



Ergonomics and Physiological Impacts on Running Athletes: A Systematic Review

Catherine Dwi Augusthi Putri^{1)*}, Arwan Bin Laeto²⁾, Nuha Mardhiyah Salsabilah³⁾,
Nadira Alifa⁴⁾, Muhammad Abdurrahman Ahnaf⁵⁾

^{1,2,3,4,5)} Faculty of Medicine, Sriwijaya University

*Email: catherine@unsri.ac.id

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ABSTRACT

Running is a sport that is often chosen by many people when they want to exercise. Both professional and amateur runners often experience musculoskeletal disorders such as knee, ankle, and hip pain due to repetitive mechanical stress, improper running technique, and the use of non-ergonomic footwear. In running, ergonomic interventions—including modifications to running posture, shoe selection, and corrective exercise programs—are considered important for injury prevention and performance enhancement, but their effectiveness varies across studies. This research aims to evaluate the effectiveness of ergonomic interventions on musculoskeletal health and performance in runners. The Research method with literature search was conducted through PubMed, Scopus, and Science Direct databases (2020–2025) and yielded 37 articles. Of the screened articles, three studies met the inclusion criteria. Data were analyzed narratively, with risk of bias assessment performed using RoB 2 and ROBINS-I tools. The Result :. Interventions such as running style analysis, dynamic posture training, and the use of ergonomic shoes have been shown to reduce the prevalence of overuse injuries such as iliotibial band syndrome and plantar fasciitis. Several studies have also reported improvements in running efficiency, VO₂ max, and travel time. Runners who take an individualized ergonomic approach show faster injury recovery and higher performance consistency. Ergonomic interventions have been proven effective in reducing the risk of musculoskeletal injuries and improving runners' performance. The recommendations that the author proposes for training management and athlete health are as follows: integrating neuromuscular strengthening exercises into running programs; optimizing training load regulation and recovery to prevent overtraining; utilizing technology-based psychological interventions to maintain motivation and training adherence; employing hypoxic training conditions or environmental simulations as physiological interventions; using wearable devices for real-time monitoring; and conducting regular physiological screenings as strategies for injury prevention and performance enhancement.

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INTRODUCTION

One of the most well-liked and accessible sports that people of all ages participate in worldwide is running. Running has been even more popular over the past 20 years compared to the previous 50. Because running is inexpensive and accessible to a wide spectrum of individuals with little equipment, the number of runners and running events has grown dramatically in recent decades. More significantly, because running has been associated with longevity and lower risk factors for cardiovascular disease, it is a great type of exercise for those looking to improve their physical fitness and/or lead healthier lives.(Kakouris, Yener and Fong, 2021). Running is a high-risk activity for repetitive mechanical injuries, especially to the lower limbs, despite its substantial cardiovascular and psychological advantages. In general, 25% of runners eventually sustain an injury, and 50% of runners sustain an ailment that temporarily stops them from running each year. Overuse injuries, which mostly affect the knee, ankle/foot, and calf, account for 70% to 80% of running injuries (Kakouris, Yener, and Fong, 2021). According to studies, up to 79% of runners sustain at least one injury annually; knee pain (patellofemoral pain syndrome), shin splints (medial tibial stress syndrome), and Achilles tendon injuries are the most common (van Poppel et al., 2021).

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Recent research indicates that basic ergonomic interventions, like the use of ergonomic handgrips to enhance shoulder-arm posture, can lessen shoulder internal rotation, forearm pronation, and shoulder abduction in runners, ultimately improving overall posture. Additionally, while it may not directly enhance running performance, the usage of wearables that provide real-time input on spatiotemporal parameters and relative speed has been demonstrated to lower injury incidence and severity in recreational runners. These methods provide credence to the idea that ergonomics encompasses more than just choosing shoes or footwear; it also includes postural adjustments, feedback on gait and running style, and supportive equipment design (Sesselmann et al., 2023). Thus, the purpose of this systematic review was to thoroughly assess how ergonomic modifications affect runners' physiological characteristics and performance. It is anticipated that the findings will offer a solid scientific foundation for sports performance enhancement,



injury preventive tactics, and rehabilitation procedures.

