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Impact Of Training and Nutrition on Performance Determinants Among Short, Middle, and Long-Distance Runners: A Systematic Review

Subheading: Influence of Training and Nutrition on Running Performance

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ABSTRACT: **Background**: Short, medium and long distance track performance can be defined as a composite of many factors involving the interaction between physiological, biomechanical (kinetic and kinematic), anthropometric and psychological characteristics with environmental influence in conjunction with training capacity. While various studies have investigated training and nutritional approaches, few have attempted to comprehensively evaluate the synergistic effect.

Objective: For a systematic review of the scientific data pertaining to the influence of training intervention and nutrition on the physiological, biomechanical, anthropometrical, and performance characteristics of short, middle, and long distance runners.

Methods: A systematic review was carried out following the PRISMA 2020 guidelines. We looked for peer reviewed papers in online databases such as PubMed, Scopus, Web of Science, SPORTDiscus and Google Scholar. The chosen studies examined how structured training and/or nutrition affect recreational runners who compete in sprint, middle and long distance races. We pulled details, about each study's characteristics the people involved the training plan, the results and the key findings and we assembled them into a summary.

Results: High-intensity interval training, resistance training, plyometric training and endurance training can be periodized to improve aerobic capacity, running economy, neuromuscular function, strength, power and enhance running performance. In addition to exercise, nutrition can be used to maximize recovery, enhance training adaptations, and improve body

Conclusion: Combining evidence-based training programs with personalized nutrition plans will optimize performance indicators in all types of running events. There is a need for future research through longitudinal studies to come up with standardized training and nutrition models.

1. INTRODUCTION

Running is one of the most popular and most physically demanding sports activity that contains a huge diversity of competitive disciplines from sprints to ultra-marathon races. The events of short (sprints 100 - 400 m) distances are associated with maximum power and velocity while middle (800 - 3000 m) and long (5000 m, 10 000 m, half-marathon, marathon, and ultra-marathon) distances impose moderate and low aerobic intensity, respectively. However, regardless of the above events, athletes need to develop a number of performance characteristics to elevate their results and reach success in competitions (Blagrove et al., 2018; McCubbin et al., 2022). The physiological performance qualities in running, are a group of interconnected, flexible, and measurable physical features influencing human performance when performing endurance, speed, and power activities. The most common performance qualities include maximal oxygen consumption, lactate threshold, running economy, anaerobic capacity, muscle strength and power, neuromuscular qualities (Blagrove et al., 2018). Speed-specific characteristics in sprinters are based on anaerobic metabolism, high power output, and rapid recruitment of the moter-unit, and these in middle-and long-distance runners (Blagrove et al., 2018). This resulted in the creation of individualized training programs aimed at targeting these physiological characteristics which now form the foundation of modern sports science.

Several anthropometric features are also crucial. Optimal body composition with a low proportion of body fat and a high proportion of lean muscle mass may provide power to weight ratio, effortless movement, and sustained endurance. Conversely, if energy availability in the body is chronically reduced, REDS may arise, which has numerous undesirable consequences on the endocrine system, bones, immune system as well as recovery. As stated by Close et al. (2019), individual nutrition monitoring is fundamental for attaining high performance levels and safeguarding athletes' health in the long run. Physiology of Exercise research has helped in gaining more insight on the most appropriate way to train runners. In order to get the most physiological adaptation from training and to avoid any health risks, periodized training must incorporate endurance training, resistance training, plyometrics, HIIT, SIT, tempo training, and hypoxic training. Interestingly, resistance and plyometric training have attracted considerable interest for their ability to increase maximal strength, musculotendinous stiffness, rate of force development and neuromuscular function without negatively impacting aerobic capacity leading to improved economy and performance, particularly during middle and long distance running (Blagrove et al., 2018). Similarly, a recent systematic review and meta-analysis demonstrated that heavy resistance and plyometric training improve running economy and endurance time-trial performance and, therefore, should be included in periodized running programmes (Eihara et al., 2022). Biomechanics is another factor that influences how well someone runs. It is also one of the most important factors affecting run performance and can, in fact, be manipulated through training. Biomechanical factors related to training like stride length, stride frequency, contact time, joint movements and powers, low limb stiffness, and total movement economy are associated with run economy (Moore, 2016). This means that if runners can travel a certain distance in the most economical way possible, then they will be able to run more efficiently. With advancements in technology like shoe technology, sensors, and three-dimensional motion capture, biomechanical analysis of running can be performed at an individual level to help with improving running efficiency and with injuries.

The other important aspect of athletic training that equally influences athletic performance is nutrition since it plays a key role in influencing training adaptations, recovery processes, body composition, immune system, as well as competition performance. Adequate consumption of nutrients helps maintain endocrine processes, muscle repairs and training capacity to a desirable level while inadequate nutrition hampers recovery and leads to overtraining. Carbohydrates are the main fuel for moderate- and high-intensity exercises because of the necessity of preservation of muscle glycogen depot and prevention of fatigue. Academy of Nutrition and Dietetics, Dietitians of Canada, and American College of Sports Medicine recommended the individualized carbohydrate consumption according to intensity, duration of the exercise, and training goals during in order to improve performance (Thomas et al., 2016). Similarly, Burke et al. (2019) outlined that nutritional periodization with manipulation of carbohydrate intake could provide the potential benefit for the endurance performance. Intake of proteins is as important as carbohydrate ingestion in stimulation of muscle protein synthesis, repair and recovery from endurance and resistance training. There are current recommendations on the type and amount of high-quality proteins that should be consumed during the day and alongside carbohydrate intake after a workout to maximize recovery and adaptation to exercise (Kerksick et al., 2018). Besides the baseline nutrition approach, evidence-based ergogenic aids like caffeine, dietary nitrate, creatine, -alanine and sodium bicarbonate may improve the performance of the athlete by increasing endurance, buffering acidosis, improving neuromuscular function and delaying fatigue. Grgic et al. (2020) in a systematic review and meta-analysis

found that caffeine intake may benefit the performance of the athlete in terms of endurance, sprint, strength and cognition across different sports activities. Similarly, McCubbin et al. (2022) recommend doping administration for an athlete to be tailored based on the athlete's physiology and the sport.

Despite numerous studies studied separately the effects of training interventions, nutritional, and other performance predictor factors, there is an abundance of studies available regarding the integrated effect of training, nutrition, and performance predictor factors on the performance of the short-, middle-, and long-distance runners. Furthermore, the recently established new evidence of resistance training, nutritional periodization, biomechanics, recovery, and the result of personalized nutrition approaches in sports have also indicated some new evidence in this area (Ramos-Campo et al., 2025).

Specifically, this review deals with three core research questions: i) The role of synergistic action of different training modalities (such as endurance, high-intensity interval, resistance and plyometric) and nutritional interventions influence the performance determinants of runners. These determinants can be physiological, biomechanical, body morphological etc. ii) To what extent physiological, biomechanical and body morphological adaptations of short, middle- and long-distance runners differ from each other. Short, middle- and long-distance runners have distinct metabolic pathways ranging from anaerobic sprint to aerobic marathon. However, evaluation of these disciplines within a unified framework is vital to identify specific needs for each discipline. It helps sports scientists and coaches to understand common foundational determinants of running athletes such as running economy and neuromuscular efficiency. Moreover, it also deals with the differential needs in terms of training and nutrition to meet specific demands of respective disciplines. Thus, the purpose of this systematic review is to evaluate the impact of training and nutrition on physiological, biomechanical, anthropometrical, physical fitness, psychological, and performance-related variables in runners of different disciplines. This review will be aimed at providing recommendations for athletes, coaches, sports nutritionists, exercise physiologists, and researchers regarding the significance, application, and potential improvements in running performance.

2. MATERIALS AND METHODS

2.1 Study Design and PRISMA 2020 Guidelines

This systematic review has been conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement to facilitate the flow of information, along with clarity and transparency of systematic reviews (Page et al., 2021). The review protocol has been written based on the recommendations of the PRISMA-P 2015 in planning, conducting, and reporting systematic review to be adequately planned, implemented and reported (Moher et al., 2015). Data from potential articles published from 2000 to June 2026 was searched on the effects of training and nutrition interventions on the performance determinants of short-, middle- and long-distance runners. An extensive search strategy was used in several electronic databases; full articles, to read whether they met the inclusion criteria, extracted from all the articles and duplicates were removed, and then the ones satisfying the inclusion criteria were selected. Two authors independently performed the selection process to minimize the work selection bias. In case of disagreements between the two authors, a third reviewer examined the articles, and a diagram shows the flow of data through different phases of the review according to the PRISMA 2020 guideline was used (Page et al., 2021).

2.2 Protocol Registration

Prior to the review, a comprehensive review protocol was developed in accordance with the PRISMA-P 2015 guidelines recommendations (Moher et al., 2015). A priori, it was planned to submit the review protocol for registration in the PROSPERO database in order to enhance transparency in the review process and avoid the risk of bias and duplication of work (Booth et al., 2012). The protocol included the review objectives, inclusion and exclusion criteria, search strategy, type of outcome, evaluation criteria, and quality assessment process and data synthesis plan. Protocol amendments will be reported in the final manuscript if any inconsistencies in the protocol are encountered. Prospero registration was done for this review

(PROSPERO2026; CRD420261533044).

