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Post-Exercise Passive Heat Exposure in Athletes – A Systematic Review of Recovery, Performance, and Adaptation

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ABSTRACT (STRUCTURED)

Background. Post-exercise passive heat exposure, including sauna bathing, infrared sauna, and hot-water immersion, has been proposed as a strategy to influence recovery, performance, and adaptation in sport, but the evidence remains heterogeneous.

Purpose. To assess the effects of post-exercise passive heat exposure on recovery-, performance-, and adaptation-related outcomes in athletes and trained individuals.

Methods. PubMed and Scopus were searched on 18 March 2026 and supplemented by citation tracking and manual reference screening. Eligible studies examined passive whole-body heat exposure after exercise, training, or competition. Linked reports were grouped. Findings were synthesized narratively, and a retrospective risk-of-bias assessment was performed.

Results. Thirteen study programs were included. The most favorable pattern was observed in repeated endurance-oriented applications, particularly when passive heat appeared to support heat adaptation. Acute effects were mixed and outcome-specific, whereas evidence in team-sport, strength-, power-, and hypertrophy-related settings was limited and mostly neutral.

Conclusion. Post-exercise passive heat exposure appears to have selective rather than general effects in athletes. Current evidence does not support broad claims of consistent benefit across athletic settings.

Keywords: passive heat exposure; sauna; infrared sauna; hot-water immersion; athletes; recovery; performance; adaptation

1. Introduction

Post-exercise passive heat exposure has attracted growing interest in sport and exercise settings as a potential strategy to influence recovery, subsequent performance, and training adaptation. Practical interest has centered mainly on sauna bathing, infrared sauna exposure, and hot-water

immersion performed after training or competition, particularly in endurance settings and in situations where athletes seek additional thermal stress without increasing external training load. Despite this interest, the evidence base remains relatively small and conceptually fragmented. Recent reviews have examined overlapping areas, including athlete-focused syntheses of post-exercise heat exposure, endurance-oriented passive heat acclimation, broader sport-specific evaluations of passive heating, and practical reviews of passive heat acclimation strategies in endurance athletes (Heathcote et al. 2018; Ahokas et al. 2025a; Menzies et al. 2025; Solomon and Laye 2025).

Several mechanisms have been proposed through which passive heating after exercise might influence recovery or adaptation. These include plasma volume expansion, altered cardiovascular and thermoregulatory strain, heat-acclimation-like responses, and possible effects on muscle soreness, neuromuscular function, or subjective readiness. However, mechanistic plausibility alone does not establish practical benefit. Broader reviews of post-exercise cooling and heating, passive recovery strategies, and heating for recovery or adaptation have emphasized that the effects of thermal interventions depend on exercise type, intervention timing, comparator choice, and the outcome measured (McGorm et al. 2018; Cullen et al. 2021; Thorpe 2021; Chaillou et al. 2022). Additional narrative and broad-scope reviews have also discussed sauna use, passive heating, and post-exercise recovery-related questions, but these were not designed as athlete-specific syntheses focused narrowly on passive whole-body heat exposure applied after exercise (Dudzik et al. 2024; Dębicki et al. 2025; Karol et al. 2026).

Interpretation of this field is complicated by the fact that adjacent literatures are often considered together despite addressing different questions. Passive heat maintenance between warm-up and performance concerns pre-performance thermal preservation rather than post-exercise recovery, whereas the larger cooling literature concerns a different intervention strategy altogether (Duffield 2008; Poppendieck et al. 2013; Hohenauer et al. 2015; Cowper et al. 2022). Similarly, studies of exercise performed in the heat, mixed hydrotherapy, or local heating do not necessarily answer the narrower question of whether passive whole-body heating applied after exercise benefits athletic recovery or adaptation.

A further distinction is required between acute and repeated post-exercise heat exposure. A single heat session may be used as a recovery intervention intended to influence soreness, neuromuscular restoration, or next-session readiness. Repeated post-exercise heating may instead be used as an adjunct to training to influence heat adaptation, endurance-related physiology, or longer-term performance markers. These are related but not identical questions, and combining them without separation risks overgeneralization.

The aim of this systematic review was to evaluate the effects of post-exercise passive heat exposure on recovery, performance, and adaptation outcomes in athletes and trained individuals. The review further considered whether findings differed between acute and repeated exposure protocols and across endurance- versus team-sport or strength/power-oriented settings.