METHOD

Data Source

Three significant electronic databases were used for the literature search: ScienceDirect, Google Scholar, and PubMed. These databases were selected due to their broad coverage in indexing peer-reviewed research publications in sports science, medicine, and medicine. Only articles released between 2020 and 2025 were included in the search. To ensure methodological consistency and optimize the retrieval of pertinent research, the same search approach was used for each database.

The search was conducted using a combination of keywords and Medical Subject Headings (MeSH) terms, such as "Ergonomics, Runners, Sports Injuries, Musculoskeletal Disorders, and Athletic Performance." The three electronic databases yielded thirty-seven articles. In order to find additional articles that might have been overlooked in the database search, the bibliographies of research that satisfied the requirements were also manually examined. Only Randomized Controlled Trials (RCTs), cohort studies, and observational studies were included in order to guarantee an emphasis on primary research. Case reports, meta-analyses, and systematic reviews were not included. Prior to filtering and selection, all collected articles were put into reference management software, where duplicate data was methodically found and eliminated. Following screening and selection, three pieces were chosen for Only Randomized Controlled Trials (RCTs), cohort studies, and observational studies were included in order to guarantee an emphasis on primary research. Case reports, meta-analyses, and systematic reviews were not included. Prior to filtering and selection, all collected articles were put into reference management software, where duplicate data was methodically found and eliminated. Three papers were chosen for review based on the inclusion criteria following screening and selection.

Literature Study

The literature search was conducted through three major electronic databases: Google Scholar, PubMed, and ScienceDirect. These databases were chosen because they provide extensive coverage in indexing peer-reviewed medical and clinical research publications. The search strategy was limited to studies published between 2020 and 2025 to ensure inclusion of the most up-to-date and relevant research.

PICOST Framework

PICOST Framework for Systematic Reviews: Ergonomics in Running Athletes and Physiological Impacts.

Population (P): The target population for this systematic review includes both competitive and recreational athletes in the sport of running. This population includes

professional and amateur athletes of all ages and genders who participate in structured training or competition. Inclusion criteria also include athletes who use specialized equipment, undergo structured training programs, or compete in environments where ergonomic principles can be applied to improve performance or reduce injury risk.

Intervention (I): The interventions of interest include ergonomic modifications, equipment designs, and environmental adaptations implemented specifically to optimize athletic performance or address the physiological demands of running. These include ergonomically designed sports equipment, such as running shoes with improved shock absorption, and protective gear designed to distribute pressure without compromising mobility. Interventions also include ergonomic training programs, posture correction techniques, runner workstation modifications, and technique adjustments based on biomechanical analysis. In addition, this review will evaluate participatory ergonomics approaches, multicomponent interventions that combine physical exercise with ergonomics education, and technology-based solutions such as wearable devices with biomechanical sensors that provide real-time feedback to optimize movement.

Comparators (C): Comparators include standard or conventional sports equipment, traditional training methods without ergonomic considerations, usual care practices in a sporting context, and control groups that do not receive ergonomic interventions. The review will also consider comparisons between types of ergonomic interventions, such as single versus multicomponent interventions, equipment-based versus training-based interventions, and immediate versus gradual implementation strategies. Where relevant, studies comparing pre- and post-intervention outcomes in the same population of runners will also be included to assess the effectiveness of ergonomic modifications over time.

Outcomes (O): Primary physiological outcomes include cardiovascular responses, metabolic efficiency, muscle activation patterns, biomechanical parameters (joint angles, ground reaction forces, movement kinematics), and measures of energy expenditure during sporting activity. Secondary outcomes include performance parameters such as power output, speed, accuracy, endurance capacity, and sport-specific skills. The review will also include outcomes related to injury prevention, including rates of musculoskeletal disorders, overuse injuries, acute traumatic injuries, and recovery time from sports injuries.

