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Recovery methods to reduce fatigue among athletes: A systematic review and future directions

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ABSTRACT

Background Problems: The recovery process plays an important role in maintaining athletic performance and preventing fatigue among players. **Research Objectives:** This systematic review aims to provide a comprehensive overview of the current research on athlete fatigue recovery, including the various methods used to enhance recovery, the limitations of existing studies, and potential areas for future research. **Methods:** This study was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). We designed the study using the PICOS strategy. We sourced the literature from established research sources in the Scopus databases. The final data used for this study consisted of 14 articles. **Findings and Results:** The main findings confirmed that aquatic therapies, such as hot-and-cold-water immersion (HWI) and cold-water immersion (CWI), along with a number of other alternative methods, provide a strong foundation for improving athletes' recovery and performance. In addition, various novel therapies such as curcumin supplements, electrostimulation, and high-intensity interval training (HIT) also offer great potential for accelerating athletes' recovery. **Conclusion:** The findings from this study highlight various recovery methods that can help reduce athletes' fatigue after competition or training. This study also noted limitations and provided suggestions for future research, guiding researchers to further understand and improve athlete recovery holistically.

Keywords: Recovery; fatigue; athletes; literature review



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INTRODUCTION

Fatigue, a prevalent phenomenon in sport, affects athletes of all levels and disciplines (Starling & Lambert, 2018). In sports, high workloads and sudden increases in training load contribute to the occurrence of fatigue and injury (Sutherland et al., 2023). This training load is related to the type of sportive periodization, for example, the block periodization has a concentrated load of strength with a high load that causes significant fatigue, but the traditional periodization of Matveev has a diluted training load with a low to high load that

causes low to medium fatigue (Dantas et al., 2022; Junior, 2020; Oliveira et al., 2018). This phenomenon has far-reaching impacts on athletes' performance, recovery, and well-being. It is characterised by decreased physical and cognitive abilities, increased risk of injury, and negative impacts on aspects of daily life (Bestwick-Stevenson et al., 2021; Naughton et al., 2023). What is more, fatigue can also affect athletes' psychological aspects, such as motivation, mental resilience, and sleep quality (Li et al., 2022). Thus, an in-depth understanding of the different dimensions of fatigue in sports is important to support athletes' overall well-being and performance.

The prevalence and impact of fatigue are not only limited to the competitive arena but also affect training patterns, injury risk, and career futures for athletes across multiple disciplines (Costa, 2022). Coaches and sports medicine practitioners play an important role in managing athlete fatigue (Alba-Jiménez et al., 2022; King et al., 2023) they implement strategies to optimise performance, reduce injury risk, and promote recovery (Brooks et al., 2022; de Borja et al., 2022). Athletes, striving to achieve optimal performance, constantly navigate the balance between pushing their physical limits and allowing sufficient time for recovery. Athlete fatigue recovery is an important process for athletes to rest, refuel, and repair their bodies after intense physical activity (Bonilla et al., 2021; Lee et al., 2017).

This fatigue recovery process involves calculating energy requirements based on activity levels and ensuring adequate intake (Siqueira et al., 2018). Migratory fish extracts in diet composition can help speed up recovery by supplying more energy to the body (Huang et al., 2018), which in turn improves exercise capacity and overall performance (Kellmann et al., 2018; Skorski et al., 2019). Understanding fatigue and muscle tissue damage is key to facilitating recovery and improving work capacity (Boguszewski, 2015), which involves adequate sleep practices, good hydration, nutritious food intake, and scheduling rest days in training. Without proper fatigue recovery, athletes risk fatigue, over training, and reduced performance (Mardiana et al., 2023; Skorski et al., 2019).

Previous research in athlete fatigue recovery has provided valuable insights into various methodologies ranging from traditional approaches such as rest and sleep (Lastella et al., 2019; Tuomilehto et al., 2017) to more contemporary techniques such as cryotherapy (Kwiecien et al., 2020; Wilson et al., 2018) and compression therapy (Pavin et al., 2019). However, the rapidly evolving nature of sports science, coupled with the inherent complexity of human physiology, necessitates a comprehensive evaluation of the existing literature to identify gaps, inconsistencies, and emerging trends. Therefore, it is important to conduct a systematic review to provide a more comprehensive view of the effectiveness of various recovery strategies as well as highlight areas that require further research to optimise athlete well-being and performance.