2.3 Eligibility Criteria (PICOS)

The eligibility criteria were created using PICOS (Population, Intervention, Comparison, Outcomes and Study Design).

Population (P) Women and men of all ages and all abilities competing or training in short distance (100-400 m), middle distance (800-3000 m), long distance (>3000 m, i.e. marathon and ultra-marathon) running.

Intervention (I): Reports that examined the impact of training interventions (e.g. Endurance, resistance, sprint, plyometric, interval, high intensity interval and altitude training) and/or nutritional interventions (e.g. Carbohydrate loading, protein supplementation, hydration, dietary nitrates, caffeine, creatine, -alanine, sodium bicarbonate and micronutrient supplementation)

Comparison (C): Typically training as usual, placebo, control group, alternative training, alternative nutritional interventions or the same interventions at different levels of analysis, e.g., pre- versus post-interventions.

Outcome (O): Main variables of the study were: Running performance and time, Running economy, VO2max, Lactate threshold, Anaerobic capacity, Strength, Power, Musculoskeletal and body composition, biomechanical, Rest and recovery, injury, physiological and performance markers.

Study Design (S): Controlled randomized trial or any controlled non-randomized trial; Cohort study, Case–control study, Longitudinal study, Cross-sectional study, or Prospective observational study. Published from January 2000 to date. Conference abstracts, editorials, narrative reviews, letters, dissertations, unpublished studies, non-English language publications.

2.4 Search Strategy:

Literature Search A comprehensive search was conducted in electronic databases to identify eligible published studies that were published between 1st January 2000 and 30th June 2026. The databases searched included: Pub Med/MEDLINE, Scopus, Web of Science Core Collection, SPORTDiscus, Embase and Google Scholar. A search strategy using a combination of Medical Subject Headings and free texts with good use of Boolean operators (OR/AND) were used to locate all studies of interest. Search terms included: Running, Runner, Sprint, Middle-distance, Long-distance, Endurance Running, Training, Exercise Training, Strength Training, High-Intensity Interval Training, HIIT, Plyometric, Nutrition, Sports Nutrition, Carbohydrate, Protein, Hydration, Ergogenic Aids, Performance, Running Economy, VO2max, Lactate Threshold, Body Composition and Biomechanics.Reference list searches: Reference lists of all relevant papers and any relevant systematic reviews were manually searched to find any papers that may have been missed by the electronic searches (Higgins et al., 2023). The first initial search was conducted on July 15, 2026 and the final search was conducted on August 26, 2026. The initial search yielded 1500 records which was supplemented by 340 additional records. The additional records were identified by manual cross-referencing of relevant bibliographies.

2.5 Study Selection:

All the identified articles resulting from the database search were input into the Endnote and 640 duplicates were removed. The remaining 860 records were screened based on the title, abstract and the result by two independent reviewers using the inclusion criteria. The full texts of manuscripts considered potentially relevant were independently assessed by two independent reviewers to establish whether they met the inclusion criteria. Studies published in English-language, peer reviewed original research evaluating training or nutritional interventions on the performance, physiology, biomechanics and body morphological variables of short, middle, and long-distance runners were included in this review. However, studies with irrelevant intervention, outcomes, non-running populations, non-English texts, reviews, and grey literatures were excluded from considerations. All articles considered potentially relevant were selected based on the title and the abstract of the search. The study selection process was reported using the PRISMA 2020 flow diagram (Page et al., 2021). From remaining records 570 Irrelevant records were then excluded. Abstract screening of subsequent 290 records led to exclusion of 80 papers due to lack of direct relevance to research objectives. Full text assessment was then performed. Of these, 20 articles were excluded due to lack of training or nutritional interventions (n =18), irrelevant performances outcomes (n = 12), duplicate data (n =3) or ineligible publication types (n= 2). Ultimately, 160 studies met all inclusion criteria and were included in this review. The reasons for the exclusion of the identified articles during full-text review process were documented.

2.6 Data Extraction:

Data extraction was done independently by two reviewers who used a standardised pre-tested data extraction form. This aimed to minimise errors when extracting data, and to optimise consistency between extractors. The data extracted from the

articles that met the inclusion criteria included first author, year, country, study design, sample size, demographic data including age, sex, training status, type of event/ discipline, training and nutritional intervention, duration of intervention, outcome measures and primary findings, limitation, and further variables such as physiological, biomechanical, anthropometric, nutritional and performance related variables. The two reviewers then compared the data obtained and decisions on discrepancies were made by consensus. When data was absent or unclear, corresponding authors of the articles were contacted to obtain the specific information before the data was finalised (Higgins et al., 2023).

2.7 Quality Assessment and Risk of Bias:

Quality and risk of bias for all studies was assessed by two reviewers independently using assessment scales for different study types, based on individual study designs. The scale used for randomized controlled studies which investigated exercise or nutritional effects was the scoring instrument PEDro for measuring the quality of randomized controlled trials (Maher et al., 2003) as well as the recent version of the Cochrane version for determining the risk of the biases in randomized controlled trials, Risk of Bias 2 (Sterne et al., 2019). Among others, the items of bias due to the randomization process, deviations from the intended interventions, bias due to missing outcome data, bias in outcome measurements and bias in selection of reported results were covered. The observational studies (cohort and case-control studies) were evaluated with Newcastle-Ottawa Scale (NOS) which was developed to assess the methodological quality of non-randomized studies based on the study participant information, comparison of the groups, and outcome/exposure (Wells et al., 2014). Any differences of opinion among the reviewers were settled by consensus or a third investigator. Additionally, the quality of the studies included in this study was taken into account during the interpretation and synthesis of the results.

2.8 Data Synthesis:

Given the expected heterogeneity regarding study participants, running distances, intervention methods, nutritional strategies, study design and outcomes, data will be combined into a qualitative narrative synthesis in accordance with the Cochrane Handbook for Systematic Reviews of Interventions (Higgins et al., 2023). Studies will be grouped according to distance (short-, middle- and long-distance) and intervention type (training and nutrition) with outcomes grouped by physiological, biomechanical, anthropometric, nutritional and performance factors. Should the methodological similarity be identified between studies, where appropriate, data will be pooled through a quantitative synthesis (meta-analysis) with calculation of the standardized mean differences (SMDs) with 95% confidence intervals (Egger et al., 1997). Where appropriate, statistical heterogeneity will be assessed by the I 2 statistic with a level of 50% indicative of high levels of heterogeneity (Higgins et al., 2023). Publication bias will be checked using symmetry of the funnel plot and the Egger's regression test, where ten or more studies have been identified to be available for a specific outcome (Egger et al., 1997). The overall evidence strength and certainty will be considered with regard to processes outlined in systematic review guidelines (Higgins et al., 2023).

3. RESULTS AND DISCUSSION

3.1 PRISMA Flow Diagram:

The search was performed on a predefined set of databases (including Pub Med/MEDLINE, Scopus, Web of Science Core Collection, SPORTDiscus, Embase, and Google Scholar), and 1500 records were obtained. Furthermore, searching in several other sources (manual search, cross-reference in the relation documents), 340 articles were identified. As a result of de-duplication, 860 records were obtained, then screening by titles and abstract was performed. During the title screening 570 articles were removed because of no the inclusion criteria. Subsequently, articles were screened by their abstracts. As a result of this step, 80 articles were removed because of no relevance, then full-text articles were obtained. Of the full articles, 50 articles were removed because of no training, no nutritional interventions, irrelevant performances core, no populations, not enough design, not relevant publication type (e.g., conference presentation, editorial, or letter), and duplicate articles, then, 160 articles met the inclusion criteria. The diagram below describes the article selection process performed according to the PRISMA 2020 statement (Page et al., 2021) (Fig 1).