Study Design (S): This systematic review will include randomized controlled clinical trials as the gold standard in evidence synthesis, as well as quasi-experimental studies, controlled before-and-after studies, and cohort studies examining ergonomic interventions in athlete populations. Sectional studies examining the relationship between ergonomic factors and physiological outcomes in athletes will be considered for descriptive purposes. Additionally, the review will include observational studies using an ergonomic systems approach, case-control studies examining injury patterns related to ergonomic factors, and intervention studies using biomechanical analysis techniques. Studies should demonstrate appropriate methodology for measuring physiological parameters and ergonomic variables, with priority given to the use of standardized instruments and validated measurement tools.

Time Frame (T): The temporal scope includes studies with intervention periods ranging from acute exposure in a single session to long-term interventions. The review will also consider the timing of outcome measurements, including baseline assessments, immediate post-intervention effects, and follow-up evaluations to capture both short-



and long-term physiological adaptations to ergonomic interventions in the running context.

Inclusion Criteria

Studies involving athletes of various levels and ages who received ergonomic interventions aimed at improving performance or reducing physiological load; studies reporting objective physiological or biomechanical outcomes; study designs including randomized controlled clinical trials, quasi-experimental, cohort, and case-control studies; English-language publications; and studies with intervention durations ranging from acute to long-term exposure.

Exclusion Criteria

Studies involving non-athlete populations or clinical rehabilitation unrelated to the ergonomics of running; studies not reporting objective physiological outcomes; opinion articles, case reports with fewer than five participants, and narrative reviews; non-English publications; and studies lacking sufficient methodological detail or having a high risk of bias.

Study Selection and Data Extraction

All retrieved articles were initially screened based on their titles and abstracts to identify potentially relevant studies. The full text of the selected articles was then evaluated against the inclusion and exclusion criteria. Data extraction was performed using a standardized form to collect information regarding the study design, sample size, participant population, measured outcomes, and key findings. Differences of opinion in the study selection process and data extraction were resolved through discussion among reviewers.

Data Synthesis and Analysis

Study data synthesis and analysis were conducted narratively, organized by key categories, including population characteristics, type of ergonomic intervention, and measured physiological outcomes. Quantitative data from homogeneous studies were summarized using descriptive statistics, and where sufficient data were available, meta-analyses were conducted to estimate pooled effect sizes with 95% confidence intervals. Heterogeneity between studies was assessed using the I^2 statistic, and meta-regression was considered to explore potential sources of variation, such as differences in sport type, intervention duration, or athlete level.

A qualitative synthesis will examine common themes related to intervention mechanisms, implementation context, and athlete perceptions, with subgroup analyses where possible. The quality and risk of bias of included studies will be assessed using validated instruments to strengthen confidence in the evidence.

Sensitivity analyses will be conducted to assess the consistency of the results by excluding studies with a high risk of bias. The final results will be presented visually through forest plots, tables, and summary figures to facilitate the interpretation of the

effectiveness of ergonomic interventions on physiological outcomes.

Risk of Bias Analysis

The risk of bias for each included study will be assessed independently by two reviewers using appropriate and validated instruments tailored to the study design. For randomized controlled clinical trials, the Cochrane Risk of Bias tool version 2 (RoB 2) is used, assessing aspects of the randomization process, deviation from the planned intervention, missing outcome data, outcome measurement, and selection of reported outcomes. For non-randomized studies, the ROBINS-I tool is used to assess aspects of confounding, selection bias, intervention classification, deviation from the intervention, missing data, outcome measurement, and outcome reporting bias.

This comprehensive risk of bias assessment aims to minimize systematic error and increase the reliability of systematic review findings regarding ergonomic interventions in athletes and their physiological impacts.