In the past decade, the topic of athlete fatigue has taken centre stage in literature review studies (Nuutila et al., 2024). Previous researchers have investigated various aspects of athlete fatigue, ranging from its impact on psychomotor (Habay et al., 2021), physical (Van Cutsem et al., 2017), and motor performance (Yuan et al., 2023) to its effect on inter-limb asymmetry (Heil et al., 2020) and decision-making in athletes (Almonroeder et al., 2020). Despite this, no review has specifically explored the different recovery methods available to holistically reduce athlete fatigue. By filling this gap, we can develop a better understanding of effective recovery strategies, which can assist athletes in reaching their maximum potential and maintaining their physical and mental health in the long term.

The findings from this systematic review have significant implications for various stakeholders involved in athlete management and performance optimisation. By describing the strengths, limitations, and future research directions in athlete fatigue recovery, this review aims to provide a comprehensive overview of current research on athlete fatigue recovery. Specifically, the aim of this study is to answer the following research questions: **RQ 1.** What are some effective recovery methods to reduce athlete fatigue after competition or training? **RQ 2.** What common limitations have researchers found in therapies aimed at reducing athlete fatigue after competition or training? **RQ 3.** What are some future research suggestions for therapies to reduce athlete fatigue after competition or training?

METHOD

This study was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (O’Dea et al., 2021; Parums, 2021). The study design was done according to the PICOS strategy (Amir-Behghadami & Janati, 2020), in which the population (P) is athletes of any age, gender, and level of competition (novice, amateur, or professional) who experience fatigue after competing or training in various sports, the intervention (I) of interest is the use of recovery techniques in helping athletes recover from fatigue after competing or training in sports, the comparator (C) is not required, the outcomes (O) of interest is the outcome measured through the effects of recovery on athletes, and the study design (S) is a randomised controlled clinical study (RCT), cohort study, or observational study. Table 1 displays the electronic search and the PICOS criteria.

Table 1. PICOS Criteria for the Systematic Review

Criteria	Inclusion Criteria	Exclusion Criteria
Population (P)	Athletes of all ages, genders, and levels of competition (beginner, amateur, or professional) who experience fatigue after competition or training in various sports.	Non-athlete population
Intervention (I)	The use of recovery techniques helps athletes recover from fatigue after competition or training in sport.	Recovery techniques that do not fall into a category or techniques that are not relevant to the athlete's recovery after fatigue.
Comparator (C)	No comparisons required.	Not applicable.
Outcome (O)	Recovery effects on athletes	The studies did not provide data on the effects of recovery on athletes.
Study design (S)	Randomised controlled clinical studies (RCTs), cohort studies, or observational studies.	Letters to editors, trial registrations, proposals for protocols, editorials, book chapters, reviews, and conference abstracts.

For searches in databases, the following combination was used with the Boolean operators (AND, OR): (“recovery technique” OR “recovery method” OR “rehabilitation method” OR “rehabilitation technique”) AND (“athlete” OR “athletes” OR “sportsman” OR “sportswoman”) AND (“fatigue” OR “exhaustion” OR “tiredness”). We conducted this search on April 21, 2024, using the following databases: Scopus. We did not impose any restrictions on the year of publication or study type, nor did we use any search filter. Also, manual research was conducted on the bibliographies of all included studies in full-text screen.