2. Research Materials and Methods

2.1. Review Approach and Eligibility Criteria

This systematic review employed a structured search methodology along with an eligibility framework to identify research studies investigating the effects of passive whole-body heat exposure administered to athletes and clearly trained individuals after exercise. Studies that met inclusion criteria included athletes or clearly trained individuals; utilized passive whole-body heat exposure administered after exercise, training or competition; used sauna bathing, infrared sauna exposure, hot-water immersion, or an equivalent passive whole-body heat exposure methodology; and reported at least one recovery, performance, or adaptation outcome. Clearly trained individuals were defined as those described by the study authors as being trained, well-trained, endurance-trained, strength-trained, competitive, subelite, elite, or engaged in structured, sport-specific training.

Exclusion criteria for studies were as follows: heat exposure was administered during exercise and not after exercise; the primary method of heat exposure was not passive; the intervention focused on local heat application versus whole-body heat; the subjects/population studied were not relevant to athletic or clearly trained sport related practices; the report was a review, commentary, protocol, or other non-primary report type; or the study did not report outcomes relevant to recovery, performance, or adaptation. Papers employing mixed hydrotherapy methodologies where passive heat was only one aspect of a larger recovery comparison methodology were not retained for the primary synthesis. Studies utilizing local heat were also excluded from the primary synthesis.

2.2. Information Sources and Search Strategy

Searches of literature databases were conducted in PubMed and Scopus. The preserved search and export records indicated that both database searches and exports were completed on 18 March 2026. Additional records were identified through citation tracking and manual screening of references for pertinent articles and reviews.

The search strategy combined the four major concepts: passive heat modality; post-exercise timing; athlete or trained population; and recovery, performance, or adaptation outcomes. At

the time of the initial search, broad population terms were used to maximize sensitivity. However, all subsequent eligibility determinations had to be consistent with the athlete/trained population focus of the current review.

The entire PubMed and Scopus search strategies are presented in the Supplementary Materials (Supplementary File S1).

2.3. Study Selection, Linked Reports, and Data Extraction

Preserved database exports yielded a total of 96 records, including 41 records from PubMed and 55 records from Scopus. After removal of 37 confirmed duplicate records due to overlapping DOIs in the preserved database exports, there remained 59 records to screen after confirmed minimum deduplication.

Due to preservation of the search and export files, no historical audit trail existed for each screening stage, therefore, the downstream study-selection counts were reconstructed retrospectively from the retained full texts, the working source map, and the exclusion log created during preparation of the manuscript. Therefore, 42 reports were requested for retrieval, 1 report was not obtained, and 41 reports were evaluated for eligibility at full-text level.

Title/abstract screening and full-text evaluation were completed by several authors. Author team discussion resulted in the resolution of uncertainty. Final decisions regarding consistency with the review's focus area, whether multiple publications represented linked reports, and the ultimate inclusion status were determined by the lead author.

Linked reports were treated as a single study program in the primary synthesis when two or more publications stemmed from the same intervention line and reported additional complementary outcomes from the same participant group. The use of this approach was applied to the Kirby runner sauna line, the Ahokas repeated infrared sauna line, the Stanley cyclist sauna line, and the Horgan volleyball water-immersion line.

A structured, study-by-study approach was used to extract data. Included items in the extraction process were: study design; participant demographics; sport or training status; heat modality; timing and duration of post-exercise heat exposure; comparator condition; principal outcomes; and primary results. Data were extracted from each study in a structured format and compared to the full texts during manuscript development and final synthesis. Notes were recorded regarding sample size limitations, whether linked companion reports existed, and study features that may have complicated interpretation.

2.4. Synthesis and Methodological Considerations

Due to differences in participant populations, thermal dose, comparator design, and selected outcomes among the various studies examined, evidence was synthesised using a narrative approach. In addition to separating acute post-exercise recovery studies and repeated exposure studies, additional stratification was also applied regarding whether the evidence was generated from an endurance-based setting, or from a team-sport, strength/power, or hypertrophy training setting.