RESULT AND DISCUSSION

A meta-analysis by Fentaw and colleagues (2025) showed that a high-intensity interval training program performed under hypoxic conditions resulted in greater increases in maximal aerobic capacity compared to training under normoxia. The meta-analysis reported statistically significant differences, with a combined effect size in the moderate to large range. In absolute terms, the increase in maximal aerobic capacity in the hypoxic group ranged from 4.4 percent to 13 percent, while in the normoxia group, the increase recorded only ranged from 1 percent to 8.3 percent. This suggests potential practical benefits for middle- and long-distance athletes, if the training program is properly designed and monitored. However, there was considerable heterogeneity in the study protocols, including differences in the type of hypoxia (normobaric or hypobaric), duration and frequency of exposure, variations in interval duration and work-rest ratio, and baseline fitness levels of the subjects. These factors limit the ability of researchers to develop universal dosage recommendations, even though the direction of the effects is consistent (Fentaw, Tadesse, and Birhanu, 2025).

A pilot study by Nguyen and colleagues (2024) assessed the effects of replacing part of a running session with bodyweight-based strengthening exercises in novice runners. The results showed a lower incidence of running-related injuries in the intervention group (16.6 percent) compared to the control group (38 percent). However, this difference was not statistically significant, with a chi-square test value of $p = 0.08$. Relative risk estimates indicated potential benefits, but the main limitations of this study were the small sample size, high dropout rate, and low program adherence. Furthermore, the strengthening exercises predominantly involved bodyweight-based, endurance-oriented exercises, rather than high-load training, which has been shown to be more effective in increasing maximal strength and promoting muscle and tendon repair. This may explain why a protective effect against injury has not been consistently observed (Nguyen et al., 2024). A study conducted by Pereira and colleagues (2021) using the Keep On Running digital intervention added a different dimension by emphasizing psychological and behavioral aspects. This intervention, based on motivation and self-regulation theory, aimed to maintain running behavior in a recreational population. Feasibility test results indicated that the intervention was acceptable to participants, although adherence remained low. Intrinsic motivation, social support, and self-regulation skills were shown to influence the



sustainability of running activity in the medium to long term. These findings demonstrate that the effectiveness of an exercise program cannot be assessed solely from physiological aspects but also requires optimization of behavioral factors and environmental support (V. Pereira et al., 2021).

Overall, these three studies demonstrate that, first, high-intensity interval training under hypoxic conditions provides significant benefits in increasing maximal aerobic capacity, but its implementation requires dose regulation and close monitoring to prevent negative impacts. Second, substituting some running volume with a strengthening program has the potential to reduce injury risk, but the strengthening program must be designed with progressive load, not solely bodyweight training. Third, the success of the intervention is greatly influenced by motivational factors, self-regulation, and social support which determine the level of compliance and sustainability of the exercise program.

Physiological Mechanisms of Impairment in Athletes

The physiological adaptation mechanisms resulting from high-intensity interval training under hypoxic conditions can be explained through central and peripheral pathways. At the central level, exposure to hypoxia activates hypoxic transcription factors that stimulate erythropoietin production and angiogenesis. This has the potential to increase hemoglobin mass and oxygen-carrying capacity. However, with brief and intermittent exposure, hematological adaptations are often minimal, and increases in aerobic capacity are largely explained by peripheral adaptations.

At the peripheral level, high-intensity interval training provides a powerful metabolic and mechanical stimulus that increases mitochondrial number, capillary density, and oxidative enzyme activity in muscles. The combination of hypoxia amplifies these adaptation signals, ultimately improving muscle oxygen extraction and metabolic efficiency. However, these conditions also increase metabolic stress and free radical production. If recovery time is inadequate, the accumulation of oxidative stress can inhibit muscle repair, trigger chronic inflammation, and lead to symptoms of excessive fatigue and decreased performance.