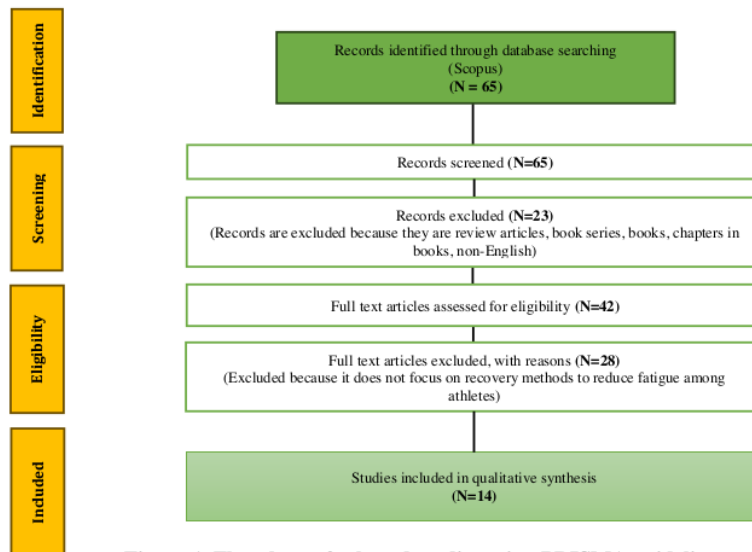


Figure 1. Flowchart of selected studies using PRISMA guidelines

RESULTS AND DISCUSSION

Table 2. Summary of Recovery Methods to Reduce Fatigue Among Athletes

Author and Year	Population Characteristics	Country	Study Design	Intervention	Type of Sport	Limitations	Findings	Journal
(Bat et al., 2023)	<ul style="list-style-type: none"> - N = 28 - 21 men & 7 women - A mean age: 17 years 	Taiwan	<ul style="list-style-type: none"> - Non-randomised prospective cohort investigation 	<ul style="list-style-type: none"> - Chinese Curcumin Supplement (Jiang Huang Powder Ko Da) 	<ul style="list-style-type: none"> - Wrestling - Football - Soft tennis 	<ul style="list-style-type: none"> - This is not a randomised, double-blind study. - Limited sample. - Selection bias as participants chose their own group. - Lack of blinding leads to performance and detection bias. - Uncertainty in subgroup analysis by gender. 	<p>Curcumin supplementation decreased levels of 8-hydroxy-2-deoxyguanosine, reduced muscle fatigue and increased the basic metabolic rate and fat-free mass in adolescent athletes.</p>	Frontiers in Nutrition
(Silva et al., 2023)	<ul style="list-style-type: none"> - N = 8 - 6 male & 2 female - 28.4 ± 4.6 years old - Tier 1 recreationally active individuals meeting WHO's minimum activity guidelines - Exclusion criteria: age outside 18-35 years, recent musculoskeletal injury, discomfort during experiments - Participants familiar with using the Biodex System-4 for torque data collection 	Portugal	<ul style="list-style-type: none"> - Experimental study, controlled, parallel design with repeated measures 	<ul style="list-style-type: none"> - Electrostimulation - Localised Heating - Compression 	Not specified.	<ul style="list-style-type: none"> - Small sample size. - Lack of homogeneity in the sample. - Potential bias due to lack of blinding participants. - Need for further research with larger and more homogeneous samples. - Need for research with blinding procedures to avoid potential biases. 	<p>Across all tested recovery methods, the 6 hrs legging demonstrated no significant capacity for acute recovery from a fatigue-inducing protocol.</p>	Sensors
(Solsona et al., 2023)	<ul style="list-style-type: none"> - N = 12 - 7 males & 5 females - Elite athletes - National-team skaters 	France	<ul style="list-style-type: none"> - Randomised cross-over study 	<ul style="list-style-type: none"> - Hot-and Cold-Water Immersion (HWI) - Cold-Water Immersion (CWI) - Active Recovery (AR) 	Skaters	<ul style="list-style-type: none"> - It requires a larger sample size to confirm results, especially in less-trained athletes. 	<p>Active recovery and hot-and-cold-water immersion resulted in higher power output compared to cold-water immersion, suggesting that cold-water immersion may slightly impair performance outcomes.</p>	Journal of Sports Sciences

Author and Year	Population Characteristics	Country	Study Design	Intervention	Type of Sport	Limitations	Findings	Journal
(Xue et al., 2023)	<ul style="list-style-type: none"> - N = 20 - Aged between 17 and 22, who were national first-class athletes - The participants were in good health, 4-hour acute and chronic diseases, smokeless and alcohol addiction, and had no recent sports injuries - Height, weight, and BMI were measured for the participants - Body composition, including fat content, fat-free body weight, and body fat percentage, was assessed for the participants 	China	<ul style="list-style-type: none"> - Controlled trial with a within-subject design 	<ul style="list-style-type: none"> - High-Intensity Interval Training (HIT) - Measurement of human morphology - Determination of VO2max - Maximum Power. 	Basketball	<ul style="list-style-type: none"> - Lack of significant difference in various parameters among the different recovery methods. - Decrease in TC, VO2mean, and VO2total in HTA compared to HIT4 and HITP after completing HIT in groups 2, 3, and 4. - Higher VO2peak, VO2mean, and VO2total in HTA compared to HTS and HITP after completing HIT in groups 2, 3, and 4. - No significant difference in VO2, kinetics, VO2peak, VO2mean, and VO2total among the three different recovery methods. 	<p>The main findings emphasize the benefits of positive recovery during HIT in enhancing exercise ability and aerobic energy output compared to negative recovery and stretching exercises.</p>	Revista Brasileira de Medicina do Esporte
(Aldar et al., 2023)	<ul style="list-style-type: none"> - N = 20 - Male Paralympic powerlifters (10 athletes at the national level and 10 at the regional level) - Each group having specific disabilities. 	Brazil	<ul style="list-style-type: none"> - Randomized controlled trial (RCT) with a crossover design. 	<ul style="list-style-type: none"> - 800 mg of Ibuprofen or Placebo - The exercise regimen included five sets of five reps at 80% of 1-RM. 	Powerlifters	<ul style="list-style-type: none"> - Lack of control over athletes' diet. - Lack of control over subjects' sleep quality. - Exposition to psychological stress factors not measured. - Potential impact of food, stress, and sleep on immune system and recovery not fully addressed. 	<p>The main findings highlight the positive effects of ibuprofen on peak torque and fatigue in national-level Paralympic powerlifters compared to a placebo, with differences observed between national and regional level athletes.</p>	Healthcare

