly reduces muscle soreness, particularly during the first 24–72 hours post-exercise (Moore et al., 2023; Xiao et al., 2023; Wang et al., 2025). Beneficial effects have been observed after both endurance and resistance exercise, suggesting that the analgesic effects of CWI are broadly applicable across exercise modalities (Moore et al., 2023; Xiao et al., 2023). These effects are primarily attributed to reduced tissue temperature and decreased nerve conduction velocity, which lower pain perception (Ihsan et al., 2021). Importantly, reduced pain perception should not be interpreted as evidence of accelerated muscle repair, as analgesic effects do not necessarily reflect faster restoration of damaged muscle tissue (Ihsan et al., 2021).

The consistency of these findings across multiple systematic reviews indicates that reducing DOMS is the most robust and reproducible benefit associated with CWI. Although the magnitude of the effect varies by cooling protocol and exercise modality, improvements in perceived muscle soreness have consistently been reported after endurance, team-sport, and resistance-based exercise (Moore et al., 2023; Wang et al., 2025). Consequently, CWI remains one of the few post-exercise recovery interventions supported by high-quality evidence for reducing post-exercise muscle soreness.

Evidence on markers of muscle damage, particularly creatine kinase (CK) activity, is considerably less consistent. Although some studies have reported moderate reductions in CK concentrations after CWI, these effects are substantially more variable than those observed for DOMS (Xiao et al., 2023; Wang et al., 2025). Such discrepancies may reflect differences in exercise modality, timing of blood sampling, and characteristics of the cooling protocol (Wang et al., 2025). Moreover, CK exhibits considerable inter-individual variability and does not always accurately reflect the extent of muscle damage or the rate of functional recovery (Moore et al., 2023; Xiao et al., 2023). Similar findings were reported by Horgan et al. (2024), who observed reduced CK concentrations after both CWI and HWI compared with a control condition, with a greater reduction after HWI. Overall, current evidence suggests that thermal interventions may influence CK activity; however, the magnitude and practical significance of these changes depend on the intervention applied, the exercise performed, and the experimental conditions.

4.1.2. Effects on Fatigue and Recovery

The beneficial effects of CWI have also been demonstrated with respect to perceived fatigue. Recent meta-analyses consistently report that athletes undergoing CWI experience lower perceived fatigue and reduced ratings of perceived exertion in the hours after strenuous exercise (Moore et al., 2023; Xiao et al., 2023). These findings are particularly relevant in sports with congested competition schedules or high training frequency, where rapid recovery between successive bouts of exercise is essential. Nevertheless, improvements in subjective recovery are not consistently accompanied by corresponding gains in objective measures of physical performance, indicating that enhanced perceptions of recovery do not necessarily reflect complete physiological restoration (Moore et al., 2023; Gustafsson et al., 2025).

The effects of CWI on objective recovery outcomes are less consistent than those observed for delayed-onset muscle soreness. Although several studies have reported faster recovery of selected neuromuscular performance measures, such as jump height and muscle power, the available findings are not entirely consistent. Moore et al. (2023) reported that CWI outperformed active recovery, contrast water therapy, and warm water immersion for selected recovery outcomes in some analyses. However, these advantages were not consistently observed across all performance measures. Similarly, Gustafsson et al. (2025) found no superiority of either CWI or HWI over placebo for recovery following a simulated soccer match or for subsequent training adaptations.

The discrepancy between subjective and objective recovery outcomes warrants particular attention. Athletes frequently report feeling less fatigued and better prepared to perform after CWI, despite modest or inconsistent improvements in objective performance measures. This distinction is of considerable practical importance, as perceived readiness may positively influence confidence, motivation, and the ability to tolerate repeated training sessions or competitions, even when physiological recovery remains incomplete (Moore et al., 2023; Gustafsson et al., 2025).