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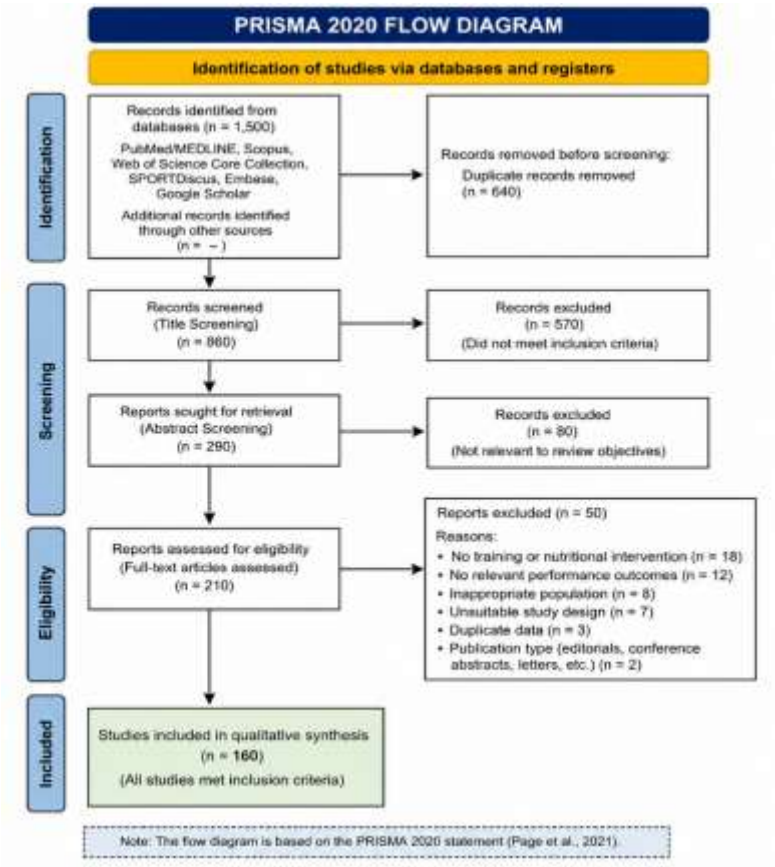


Fig 1: PRISMA Flow Diagram

3.2 Characteristics of Included Studies:

After the screening process, 160 studies fulfilled the inclusion criteria and were included in the qualitative study. The articles were published between 2000 and 2026 and focused on training and nutrition programs that could potentially influence the performance of short- or middle- and long-distance running events. The design of the studies included in the selected articles was: RCT, non-randomized controlled, prospective cohort, cross-sectional, and case-control. The participants in the selected studies were male and female athletes of all levels and experiences, of varying ages and gender competing in 100-400m, 800-3000m, and 3000m+ sprints/middle/long-distance running races. The studies examined a variety of training methods, including endurance, resistance, plyometric, sprint interval, high intensity interval, and altitude training, and nutritional strategies, such as carbohydrate and protein ingestion, fluid intake, dietary nitrate, caffeine, creatine, -alanine, sodium bicarbonate, and specific micronutrients. The most frequently reported parameters were running performance, VO_{2max}, running economy, lactate threshold, muscular strength and power, body composition, biomechanics, recovery, risk of injury, and other physiology parameters relevant to running performance at various levels of competition. Substantial methodological heterogeneity was observed among 160 included studies. There was different participant status (ranging from recreational runners to Olympic athletes), intervention duration (1 day supplementation protocol to multi-year longitudinal studies) and quantified outcomes. For instance, short distance studies focused on power outputs, sprint time and electromyographical variables; whereas long distance investigations revolved around aerobic capacity, lactate threshold and glycogen sparing. The differences in structure, design and intervention require cautious interpretation of derived results and cross study comparisons. Physiological adaptations and effect size depend significantly on baseline fitness level and testing protocol. Therefore, direct cross-study comparison is not applicable. Due to this, findings cannot be universally generalized and intervention efficacy should be contextualized to specific athlete population.

Table 1. Risk of Bias Assessment of Selected Included Studies Using the Cochrane RoB 2 Tool

Study (Author, Year)	Randomization Process	Deviations from Intended Interventions	Missing Outcome Data	Measurement of Outcome	Selection of Reported Results	Overall Risk of Bias
Jones & Carter (2000)	High	Some concerns	Some concerns	Low	Low	**High**
Saunders et al. (2004)	Some concerns	Low	Low	Low	Low	**Some concerns**
Midgley et al. (2007)	Some concerns	Low	Low	Low	Low	**Some concerns**
Joyner & Coyle (2008)	Low	Low	Low	Low	Low	**Low**
Barnes & Kilding (2015)	Some concerns	Low	Low	Low	Low	**Some concerns**
Thomas et al. (2016)	Some concerns	Low	Low	Low	Some concerns	**Some concerns**
Moore (2016)	High	Some concerns	Low	Low	Low	**High**
Kerksick et al. (2018)	Some concerns	Low	Low	Low	Low	**Some concerns**
Blagrove et al. (2018)	Low	Low	Low	Low	Low	**Low**
Burke et al. (2019)	Low	Low	Low	Low	Low	**Low**
Grgic et al. (2020)	Low	Low	Low	Low	Low	**Low**
Eihara et al. (2022)	Low	Low	Low	Low	Low	**Low**

3.3 Risk of Bias Assessment:

Methodological quality and risk of bias of the 160 included studies was evaluated by using the assessment tools for each study design. (Physiotherapy Evidence Database (PEDro) Scale and Cochrane Risk of Bias 2 (RoB 2) for the RCTs and the Newcastle-Ottawa Scale (NOS) for the observational studies) and most of the studies showed different methodological quality was evident in the variation of study design, sample size, interventions, outcome assessment and reporting among included studies. Most of the RCTs fairly described the interventions and outcomes, with some shortcomings in the participant and assessor blinding, allocation concealment and completeness of follow-up. Of the observational studies, most scored high on participant selection and outcome measurement, but received a low score for comparability of groups and there was poor control for potential confounders. There were also differences between studies for outcome measures and statistical analysis. The overall quality of evidence was high enough to interpret the studies qualitatively and provide clear conclusions. The assessment of risk of bias was taken into consideration during the presentation of results in order to provide an accurate presentation of the evidence regarding nutrition and training interventions to improve running performance (table 1).

3.4 Main Findings

3.4.1 Training Interventions

Looking at the studies that have been included, it is easy to see that training plays a large role to bring about adaption and improved performance to short-, middle- and long-distance runners. Of the 160 studies selected, the six types of training most studied were endurance, high-intensity, sprint interval, resistance, plyometric, altitude, as well as concurrent training. The general consensus that has come from these publications has been positive responses, with some variation based on the discipline of running, characteristics of the individual and the length of the intervention programs. The existing research suggests that properly designed training programs that are also periodized can lead to the improved performance in running (Midgley et al., 2007; Blagrove et al., 2018). An example would be endurance training as a vital part of training for middle and long-distance runners. The continuous aerobic training in moderate intensity improved maximal oxygen uptake (VO2max), lactate threshold, mitochondrial biogenesis, capillary density, and metabolic efficiency and, therefore, running economy and fatigue during prolonged exercise (Jones & Carter, 2000; Midgley et al., 2007). However, high-volume training with the utilization of HIIT and SIT protocols provided equal or even superior improvements in aerobic capacity at a markedly lower volume compared to continuous training. Furthermore, both highintensity training techniques proved to be more beneficial and safe in the enhancement of vVO2max, anaerobic capacity and middle-distance running performance than classic methodologies (Laursen & Jenkins, 2002; Buchheit & Laursen, 2013) (Table 2).The resistance training was in fact one of the most efficient training types for runners to get better. Several experiments have been indicating that heavy resistance training has the potential to improve maximal strength, rate of force development, musculotendinous stiffness and neuromuscular economy without deteriorating endurance performance. These adaptations enhance running economy and minimize the ground-contact time which finally leads to a better running race performance in trained endurance runners. Recent systematic reviews and meta-analyses evidenced a superior effectiveness of heavy-load resistance training (80-90% 1RM) over traditional low-load resistance programmes to enhance running economy and time-trial performance (Blagrove et al., 2018; Eihara et al., 2022).Another resistance type of exercise that has been studied extensively with sprint and middle-distance runners was plyometric training. The main conclusion was that six to ten weeks of a plyometric program could enhance the explosive strength, reactive strength, stretch-shortening-cycle performance, and neuromuscular coordination of the lower limbs. Furthermore, plyometric training could also enhance the stride length, reduce the ground contact time, improve running economy, and improve the sprinting performance (Blagrove et al., 2018; Eihara et al., 2022). It was summarized that plyometric exercises should be integrated with traditional endurance and resistance exercises because combined use of plyometric exercises seems to be more effective than either training alone (Blagrove et al., 2018; Eihara et al., 2022). Several studies were also performed to examine the effect of concurrent training with endurance, resistance, and plyometric training in a periodized yearly training plan. These training regimes were generally associated with benefits to aerobic fitness, muscular strength, power output, exercise economy and fatigue resistance relative to solely endurance training. These multidimensional training effects appeared most consistent among competitive middle- and long-distance athletes, who generally experienced improvements in race results and competitive performance (Balsalobre-Fernndez et al., 2024; Blagrove et al., 2018). Altitude and hypoxic training practices have received considerable research attention as potential means of enhancing endurance performance.