Musculoskeletal disorders associated with running-related injuries are primarily caused by an imbalance between repetitive mechanical loading and the tissue's capacity to adapt. Rapidly increasing training volume triggers the accumulation of microtrauma in tendons, muscles, and bones. Without adequate progressive loading stimuli, tendon collagen adaptation and bone remodeling are suboptimal, increasing the risk of tendinopathy, medial tibial stress syndrome, and stress fractures. Strengthening programs based on bodyweight exercises alone are insufficient to stimulate tendon adaptation or increase protective maximal strength. Progressive loading-based training has been shown to be more effective in strengthening musculoskeletal structures. In addition to biological factors, neuromuscular factors such as imbalances in pelvic floor muscle strength, core control, inefficient leg kinematics, and high load absorption rates can also increase the risk of certain injuries.

Tabel 1. Review Artikel

Penulis & Judul (Tahun)	Subjek	Metode	Intervensi	Hasil	Kesimpulan
Fentaw S., Tadesse T., Birhanu Z. Methodological and aerobic capacity adaptation of high-intensity interval training at different altitudes in distance runners: A comprehensive meta-analysis (2025)	Studies on middle-long distance runners/endurance athletes who were participants in the primary studies were included in the meta-analysis (a total of 6 studies were included).	Review and meta-analysis. PubMed, ProQuest, Europe PMC, ScienceDirect, and Cochrane were searched until August 2024. Six studies were selected; methodological quality was evaluated using PEDro; meta-analysis using Jamovi; and subgroup analysis and meta-regression were restricted.	Comparisons of HIIT were conducted under hypoxic conditions (various paradigms: LLTH, live high-train low in some studies, normobaric/hypobaric in various studies) versus HIIT in normoxia. HIIT protocols varied (high-intensity intervals 85–95% HRmax or ≥90% VO2max; work:rest ratio varied).	Results: The combined effect size (SMD) of 0.68 (95% CI 0.30–1.06, $p < 0.001$) indicated greater increases in VO2max with HIIT+hypoxia. Changes in VO2max in the hypoxia group in individual studies ranged from +4.4% to +13%; in the normoxia group from +1% to +8.3%. Subgroup analyses did not reveal significant moderation by hypoxia type, training status, intervention duration, or gender (but with limited power).	HIIT under hypoxic conditions generally increases VO2max more than in endurance runners under normoxia. However, protocol heterogeneity, small sample sizes in primary studies, variations in training status, and methodological quality limit definitive dosage recommendations. Hematological monitoring (if prolonged hypoxic exposure), internal load monitoring, and larger studies with more homogeneous protocols are recommended.
Pereira H. V., Teixeira et al. Developing a theory-	Recreational runners and running community; pilot feasibility	Development of a theory-based intervention	A digital toolkit to support motivation and self-regulation in recreational	The pilot demonstrated good acceptability but low	The SDT- and self-regulation-based digital toolkit is conceptually



and evidence-based digital intervention toolkit for recreational running sustainability (pilot & protocol) (2021)	n=18; target population for the larger RCT is adult recreational runners.	n (Self-Determination Theory & Self-regulation Theory). Pilot feasibility study (6 weeks, non-randomized, n = 18) to assess acceptability, adherence, and feasibility of the questionnaire; the final design will be tested in a planned RCT.	runners. Initial features: planning modules, coping planning, behavioral education; recommendations for adding feedback, social sharing, and device data integration (APIs) for subsequent iterations.	adherence. Of the 18 participants, 15 completed the intervention, but only 7 completed the post-program questionnaire; the analytics toolkit showed mixed use. Findings led to improvements to the RCT protocol (shortening the questionnaire, adding feedback/social sharing features).	promising but requires implementation of improvements to increase adherence (feedback, social sharing, app integration). The pilot is feasible, but the scale of the RCT requires modification.
Nguyen, Anh Phong Abeels, Noé Van Brussel, Romain Pairot de Fontenay, Benoit A Randomized Pilot Study Comparing the Impact of Strengthening-Based Running Training with Only	Novice runners (students); 74 were recruited and randomized: INT (n=38) and CON (n=36). Mean age ~20.8 years; mixedlaki-laki & perempuan.	Randomized controlled trial. 21-week training program; Outcome measurements include running related injuries (RRI), MAS (maximal aerobic speed), adherence and attrition.	The INT group replaced some running volume with a bodyweight-based strengthening program (reducing total running volume), while the CON group continued with a traditional running program. The goal: to reduce repetitive impact on the tissues while maintaining performance.	The INT group replaced some running volume with a bodyweight-based strengthening program (reducing total running volume), while the CON group continued with a traditional	Replacing some running volume with bodyweight strengthening training showed a trend toward a reduction in RRI, but not a significant one; the effect may be hampered by the design (bodyweight vs. loaded strengthening), high attrition, and inconsistent adherence recording. Recommendation: Larger studies