A retrospective assessment of study-level risk of bias was performed for all of the included evidence based on the full-text versions of the evidence available. The RoB 2 tool was used to assess randomized parallel-group and randomized crossover trials; when applicable, crossover trial-specific factors were also taken into consideration. Non-randomised or insufficiently randomised intervention studies were assessed using the ROBINS-I tool. Each of the authors (Authors 1, 2 & 3) made separate retrospective study-level assessments of each of the included studies based solely on the information contained within the retrieved reports. When necessary, disagreements between the authors' assessments were discussed until a consensus could be reached, with the author who had responsibility for the majority of the work being asked to make the final determination. Summary of study-level assessments can be found in Supplementary Table S2. While risk-of-bias assessments were used to inform the interpretation and confidence in the findings of the studies included in this systematic review, they were not used to determine quantitative exclusions.

Results

3.1. Overview of the Included Evidence Base and Study Selection

A total of 96 records were exported from the preserved databases; these records included 41 from PubMed and 55 from Scopus. Following removal of 37 confirmed duplicate records identified due to DOI overlap between the preserved exports, a total of 59 records remained for screening. Due to the failure of the preserved search and export files to retain a record of the original screening-stage audit trail, the subsequent study selection numbers were reconstructed retrospectively from the remaining full-text versions, the working source map, and the exclusion log. Accordingly, 42 reports were sought for retrieval; 1 report could not be located for retrieval and 41 reports underwent full-text eligibility screening.

A total of 13 main study programmes contributed evidence towards the primary synthesis. Several companion publications linked to the primary studies were identified but were not counted as separate studies. Further full-text versions were excluded from the primary synthesis

because they represented either review-only publication formats, employed local heating rather than passive whole-body heating, incorporated mixed hydrotherapy designs in which passive heat was not adequately isolated, failed to specify the timing of heat exposure relative to the exercise protocol, targeted incorrect populations or lacked sufficient direct relevance to the review question. A report-level exclusion log is presented in Supplementary Table S3.

Studies contributing evidence toward the primary synthesis include Scoon et al. (2007), Stanley et al. (2015), Zurawlew et al. (2016), Hung et al. (2018), Skorski et al. (2020), Stevens et al. (2021), Kirby et al. (2021a), Ahokas et al. (2023), Coertjens et al. (2023), Horgan et al. (2023), Ahokas et al. (2025b), Gustafsson et al. (2025), and Kjertakov et al. (2025). Companion publications were identified for Leicht et al. (2018), Kirby et al. (2021b), Horgan et al. (2022) and Ahokas et al. (2025c).

The evidence base included primarily small-scale exercise-intervention studies with participants from endurance-orientated populations, team sports and clearly trained sport-related populations. The majority of studies investigated the effects of passive heat exposure via sauna bathing, infrared sauna exposure, or hot water immersion.

3.2. Risk of bias of included studies

Overall, the risk-of-bias profile of the included evidence was mixed and generally not low. The randomized crossover trials were most often judged as having some concerns, mainly because of incomplete reporting of sequence generation details, the practical impossibility of participant blinding to thermal interventions, and the inclusion of subjective or perceptual outcomes alongside objective performance measures. Several parallel-group athlete studies were more appropriately treated as non-randomized or insufficiently randomized interventions and were judged as having moderate risk of bias under ROBINS-I. One longitudinal single-cohort sauna study was judged at serious risk of bias because of the absence of a concurrent control group and strong vulnerability to time-related confounding. Study-level overall judgements are summarized in Table 1, and detailed domain-level judgements are provided in Supplementary Table S2. Taken together, the evidence base is better described as small, heterogeneous, and methodologically vulnerable than as consistently low risk.

Table 1. Characteristics and overall risk-of-bias judgements of included study programs.

| Study program | Population/sport | Intervention and comparator | Main finding | Overall RoB |
|----------------------|---|--|--|--------------------|
| Scoon 2007 | Competitive male runners | Post-exercise sauna bathing for 3 weeks vs training control | Improved endurance running capacity and plasma volume | Some concerns |
| Stanley 2015 | Well-trained male cyclists | Repeated post-exercise sauna bathing; no concurrent randomized control | Plasma-volume expansion; performance evidence limited | Serious |
| Zurawlew 2016 | Trained runners | Post-exercise hot-water immersion vs thermoneutral immersion | Improved heat acclimation and hot-condition 5-km performance | Moderate |
| Hung 2018 | Elite teen archers | Repeated hot-water bathing 1 h after training vs control | Impaired training adaptation and postural stability | Some concerns |
| Skorski 2020 | Competitive swimmers/triathletes | Post-exercise sauna vs placebo/control in crossover design | Impaired next-day swim performance | Some concerns |
| Stevens 2021 | Elite/pre-elite endurance athletes training in heat | Post-exercise hot-water immersion vs matched control recovery | No added benefit beyond heat training | Moderate |
| Kirby 2021a | Trained middle-distance runners | Intermittent post-exercise sauna bathing vs training control | Improved heat tolerance and exercise-capacity markers | Moderate |