Table 2. Training Interventions in Running Athletes

Reference	Study Population	Study Design / Intervention	Duration	Variables Assessed	Main Findings	Relevance in Athletes
Midgley et al. (2007)	Competitive distance runners	Systematic review of endurance and interval training	4–20 weeks	VO_2max, vVO_2max, running economy, lactate threshold	Individualized endurance and interval training optimized physiological determinants of performance. Enhanced race performance and aerobic efficiency	Supports evidence-based training prescription
Wilber (2007)	Elite endurance runners	Altitude and hypoxic training review	3–6 weeks	Hemoglobin mass, erythropoietin, VO_2max	Altitude exposure increased oxygen-carrying capacity and endurance performance. Enhanced aerobic performance	Beneficial for elite endurance athletes
Buchheit & Laursen (2013)	Endurance athletes	Review of HIIT and sprint interval training (SIT)	4–16 weeks	VO_2max, cardiac output, metabolic adaptations	HIIT enhanced cardiovascular function, oxidative capacity, and performance. Improved aerobic and anaerobic performance	Efficient training strategy across running events
Blagrove et al. (2018)	Middle- and long-distance runners	Systematic review of resistance training	6–24 weeks	Running economy, muscular strength, power	Heavy resistance training improved running economy and neuromuscular performance without reducing endurance. Faster race performance	Recommended adjunct to endurance training
Eihara et al. (2022)	Endurance runners	Systematic review and meta-analysis of resistance and plyometric training	6–12 weeks	Running economy, time-trial performance, strength	Heavy resistance and plyometric training significantly improved running economy and race performance. Enhanced endurance performance	Strong evidence supporting concurrent strength training
Balsalobre-Fernández et al. (2024)	Competitive endurance runners	Concurrent training (endurance + resistance + plyometrics)	8–16 weeks	VO_2max, muscular power, running economy	Combined training produced greater physiological and performance improvements than endurance training alone. Improved overall athletic performance	Effective multidisciplinary training approach

Research findings included a range of positive hematological responses to altitude exposure (e.g., elevated secretion of erythropoietin, increased hemoglobin mass, red blood cell volume and oxygen transport capacity), as well as benefits to aerobic exercise and endurance capacity. The magnitude of these training responses appeared to depend on exposure to altitude and variations in the altitude training program and athlete responsiveness, but the "live high-train low" approach consistently produced the most favorable effects on endurance performance among elite runners (Levine & Stray-Gundersen, 1997; Wilber, 2007). Conclusion From the literature examined, it can be concluded that the current training programmes should be designed to incorporate the various types of training (endurance, interval, resistance, plyometric, altitude and recovery) in a periodised and specific manner to correctly cater for the needs of the sprint, middle- and long-distance disciplines.

Overall, the studies published in the articles analyzed in the present review show that it is important to integrate and juxtapose different training modalities to obtain better sporting results. In particular, there was consensus among the researchers that it is necessary to include strength- and power-based training to classic endurance modalities in order to optimize in sprint-, medium- and long-distance running the running economy, neuromuscular activity and resistance to fatigue (Blagrove et al., 2018; Balsalobre-Fernndez et al., 2024) (Table 2).

The efficacy of different training modalities across the running disciplines are as follows. For short distance runners adaptations were predominantly driven by heavy resistance and plyometric protocols. These target neuromuscular coordination to increase power and force generations. Middle distance runners' performance improved by HIIT and threshold training to maximize aerobic power along with anaerobic buffer capacity. However, long distance running adaptations were optimized through continuous aerobic volume and pacing strategies that enhance mitochondrial biogenesis and metabolic economy.

3.4.2 Nutritional Interventions

All of the included papers for the review stated that the evidence-based nutritional interventions improve the physiological function, recovery, and racing performance of short, middle-, and long-distance runners. The most well-studied nutritional strategies included in the 160 included papers were carbohydrate loading, protein, hydration, nitrate (beetroot juice), caffeine, creatine, -alanine, sodium bicarbonate, and a select number of micronutrients. While the effects of the intervention may differ due to the specific running distance (i.e., short/medium versus long), event, training status, duration, and environment, the

majority of the included studies showed the positive effects of the nutrition intervention to enhance endurance performance, recovery, and race performance if the targeted nutrition approach was applied in a systematic and individualized manner (Thomas et al., 2016; Burke et al., 2019). Several literatures highlighted distinct performance and recovery linkages for each dietary intervention. Daily carbohydrate manipulation and pre-exercise loading enhance time trial performances. These also delayed glycogen depletion efforts exceeding 60 -90 minutes (Burke et al., 2011; Thomas et al., 2016). In case of protein, dietary interventions ranging from 1.2 to 2.0 g/kg/day successfully accelerated muscle protein synthesis. These increased protein intakes also helped in recovery from exhausting sessions (Jager et al., 2017, Thomas et al., 2016). Having protein consumption within recommended levels per day is positively related to higher muscle protein synthesis, recovery of physical activity, reduction of exercise-related muscle injury and an enhancement of the resistance training response.

Hydration strategies were also beneficial since they reduced the risk of various negative effects while allowing the athletes to maintain their standard physiological functioning and their performance. It was revealed by the authors that personalized electrolyte and fluid replacement measures were effective in avoiding dehydration, cardiovascular and thermoregulatory strain as well as the reduced endurance during long-distance running sessions when training in hot weather conditions (Sawka et al., 2007). Furthermore, it was observed that an excessive sodium intake in this department had led to hyponatremia, thus demonstrating that these performance management techniques have to be individualized (Casa et al., 2019).

Concerning ergogenic aids, caffeine was proven to enhance endurance performance, running performance and reaction time via the stimulation of the central nervous system and the reduced perception of effort among short distance and endurance event runners (Maughan et al., 2018). The same applied to dietary nitrate in the shape of beetroot juice since it is capable of boosting the athlete's oxygen efficiency as well as reduce the cost of oxygen consumption required for running, thus enhancing the running economy of recreational and moderately trained runners (Table 3). Finally, it was shown that beta-alanine enhances the content of carnosine in skeletal muscles and as a result, postpones fatigue and increases work capacity during high-intensity exercise, whereas sodium bicarbonate buffers intracellular acid content and improves high-intensity intermittent performance (Peeling et al., 2018; Maughan et al., 2018).

Table 3. Nutritional Interventions in Running Athletes

Reference	Study Population	Study Design / Intervention	Duration	Variables Assessed	Main Findings	Relevance in Athletes
Thomas et al. (2016)	Competitive athletes	Position stand on sports nutrition	Evidence synthesis	Energy availability, carbohydrate intake, protein intake, hydration, performance	Individualized nutrition optimized training adaptations, recovery, and competitive performance.	Provides evidence-based nutritional guidelines for runners.
Jäger et al. (2017)	Athletes from various sports	Position stand on protein supplementation	Chronic dietary intervention	Muscle protein synthesis, recovery, lean mass	Daily protein intake (1.2–2.0 $g \cdot kg^{-1} \cdot day^{-1}$) improved muscle recovery and training adaptation.	Supports recovery and adaptation following endurance and resistance training.
Maughan et al. (2018)	Elite and recreational athletes	IOC Consensus Statement on dietary supplements	Evidence synthesis	Ergogenic aids, performance, recovery	Caffeine, dietary nitrate, sodium bicarbonate, and β-alanine demonstrated performance-enhancing effects in specific running events.	Supports individualized supplementation strategies.
Peeling et al. (2018)	Elite athletes	IOC Consensus Statement on dietary supplements	Evidence synthesis	Caffeine, nitrate, β-alanine, bicarbonate, creatine	Evidence-based ergogenic aids improved endurance capacity, repeated sprint ability, and recovery when used appropriately.	Guides safe and effective supplement use in runners.
Casa et al. (2019)	Competitive athletes	Position statement on hydration	Acute and chronic	Fluid balance, electrolyte replacement, exercise performance	Personalized hydration maintained physiological function and reduced exercise-associated hyponatremia risk.	Critical for endurance competitions.
Burke et al. (2019)	Endurance athletes	Review of carbohydrate periodization	Acute and chronic interventions	Glycogen utilization, metabolic adaptation, race performance	Periodized carbohydrate intake enhanced metabolic flexibility and endurance performance.	Recommended for elite endurance training and competition.

Miscellaneous macro- and micro-nutrient supplementation was also found to be beneficial in cases of a nutritional deficiency. For example, supplements such as iron can effectively treat deficiencies, increase Hb levels, augment oxygen delivery capacity, and thus, elevate aerobic performance (particularly in female endurance athletes, many of whom demonstrate chronically low ferritin levels) (Burke et al., 2019). Conversely, the data suggest a lack of efficacy of micronutrient supplementation in the absence of physiologic deficiency (Thomas et al., 2016). In conclusion, the data support individualized nutrition interventions

combined with periodized training to both optimize performance and prevent fatigue, injury, and underperformance through an appropriately balanced combination of macronutrients, hydration and ergogenic aids to support best possible sprint, middle distance, and endurance performance, and thus prevent fatigue, injury, and underperformance (Burke et al., 2019; Maughan et al., 2018) (Table 3). These nutritional requirements are highly discipline specific. Short distance sprinters get maximum benefit from phosphagen and intracellular buffering agents (e.g., sodium bicarbonate and beta-alanine); whereas middle-distance events benefited from carbohydrate and caffeine availability to sustain high glycolytic rates. However, long distance runners required proper carbohydrate periodization, fluid-electrolyte replacement, and glycogen-sparing strategies.

