International Journal of Scientific Research & Engineering Trends
Volume 11, Issue 6, Nov-Dec-2025, ISSN (Online): 2395-566X

Post-Exercise Recovery and Long-Term Training Adaptation in Grassroots Athletes: A Evidence Review

Ms. Suja Mary George[1], Dr. Babu.P[2]
Associate Professor, Physical Education, Assumption College, Changanacherry (Autonomous), Kerala, India[1]
Assistant Professor (SG), Good Samirthan College of Physical Education, Kangyam, Thirupur, Tamil Nadu[2]

Abstract — Research on recovery is dominated by samples drawn from elite and collegiate populations, although the majority of individuals who participate in organised sport do so at the community level. This review synthesises published systematic reviews and meta-analyses, chiefly from 2018 to 2026, concerning post-exercise recovery and long-term training adaptation, and evaluates which strategies are appropriate for grassroots athletes. This is a narrative, umbrella-style synthesis: the reported statistics were extracted and plotted, and no raw data were pooled. Cold-water immersion (CWI) reduced soreness (Hedges g = −0.40, 95% CI −0.64 to −0.16) and creatine kinase (g = −0.24, −0.37 to −0.10), yet it did not restore strength. Repeated CWI following resistance training was associated with smaller gains in strength and hypertrophy. Protein supplementation contributed approximately 0.30 kg of fat-free mass and 2.49 kg of one-repetition-maximum strength, with no additional fat-free-mass benefit above a total intake of roughly 1.6 g/kg/day. Training guided by heart-rate variability improved submaximal markers (g = 0.296) but not performance (g = 0.079, not significant). The acute:chronic workload ratio was associated with injury, although its lowest-incidence band (0.8–1.3) carried a 95% interval of 14–94%. Surveys indicated that approximately two thirds of sub-elite athletes slept poorly (65%, PSQI ≥ 5). A five-tier framework is proposed: protect sleep, secure adequate protein, progress load gradually with simple monitoring, use low-cost physical recovery, and ration CWI to tournaments and endurance blocks. Direct trials in grassroots populations remain scarce, and these conclusions are therefore provisional.

Keywords— post-exercise recovery; grassroots athletes; cold-water immersion; training adaptation; sleep; protein; load monitoring

I. INTRODUCTION

Recovery is the process through which training stress becomes adaptation, so errors in recovery practice accumulate over months. The recovery literature is dominated by professional, collegiate and highly trained participants, whereas most athletes train at the community level. In this review, grassroots athletes are defined as amateur or recreational competitors in club, school, community or masters sport who typically train 3–8 hours a week alongside work or study and without dedicated sports-science support. The definition adopted here is our own; the studies cited employ a range of labels, including physically active, sub-elite and amateur.

Strategies for acute recovery alleviate soreness and perceived fatigue, yet only a few accelerate the restoration of strength or power. Cold-water immersion decreases creatine kinase and soreness, with whole-body and partial immersion proving equally effective, although jump power is suppressed immediately thereafter [1]. Network analyses rank massage highest for early relief of soreness and active recovery highest for short-term jump recovery [2], and a meta-analysis of 99 studies found that massage, compression, immersion and active recovery all alleviated soreness, whereas stretching did not [5]. For soreness, the immersion dose with the strongest support is 10–15 minutes at 11–15 °C [3].

Recovery also influences long-term adaptation. Cold-water immersion after exercise attenuated gains in muscular strength from resistance training [17]. A Bayesian meta-analysis of eight studies indicated a strong likelihood that regular CWI following resistance sessions reduces hypertrophy [18], and a 12-week trial found blunted whole-muscle hypertrophy and type II fibre size with CWI relative to active recovery [19]. A 2026 synthesis characterises this as a recovery–adaptation paradox, with endurance adaptations appearing less affected [16].