4.1.3. Effects on Training Adaptations

The effects of CWI extend beyond short-term recovery and may also influence training adaptations. This issue has received considerable attention in recent years, particularly in resistance training. Experimental studies indicate that regular use of CWI after resistance exercise may attenuate anabolic signaling, reduce satellite cell activity, and limit skeletal muscle hypertrophy (Roberts et al., 2015; Fyfe et al., 2019). More recent evidence supports these observations. A meta-analysis by Piñero et al. (2024) reported that regular post-exercise CWI may yield smaller gains in muscle mass than other recovery strategies. In contrast, Grgic's (2023) meta-analysis found that evidence regarding strength development is less consistent and considerably weaker than that for muscle hypertrophy. Collectively, these findings suggest that the potential adverse effects of regular CWI are primarily associated with hypertrophic adaptations, whereas its influence on maximal strength remains inconclusive.

A different pattern emerges after endurance exercise. Current evidence does not indicate that regular use of CWI attenuates endurance-related adaptations to the same extent as it does after resistance training. Some experimental studies suggest that post-exercise cooling may increase expression of peroxisome proliferator-activated receptor gamma coactivator-1 alpha (PGC-1α), a key regulator of mitochondrial biogenesis (Ihsan et al., 2014). However, there is currently no convincing evidence that this molecular response translates into superior long-term endurance adaptations. As highlighted by Ihsan et al. (2021), the physiological significance of increased PGC-1α expression remains uncertain and requires further investigation. These findings suggest that the effects of CWI on training adaptations depend largely on the type of exercise performed and the physiological pathways involved.

Importantly, current evidence does not indicate that the effects of CWI on training adaptations are uniformly detrimental. Although attenuation of muscle hypertrophy has been consistently reported after resistance training, comparable reductions in maximal strength or endurance adaptations have not been demonstrated with the same consistency. This distinction suggests that the physiological mechanisms regulating muscle hypertrophy, strength development, and endurance adaptations respond differently to post-exercise cooling. Consequently, the potential impact of CWI should be interpreted in the context of the specific exercise modality and the desired training adaptations rather than generalized across all forms of exercise (Fyfe et al., 2019; Grgic, 2023; Piñero et al., 2024).

4.1.4. Practical Implications of Using Cold Water Immersion

The practical effectiveness of CWI depends not only on the application of cold but also on selecting appropriate intervention parameters and the training context in which it is used. The most recent network meta-analysis, which included 55 randomized controlled trials, found that immersion for 10–15 minutes at 11–15°C was most effective for reducing delayed-onset muscle soreness, whereas immersion at 5–10°C for a similar duration produced greater reductions in creatine kinase (CK) activity and more favorable effects on selected neuromuscular performance outcomes (Wang et al., 2025). Nevertheless, substantial heterogeneity in study protocols limits the ability to define a universally optimal cooling strategy, highlighting the need to individualize CWI protocols according to the intended application.

Overall, current evidence supports the use of CWI primarily to reduce delayed-onset muscle soreness and improve subjective perceptions of recovery (Moore et al., 2023; Xiao et al., 2023; Wang et al., 2025). In contrast, evidence on its effects on muscle damage markers and objective measures of physical performance recovery remains less consistent (Moore et al., 2023; Gustafsson et al., 2025). Furthermore, regular use of CWI after resistance exercise may attenuate hypertrophic adaptations, whereas comparable effects on maximal strength or endurance adaptations have not been consistently demonstrated (Roberts et al., 2015; Fyfe et al., 2019; Grgic, 2023; Piñero et al., 2024). These findings suggest that CWI should be implemented selectively, with consideration of the exercise modality, recovery demands, and intended training adaptations.

4.2. Hot Water Immersion (HWI)

Hot water immersion (HWI) has become an increasingly popular post-exercise recovery strategy in recent years. Current evidence suggests that HWI may support post-exercise recovery and selected training adaptations, particularly those related to thermoregulation and endurance performance. However, compared with CWI, the available evidence remains considerably less extensive and is marked by substantial heterogeneity in intervention protocols, participant characteristics, and outcome measures (Ahokas et al., 2025; Normand-Gravier et al., 2025).

4.2.1. Effects of HWI on Post-Exercise Recovery

Interest in the effects of hot water immersion (HWI) on post-exercise recovery has grown markedly in recent years. Although the available evidence remains substantially less extensive than that for cold water immersion, existing studies suggest that heat exposure may facilitate recovery by raising muscle temperature, activating heat stress responses, and modulating inflammatory processes (Ahokas et al., 2025; Normand-Gravier et al., 2025).