Author and Year	Population Characteristics	Country	Study Design	Intervention	Type of Sport	Limitations	Findings	Journal
(Chaiyavakul & Chahbal, 2021)	<ul style="list-style-type: none"> - N = 11 - Male basketball - Regularly exercising at least two hours per day and three days per week for more than one year - Body mass index between 18.50-25.00 kg/m² - Must have at least one year of experience in competitions in university games - Exclusion criteria: individuals with musculoskeletal problems within the six-week study period, skin allergies, open wounds, abnormal skin sensations, and cardiopulmonary diseases 	Thailand	Crossover design	<ul style="list-style-type: none"> - Cold Water - Immersion (CWI) 	Basketball	<ul style="list-style-type: none"> - The study did not compare the effects of cold water immersion at different temperatures. - The study did not investigate the effects of cold water immersion on female basketball players. - The study did not explore the long-term effects of delayed cold water immersion on exercise performance. - The study did not assess the impact of delayed cold water immersion on other recovery parameters such as inflammation markers or muscle damage indicators. 	<ul style="list-style-type: none"> - Delayed cold water immersion one and three hours after high-intensity interval exercise can restore anaerobic performance to pre-test values, unlike passive recovery. - There was no significant difference in the effects of cold water immersion at one and three hours post-exercise. - Both cold water immersion conditions were effective in restoring maximum vertical jump capacity. 	Sport Mont
(Onishi et al., 2021)	<ul style="list-style-type: none"> - N = 8 - Female athletes specialized in 400m and 800m track events - Sealevel residents with no recent exposure to higher altitude or hypoxic conditions 	Japan	<ul style="list-style-type: none"> - Observational study with pre-post design 	<ul style="list-style-type: none"> - High-Intensity Interval Training (HIIT) - Endurance Training 	Athletics (400 and 800 metres)	<ul style="list-style-type: none"> - Lack of clear understanding of improvements in performance after short-term hypoxic training. - Absence of measurements on peripheral function. - Need for further study to determine the appropriate duration of recovery. - Lack of measurements beyond 9 days after the training period 	<ul style="list-style-type: none"> - Short-term hypoxic training improved maximal anaerobic running performance, increased time to exhaustion in increment 14-mining tests, and decreased mean power during the 10-s maximal pedalling test. 	Gazzetta Medica Italiana Archivio per le Scienze Mediche

Author and Year	Population Characteristics	Country	Study Design	Intervention	Type of Sport	Limitations	Findings	Journal
(Peltana et al., 2019)	<ul style="list-style-type: none"> - N = 30 - Male futsal athletes - Non-smokers - Exclusion criteria: cardiovascular or respiratory diseases 	Indonesia	<ul style="list-style-type: none"> - Parallel - 2-group - Pretest-posttest design 	<ul style="list-style-type: none"> - Contrast Water Therapy (CWT) - Slow Jogging Recovery (SJR) 	Futsal	<ul style="list-style-type: none"> - Potential impact of physical, role-related, emotional functioning, and lifestyle differences on results. - Short duration of time for alternating between cold and hot water may influence outcomes. 	<ul style="list-style-type: none"> - CWT was more effective in reducing lactate concentration compared to SJR in elite futsal players after HiT. - CWT led to a rapid recovery of heart rate in elite futsal players after HiT. - CWT, with periodic immersions in cold and hot water, can be a beneficial recovery strategy for elite futsal players post-exercise. 	Physiotherapy Quarterly
(Crowther et al., 2017)	<ul style="list-style-type: none"> - N = 34 - Not elite athletes. - A mean age of 27 years - A mean height of 180 cm - A mean weight of 80 kg - A mean vo₂ max of 43 ml/kg/min. 	Australia	<ul style="list-style-type: none"> - Randomized controlled trial design 	<ul style="list-style-type: none"> 12 Cold water immersion (CWI) - Contrast water immersion (CWT) - Active recovery (ACT) - Combined recovery (COMB) 	Not specified.	<ul style="list-style-type: none"> 12 study used a simulated team sport game, not an actual game. - The fitness and ability of the participants may not replicate that of high-performance contact team sport athletes. 	<ul style="list-style-type: none"> - Contrast water immersion enhanced perceptual recovery significantly at 1 hour post-exercise compared to other strategies. - Cold water immersion and combined recovery strategies resulted in decreased jump 10 per performance at 1 hour. - No differences were observed in perceptual or performance variables between recovery strategies and control at 24 and 48 hours. 	BMC Sports Science, Medicine and Rehabilitation
(Sajadian et al., 2017)	<ul style="list-style-type: none"> - N = 18 - Participants are between 19-21 years old - Participants have a body mass index (BMI) between 19 and 24 KGs per square meter 	Iran	<ul style="list-style-type: none"> - Semi-experimental study with a pre-test post-test design 	<ul style="list-style-type: none"> - Active recovery (AR) - Deep water running (DWR) 	Football	<ul style="list-style-type: none"> - Small sample size 	<ul style="list-style-type: none"> - No statistically significant differences were found in the effects of active recovery (AR) and deep water running (DWR) on muscular damage indices among soccer players after a simulated soccer game. 	National Journal of Physiology, Pharmacy and Pharmacology