Behavioural foundations offer the strongest and least costly evidence. In athletes, sleep extension and naps proved the most effective sleep strategies [9, 10]. Protein supplementation yields small gains in strength and fat-free mass that plateau once total intake exceeds approximately 1.62 g/kg/day [14, 15]. Monitoring tools are less conclusive: HRV-guided training produced only small, non-significant performance effects [20, 21], and the acute: chronic workload ratio (ACWR) displays variable associations with injury [22–25]. At the same time,

© 2025 IJSRET

64% of elite and 65% of sub-elite athletes reported poor sleep in a survey of 338 athletes [26].

Integrated programmes have also been directly tested in young athletes. A 12-week randomised trial involving 84 competitive adolescent athletes combined strength-conditioning with HRV-guided load adjustment, at least 8 hours of sleep, foam rolling and twice-weekly cold-water immersion; it reported greater sprint, jump and VO_2max gains and a lower injury incidence rate than routine training (IRR 0.63, 95% CI 0.41–0.88) [30]. Since these components were delivered together, the contribution of each—including immersion—cannot be isolated, which is why the present review examines them one domain at a time.

Three questions structure this review: (i) which post-exercise strategies work during the first 0–96 hours and to what extent; (ii) whether those acute benefits aid or impair long-term adaptation; and (iii) which monitoring, behavioural and psychological factors determine whether grassroots athletes can apply the evidence.

II. PROPOSED METHODOLOGY

1. Design review

An umbrella-style narrative synthesis was undertaken of published systematic reviews and meta-analyses, complemented by large surveys for the behavioural domain. No additional meta-analysis was carried out, and no raw data were pooled.

2. Search and eligibility

Searches conducted in October 2026 encompassed recovery modalities, cold-water immersion and adaptation, sleep interventions, protein and resistance training, HRV-guided training, ACWR, recovery–stress monitoring, and surveys of sleep and recovery practice among amateur and sub-elite athletes.

Random-effects or network meta-analyses were given priority, followed by systematic reviews, and then surveys involving at least 50 athletes. Eligible studies comprised physically active, amateur, sub-elite and competitive adults; samples consisting solely of elite athletes were employed as proxies and identified as such.

3. Data extraction and conventions

Effect sizes are expressed as standardised mean differences (SMD or Hedges g). For soreness and creatine kinase, negative values indicate a favourable effect of the intervention.

Statistics are reported as printed by each source; intervals that are not centred on their point estimates (HRV performance effect, protein strength effect) are identified. Pooled values drawn from different reviews are plotted side by side solely for orientation and are not combined.

Certainty was not raised above the level stated by the source reviews, which frequently report low certainty and substantial heterogeneity.

4. Proposed tiered recovery framework for grassroots athletes

Strategies were ranked according to evidence strength, cost and risk in order to construct the framework presented in Table 1. This constitutes a synthesis of the cited evidence rather than a clinical guideline; injury, persistent fatigue or illness warrants clinical review.

Table 1: Proposed tiered recovery framework for grassroots athletes.

Sl.no.	Strategy	Basis in the reviewed evidence
1	Protect sleep (7–9 h, extend by about 46–113 min if habitual sleep is ~7 h; naps)	Sleep extension and naps were the most effective interventions; sleep loss impairs performance
2	Total protein about 1.6 g/kg/day during resistance training	Supplement gains plateau above about 1.62 g/kg/day; small gains in fat-free mass and 1RM
3	Gradual load progression with simple monitoring	ACWR and HRV evidence is modest; benefit is individualisation and avoiding load spikes
4	Low-cost physical recovery: light activity, massage or foam rolling, compression	Reduce soreness and perceived fatigue; no adaptation penalty reported
5	Ration cold-water immersion (10–15 min at 11–15 °C); tournaments and endurance blocks only	Soreness benefit with wide uncertainty; repeated use after strength training attenuates strength and hypertrophy

© 2025 IJSRET

International Journal of Scientific Research & Engineering Trends
Volume 11, Issue 6, Nov-Dec-2025, ISSN (Online): 2395-566X

III. FIGURES

Figure 1.
standardised mean difference in muscle soreness and creatine kinase after cold-water immersion