Most studies have focused on delayed-onset muscle soreness (DOMS) and markers of muscle damage. In an experimental model of muscle injury induced by electrically stimulated eccentric contractions, HWI reduced muscle soreness compared with thermoneutral water immersion. In contrast, comparable benefits were not observed with cold water immersion. Furthermore, HWI was associated with lower concentrations of creatine kinase (CK) and myoglobin, suggesting a potentially more favorable recovery response after muscle damage (Dablainville et al., 2025).

These findings should, however, be interpreted cautiously. Although reductions in muscle soreness and circulating markers of muscle damage may indicate beneficial physiological responses, biochemical markers do not necessarily reflect the restoration of muscle function. Consequently, the effectiveness of heat-based recovery interventions should be evaluated by integrating clinical, functional, and molecular outcomes rather than relying exclusively on individual laboratory markers (Ahokas et al., 2025; Dablainville et al., 2025).

Increasing attention has also focused on the biological mechanisms underlying the effects of HWI. Heat exposure has been shown to increase expression of the heat shock proteins HSP27 and HSP70, enhance expression of the anti-inflammatory cytokine interleukin-10 (IL-10), and reduce activation of nuclear factor kappa B (NF-κB), a key regulator of the inflammatory response. These findings suggest that HWI may facilitate an earlier transition from the pro-inflammatory to the regenerative phase, thereby creating conditions that may favor muscle tissue repair (Dablainville et al., 2025).

4.2.2. Effects of HWI on Training Adaptations

Hot water immersion (HWI) is one of the few post-exercise recovery interventions that may influence not only recovery but also the development of specific training adaptations. Current evidence suggests that repeated heat exposure induces physiological adaptations across the thermoregulatory, cardiovascular, and muscular systems. However, the magnitude of these adaptations depends on the intervention protocol, frequency of exposure, and the type of training performed (Ahokas et al., 2025; Normand-Gravier et al., 2025).

The strongest evidence supports the development of thermoregulatory adaptations associated with heat acclimation. Repeated post-exercise heat exposure reduces core temperature during subsequent exercise, promotes an earlier onset of sweating, and lessens cardiovascular strain. These responses are accompanied by plasma volume expansion, enhanced heat dissipation, and lower perceived exertion, collectively improving exercise tolerance in hot environments (Zurawlew et al., 2015).

The practical relevance of these adaptations has been demonstrated in studies assessing exercise performance after repeated heat exposure. A six-day protocol involving 40 minutes of hot water immersion at 40°C immediately after exercise improved 5-km running performance in hot environmental conditions without significantly affecting performance in thermoneutral conditions (Zurawlew et al., 2015). Similar findings were reported by Kirby et al. (2021), who showed that a three-week post-exercise sauna intervention effectively promoted heat acclimation in both women and men, yielding comparable improvements in VO_2max and running speed at the lactate threshold. Notably, the physiological mechanisms underlying these adaptations differed between sexes. Men exhibited greater increases in skin blood flow, whereas women demonstrated a more pronounced sweating response, suggesting distinct thermoregulatory strategies that yield similar functional outcomes (Kirby et al., 2021).

Similarly, regular sauna bathing after endurance training has been linked to increased plasma volume and a longer time to exhaustion, suggesting that repeated heat exposure may enhance adaptations relevant to endurance performance (Scoon et al., 2007). Although improvements in exercise performance in hot environments are well established, evidence supporting comparable benefits in thermoneutral environments remains inconsistent (Solomon and Laye, 2025).

Beyond thermoregulatory adaptations, increasing attention has focused on the effects of HWI on skeletal muscle adaptation. Experimental evidence suggests that heat exposure may enhance heat shock protein expression and modulate inflammatory signaling, creating a physiological environment that may support muscle remodeling and recovery. Heat exposure has also been linked to activation of molecular pathways involved in angiogenesis, protein synthesis, and satellite cell function. However, the relevance of these cellular responses to long-term training adaptations in humans remains uncertain (Normand-Gravier et al., 2025).