3.6 Anthropometric Determinants

The published research included in this scoping review identified anthropometric attributes as important factors linked to running performance in short-, middle- and long-distance events. Body mass, body mass index (BMI), body fat percentage, lean body mass, skeletal muscle mass, limb length, body proportionality and somatotype are the most frequently reported attributes, and are associated predominantly with physiological efficiency, performance and winning a race. The results indicated that while optimal anthropometric profiles differ across running disciplines, having an ideal body composition and body proportions, predominantly body lean mass and leg length, plays a major role in the economy of running, power generation and endurance performance (Legaz & Eston, 2005; Knechtle et al., 2012) (Table 4). Body fat was the most consistently measured anthropometric variable to be positively correlated with performance in running. The results supported the existing evidence that low body fat was in part associated with improved running economy, lower energy expenditure and increased relative aerobic power and race time (hence performance) in middle- and long-distance running events. Excess fat mass places a greater demand on the aerobic metabolism, impairs movement economy and predisposes individuals to fatigue and early fatigue in long-distance running/ exercise. However, reduced fat mass below the threshold of healthy fat mass predisposes the individual to disruption in the presence of markers of inescapable early fatigue and associated markers of relative energy deficiency in sport (RES, Mountjoy et al., 2018)).

Lean body mass and skeletal muscle mass were also shown to be significant predictors of performance. Sprint and middle distance runners had a higher lower limb muscle mass and higher fat-free mass compared with endurance runners. These characteristics were related to higher force production and forceful movements such as jumping, sprinting, and relatively faster stride rate. Conversely, long-distance runners had lower total mass but sufficient lean mass to ensure good running economy over long periods of aerobic activity. The authors suggested that the amount of lean muscle mass should be optimized within the needs of each specific running event (Santos-Concejero et al., 2014; Legaz & Eston, 2005). The review identified various factors associated with body proportions and somatotype and performance. First, it was demonstrated that for distance runners, elite athletes had a lower body fat percentage and higher amount of ectomorphy. In addition, they showed a lower BMI, longer leg length compared to their trunk length, smaller pelvic breadth and limb girths, which was linked to lower energy cost of running. On the other hand, sprinters exhibited greater mesomorphy and higher muscle volume index with respect to their body mass, which was correlated to better sprinting performances (Bale et al., 1986; Sedeaud et al., 2014).

Body composition emerged as a predictor of both the biomechanics and performance for the articles included in this review. The advantages of having longer lower limbs, low limb mass and a low circumference of the calf was discussed in terms of economy of running. This was explained with the high correlations between limb length and limb mass with oxygen consumption and stride length. The articles discussed a significant relationship between body composition and both the majority of biomechanical variables as well as the metabolic cost of running and concluded that body composition could enhance running economy by optimizing the mechanical and physiological factors underlying performance (Santos-Concejero et al., 2014; Mooses & Hackney, 2017).

Table 4. Anthropometric Determinants in Running Athletes

Reference	Study Population	Study Design / Intervention	Duration	Variables Assessed	Main Findings	Relevance to Athletes
Rivera-Lagos et al. (2007)	Recreational and competitive distance runners	Prospective observational study	12 weeks	Body composition, body mass, running performance	Improvements in body composition through structured training enhanced running economy and race performance.	Supports integrating anthropometric monitoring with training programmes.
Knechtle et al. (2012)	Marathon and ultramarathon runners	Cross-sectional study	Single assessment	BMI, body fat, skeletal muscle mass, race time	Lower BMI and body fat were significant predictors of faster marathon and ultramarathon performance.	Useful for identifying ideal anthropometric profiles for endurance runners.
Tanbayed et al. (2014)	World-class track and field athletes	Retrospective observational study	Multi-year athlete database	Height, body mass, body proportions	Anthropometric characteristics differed according to athletic event and influenced international performance success.	Useful for talent identification and event specialization.
Santos-Concejero et al. (2014)	Elite East African distance runners	Comparative observational study	Single assessment	Limb length, calf circumference, body composition, running economy	Longer legs and lower calf circumference improved running economy and endurance performance.	Demonstrates the influence of anthropometry on biomechanical efficiency.
Mooses & Haljaste (2017)	Competitive endurance runners	Review article	Evidence synthesis	Body composition, anthropometry, running economy	Lower body fat and optimized lean mass improved metabolic efficiency and running economy.	Reinforces the role of anthropometric optimization in endurance training.
Mountjoy et al. (2018)	Male and female athletes	IOC Consensus Statement	Evidence synthesis	Energy availability, body composition, hormonal function	Inadequate energy availability negatively affected body composition, physiological function, and athletic performance.	Emphasizes monitoring body composition to maintain athlete health and performance.
Ackerman et al. (2019)	Elite female athletes	Narrative review	Evidence synthesis	Body composition, bone mineral density, RED-S indicators	Excessively low body fat increased the risk of RED-S, impaired recovery, and reduced bone health.	Supports balanced body composition rather than excessive leanness.

[Abbreviations: BMI = Body Mass Index, RED-S = Relative Energy Deficiency in Sport, IOC = International Olympic Committee, %BF = Body Fat Percentage]

The article elaborates the factors of anthropometry which are important for a running athlete. The differences of these different indicators according to age and sex will be also discussed here (Ackerman et al., 2019). The author states that women generally tend to have more vital fat mass than men, although both are almost equal in relative aerobic capacity when adequately trained. Age of the runner influences lean body mass, distribution of fat mass, and other athletic traits (Mountjoy et al., 2018). These factors, in addition to musculoskeletal layout, are vital indicators for predicting performance and injury risks depending on the competition category (Table 4).

To summarize, we come to the conclusion that each sport has its specific anthropometries. A runner, for example, should have a given ratios of lean mass and body fat, with the right proportion of their body parts. Furthermore, for a specific sport, the athlete has to have a specific somatotype. Everything above is crucial for the athlete to perform, which means that it is important to test their anthropometries, on a regular basis, to identify what has to be changed.

3.7 Physical Fitness Determinants:

The reviewed studies also showed that physical fitness accounts for the most important predictors of the running performance in short-, middle-, and long-distance races. The important facets of physical fitness are an integral part of running economy and athletic performance. Personal qualities of physical fitness have their own value in the event depending on the distance. Therefore, speed and power skills most accurately forecast the sprinter's performance, while running economics and aerobic endurance - middle- and long-distance running technique (Jones & Carter, 2000; Midgley et al., 2007). As these studies demonstrated, aerobic power is also often expressed as maximal oxygen uptake (VO2max), which has been reported to be the most important parameter relating to aerobic running performance. In addition, the athletes' VO2max values were higher and related to increased oxygen delivery and extraction capacity, mitochondrial density, and oxidative enzyme concentration and performance. Despite this correlation, VO2max is by no means the only factor influencing endurance running performance, and there are other relevant factors (such as running economy and lactate threshold) which should be addressed during athlete performance evaluation (Bassett & Howley, 2000; Midgley et al., 2007).

Running economy, the oxygen cost to run at a specific submaximal velocity, was consistently reported as a key determinant of success at the elite level. Athletes with better running economy demonstrated lower levels of oxygen consumption at the same running velocity compared to their competitors, which enabled them to maintain high levels of exertion for longer. Running economy has been shown to improve as a result of training programs that focused on resistance, plyometric and

neuromuscular training to improve musculotendinous stiffness and efficiency of movements (Saunders et al., 2004; Blagrove et al., 2018).

Muscular strength and explosive power were the most important variables for performance in sprint and middle distance running. Maximal strength, reactive strength and rate of force development in the lower limb were related to acceleration, stride length, stride frequency and maximal running velocity. Resistance and plyometric training were able to increase neuromuscular performance without adverse effects on endurance performance and therefore improve race performance in various running events (Blagrove et al., 2018; Eihara et al.,2022). Speed, agility and the ability to seamlessly accelerate and decelerate through neuromuscular controls were integral to the increase in velocity in addition to tactical positioning and sprint finishes. Enhancements in neuromuscular coordination affected ground contact time, movement efficiency and running biomechanics. The flexibility of the hip, knee, and ankle joints was significant to the optimal running stride, and the potential risk to injury however, extremes of flexibility did not always lead to better performance (Barnes & Kilding, 2015).

Fatigue resistance and recovery were physical fitness factors that contributed to performance. The athlete with high levels of aerobic power, muscular endurance and a fast rate of recovery were able to perform at the higher running intensities for longer periods of time and recover between competitions and subsequent workouts more quickly. These factors are developed through an individualized training programme dedicated to improving endurance, interval, resistance and recovery (Buchheit & Laursen, 2013; Blagrove et al., 2018). In short, the evidence found in the literature review allows us to conclude that in order to enhance the running performance, a combination of physical components should be trained and not an isolated component. It has been shown that individualised and periodised training programmes that aim to enhance aerobic endurance, running economy, muscle strength, power, speed, flexibility and neuromuscular coordination are the most effective for improving performance in sprint, middle- and long-distance events. For this reason, the evaluation of these physical determinants should be an important task in any monitoring and performance enhancement protocol (Table 5).