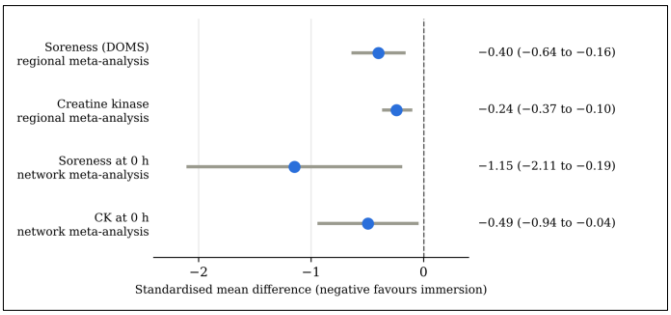
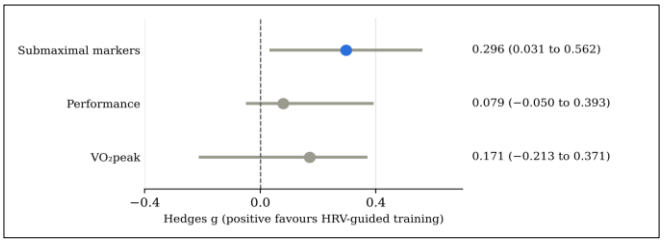
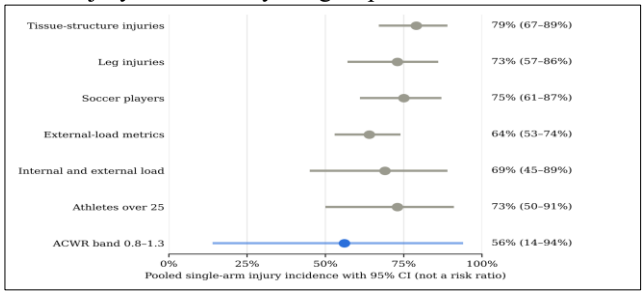


Figure 2.
Hedges G For Hrv-Guided Versus Predefined Enduranc Training



E

Figure 3.
Pooled injury incidence by subgroup and ACWR band



IV. A PRACTICAL FRAMEWORK FOR GRASSROOTS ATHLETES AND COACHES

The present ordering represents our synthesis of the evidence presented above, ranked according to evidence strength, cost and risk. It does not constitute a clinical guideline; injuries, persistent fatigue or illness require the attention of a clinician. Prioritise the protection of sleep. Adult guidance recommends 7–9 hours; in the trials reviewed, athletes who habitually slept about 7 hours gained 46–113 minutes, and naps were also beneficial [9, 10].

Ensure an adequate protein intake. During resistance training, aim for a total of approximately 1.6 g/kg/day; supplements are chiefly helpful when food intake is insufficient [14, 15]. Increase load gradually and monitor it with a simple method. Multiplying session-RPE by minutes, together with a weekly wellbeing check, supplies the load input required by ACWR at almost no cost. Avoid substantial week-to-week spikes [22–25]. Employ inexpensive physical recovery methods to address soreness. Light activity, massage or foam rolling, and compression garments alleviate soreness and perceived fatigue; stretching does not [5].

Cold-water immersion should be used sparingly. When employed, 10–15 minutes at approximately 11–15 °C targets soreness; reserve it for tournament weekends and avoid it during hypertrophy-focused blocks [3, 16–19]. Coaches can incorporate one structural measure: schedule demanding sessions with at least one low-stress day following them, so that recovery has sufficient opportunity to occur.

V. CONCLUSION

Grassroots athletes can obtain most of the available recovery and adaptation benefit through low-cost habits: safeguarding sleep, consuming sufficient protein, progressing load gradually, and employing simple physical recovery. These foundations possess the strongest evidence and the lowest cost and risk [5, 9, 10, 14, 15], and therefore constitute the best initial area for investment. Cold-water immersion remains a valuable tool when its timing is appropriate. Its short-term comfort benefit must be balanced against an adaptation cost, and the adaptation evidence is consistent in direction:

A meta-analysis determined that post-exercise Cold-water immersion reduced resistance-training gains in muscular strength [17]. A Bayesian meta-analysis of 8 studies demonstrated a strong likelihood that regular CWI following resistance sessions attenuates hypertrophy [18]. In a 12-week trial, Cold-water immersion compared with active recovery reduced whole-muscle hypertrophy and type II fibre size [19]. For athletes training for long-term strength, fitness and health, the practical recommendation is to employ active recovery, massage or foam rolling, and compression after sessions, since these alleviate soreness at minimal cost and without the adaptation concern. CWI can then be reserved for occasions when readiness is more important than long-term gains, such as

© 2025 IJSRET

tournament weekends, or following endurance sessions where adaptation appears less affected. Applied in this manner, 10–15 minutes at 11–15 °C is the most strongly supported dose for soreness (Figure 1) [3]. Athletes and coaches can begin this week: establish a sleep target, verify daily protein against approximately 1.6 g/kg/day, record session-RPE and a brief wellbeing score, and plan a low-stress day following each demanding session. These measures require no equipment, and they generate the data for subsequent refinement.

The evidence base continues to expand. The hypertrophy evidence comprises a preprint and a trial summary; most studies were of short duration, and none has examined these choices in a genuinely grassroots population. This gap represents an opportunity: clubs and community programmes are well positioned to conduct low-cost pragmatic trials of sleep extension, protein targets and simple monitoring, drawing on integrated youth programmes such as the one described in ref [30]. In the meantime, the framework outlined above constitutes the best available proxy, presented as a reasonable starting point rather than a fixed protocol.

REFERENCES

1. Zhu Y, Yang L, Liu T, Yao F, Wang Q, Yi Z. Effects of cold-water immersion at different body regions on post-exercise muscle damage recovery: a systematic review and meta-analysis. 2026. https://pubmed.ncbi.nlm.nih.gov/41716304/
2. Acute and delayed effects of post-exercise recovery strategies on explosive performance and markers of muscle damage: a systematic review and network meta-analysis. Healthcare. 2026. https://doi.org/10.3390/healthcare14101321
3. 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. Front Physiol. 2025. https://www.frontiersin.org/journals/physiology/articles/10.3389/fphys.2025.1525726/full
4. Impact of cold-water immersion compared with passive recovery following a single bout of strenuous exercise on athletic performance in physically active participants: a systematic review with meta-analysis and meta-regression. Sports Med. 2022. https://link.springer.com/article/10.1007/s40279-022-01644-9
5. Dupuy O, et al. An evidence-based approach for choosing post-exercise recovery techniques to reduce markers of muscle damage, soreness, fatigue, and inflammation: a systematic review with meta-analysis. Front Physiol. 2018; 9:403. https://pubmed.ncbi.nlm.nih.gov/29755363/
6. Blood lactate clearance during active recovery after an intense running bout depends on the intensity of the active recovery. University of Glasgow. 2010. https://eprints.gla.ac.uk/34120
7. Nalbandian HM, Radak Z, Takeda M. Active recovery between interval bouts reduces blood lactate while improving subsequent exercise performance in trained men. Sports. 2018. https://www.bisp-surf.de/Record/PU201808005789
8. The effect of active recovery, massage and passive recovery on blood lactate concentration and swimming performance. https://lida.sport-iat.de/ta/Record/4004961
9. Silva AC, Silva A, Edwards B, Tod D, et al. Sleep extension in athletes: what we know so far – a systematic review. Sleep Med. 2021; 77:128–135. https://pubmed.ncbi.nlm.nih.gov/33352457/
10. The impact of sleep interventions on athletic performance: a systematic review. https://pmc.ncbi.nlm.nih.gov/articles/PMC10354314
11. Sleep interventions for performance, mood and sleep outcomes in athletes: a systematic review and meta-analysis. Psychol Sport Exerc. 2021. https://minerva-access.unimelb.edu.au/rest/bitstreams/54b318da-58c2-58d5-861c-7853582bd10f/retrieve
12. The impact of sleep duration on performance among competitive athletes: a systematic literature review. https://researchconnect.stonybrook.edu/en/publications/the-impact-of-sleep-duration-on-performance-among-competitive-ath/
13. The effect of sleep on physical performance, regeneration and risk of injuries in athletes. https://apcz.umk.pl/QS/article/download/76208/48038/261258
14. A systematic review, meta-analysis and meta-regression of the effect of protein supplementation on resistance training-induced gains in muscle mass and strength in healthy adults. Br J Sports Med. 2018;52(6):376–384. https://pubmed.ncbi.nlm.nih.gov/28698222/
15. Nunes EA, et al. Systematic review and meta-analysis of protein intake to support muscle mass and function in healthy adults. J Cachexia Sarcopenia Muscle. 2022;13(2):795–810. https://pubmed.ncbi.nlm.nih.gov/35187864/
16. The cold-water immersion recovery–adaptation paradox: reconciling acute parasympathetic and analgesic benefits with chronic hypertrophy attenuation. Exp Physiol. 2026. doi:10.1113/EP094042.