Overall, the strongest evidence supports using HWI to promote thermoregulatory adaptations and improve heat tolerance, whereas its effects on skeletal muscle adaptation and exercise performance outside hot environments remain less clearly established (Zurawlew et al., 2015; Solomon and Laye, 2025).

4.2.3. Practical Implications of Using HWI

The practical application of hot water immersion (HWI) depends primarily on the intended training objective and the context in which the intervention is implemented. Unlike cold water immersion, which is primarily used to facilitate short-term recovery, HWI may support selected recovery processes while promoting physiological adaptations, particularly those related to thermoregulation and exercise tolerance in hot environments. Consequently, HWI appears especially relevant for athletes preparing for competition in the heat or undertaking endurance-oriented training (Ahokas et al., 2025; Normand-Gravier et al., 2025).

The strongest evidence supports the regular use of HWI as part of a heat acclimation strategy. Repeated post-exercise heat exposure promotes plasma volume expansion, improves thermoregulatory function, and reduces physiological strain during exercise in hot conditions. These adaptations may enhance exercise tolerance and performance in the heat, making HWI a valuable adjunct to preparation for competitions in warm climates and other situations requiring improved heat tolerance (Zurawlew et al., 2015; Scoon et al., 2007).

5. Discussion

The available evidence indicates that the effects of post-exercise thermal therapies extend beyond short-term recovery and also influence the physiological processes that underlie training adaptations. Cold water immersion (CWI) and hot water immersion (HWI) elicit distinct physiological responses, and their effectiveness depends primarily on the intervention's intended purpose, the type of exercise performed, and the stage of the training process. Consequently, these interventions should not be viewed as competing recovery strategies but rather as complementary approaches that can be implemented according to specific training objectives (Ahokas et al., 2025; Normand-Gravier et al., 2025).

5.1. Post-Exercise Recovery and Long-Term Training Adaptations

One key finding from the available literature is the need to distinguish between short-term recovery gains and long-term training adaptations. Accelerating recovery may help maintain the quality of subsequent training sessions or competitions, but it does not necessarily optimize the physiological processes that improve performance or promote muscle hypertrophy. In the case of CWI, mechanisms that reduce muscle soreness and modulate inflammatory responses may simultaneously attenuate anabolic signaling pathways involved in skeletal muscle remodeling. This apparent trade-off illustrates that interventions beneficial for short-term recovery may not always support long-term training adaptations (Roberts et al., 2015; Fyfe et al., 2019).

The present review also highlights that the effectiveness of thermal therapies should be interpreted in the context of the exercise modality and the desired training adaptations. Most studies investigating CWI have focused on short-term recovery outcomes, including reductions in delayed-onset muscle soreness and improvements in perceived recovery. In contrast, comparatively few have examined long-term physiological adaptations. This imbalance is even more pronounced for HWI, where evidence on training adaptations remains limited and is derived primarily from a relatively small number of experimental studies and recent reviews. Consequently, the strength of current recommendations varies substantially between these interventions and should be interpreted in light of the quality and quantity of the available evidence (Ahokas et al., 2025; Normand-Gravier et al., 2025; Poręba et al., 2025).

5.2. Practical Application of Thermal Therapies According to Training Objectives

The practical use of CWI appears most appropriate when the primary objective is the rapid restoration of exercise capacity between successive training sessions or competitions. This is particularly relevant in team sports, tournament settings, and disciplines with high training or competition density, where reducing delayed-onset muscle soreness and perceived fatigue may help maintain performance across repeated bouts of exercise (Poręba et al., 2025; Moore et al., 2023).

In contrast, routine use of CWI during periods primarily focused on maximizing muscle hypertrophy and strength development warrants more careful consideration. Current evidence suggests that regular post-exercise cooling may attenuate molecular pathways involved in skeletal muscle remodeling, potentially limiting hypertrophic adaptations over time.

Nevertheless, these findings do not support eliminating CWI from resistance training altogether. Instead, its use should be strategically integrated into periods of intensified training or competition, taking into account the potential trade-off between accelerated recovery and the maximization of long-term training adaptations (Roberts et al., 2015; Fyfe et al., 2019; Poręba et al., 2025).