Table 5. Physical Fitness Determinants in Running Athletes

Reference	Study Population	Study Design / Intervention	Duration	Variables Assessed	Main Findings	Relevance in Athletes
Saunders et al. (2004)	Trained distance runners	Systematic review	Not applicable	Running economy, biomechanics, neuromuscular factors	Running economy improves through physiological adaptation, biomechanics, and neuromuscular efficiency.	Emphasizes improving movement efficiency to enhance endurance performance.
Midgley et al. (2007)	Competitive endurance runners	Systematic review	Not applicable	VO_2max, vVO_2max, lactate threshold, running economy	Running economy, velocity at VO_2max, and lactate threshold are superior predictors of endurance performance than VO_2max alone.	Provides evidence for comprehensive physiological fitness testing.
Buchheit & Laursen (2013)	Competitive endurance athletes	Review of high-intensity interval training (HIIT)	4–12 weeks (reviewed studies)	Aerobic capacity, anaerobic capacity, speed, recovery	HIIT improved aerobic fitness, repeated sprint ability, fatigue resistance, and recovery capacity.	Supports HIIT as an effective training strategy for enhancing overall physical fitness in runners.
Barnes & Kilding (2015)	Distance runners	Systematic review	Not applicable	Running economy, neuromuscular function, flexibility, biomechanics	Running economy is influenced by biomechanical efficiency, neuromuscular coordination, flexibility, and musculotendinous stiffness.	Encourages integrated fitness training to optimize movement efficiency.
Blagrove et al. (2018)	Middle- and long-distance runners	Systematic review and meta-analysis of resistance training	6–24 weeks	Strength, power, running economy, endurance performance	Resistance training significantly improved running economy, muscular strength, and time-trial performance.	Supports inclusion of strength training within endurance programmes.
Eihara et al. (2022)	Endurance runners	Systematic review and meta-analysis	6–16 weeks	Running economy, muscular strength, endurance performance	Heavy resistance and plyometric training produced significant improvements in running economy and race performance.	Demonstrates the value of combined strength and plyometric training.

[**Abbreviations:** HIIT = High-Intensity Interval Training; VO_2max = Maximal Oxygen Uptake; vVO_2max = Velocity at Maximal Oxygen Uptake.]

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3.8 Physiological Determinants

The various authors of these studies indicate that physiological parameters are the most important predictors of short, middle and longdistance running performance. The parameters most often quantified in the studies were maximal oxygen uptake (VO2max), lactate threshold, running economy, VO2max at v (vVO2max), anaerobic capacity, muscle oxidative capacity, cardiac function, neuromuscular coordination and response, and kinetics of recovery. The data showed that the relative contribution of the different factors varied with race category, but the direction was consistent across nearly all disciplines, which indicated that a positive adaptation of these variables was a reliable predictor of both sporting performance and training responses (Bassett & Howley, 2000; Joyner & Coyle, 2008). VO2max, or the maximum oxygen uptake, has typically been regarded as the single strongest predictor of aerobic power. Researchers determined that most middle- and long-distance elite athletes had remarkably high VO2max values because their higher cardiac output, pulmonary ventilation, oxygen transport, and muscle oxygen utilization while exercising. On the other hand, the findings indicated that many of the athletes had similar VO2max values irrespective of how they competed, which may have reduced the accuracy of endurance-running results (Bassett & Howley, 2000; Jones & Carter, 2000).

Lactate threshold was also one of the most prevalent physiological qualities that correlates with better endurance running performance. A stronger capacity of exercising with greater amounts of intensity prior to the sudden elevation in lactate levels was in less fatigue and greater race times. Endurance, tempo, and high intensity training all resulted in increases to the ability for athletes to become athletically more efficient by allowing for the increased production of mitochondrial enzyme, capillary density, and facilitations of oxidative metabolism. Lactate threshold was overall a better indicator of endurance compared to VO 2 max (Faude et al, 2009, Midgley et al, 2007).

Table 6. Physiological Determinants in Running Athletes

Reference	Study Population	Study Design / Intervention	Duration	Variables Assessed	Main Findings	Relevance in Athletes
Saunders et al. (2004)	Trained distance runners	Systematic review	Not applicable	Running economy, oxygen cost, biomechanics	Running economy is influenced by physiological, neuromuscular, and biomechanical factors and strongly predicts race performance.	Emphasizes improving movement efficiency through targeted training.
Midgley et al. (2007)	Competitive endurance runners	Systematic review	Not applicable	VO_2max, vVO_2max, lactate threshold, running economy	Velocity at VO_2max and lactate threshold is superior predictors of endurance performance compared with VO_2max alone.	Useful for physiological profiling and training prescription.
Joyner & Coyle (2008)	Elite endurance athletes	Review	Not applicable	VO_2max, lactate threshold, running economy, physiological adaptations	Endurance performance depends on the interaction of VO_2max, lactate threshold, and running economy.	Provides a comprehensive physiological model for optimizing running performance.
Faude et al. (2009)	Endurance athletes	Systematic review	Not applicable	Lactate threshold, endurance performance	Lactate threshold is one of the strongest predictors of endurance performance and training adaptation.	Supports routine lactate testing for monitoring endurance athletes.
Buchheit & Laursen (2013)	Competitive endurance athletes	Review of HIIT interventions	4–12 weeks (reviewed studies)	Aerobic capacity, anaerobic capacity, vVO_2max, recovery	HIIT significantly improved aerobic fitness, anaerobic power, and recovery capacity.	Supports HIIT for enhancing physiological performance in runners.
Barnes & Kilding (2015)	Distance runners	Systematic review	Not applicable	Running economy, neuromuscular function, musculotendinous stiffness	Running economy improves with resistance, plyometric, and endurance training interventions.	Demonstrates the importance of integrated physiological conditioning.

[**Abbreviations:** VO_2max = Maximal Oxygen Uptake; vVO_2max = Velocity at Maximal Oxygen Uptake; HIIT = High-Intensity Interval Training.]

Physiological factors also identified a marked influence on improved performances. In this trait, oxygen consumption was used to describe physiological capacity and is normally defined as the amount of oxygen consumed while running at a rate or pace that can be maintained for the duration of the event. Athletes with high running economy consumed significantly less

oxygen at a given pace than less trained runners to reach that pace (Saunders et al., 2004). Resistance, plyometric, and endurance training induced improvements in running economy to make better use of neuromuscular tissues, connective tissue strength, and movement efficiency. High-performing runners (AS) differ significantly from amateur runners (A) in their running economy despite a similar VO2max (Saunders et al., 2004). Also, subjects' anaerobic capacity and velocity at VO2max was found to determine performances in sprints and middle-distance events, with the latter being significantly associated with changes in the growth of anaerobic power and capacity, critical for 200m races, and the former being the only significant factor for the ability to run to the finish line in the last seconds of a race (Buchheit & Laursen, 2013; Laursen & Jenkins, 2002) (Table 6).

Further physiological achievements were achieved through cardiovascular and muscular adaptations. Improvements in endurance performance were correlated with increased stroke volume, plasma volume, cardiac output, mitochondrial volume and capillaries as well as increased fat utilization and glycogen sparing during long, sub-maximal efforts and then, the postponement of fatigue and rapid recovery from training between repetitions and competitions. The periodized training programmes optimized the neuromuscular functioning as well as the autonomic recovery processes, which allow an athlete to perform consistently throughout the entire season (Joyner & Coyle, 2008; Midgley et al., 2007). In conclusion, based on the research, it can be said that the variables that influence running performance also occur in more than one physiologic variable. Training programmes specific to the individual that will improve VO2max, lactate threshold, running economy, anaerobic capacity, cardiovascular fitness and neuromuscular function are the optimal way to enhance performance in the three disciplines (Table 6).

3.9 Biomechanical Determinants:

The included studies showed that biomechanics is one of the main components that can influence the performance of a runner in short, middle and long-distance events. Ground-contact time, flight time, leg stiffness, kinematics, striding time, frequency, and length, as well as the ground reaction forces, were some of the variables most frequently analysed in order to evaluate the influence of biomechanics on running performance. It was observed that they, together with the foot strike pattern, the movement economy and the lower-limb alignment, can influence negatively or positively the forward propulsion, the running economy and the risk to suffer an injury. The studies showed that the most performing runners display similar movement patterns independently of the running distance and of the level of competence, but each athlete has some biomechanical characteristics that need to be developed in training to improve their performance (Novacheck, 1998; Saunders et al., 2004). Ankle and knee flexion, shoulder angle, and stride length are ways you can improve your efficiency for the long-distance type race. It was discovered that the most critical factor in short distance, middle distance, and long-distance running performance was that of biomechanics. It was stated that "elite runners adopt the most economical running pattern where they minimize vertical oscillation and forward propulsion, thereby lowering the energy cost of running (Saunders et al., 2004; Barnes & Kilding, 2015).

The stride length and the stride frequency were cited as the key leading factors affecting the running velocity. The run performance is determined by the combination of these two variable factors rather than singling one out for improvement in a sprint (Mann, 2018). Moreover, elite sprinters will improve the running velocity by producing bigger propulsive force with relatively fast stride frequency and the ability to efficiently apply the force. For the middle- and long-distance runners, they likely employ stride length that maximizes the running efficiency and minimizes the energy cost over the long-distance (Cavanagh & Kram, 1989) (Table 7). Both ground-contact time and leg stiffness had correlations with the running biomechanics. Reduced ground-contact time was most likely to allow for more optimal use of the stretch-shortening cycle used for maximum force output and running velocity. Increased leg stiffness has also been linked with optimized stretch-shortening cycles and decreases the load on the muscular system during running. Both plyometric and resistance-training interventions showed consistent effect on optimizing the biomechanics by changing the neuromuscular and tendon stiffness related characteristics of the individuals in the sample (Blagrove et al., 2018; Barnes & Kilding, 2015).