© 2025 IJSRET

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC13525907/
17. Grgic J. Effects of post-exercise cold-water immersion on resistance training-induced gains in muscular strength: a systematic review and meta-analysis. Eur J Sport Sci. 2022. https://vu-9.eprints-hosting.org/42998/
18. Piñero A, et al. 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. SportRxiv preprint. 2024. https://sportrxiv.org/index.php/server/preprint/download/301/603
19. Cold-water immersion: hypertrophic friend or foe? Human Kinetics excerpt. https://us.humankinetics.com/blogs/excerpt/cold-water-immersion-hypertrophic-friend-or-foe
20. Granero-Gallegos A, González-Quilez A, Plews D, Carrasco-Poyatos M. HRV-based training for improving VO2max in endurance athletes: a systematic review with meta-analysis. Int J Environ Res Public Health. 2020;17(21):7999. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7663087/
21. Monitoring and adapting endurance training on the basis of heart rate variability monitored by wearable technologies: a systematic review with meta-analysis. J Sci Med Sport. 2021. https://lida.sport-iat.de/ta/Record/4073164?lng=en
22. The relationship between acute:chronic workload ratios and injury risk in sports: a systematic review. https://research.bond.edu.au/en/publications/the-relationship-between-acute-chronic-workload-ratios-and-injury/
23. Griffin A, Kenny IC, Comyns TM, Lyons M. The association between the acute:chronic workload ratio and injury and its application in team sports: a systematic review. Sports Med. 2020. https://pure.ul.ie/en/publications/the-association-between-the-acutechronic-workload-ratio-and-injur/
24. Acute to chronic workload ratio (ACWR) for predicting sports injury risk: a systematic review and meta-analysis. BMC Sports Sci Med Rehabil. 2025. https://pubmed.ncbi.nlm.nih.gov/41029871/
25. The acute:chronic workload ratio: challenges and prospects for improvement. arXiv:1907.05326. https://arxiv.org/pdf/1907.05326
26. Doherty R, Madigan SM, Nevill A, et al. The sleep and recovery practices of athletes. Nutrients. 2021;13(4). https://core.ac.uk/outputs/475698183
27. The sleep, recovery, and nutrition characteristics of elite adolescent athletes. Sports. 2025. https://pmc.ncbi.nlm.nih.gov/articles/PMC11860358
28. Sleep behaviors and nutritional knowledge in amateur and professional combat sport athletes. Edith Cowan University. https://ro.ecu.edu.au/ecuworks2022-2026/4501
29. Gnacinski SL. A psychometric evaluation of the Recovery Stress Questionnaire for Athletes (RESTQ-Sport). Dissertation, University of Wisconsin–Milwaukee; 2017. https://dc.uwm.edu/etd/1478
30. Ramesha HN, Sandeep, Babu P. Effect of integrated strength-conditioning and recovery protocols on performance and injury risk in young athletes: a randomized controlled trial. Int J Sci Res. 2026;15(8). https://dx.doi.org/10.21275/SR26728102340

© 2025 IJSRET