Author and Year	Population Characteristics	Country	Study Design	Intervention	Type of Sport	Limitations	Findings	Journal
(Morales et al., 2016)	<ul style="list-style-type: none"> - N = 11 - International-standard judo athletes (7 males and 4 females) - A mean age of 20.73 years - A mean height of 1.72 m - A mean body mass of 67.36 kg. - More than 5 years of experience in national and international judo competitions. 	Spain	<ul style="list-style-type: none"> - Cross-sectional study design 	<ul style="list-style-type: none"> - WER method (Stagno Method, Lucia Method, and Session Rating of Perceived Exertion (RPE) session) 	Judo	<ul style="list-style-type: none"> - There is recovery in the literature about the adaptation of certain methods to specific training. - Heart rate-based methods may not reflect maximal intensity in combination with different types of effort. - Heart rate-based methods - Controlling internal TL in randori sessions. 	<p>5</p> <p>The WER method, incorporating time to exhaustion, showed high correlations with other methods for quantifying training load in judo. The WER method is RMTE adaptable for quantifying randori judo sessions and planning individualized training loads. The study highlights the reliability and effectiveness of the WER method in assessing external and internal training loads in judo sessions.</p>	International Journal of Sports, Physiology and Performance
(Bahner et al., 2013)	<ul style="list-style-type: none"> - N = 44 - Elite male Australian Football League (AFL) players - Mean age of 23.3 years - Average height of 187.6 cm and weight of 85.0 kg 	Australia	<ul style="list-style-type: none"> - Longitudinal quasi-experimental study design 	<ul style="list-style-type: none"> - Cold Water Immersion (CWI) - Floor Stretching - Compression Garments 	Australian Football	<ul style="list-style-type: none"> - Quasi-experimental design may limit causality establishment. - Lack of associations between recovery protocols and performance measures. - Small sample size. - Reliance on self-reported measures. - Lack of exploration of long-term effects. - Lack of consideration of interactions between recovery modalities. - Lack of investigation into individual player characteristics or preferences. 	<ul style="list-style-type: none"> - Specific combinations of post-game recovery protocols were associated with enhanced perceptual recovery, including cold-water immersion, floor stretching, no active recovery, and the use of a compression garment. - No associations were found between post-game recovery methods and physical or game performance measures. 	Journal of Science and Medicine in Sport

Author and Year	Population Characteristics	Country	Study Design	Intervention	Type of Sport	Limitations	Findings	Journal
(Heyman et al., 2009)	<ul style="list-style-type: none"> - N = 13 - Female climbers - Average age of 27.1 years - Climbing experience ranging from 6b to 7b+ 	Belgium	<ul style="list-style-type: none"> - Randomized crossover design study 	<ul style="list-style-type: none"> - Passive Recovery (PR) - Active Recovery (AR) - Electromyostimulation Cold Water Immersion (CWI) 	Climbing	<ul style="list-style-type: none"> - Caution needed when using cold water immersion due to potential hypersensitivity to cold. - Individualization of the protocol is necessary. - Immersion in lower temperatures may decrease grip strength. - Deeper immersion could impair muscle blood flow and oxygen supply. 	<ul style="list-style-type: none"> - Active recovery immersion were effective in maintaining subsequent climbing performance in female climbers. - Cold water immersion (CWI) was particularly highlighted as a beneficial recovery method for preserving climbing performance. - Electromyostimulation and passive recovery were not as effective as active recovery and CWI in maintaining climbing performance. 	Medicine & Science in Sports & Exercise
(Ingram et al., 2009)	<ul style="list-style-type: none"> - N = 11 - A male team-sport athletes - A mean age of 27.5 years - A mean height of 178.3 cm - A mean body mass of 76.0 kg 	Australia	<ul style="list-style-type: none"> - The experimental design was counterbalanced. However, details about randomization, blinding, or control groups are not provided. 	<ul style="list-style-type: none"> - Cold Water Immersion (CWI) 	Not specified.	<ul style="list-style-type: none"> - Assessed the variables over a 48-hour period, potentially missing long-term effects or differences that may appear over a longer duration of observation. 	<ul style="list-style-type: none"> - COLD was superior to both CWI and control treatments in post-exercise recovery following exhaustive team game exercise. 	Journal of Science and Medicine in Sport