| | | | | |
|--------------------------------------|--|---|--|---------------|
| Ahokas 2023 | Male basketball players | Single post-exercise infrared sauna vs passive recovery | Improved soreness and selected neuromuscular recovery outcomes | Some concerns |
| Coertjens 2023 | Trained cyclists/triathletes | Hot-water, cold-water, and control immersion between Wingate tests | Hot-water immersion improved second-Wingate mean power | Some concerns |
| Horgan intervention line (2022/2023) | Junior international/subelite male volleyball athletes | Randomized crossover comparison of control, cold-water immersion, contrast-water immersion, and hot-water immersion after resistance exercise | No clear overall superiority of hot-water immersion despite selected treatment-level signals | Some concerns |
| Ahokas 2025b | Female team-sport athletes | Repeated post-exercise infrared sauna vs training control | No meaningful hypertrophy benefit; limited neuromuscular signal | Moderate |
| Gustafsson 2025 | National-level male soccer players | Hot-water immersion, cold-water immersion, and placebo | Neither hot-water nor cold-water immersion outperformed placebo | Some concerns |

| | | | | |
|----------------|-----------------------|---|--|----------|
| Kjertakov 2025 | Well-trained cyclists | Repeated post-exercise hot-water immersion added to HIIT vs control | No added benefit for performance or mitochondrial adaptation | Moderate |
|----------------|-----------------------|---|--|----------|

3.3. Repeated post-exercise passive heat exposure in endurance settings

Repeatedly exposing individuals to passive heat stress in an endurance setting has shown positive results; several studies have demonstrated positive physiological or performance related outcomes. For example, competitive male distance runners who participated in three weeks of post-exercise sauna bathing had an increase in their endurance running capacity and plasma volume (Scoon et al. 2007) while trained runners who used post-exercise hot-water immersion experienced heat acclimatization and improved five-kilometer treadmill time trials in the heat, however, they did not experience improved performance at temperate temperatures to the same degree (Zurawlew et al. 2016). Also, trained middle distance runners who intermittently took post-exercise saunas had better markers of heat tolerance and improved temperature specific exercise capacity than those who just trained (Kirby et al. 2021a). Although there was some variation, a secondary article to this study indicated that both male and female runners benefited from the intervention, with some thermoeffector differences between males and females (Kirby et al. 2021b).

However, not all repeated endurance studies produced beneficial results. Well trained male cyclists who participated in post-exercise sauna baths experienced plasma volume expansion, although direct performance evidence was not provided in the primary article (Stanley et al. 2015). A secondary article to the same study line indicated that there was no significant difference in the acute heart rate variability response to repeated sauna baths, despite experiencing a high level of autonomic perturbation in each individual (Leicht et al. 2018). Additionally, in endurance athletes who already train in a hot climate, repeated post-exercise hot-water immersion did not increase heat adaptation or performance above what the training stimulus could achieve (Stevens et al. 2021). Similarly, well trained cyclists who used repeated post-exercise hot-water immersion experienced no measurable improvement in temperature specific endurance performance or mitochondrial function (Kjertakov et al. 2025).

The repeated endurance research indicates that passive heat stress is likely most applicable when it increases the total thermal stress in a way that is conducive to either heat acclimatization

or endurance preparation. However, the data currently available does not indicate a consistent ergogenic effect across endurance settings.

3.4. Acute post-exercise passive heat exposure and short term recovery

There was mixed evidence supporting the concept of short-term recovery benefits. Male basketball players that completed a post-exercise infrared sauna session after a bout of resistance exercise experienced improvements in certain neuromuscular measures and reductions in delayed onset muscle soreness (DOMS) after the recovery session (Ahokas et al. 2023). Trained cyclists that used hot water immersion as a recovery method between two wingate tests experienced improvements in mean power output in the second test, whereas cold water immersion decreased mean power output in the second test (Coertjens et al. 2023). These findings suggest that the potential for short-term recovery benefits is dependent on the specific outcome being measured and the recovery context.