Foot strike pattern has been shown to be an important part of running performance and injury risk. Although forefoot striking may lessen the vertical ground reaction load at the knee joint and improve elastic energy recycling at the sprint speed range, it cannot be said that one particular pattern is more functional at endurance performance than another. The most efficient pattern is individual and will depend on your morphology, running velocity, footwear and how much you trained. A change in running pattern can be more detrimental than advantageous (Lieberman et al., 2010; Hamill et al., 2014).

Another critical factor of running performance is the lower limb kinematic that directly affects the joint ROM and the force that lands on the ground. Successful at running is characterized by well-coordinated the lower limb joints movements, which can lead to less energy cost, better efficiency in force transfer, and higher injury risk if the movement range is larger and asymmetrical (Hamill et al., 2014). Several studies proved that elite runners have better coordination in neuromuscular, proper lower limb alignment, and less side-to-side motion, which enables to absorb the force and efficiency of movement (Novacheck, 1998; Mann,2018). In conclusion, according to all the references reviewed, determinants of running performance in terms of kinematic and kinetic factors are highly linked to individual morphology, neuromuscular efficiency, and the proficiency of running. Hence, it is very important to include individual biomechanics and running gait analysis in the training program to optimize the stride kinetics, running economy, force production, and avoid the running related injury of any sport and endurance event.

3.10 Psychological Determinants

These three studies from the overall available works on the selected training indicators found in this review confirmed the influence of psychological indicators across various stages of the short- middle- and long-distance runners, including adaptation to training, competitive performance, and athletic development. The most common psychological indicators involved in training were motivation, self-confidence, mental toughness, emotions control, anxiety, stress, focus, self-efficacy, resilience, goal orientation, and psychological recovery. The influence of each indicator differed according to the running discipline, and the level of competition; regardless, the general result of the studies indicated that runners achieve better performance, higher resistance to competitive pressure, and a better training adherence when they develop the use of more psychological skills (Birrer & Morgan, 2010; Gucciardi et al., 2015).

Motivation was the most influential predictor of runner's performance and engagement in training and competition. Among the few studies that examine motivation using the motivational types described in the Self-Determination Theory, one showed that the intrinsically motivated athletes performed better in training, exercise adherence and recovery, and achieved better long-term results compared with the non-autonomous runners (Deci & Ryan, 2008; Teixeira et al., 2012). The latter runner's group experienced better overall psychological well-being and was less susceptible to overtraining and burnout in the demanding context of prolonged endurance training (Teixeira et al., 2012). Mental toughness has been found to be a consistent performer predictor in all of the disciplines of running that have been reviewed. The researchers indicated that runners with a higher degree of mental toughness expressed significantly higher levels of endurance time, emotion control, self-confidence, persistence, and decision-making skills in regular training and competitions (Gucciardi et al., 2015). Moreover, they were able to tolerate fatigue, make optimal pacing, and perform at the highest capacity in the face of the competitive environment. The studies further established that elite distance runners presented higher levels of psychological toughness than the amateur runners in major races (Jones et al., 2007) (Table 8).

Management of performance anxiety and stress was another variable that affected the result of the event. Hypothesis was that some level of arousal helped concentration and racing, whereas excessive anxiety caused attention, pacing, muscular activity, and physiological functioning to decline. Psychological approaches such as relaxation, mindfulness, breathing, restructuring and the like decreased anxious feelings and improved the athletes' effectiveness in emotion regulation (Craft et al., 2003; Baltzell & Akhtar, 2014). Self-efficacy and confidence were also key predictors of performance. Those with a high efficacy belief tended to be more willing to engage in high effort levels for training, set stretching goals for themselves and recover from failures and setbacks (an important skill for reaching high levels of performance). In combination with goal-setting and feedback, confidence building proved an effective way of improving performance and motivation at all levels of competition (Bandura, 1997; Weinberg & Gould, 2019). Additionally, it has been found that running requires attention focus and cognitive strategies. This means that as an elite distance runner, one can switch their concentration, inward or outward, depending on what they need to control such as pace, running technique and awareness of fatigue (Weinberg & Gould, 2019; Birrer & Morgan, 2010). Imagery and self-talk techniques were also effective with concentration, technical issues in the race and pre-race mental skills.

The second factor relevant to long term success and athlete adaptability is the recovery from the detrimental psychological impacts. For instance, if an athlete is unable to recover from extended periods of psychological stress or chronically poor sleep, the potential for degradation, injury, or maladaptation to training loads, is greatly increased. This holds true in terms of insufficient rest and recovery from fatigue as it was found to impair athlete's psychological states as well as negatively impacts

competition performance (Kellmann et al., 2018; Baltzell & Akhtar, 2014). Thus, by a quick perusal of these literature sources, it can be reported that the influence of the psychological factors to human anatomy should never be taken for granted. As a matter of fact, it was identified that psychological factors can preclude physiological, biomechanical, and nutritional factors from affecting an athlete's race performance. In this sense, the application of psychological skill training, motivational instruction, and relaxation strategies during the periodization process has the potential to benefit the majority of short, middle, and long-distance running strategies and skill execution to optimize flexibility and competitive outcome.

3.11 Performance Outcomes:

All of the previous studies' results showed that, with the correct implementation of the relevant training programmes, targeted nutritional interventions, enhancement of physiological, biomechanical, anthropometrical, physical fitness and psychological elements as well as with the improvements of running performance on the respective short-, middle- and long-distance races, performance indicators such as: time (race time or time-trial results), maximal sprint speed, running economy, maximal oxygen consumption (VO2max), VO2max velocity (vVO2max), lactate threshold, lactate and capacity, muscle strength and power, fatigability, recovery, indices and incidence of injury, were used to establish the performance. According to the studies' findings, successfully adapting athletes utilizing the individualized, cyclically scheduled and, 14 multidisciplinary training interventions achieve to better competing results than the runners applying traditional endurance training (Joyner & Coyle, 2008; Blagrove et al., 2018).

For the 100 – 400 m runners, the adaptations that resulted in the greatest performance improvements were greater maximal sprint velocity, better acceleration, higher stride frequency, greater lower limb power, and better neuromuscular coordination. Sprint interval training, resistance training and plyometrics greatly increased reactive strength, rate of force development and sprinting mechanics, ultimately resulting in faster race times and increased explosiveness. These runners also experienced increases in anaerobic capacity and neuromuscular strength, both of which are critical for the delivery of speed during a 100 – 400 m race (Rumpf et al., 2016; Eihara et al., 2022). In middle distance athletes (800-3000m), training can be divided into anaerobic and aerobic adaptations. Through consistent regimes of HIIT, tempo running, resistance training and concurrent training programmes, VO2max, lactate threshold, velocity at VO2max, running economy increased as the athlete also performed positive adaptations including increased fatigue resistance and muscular strength. These changes in physiological factors contributed to a decrease in race times in the middle distance athlete (Midgley et al., 2007; Buchheit and Laursen, 2013).

Long-distance runners (3 000 m, marathon & ultra-marathon runners) gained in aerobic capacity, metabolisms and recovery. Endurance training, periodized nutrition (carbohydrate periodization, nitrate supplementation), power of submaximal efforts, optimization of protein and hydration and recovery techniques enhance running economy, glycogen storage, mitochondrial activity and endurance performance of long-distance runners. These athletes had improved performance on the marathon, decreased perception of fatigue & paced better in the race (Thomas et al., 2016; Barnes & Kilding, 2015). In the present review, evidence reveals that multi-intervention treatment was more effective than single intervention per domain. It was documented that resistance training, biomechanics, psychological skills training, personalized nutritional management & adequate recovery plans optimized multiple performance variables at the same time as well as enhanced the quality of training, decreased risk of injuries & provided accelerated between-sessional recovery (Blagrove et al., 2018; Kellmann et al., 2018) (Table 9). The extant literature indicates that running performance is the result of multiple factors interacting such as physiological capacity, physical conditioning, biomechanics, anthropometry, nutrition, and mental preparation. Personalized, evidence-based, periodized, training regimens with the aid of adequate nutritional support and recovery measures produce better outcomes than the classic methods among athletes in the long-distance sport. Athletes who adhere to such training regimens experience faster race times, better movement economy, and less fatigue, and superior competitive success across all the different running events.

3.12 Discussion

This systematic review collated findings of 160 articles focused on the influence of training interventions, nutrition interventions and nutritional strategies, and anthropometric, physiological, physical fitness, biomechanical, and psychological factors on short-, middle-, and long-distance runners' performance. In general, the findings of the studies presented here suggest that running performance depends on physiological adaptations, optimal training prescription, nutrition, body

composition, biomechanics, and psychological traits, and not on any single factor. This literature review emphasizes the importance of individualized and periodized training with multiple performance-enhancing strategies while optimizing race performances. Of all training interventions, however, it is endurance training that seems to be the training intervention at the heart of aerobic capacity, mitochondrial, capillary, and metabolic modifications, especially in middle- and long-distance runners. In fact, the results of this review are consistent with previous reviews that indicate that endurance training can promote improvements in VO2max, lactate threshold, and running economy (Jones & Carter, 2000; Midgley et al., 2007). The present review, however, also underscores the role of high- and sprint-interval training, which could produce similar or even larger physiological adaptations while not increasing the volume of training. In this context, it is worth noting that the results of the present review are consistent with those of Buchheit and Laursen (2013), who showed that interval-based training can improve velocity at VO2max, anaerobic capacity, and competition performance via cardiovascular and metabolic adaptations.