RQ 1. What are some effective recovery methods to reduce athlete fatigue after competition or training? *Water Therapy*

Recent research highlights the important role of water therapy in supporting athletes' recovery and performance. Hot-and-cold-water immersion (HWI) has been shown to be effective in improving athletes' power output compared to cold-water immersion alone. These findings, observed in national-level skaters by Solsona et al. (2023), show the great potential of this therapy in improving the performance of athletes involved in high-level sports. On the other hand, cold-water immersion (CWI) has also shown significant benefits. Studies by Chaikyul and Chaibal (2021), Pelana et al. (2019), Crowther et al. (2017), and Ingram et al. (2009) highlighted that CWI can help reduce lactate concentration, improve perceptual recovery, and address post-exercise performance declines. Thus, the use of water therapy, whether in the form of HWI or CWI, can be an effective strategy for sports coaches and practitioners to improve the well-being and performance of their athletes.

Other Therapy

Through the analysis of various related studies, several alternative therapies have attracted attention in the context of athlete recovery. Chinese Curcumin Supplement (Jiang Huang Powder Ko Da), as shown in a study by Bai et al. (2023), showed potential in reducing muscle fatigue and soreness while increasing metabolic rate and fat-free mass in adolescent athletes. On the other hand, various methods such as electrostimulation, localised heating, and compression, as observed in the study by Silva et al. (2023), did not show significant capacity for acute recovery from fatigue-inducing protocols. High-intensity interval training (HIT), as observed in studies by Xue et al. (2023) and Oriishi et al. (2021), highlighted the positive benefits of HIT recovery in improving exercise ability and aerobic energy output. The use of medication such as 800 mg of Ibuprofen, as observed in the study by Aidar et al. (2022), was found to positively impact peak torque and fatigue in national-level Paralympic powerlifters. Another study explored active recovery methods, such as Active Recovery (AR) and Deep Water Running (DWR), in football players, with results showing no significant difference in their effects on muscle damage indices, as observed in the study by Sajadian et al. (2017).

At the level of other sports, methods such as the WER (Weighted External Resistance) Method, as observed in the study by Morales et al. (2016), showed a high correlation with other methods in measuring training load in judo athletes. Additionally, a combination of post-race recovery protocols, such as floor stretching and the use of compression garments, as observed in the study by Bahnert et al. (2013), was associated with improved perceptual recovery in Australian Football League players. Lastly, passive and active recovery methods, such as passive recovery (PR) and active recovery (AR), in combination with electromyostimulation, showed effectiveness in maintaining climbing performance in female climbers, as observed in the study by Heyman et al., (2009). As such, an in-depth understanding of these alternative recovery methods can provide valuable guidance for sports coaches and practitioners in planning effective recovery programmes for their athletes.

RQ 2. What common limitations have researchers found in therapies aimed at reducing athlete fatigue after competition or training?

Based on the research results presented in the table, there are a number of limitations that need to be considered. The study by Bai et al. (2023) was constrained by its non-randomised, non-double-blind design and limited sample size. Similarly, Silva et al. (2023) found that although various recovery methods were tested, sportswear did not have a significant impact on acute recovery, but the sample size was small and not homogeneous. The study by Solsona et al. (2023), although showing interesting results, still requires a larger sample size to confirm its findings, especially in less trained athletes. The study of Xue et al. (2023), meanwhile, found that there were no significant differences in various parameters among different recovery methods, but there was still uncertainty in the subgroup analysis based on gender. Furthermore, the study by Aidar et al. (2022) had limitations in controlling for athletes' diet and sleep quality and did not measure psychological stress factors that may have influenced the results.

Other factors also constrain some studies. For example, the study by Chaikyul and Chaibal (2021) did not compare the effects of cold water immersion at various temperatures, while the study by Oriishi et al. (2021) did not fully understand performance improvements after short-term hypoxic exercise. Additionally, the study by Bahnert et al. (2013) did not link recovery protocols to performance measures, and the study by Heyman et al. (2009) highlighted the need to individualise recovery protocols and consider individual sensitivity to cold temperatures. While the results offer valuable insights, the limitations indicate the need for additional research with improved designs and larger sample sizes to bolster these findings.