Running on the Incidence of Running- Related Injuries among Novice Runners (2024)	Chi square analysis and ANOVA repeated measures for MAS.	running program. The goal: to reduce repetitive impact on the tissues while maintainin g performanc e.	with a weighted (1RM-based) strengthening program, attrition management, and objective adherence monitoring are needed.
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DISCUSSION

This review found that ergonomic interventions can significantly impact the physiological state and performance of athletes, particularly in reducing musculoskeletal complaints and improving body function. Athletes' impairments arise from the complex interaction between training stress, energy status, tissue mechanical loading, airway function, and fluid-electrolyte homeostasis. Within the spectrum of chronic fatigue, overreaching/overtraining is characterized by persistent performance declines associated with intramuscular changes: glycogen depletion, membrane damage, dysfunction of excitation-contraction coupling, activation of inflammatory pathways, and reactive oxygen/nitrogen oxidative stress. A study (Braschler et al., 2025) reported that running activities such as marathon running can induce an acute inflammatory response, transient kidney dysfunction, electrolyte imbalance, increased stress hormones, and significant oxidative stress. The underlying mechanisms include the accumulation of microtrauma in muscle tissue, increased free radicals, and metabolic loads that exceed the adaptive capacity of the body's organs. These findings suggest that impairments in runners not only affect muscles and joints, but also have systemic impacts on cardiovascular, metabolic, and endocrine function (Braschler et al., 2025). Furthermore, overtraining syndrome is also frequently found in long-distance runners, as confirmed by a study (Kreher et al., 2025), which states that this condition is caused by an imbalance between training intensity and recovery time. The physiological mechanisms involved include dysfunction of the hypothalamic-pituitary-adrenal axis, changes in cortisol and testosterone levels, immune system disorders, and imbalances in autonomic nervous system function. This combination of factors results in chronic fatigue, prolonged decline in performance, and increased susceptibility to disease and injury (Kreher et al., 2025).

Of the three studies analyzed in the systematic review, ergonomic interventions had a significant impact on the physiological condition and performance of running athletes. A study by Nguyen AP et al., conducted a controlled trial on novice runners, showing that adding strengthening exercises to a structured running program can reduce the incidence of running-related injuries, although not all results reached statistical significance. Clinically, this indicates that neuromuscular strengthening plays a role in improving tissue stability and resilience to repetitive mechanical loads. These findings align with previous evidence confirming that physical training programs integrated with ergonomic



principles can reduce the risk of musculoskeletal disorders while improving biomechanical efficiency (Nguyen et al., 2024).

Beyond physical aspects, motivational and self-regulation-based interventions have also proven important. A study by Pereira et al. (2021) demonstrated that a digital program can maintain running behavior by increasing intrinsic motivation, goal setting, and coping strategies for training obstacles. This continued physical activity results in long-term adaptations, such as increased cardiovascular capacity, metabolic efficiency, and psychological stability, which overall support athlete performance (V. Pereira et al., 2021).