The available evidence yields conflicting conclusions about HWI. Although substantially fewer studies have examined this intervention, repeated heat exposure appears to promote thermoregulatory adaptations and improve exercise tolerance in hot environments. Expansion of plasma volume, enhanced heat dissipation, and reduced cardiovascular strain during exercise suggest that HWI may be a valuable strategy for athletes preparing for endurance events or competitions in hot environmental conditions (Zurawlew et al., 2015; Scoon et al., 2007; Normand-Gravier et al., 2025).

Rather than representing competing recovery strategies, CWI and HWI should be viewed as complementary interventions with distinct physiological applications. Their use should therefore be guided by the desired training adaptations and the specific demands of the training process, rather than by the assumption that one method is universally superior to the other (Ahokas et al., 2025; Normand-Gravier et al., 2025).

5.3. Limitations of the Available Evidence and Future Research Directions

Several limitations of the available evidence should be considered when interpreting the findings presented in this review. Considerable heterogeneity across studies exists with respect to water temperature, immersion duration, immersion depth, and the timing of intervention after exercise. Furthermore, the included studies involve participants with different training statuses, sporting backgrounds, and exercise protocols, making direct comparisons difficult and limiting the generalizability of current recommendations (Ahokas et al., 2025; Poręba et al., 2025).

Another important limitation is the underrepresentation of women in the available literature. Solomon and Laye (2025) reported that women accounted for only about 21% of participants in studies investigating passive heat acclimation. Together with the limited number of investigations examining menstrual cycle phase and recent evidence demonstrating sex-specific responses to thermal interventions (Wellauer et al., 2025), these findings indicate that current recommendations should be applied cautiously to female athletes.

Direct comparisons of CWI and HWI using standardized experimental protocols remain scarce. Most studies assess individual interventions separately, making it difficult to determine their relative effectiveness under comparable conditions or to establish evidence-based recommendations for specific training contexts (Ahokas et al., 2025; Normand-Gravier et al., 2025).

Finally, substantial variability exists in the outcome measures used across studies. Investigators have assessed subjective perceptions of recovery, biochemical markers of muscle damage, inflammatory and molecular responses, performance outcomes, and long-term training adaptations. This methodological heterogeneity complicates comparisons across studies and limits the possibility of robust quantitative synthesis. Future research should prioritize standardized intervention protocols and comprehensive assessment of both short-term recovery and long-term training adaptations to strengthen the evidence base for thermal recovery strategies.

6. Conclusion

Thermal therapies are valuable tools for supporting post-exercise recovery and optimizing training outcomes in athletes. However, their effectiveness depends on the context in which they are applied, as cold water immersion (CWI) and hot water immersion (HWI) elicit distinct physiological responses and serve different purposes within the training process. Rather than competing interventions, they should be viewed as complementary strategies.

Available evidence confirms that CWI effectively reduces delayed-onset muscle soreness and supports short-term recovery, particularly when rapid restoration of exercise capacity is required. Nevertheless, regular use after resistance exercise may attenuate mechanisms involved in muscle hypertrophy, underscoring the importance of aligning its use with specific training objectives. In contrast, HWI appears most beneficial for promoting thermoregulatory adaptations and improving exercise tolerance in hot environments, although the evidence supporting its broader application remains less extensive than that for CWI.

The appropriate use of thermal therapies should therefore be based on the intended training objective, exercise characteristics, and the phase of the training cycle. Integrating CWI and HWI into the training process, aligned with their specific physiological effects, may optimize both short-term recovery and long-term training adaptations, providing a more individualized and evidence-informed approach to athlete preparation.

Disclosure

Author's contribution

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Declaration of AI Use

Artificial intelligence (AI) was used only for language enhancement purposes, such as grammar correction and stylistic refinement.

REFERENCES

Ahokas EK, Hennessy RS, Hanstock HG, Kyröläinen H, Ihalainen JK. Effects of post-exercise heat exposure on acute recovery and training-induced performance adaptations: A systematic review. Sports Medicine – Open. 2025;11:106. https://doi.org/10.1186/s40798-025-00910-0.