RQ 3. What are some future research suggestions for therapies to reduce athlete fatigue after competition or training?

Table 2 presents a number of research recommendations based on existing research to reduce athlete fatigue after competition or training. These recommendations highlight the need for further investigation into the effects of curcumin supplementation on specific muscle groups and movement types, as well as its impact on athletic performance and post-exercise recovery over longer study periods. Additionally, exploring other potential interventions and their effects on fatigue reduction could provide valuable insights for optimising athlete recovery strategies.

Table 3. Future Research Suggestions for Therapies to Reduce Athlete Fatigue

Title, Author and Year	Future Research		
	1	2	3
12-Week Curcumin Supplementation May Relieve Postexercise Muscle Fatigue in Adolescent Athletes (Bai et al., 2023)	Investigate the effects of curcumin supplementation on specific muscle groups and movement types. Further investigate the acute recovery effects of curcumin supplementation.	Examine curcumin's impact on athletic performance and post-exercise recovery over longer study periods.	-
6 Acute Recovery after a Fatigue Protocol Using a Recovery Sports Legging: An Experimental Study (Silva et al., 2023)	Investigate the acute recovery effects of sports legging by combining multiple methods, potentially in larger and more homogeneous samples. Future research should involve studies with larger samples to confirm the results, especially in less trained athletes.	Analyse inflammatory and muscle damage markers, along with perceived recovery status, in future studies.	To avoid bias, consider blinding participants to recovery methods.
Active recovery vs hot- or cold-water immersion for repeated sprint ability after a strenuous exercise training session in elite skaters (Solsona et al., 2023)	-	-	-
4 Power Supply Characteristics of Basketball Players At Different Training Intensities (Xue et al., 2023)	For recovery, investigate optimal exercise intensity levels based on VO2max and VT.	Explore the effects of low-intensity aerobic exercise on functional recovery.	Examine the relationship between active recovery, exercise intensity, blood clearance rates, and plasma CK levels.
Evaluation of Ibuprofen Use on the Immune System Indicators and Force in Disabled Paralympic Powerlifters of Different Sport Levels (Aidar et al., 2022)	Explore ibuprofen's effects on erythrocytes, haemoglobin, and hematocrit levels across various sports disciplines.	Assess ibuprofen's impact on inflammation markers and long-term muscle recovery in Paralympic athletes.	-
2 Effects of delayed cold water immersion after high-intensity intermittent exercise on subsequent exercise performance in basketball players (Chaikyul & Chaibal, 2021)	Investigate the long-term effects of delayed cold water immersion on performance.	Explore optimal immersion parameters.	Compare recovery methods in real-life competition scenarios.
14 Short-term hypoxic training improves maximal anaerobic power after a week of recovery (Oriishi et al., 2021)	To understand hypoxia adaptation, measure peripheral function.	Determine the optimal duration of recovery post-hypoxia training.	Investigate the effectiveness of short-term hypoxic training for enhancing performance in competitive runners.

Title, Author and Year	Future Research		
	1	2	3
15 Effect of contrast water therapy on blood lactate concentration after high-intensity interval training in elite futsal players (Pelana et al., 2019)	Investigate specific mechanisms of contrast water therapy (CWT) on post-exercise recovery, including temperature regulation and tissue healing.	Explore optimal CWT protocols, considering variations in water temperature, timing, and immersion duration.	-
Influence of recovery strategies upon performance and perceptions following fatiguing exercise: A randomized controlled trial (Crowther et al., 2017)	Investigate the mechanisms behind various recovery strategies for short-term recovery.	Identify an optimal recovery strategy for enhanced sporting performance. Additional variables related to tissue damages, inflammatory elements, and oxidative stresses will enhance understanding of effective recovery methods for football players.	-
7 Comparison of effects of active recovery and deep water running on soccer players' indices of muscular damage (Sajadian et al., 2017)	Conduct further studies with larger sample sizes and control groups.	Explore strategies for adjusting training loads based on changes in athletes' fitness levels.	-
The work endurance recovery method for quantifying training loads in Judo (Morales et al., 2016)	Investigate RMTE's long-term stability and adaptation to continuous training.	Explore the potential benefits of combining CWI with other recovery modalities.	Understand why certain recovery protocols promote perceptual recovery but not physical or game performance measures.
Association between post-game recovery protocols, physical and perceived recovery, and performance in elite Australian Football League players (Bahnert et al., 2013)	Investigate specific mechanisms behind CWI's positive effects on recovery.	Investigate the impact of cycling and CWI on recovery and subsequent exercise performance in climbers.	-
Effects of four recovery methods on repeated maximal rock climbing performance (Heyman et al., 2009)	Examine the combined effects of active recovery and CWI on performance enhancement.	Compare these modalities with emerging techniques for recovery optimization.	Explore mechanisms behind COLD's superior benefits over CWI for better recovery strategy design.
Effect of water immersion methods on post-exercise recovery from simulated team sport exercise (Ingram et al., 2009)	Further investigate long-term effects of COLD and CWI on athlete performance.		