Resistance and plyometric training were once thought of as supplements to endurance programmes, but the present review shows they are now essential components of performance optimisation in running. Similarly, plyometric training trains stretch-shortening cycle efficiency, reactive strength and movement coordination which also promotes improvements in sprint acceleration and running economy. These findings are in line with the recent systematic reviews by Blagrove et al. (2018) and Eihara et al. (2022) who found that combined endurance and strength training was superior to endurance training alone for performance-related outcomes. Altitude and hypoxic training protocols are also an effective training stimulus for the world's top endurance athletes by elevating erythropoietin and oxygen transport capacity (Levine & Stray-Gundersen, 1997; Wilber, 2007). Nutritional interventions proved to be equally crucial when determining runners' performances. According to the current sports nutrition considerations, carbohydrate availability and nutrition strategies are still considered to be the primary determinants of sustained muscle glycogen status, maintained blood glucose levels and high fighting performance during endurance performance (Burke et al., 2011; Thomas et al., 2016). Besides, an adequate protein intake can facilitate muscle recovery, damage, repair and adaptation to aerobic exercise, while optimized hydration strategies might buffer cardiovascular stability, thermoregulatory and other important function during sustained exercise (Jäger et al., 2017; Casa et al., 2019). Moreover, the present review also indicates the ergogenic benefits of caffeine, dietary nitrates, beta-alanine and sodium bicarbonate supplement use to improve power output, endurance capacity and dampen fatigue. Iron supplementation has proved to be worth rewarding in athletes with authenticated deficiencies and therefore supported the concept of personally targeted nutrition strategies rather than widespread supplementation of nutrients and the reaffirmation of new standards suggested by the IOC (International Olympic Committee) and the AOSM (American College of Sports Medicine) (Jäger et al., 2017).

Additional findings from the associations between anthropometric features and running performance emerged in the form of body composition. For example, lower body fat percentage increased running economy due to lower movement energy expenditure, while lean body mass increased force production and sprinting performance (Legaz & Eston, 2005). Excessively low percentage of body fat was associated with signs of developing RED-S, menstrual failure, weakening of bones, fatigue, low force production, delay in recovery, and an increased likelihood of experiencing bone stress fractures (Mountjoy et al., 2018; Ackerman et al., 2019). As was shown in many of the reviewed studies, discipline-specific optimum body composition is characterized by increased muscle mass and mesomorphism in sprinters and by low body mass and ectomorphy in long-distance racers, which reduces movement energy expenditure (Legaz & Eston, 2005; Santos-Concejero et al., 2014). It can be concluded that the type of event requires different anatomy even in the range of athletic performance. Physiological and physical fitness factors were the most powerful determinants of performance. Though VO2max has been traditionally regarded as the most important predictor of endurance running performance, the present review results demonstrated that the lactate threshold, running economy and VO2max velocity have more power to differentiate the highest level of competition level. Results also support the conclusion of Joyner and Coyle (2008), indicating that optimal performance at the highest levels is a result of interactions among the physiological variables (not by a single marker of aerobic capacity). Furthermore, muscular strength, power, speed, neuromuscular coordination and fatigue are all determining aspects of both sprinting and middle-distance running. Hence, a program that enhances aerobic endurance, muscular power and neuromuscular control of the movement patterns would be more suitable in terms of performance in all three types of running.

The review demonstrated the significant role biomechanics has for performance efficiency and injury prevention. The review identified that the better the stride short ground contact short stride length and the higher the stride frequency and leg

stiffness provides better economy and less energy required. The reviews research for the importance of footfall pattern changes during running, was conflicting, the majority of the research showed that it is not an optimal footfall pattern, as it is dependant on speed, personal characteristics, running shoes and experience (Lieberman et al., 2010; Hamill et al., 2014). The review concludes that special attention should be paid to regular biomechanical and gait assessments to examine where a form of inefficiency exists and where weakness may provide injury risk. The review additionally stated that psychological skills training (PST) in the form of goal-setting, imagery, relaxation, mindfulness and self-talk contributed to focus and anxiety reduction (Birrer & Morgan, 2010; Gucciardi et al., 2015; Weinberg & Gould, 2019). In accordance with the review's conclusion, PST must be integrated as an essential part of training, along with nutritional and physical preparation, to promote optimal performance.

In general, the review indicates that the key to optimizing running performance is combining the methods of training, nutrition, anthropometry, physiology, biomechanics, and psychological conditions. The advantage of this review is that the authors managed to identify 160 articles that investigated the various factors affecting the running performance. However, many studies revealed different results, which may be inadequate to make a final decision. Thus, future research with more multifarious studies should be conducted to monitor the participants background, the duration of a study, and the physical activity performed in studies. The use of a wearable technology and artificial intelligence has to be demonstrated in the further studies, as well. This technology has been defined as the emerging fields for the individualization of sports training. To summarize, the review discloses the need for multiple intervention trials to individualize the improvement of a runner's performance in sprint, middle- and long-distance running based on physiological, psychological, and biomechanical components.

Strengths and Limitations

The systematic review summarized 160 studies of the various factors influencing short, middle and long-distance running performance. One advantage of the review is that it encompasses many elements of running, e.g., training, nutrition, physiological, anthropometric, biomechanical, physical fitness, and psychological factors. Its disadvantage is the heterogeneity of the studies and participants included. The authors reported a wide variety of study designs, populations, training interventions, length of interventions, outcomes measured, and competition levels. The number of runners in the studies included also ranged widely. The findings of the review may be relevant for runners because the authors reported that individualization of training depending on the runner's age, body weight, or height is very important. Moreover, notable limitations aroused from wide-ranging variation in study population, unstandardized nutritional dietary logs, training methods, performance testing protocols across selected literatures. Nevertheless, to determine the efficacy of different training interventions and optimal nutrition for athletes, there is a need for more high-quality randomized control trials with longer-term follow-up.

Future Research Directions

The promise of new technologies, such as wearables, artificial intelligence, machine learning, and others that need to be studied in greater detail in relation to monitoring and individual adaptation should also be considered. Important is also the delineation of the linkages between biomechanical, the gut microbiome, nutrigenomics, metabolomics, and recovery strategies. The relevance of training and nutritional strategies for females, adolescents, well-trained athletes, masters and world elite competitors also deserves greater attention in order to take and maintain an individualized personalized approach to optimize athletic performance. Potential areas of exploration for upcoming studies are standardized, reproducible, muti-centre training and dietary interventions with uniform performance and training load measuring techniques. This will strengthen the centrality and generalizability of findings. The primary attention should be given to examine the effects of single variables in the large number of them (e.g. Sex, age, genetics, nutritional status, training status, event-specific needs) and the progression of physiological and performance adaptations following concomitant application of training, nutrition, recovery, and mental techniques.

Practical Applications

The results of the experiment conducted by professionals in the field lead to the conclusion of the necessity of a personalized and periodized mode of training that includes various types of training: endurance, interval, resistance, and plyometric. In addition, coaches and trainers could combine various types of nutritional strategies and recommendations, such as the

introduction of the proper carbohydrate availability, fluid intake, supplementation of proteins, and ergogenic aids for more favorable results and the maximum performance. The monitoring of physiological, anthropometric, biomechanical, and psychological parameters during training would also benefit from the inclusion of periodization in sports. A single approach to working with the athlete may raise the motivation and performance of the sportsman and prevent the occurrence of possible injuries. The use of information technologies and monitoring facilities for athletes may help individualize the process of load buildup and appointment of training more efficiently. To obtain the most favorable and positive results of training and the effectiveness of training, the coach has to work in a team with a nutritionist, physiologist, biomechanist, sport psychologist, and medic.

4. CONCLUSION

The included studies show evidence that running performance is a multidimensional matter resulting from the interaction between the training process, dietetics strategy, adaptation to physiological demands, anthropometric features, physical fitness, biomechanical factors, and psychological profile. This systemic review found that identical interventions do not yield uniform outcomes across all running categories. The efficacy of training and nutritional interventions are highly discipline specific. High intensity interval training sprint interval training, resistance training and plyometric training predominantly improve anaerobic power, maximum velocity, and rate of force generation among short and middle-distance runners. However, to optimize metabolic economy and endurance in long distance runners, continuous endurance training along with carbohydrate and fluid periodization is needed. Consequently, current evidences support the need of discipline-specific individualized periodization of training and diet rather than generalized models. Furthermore, the continuous assessment of some performance-related variables is of paramount importance because this practice will allow us to alter the loads imposed to the body and other parameters. Consequently, the most effective way to improve running performance and, subsequently, to achieve competition success and to prevent injury in the sport of running is to implement a multidisciplinary approach with the combination of training principles, nutritional protocol, biomechanical features, and application of psychological strategies.

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