Ahokas EK, Hanstock HG, Kyröläinen H, Ihalainen JK. Effects of repeated use of post-exercise infrared sauna on neuromuscular performance and muscle hypertrophy. Frontiers in Sports and Active Living. 2025;7:1462901. https://doi.org/10.3389/fspor.2025.1462901.

Dablainville V, Mornas A, Normand-Gravier T, Al-Mulla M, Papakostas E, Olory B, Fermin TM, Zampeli F, Nader N, Alhammoud M, Bayne F, Sanchez AMJ, Cardinale M, Candau R, Bernardi H, Racinais S. Muscle regeneration is improved by hot water immersion but unchanged by cold following a simulated musculoskeletal injury in humans. The Journal of Physiology. 2025; 603(23):7603–7625. https://doi.org/10.1113/JP287777.

Fyfe JJ, Broatch JR, Trewin AJ, Hanson ED, Argus CK, Garnham AP, Halson SL, Petersen AC, Bishop DJ. Cold water immersion attenuates anabolic signaling and skeletal muscle fiber hypertrophy, but not strength gain, following whole-body resistance training. Journal of Applied Physiology. 2019; 127(5):1403–1418. https://doi.org/10.1152/japplphysiol.00127.2019.

Grgic J. Effects of post-exercise cold-water immersion on resistance training-induced gains in muscular strength: A meta-analysis. European Journal of Sport Science. 2023; 23(3):372–380. https://doi.org/10.1080/17461391.2022.2033851.

Gustafsson J, Montiel-Rojas D, Romare MGA, Johansson E, Folkesson M, Pernigoni M, Frolova A, Brazaitis M, Venckunas T, Ponsot E, Chaillou T, Edholm P. Cold- and hot-water immersion are not more effective than placebo for the recovery of physical performance and training adaptations in national level soccer players. European Journal of Applied Physiology. 2025; 125:3179–3194. https://doi.org/10.1007/s00421-025-05835-w.

Horgan BG, West NP, Tee N, Halson SL, Drinkwater EJ, Chapman DW, Haff GG. Effect of repeated post-resistance exercise cold or hot water immersion on in-season inflammatory responses in academy rugby players: A randomised controlled cross-over design. European Journal of Applied Physiology. 2024; 124:2615–2628. https://doi.org/10.1007/s00421-024-05424-3.

Hussain J, Cohen M. Clinical effects of regular dry sauna bathing: A systematic review. Evidence-Based Complementary and Alternative Medicine. 2018;2018:1857413. https://doi.org/10.1155/2018/1857413.

Ihsan M, Abbiss CR, Allan R, Watson G. Adaptations to post-exercise cold water immersion: Friend, foe, or futile? Frontiers in Sports and Active Living. 2021;3:714148. https://doi.org/10.3389/fspor.2021.714148

Ihsan M, Watson G, Choo HC, Lewandowski P, Papazzo A, Cameron-Smith D, Abbiss CR. Postexercise muscle cooling enhances gene expression of PGC-1α. Medicine & Science in Sports & Exercise. 2014; 46(10):1900–1907. DOI: 10.1249/MSS.0000000000000308

Jackman JS, Bell PG, van Someren K, Gondek MB, Hills FA, Wilson LJ, Cockburn E. Effect of hot water immersion on acute physiological responses following resistance exercise. Frontiers and Physiology. 2023;14:1213733. https://doi.org/10.3389/fphys.2023.1213733.

Kirby NV, Lucas SJE, Cable TG, Armstrong OJ, Weaver SR, Lucas RAI. Sex differences in adaptation to intermittent post-exercise sauna bathing in trained middle-distance runners. Sports Medicine – Open. 2021;7:51. https://doi.org/10.1186/s40798-021-00342-6.

Moore E, Fuller JT, Bellenger CR, Saunders S, Halson SL, Broatch JR, Buckley JD. Effects of cold-water immersion compared with other recovery modalities on athletic performance following acute strenuous exercise in physically active participants: A systematic review, meta-analysis, and meta-regression. Sports Medicine. 2023; 53(3):687–705. https://doi.org/10.1007/s40279-022-01800-1.