The present systematic review highlights several effective methods to reduce fatigue among athletes, corroborating earlier findings. For instance, the use of cold-water immersion and contrast water therapy in hydrotherapy consistently alleviates muscle soreness and speeds up recovery (Pelana et al., 2019). This method leverages the physiological benefits of temperature variations to enhance blood flow and reduce inflammation. Research has demonstrated that cold-water immersion can significantly decrease the perception of muscle soreness and improve recovery time. Additionally, athletes across different sports can easily implement the use of hydrotherapy in various training environments. However, the use of the CWI causes deterioration of the athlete's strength in most studies (Malta et al., 2021), but in some studies the CWI increased the athlete's strength (Roberts et al., 2015). Therefore, the use of the CWI needs of attention and more study to determine when the athlete's strength returns to the normal levels.

Multiple studies have supported the use of curcumin supplements, indicating that its anti-inflammatory and antioxidant properties aid in muscle recovery and reduce delayed-onset muscle soreness (DOMS). Research by Bai et al. (2023) and Campbell et al. (2021) found that curcumin supplements significantly improved recovery times post-exercise, while Hu et al. (2023) demonstrated its effectiveness in reducing markers of muscle damage. Moreover, studies have demonstrated that curcumin modulates inflammatory pathways, a

beneficial effect for athletes undergoing intense training regimens. These findings suggest that curcumin supplementation could be a valuable addition to an athlete's recovery protocol.

Furthermore, the integration of high-intensity exercise within recovery programmes, although seemingly counter intuitive, has shown positive effects. This approach is based on the principle of post-activation potentiation, which enhances subsequent performance through brief periods of intense activity. [Juan et al. \(2023\)](#) highlighted that high-intensity interval training (HIIT) not only maintains fitness levels but also accelerates the recovery process compared to traditional low-intensity recovery methods. HIIT has also been associated with improvements in metabolic health and cardiovascular fitness, making it a versatile tool for athlete recovery. HIIT's adaptability allows for customisation to individual athlete needs, resulting in a tailored recovery approach.

Despite these promising findings, the study acknowledges several limitations. The small sample sizes and non-randomised designs in many of the included studies limit the generalisability of the results. Additionally, potential biases in the measurement of recovery outcomes and the placebo effect must be considered. It is also important to note that the variability in recovery protocols across studies can complicate direct comparisons. The lack of standardisation in recovery protocols can lead to inconsistent outcomes and difficulty replicating results. These limitations highlight the need for more rigorous and standardised research methodologies in future studies.

Future research should aim to address these limitations by employing larger, more diverse sample populations and randomised controlled trial designs. Moreover, investigating the combined effects of different recovery strategies could provide a more holistic understanding of their interactions and potential synergies. Understanding the underlying mechanisms through which these methods operate will also be crucial in refining and optimising recovery protocols for athletes. Further exploration into the psychological aspects of recovery methods can also offer deeper insights into their effectiveness. By exploring these areas, researchers can develop more effective and evidence-based recovery strategies that enhance athletic performance and reduce the risk of injury.

CONCLUSION

The findings of this literature review study confirm that aquatic therapies, such as hot-and-cold-water immersion (HWI) and cold-water immersion (CWI), along with a number of other alternative methods, provide a strong foundation for improving athletes' recovery and performance after competition or training. In addition, new therapies such as curcumin supplements, electrostimulation, and high-intensity interval training (HIT) also offer great potential for accelerating athletes' recovery. However, despite these promising findings, there are also a number of research limitations that need to be addressed to strengthen these results. Limitations such as the small sample size and less than ideal research design highlight the need for further research with more sophisticated approaches and larger samples. Therefore, suggestions for future research include overcoming these limitations and continuing exploration of promising recovery methods.

As such, future research is expected to provide deeper insights and more effective solutions for supporting athletes' recovery and improving their overall performance. In addition to identifying a variety of promising recovery methods, this literature review study also made an important contribution by highlighting the need for further research that is more in-depth and focuses on improving research design and increasing sample size. As such, it provides direction for researchers to develop more sophisticated approaches to strengthen the existing evidence and further investigate the effectiveness of the identified recovery methods. This contribution provides an important foundation for the development of knowledge and practices related to athlete recovery, with the hope that it can have a significant positive impact on supporting athletes' overall well-being and performance.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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