Additionally, other acute studies did not support the idea of a broad based favorable interpretation. Junior international and sub-elite male volleyball athletes were involved in a crossover study examining post-resistance exercise water immersion using four different strategies: control, cold water immersion, contrast water immersion, and hot water immersion. Two articles derived from the study, one in 2022 and the other in 2023, examined inflammation, anthropometry, perception, performance, daily wellness, and hormonal outcomes. Both articles failed to find superior results from any of the immersion strategies compared to control and the articles found some favorable treatment level effects in select areas such as sleep quality, fatigue, and testosterone (Horgan et al. 2022; Horgan et al. 2023).

Furthermore, two additional studies found that passive heat stress was detrimental to performance. Post-exercise sauna bathing was found to negatively impact next day swimming performance in competitive swimmers and triathletes (Skorski et al. 2020). Similarly, repeated hot water bathing after training was found to impede training adaptation in elite teen archers and negatively impacted shooting performance and postural stability (Hung et al. 2018).

Taken collectively, the current acute literature does not support a generalized statement that passive heat is a reliable means to improve short-term recovery or next session performance. Instead, the literature indicates that acute effects are highly dependent on the outcome measure and the sport-specific context.

3.5. Team sport, strength/power, and hypertrophy

The literature outside of endurance sports was much more limited. Female team sport athletes that used infrared sauna for six weeks as a recovery method did not experience significant improvements in hypertrophy-related outcomes; however, some limited signs of improvement were seen in select neuromuscular variables (Ahokas et al. 2025b). A secondary article to this study found that the salivary cortisol response to infrared sauna decreased over the course of the study; however, this finding did not significantly affect the authors' conclusion that the study represented a largely neutral adaptation trial (Ahokas et al. 2025c).

National level soccer players that underwent hot or cold water immersion as a recovery method did not find either form of water immersion to be more effective than a placebo for immediate post-recovery physical performance and repeated use of water immersion did not improve long-term adaptations to training (Gustafsson et al. 2025). These findings represent very little support for recommending passive heat as a universally effective recovery or adaptation tool for team sport athletes.

3.6. Full-Text Studies Not Included in the Review; Informative for Scope

At full-text stage, Sautillet et al. (2024) was excluded because their population consisted of physically active men and not an athlete-specific cohort as defined by the final review scope. Other full-text studies were removed from the primary synthesis but provided information regarding the scope of the review. Bartolomé et al. (2021) indicated positive responses to a passive dry-sauna acclimatization program in semi-professional football players, however, the intervention was not specifically framed as a post-exercise heat exposure protocol, and thus not included in the primary synthesis. John et al. (2024) used passive leg heating versus whole-body heating. Kim et al. (2019) and Kim et al. (2020) evaluated local heat therapy versus whole-body passive heating. Vaile et al. (2008); Monedero and Donne (2000), and Pournot et al. (2011) evaluated broader mixed recovery or immersion designs versus discrete passive heat interventions. Additionally, Siquier-Coll et al. (2024) evaluated lactate physiology in relation to sport-specific recovery or performance outcomes.

3.7. Overall Pattern

Repeated post-exercise passive heat exposure demonstrated the most consistent and favorable pattern in endurance-oriented settings, especially when heat adaptation was a component of the practical objective. However, the pattern was not consistent throughout all studies. Acute studies yielded mixed results and demonstrated favorable signals for muscle soreness, select

neuromuscular outcomes or short-term anaerobic performance. However, numerous neutral or unfavorable studies were also identified in applied athlete settings. Team-sport, strength-power, and hypertrophy contexts lacked sufficient evidence to provide strong practical recommendations.

4. Discussion

Post-exercise passive heat exposure demonstrated a non-uniform effect across various athletic settings. Favorable patterns were identified in repeated endurance-oriented applications, particularly when the intervention increased thermal strain to a degree relevant to heat adaptation. Positive findings were reported in runners by Scoon et al. (2007); Zurawlew et al. (2016); and Kirby et al. (2021a), however, these findings were not replicated consistently in subsequent studies. Neutral findings were also noted in athletes who had been previously exposed to considerable thermal or training stress. These findings suggest that post-exercise passive heat exposure may offer little additional benefit beyond that of the underlying training environment (Stevens et al. 2021; Kjertakov et al. 2025).