Normand-Gravier T, Solsona R, Dablainville V, Racinais S, Borrani F, Bernardi H, Sanchez AMJ. Effects of thermal interventions on skeletal muscle adaptations and regeneration: Perspectives on epigenetics. European Journal of Applied Physiology. 2025; 125:277–301. https://doi.org/10.1007/s00421-024-05642-9.

Piñero A, Burke R, Augustin F, Mohan AE, DeJesus K, Sapuppo M, Weisenthal M, Androulakis-Korakakis P, Grgic J, Swinton PA, Schoenfeld BJ. Throwing cold water on muscle growth: A systematic review with meta-analysis of the effects of post-exercise cold-water immersion on resistance training-induced hypertrophy. European Journal of Sport Science. 2024; 24(7):1004–1018. https://doi.org/10.1002/ejsc.12074.

Poręba K, Poręba M, Lewandowska-Mackiewicz A, Wasilczuk A, Peszt MJ, Szaryński M, Prokopczyk K, Rusiłowicz R, Jakubowska P, Matuszewska J. Cold Water Immersion After Training: Regeneration vs Adaptation - A Systematic Review. Quality in Sport. 2025;47:66734. https://doi.org/10.12775/QS.2025.47.66734.

Roberts LA, Raastad T, Markworth JF, Figueiredo VC, Egner IM, Shield A, Cameron-Smith D, Coombes JS, Peake JM. Post-exercise cold water immersion attenuates acute anabolic signalling and long-term adaptations in muscle to strength training. The

Journal of Physiology. 2015; 593(18):4285–4301. https://doi.org/10.1113/JP270570.

Sautillet B, Bourdillon N, Millet GP, Billaut F, Hassar A, Moufti H, Ahmaïdi S, Costalat G. Hot but not cold water immersion mitigates the decline in rate of force development following exercise-induced muscle damage. Medicine & Science in Sports & Exercise. 2024; 56(12):2362–2371. https://doi.org/10.1249/MSS.0000000000003513.

Scoon GSM, Hopkins WG, Mayhew S, Cotter JD. Effect of post-exercise sauna bathing on the endurance performance of competitive male runners. Journal of Science and Medicine in Sport. 2007; 10(4):259–262. https://doi.org/10.1016/j.jsams.2006.06.009.

Solomon TPJ, Laye MJ. The effect of post-exercise heat exposure (passive heat acclimation) on endurance exercise performance: A systematic review and meta-analysis. BMC Sports Science, Medicine and Rehabilitation. 2025;17:4. https://doi.org/10.1186/s13102-024-01038-6.

Wang H, Wang L, Pan Y. Impact of different doses of cold water immersion (duration and temperature variations) on recovery from acute exercise-induced muscle damage: A network meta-analysis. Frontiers and Physiology. 2025;16:1525726. DOI: 10.3389/fphys.2025.1525726

Wellauer V, Clijsen R, Bianchi G, Riggi E, Hohenauer E. No acceleration of recovery from exercise-induced muscle damage after cold or hot water immersion in women: A randomised controlled trial. PLoS ONE. 2025; 20(5):E0322416. https://doi.org/10.1371/journal.pone.0322416.

Xiao F, Kabachkova AV, Jiao L, Zhao H, Kapilevich LV. Effects of cold water immersion after exercise on fatigue recovery and exercise performance: Meta-analysis. Frontiers and Physiology. 2023;14:1006512. https://doi.org/10.3389/fphys.2023.1006512.

Zurawlew MJ, Walsh NP, Fortes MB, Potter C. Post-exercise hot water immersion induces heat acclimation and improves endurance exercise performance in the heat. Scandinavian Journal of Medicine & Science in Sports. 2015; 26(7):745-754. https://doi.org/10.1111/sms.12638.

Zurawlew MJ, Mee JA, Walsh NP. Post-exercise Hot Water Immersion Elicits Heat Acclimation Adaptations in Endurance Trained and Recreationally Active Individuals. Frontiers and Physiology. 2018;9:1824. https://doi.org/10.3389/fphys.2018.01824.