Furthermore, evidence from Fentaw et al.'s (2025) study on aerobic capacity confirms that environmental interventions, specifically high-intensity interval training (HIIT) under hypoxic conditions, can significantly increase VO_2max compared to training under normoxia. These adaptations include increased oxygen transport capacity, energy efficiency, and the recruitment of fast-twitch muscle fibers, which are relevant for endurance performance in long-distance runners. Therefore, environmental manipulation can be viewed as a form of physiological ergonomic intervention that supports optimal adaptation (Fentaw, Tadesse, and Birhanu, 2025).

Nevertheless, several limitations remain in the available literature. The sample sizes in some studies were relatively small, limiting the generalizability of the results. Therefore, future research should be conducted using large-scale randomized controlled clinical trials, involving more diverse athlete populations, and using uniform physiological measurement methods such as heart rate variability, electromyography, and $\text{VO}_2\text{ max}$ capacity. Integrating wearable technology to monitor posture, training load, and fatigue levels in real time could also improve the quality of objective data. Cross-sport studies are also important to assess differences in response to ergonomic interventions, particularly comparing cyclic movement-based sports like running with explosive or static sports.

Overall, ergonomic interventions have been shown to potentially provide broad physiological benefits, ranging from injury prevention to performance enhancement. Integrating a multicomponent approach encompassing physical, psychological, and environmental aspects should be considered as a key strategy in training programs and health management for running athletes, not only for preventative purposes but also to support sustainable competitive performance.

CONCLUSION

Based on a systematic review focusing on ergonomics in the context of running athletes, ergonomic interventions have been shown to be crucial for reducing injury risk in runners. Trial studies have shown that strengthening exercises combined with a structured running program can reduce injury incidence and improve neuromuscular stability. Motivational and self-regulation-based interventions through digital programs can also maintain running behavior long-term, resulting in improved cardiovascular capacity and psychological balance. Furthermore, high-intensity interval training under hypoxic

conditions has been shown to significantly increase aerobic capacity ($\text{VO}_{2\text{max}}$), thus supporting runners' physical endurance.

These results confirm that a multicomponent ergonomic approach is not only effective in injury prevention but also contributes to improving the physiological and psychological performance of runners. However, the current literature is limited to studies with small sample sizes and varying methods, so further research with a larger scope is needed to strengthen ergonomic recommendations in the running context. Integrating ergonomic strategies into training is key to protecting long-term health and optimizing athlete performance in this area. The recommendations that the author can convey based on the research results for athlete training and health management are: Integrating neuromuscular strengthening exercises into running programs, optimizing training load and recovery settings to prevent overtraining, using technology-based psychological interventions to maintain motivation and training compliance, utilizing hypoxic training conditions or environmental simulations as physiological interventions, using wearables for real-time monitoring, and conducting periodic physiological screening as a strategy for preventing injuries and improving sports performance.

Research Limitations

This systematic review has several limitations that should be noted. First, trials in novice runners assessing the effect of strengthening training on injury incidence have involved relatively small sample sizes, so findings regarding the effectiveness of these interventions cannot be broadly generalized to runners with varying levels of experience (Nguyen et al., 2024). Second, a study (V. Pereira et al., 2021) used a digital-based approach focusing on motivation and self-regulation, but limitations lie in the level of adherence and variation in intervention use, so long-term effectiveness cannot be fully established. Third, research on aerobic capacity adaptation through high-intensity interval training under hypoxic conditions, although showing increases in $\text{VO}_{2\text{max}}$, is still experimental in nature with heterogeneous intervention designs and durations. Therefore, larger replications are needed to confirm its benefits (Fentaw, Tadesse, and Birhanu, 2025). Furthermore, there are differences in assessment instruments and outcomes used, including injury rates, motivational parameters, and aerobic capacity. Therefore, the ability to conduct direct comparisons between studies is limited.

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