These findings are generally consistent with recent review-level summaries that suggest post-exercise passive heat can enhance selected physiological markers and certain heat-related performance outcomes in endurance settings; however, emphasize considerable variability and uncertainty (Ahokas et al. 2025a; Menzies et al. 2025; Solomon and Laye 2025). Practical reviews of passive heat acclimation also suggest that passive heat may be more beneficial as an adjunct to heat adaptation than as a general performance strategy (Heathcote et al. 2018).

Acute studies demonstrated less consistency. Favorable findings were reported for muscle soreness, select neuromuscular outcomes, and short-term anaerobic performance (Ahokas et al. 2023; Coertjens et al. 2023), although these findings were countered by neutral or unfavorable findings in other athlete populations. The water-immersion (hot) study in volleyball also did not demonstrate clear overall superiority of hot-water immersion over cold-water immersion, despite demonstrating signals in biological, perceptual, well-being, and hormonal outcomes (Horgan et al. 2022; Horgan et al. 2023). Most notably, however, the negative findings by Skorski et al. (2020) and Hung et al. (2018) provide evidence that passive heat may reduce next-day performance or training adaptations in some contexts. These findings severely limit the utility of positive findings in endurance studies.

Outside of endurance, evidence remains limited. A repeated infrared sauna trial in female team-sport athletes was largely neutral for hypertrophy and only weakly indicative of select neuromuscular variables (Ahokas et al. 2025b). Similarly, the soccer study by Gustafsson et al.

(2025) was largely neutral in both acute and long-term aspects. As such, currently available data do not support a broad recommendation for routine post-exercise passive heat exposure in team-sport and strength/power oriented settings.

Context from the larger recovery literature is important. Review articles examining post-exercise heating and cooling emphasize the importance of matching thermal recovery strategies to the specific demands of the sport, the training phase, and the desired outcome, as opposed to applying them indiscriminately (Thorpe 2021; Chaillou et al. 2022). The cooling-based recovery literature is also much more extensive than the heating-based literature and is based on a more developed comparative framework (Duffield 2008; Poppendieck et al. 2013; Hohenauer et al. 2015). This disparity in evidence development should be taken into account when evaluating the passive heat literature.

A number of weaknesses exist in the current review. First, the amount of supporting evidence is relatively limited, and most of it derives from the results of small-scale exercise intervention trials. Second, each trial varied significantly in terms of type of intervention; temperature; length of time; frequency of intervention; comparative design; and selected outcomes. Third, more than one publication was produced by several of the intervention lines that were identified, which made it necessary to group related publications together in order to prevent the duplication of studies. Fourth, while the authors retained their search database exports, they did not retain their original screening-stage audit trail, so they could only reconstruct later study selection counts from the remaining full-text articles and the source map. Fifth, the formal assessment of the risk of bias associated with each of the included trials was also done retrospectively, instead of prospectively during the original review process. These limitations will likely diminish both the reliability and the ability to reproduce the findings of the current review, and therefore, they do not provide sufficient evidence to make conclusions about causality or recommendations for a wide range of practices.

Overall, the existing body of literature provides a basis for an interpretive approach based on selectivity rather than a general approach. Passive heat after exercise may be beneficial in certain types of endurance and heat adaptation situations and there is some evidence that some acute protocols can affect muscle soreness, selected neuromuscular outcomes, or short-term performance in anaerobic tasks. However, the current evidence does not provide support for the promotion of passive heat as a universally effective post-exercise recovery strategy across all sports.

5. Conclusion

Passive heat after exercise has selective rather than general effects among athletes. The best rationale for using it is for repeated endurance-oriented applications, such as heat acclimation or increasing thermal load. There is considerable variability in the acute effects, which appear to be dependent upon the sport setting and/or the outcomes measured. The evidence currently available does not support general claims of consistent recovery or improved performance across various sports. Additional, better reported studies are required, especially in team sports and strength/power oriented populations.

Disclosures

Supplemental Data

Supplementary File S1: PubMed and Scopus search strategies used to search for databases.
Supplementary Table S2: Study-level retrospective risk-of-bias judgments for the included programs.

Supplementary Table S3: Report-level exclusion log and retrieval status of the full texts.

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Conflict of Interest

The authors declare no conflicts of interest.

Declarations Regarding Generative AI and AI-Assisted Technologies Used in Writing Process

ChatGPT (OpenAI) was used exclusively for enhancing the linguistic quality and structural organization of the manuscript. All AI-assisted output was reviewed and revised by the authors. The authors assume full responsibility for the scientific content and interpretation of data and for the final version of the manuscript.

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