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EVALUATING THE IMPACT OF VO_2MAX ON RUNNING ECONOMY AMONG RECREATIONAL ATHLETES: A SYSTEMATIC REVIEW

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Abstract
Maximal oxygen uptake (VO_2max) and running economy (RE) are important physiological determinants of endurance running performance. VO_2max represents the maximum capacity of the body to transport and utilize oxygen during exercise, whereas RE reflects the oxygen or energy required to maintain a given running speed. This study aim to systematically review the scientific literature examining the relationship between VO_2max and running economy among recreational runners and recreational athletes. A systematic literature review was designed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. Literature searches were planned across PubMed, Scopus, ScienceDirect, and Google Scholar for studies published between October 27, 2016, and October 27, 2026. Search terms included VO_2max, maximal oxygen uptake, aerobic capacity, running economy, running efficiency, recreational runners, and amateur runners. Eligible studies were defined as peer-reviewed original research involving recreational runners or athletes aged 18–50 years, with validated VO_2max measurements and running-economy assessments. Methodological quality was to be evaluated using appropriate Joanna Briggs Institute (JBI) critical appraisal tools. Preliminary evidence indicates that VO_2max and running economy contribute to endurance performance through related but distinct physiological mechanisms. Findings from recreational runners suggest that differences in oxygen cost may occur despite comparable relative cardiovascular fitness. Furthermore, a high-intensity interval training study reported improvements in VO_2max and time to exhaustion without significant overall changes in submaximal oxygen uptake. These findings suggest that improvements in maximal aerobic capacity do not necessarily result in better running economy. However, the final number of eligible studies and the consistency of the relationship remain undetermined pending completion of the systematic screening and quality assessment. Current preliminary evidence does not establish a consistent direct relationship between higher VO_2max and better running economy among recreational runners. Completion of the systematic review is required to clarify this relationship and identify the physiological and methodological factors influencing running economy.

Keywords: *Vo_2Max; Running Economy; Recreational Runners; Aerobic Capacity;Oxygen Cost; Endurance Performance; Systematic Literature Review.*

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INTRODUCTION

Endurance running performance is determined by the interaction of several physiological characteristics, including maximal oxygen uptake (VO_2max), running

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economy (RE), and the ability to sustain a high proportion of maximal aerobic capacity during prolonged exercise. These characteristics influence the amount of oxygen available for energy production, the physiological cost of running at a given speed, and the duration for which a particular intensity can be maintained. Although VO_2max has traditionally been considered an important indicator of endurance fitness, running economy provides complementary information about the efficiency with which an athlete converts physiological capacity into running performance. Understanding the relationship between these variables is particularly relevant among recreational runners, whose training backgrounds, physical characteristics, and levels of aerobic development vary considerably (Mougin et al., 2026).

Maximal oxygen uptake, commonly expressed as VO_2max, is defined as the highest rate at which an individual can take up, transport, and utilize oxygen during maximal or near-maximal exercise. It is commonly reported in absolute terms ($L \cdot min^{-1}$) or relative to body mass ($mL \cdot kg^{-1} \cdot min^{-1}$). VO_2max reflects the integrated function of the cardiovascular, respiratory, and muscular systems, including oxygen delivery through the circulation and oxygen utilization by working skeletal muscles. In endurance sports, VO_2max represents the upper limit of aerobic energy production and consequently influences the potential speed that an athlete can sustain during prolonged running. A higher VO_2max generally provides a greater aerobic capacity, although actual performance also depends on running economy and the fraction of this capacity that can be sustained during competition (Mougin et al., 2026).

The importance of VO_2max in endurance performance is supported by recent research examining the physiological determinants of exercise performance. Mougin et al. (2026) investigated 888 runners and cyclists ranging from recreational to world-class levels and found that VO_2max was the strongest predictor of speed or power at lactate threshold and lactate turnpoint. In running, VO_2max accounted for approximately 72% of the variation in speed at lactate threshold and 76% at lactate turnpoint in their statistical models. Running economy contributed approximately 20–22%, while the fractional utilization of VO_2max

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contributed a smaller proportion. These findings demonstrate the importance of VO_2max for endurance performance while also indicating that aerobic capacity alone cannot fully explain differences in running ability. However, these results concern performance proxies rather than evidence that increasing VO_2max directly improves running economy.

Running economy describes the energetic or oxygen cost of maintaining a given submaximal running speed. It is commonly assessed by measuring steady-state oxygen consumption during standardized treadmill or overground running. When expressed as oxygen cost per unit of distance, such as $mL \cdot kg^{-1} \cdot km^{-1}$, lower values generally indicate better running economy because the runner requires less oxygen to cover the same distance. Energy cost may also be expressed in metabolic units, such as $kcal \cdot kg^{-1} \cdot km^{-1}$. Consistent running speed, environmental conditions, measurement procedures, and appropriate scaling of oxygen uptake are important for meaningful comparisons between athletes (Lee et al., 2024). Running economy therefore differs conceptually from VO_2max: the former indicates the cost of performing a task, whereas the latter represents the maximal capacity to supply and utilize oxygen.

Among recreational athletes, running economy is particularly important because this population includes individuals with different training histories, running volumes, body compositions, and degrees of biomechanical adaptation. Compared with highly trained runners, recreational runners may demonstrate greater variability in movement patterns and physiological responses to a given running speed. Some runners can maintain a relatively fast pace despite having a moderate VO_2max because their oxygen cost is comparatively low. Conversely, runners with high VO_2max values may consume more oxygen than others while running at the same speed. Consequently, aerobic capacity and running economy provide different but complementary information for evaluating endurance potential (Bayissa et al., 2025; Mougin et al., 2026).

Several interacting factors influence running economy. Anthropometric characteristics, including body mass, body composition, and the distribution of lean

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and fat mass, can affect the energy required to move the body during running. Neuromuscular function, muscle-tendon characteristics, biomechanical coordination, and the ability to produce and absorb forces also contribute to movement efficiency. Training experience may influence these characteristics through adaptations in muscular function and the coordination of running movements. In addition, running speed, footwear, and testing conditions may alter the measured oxygen cost. Evidence from a systematic review and meta-analysis by Van Hooren et al. (2024) indicates that individual biomechanical variables generally explain only a limited proportion of the variation in running economy when considered separately. This suggests that economy arises from multiple interacting mechanisms rather than a single physiological or mechanical characteristic.

VO_2max may be associated with running economy because both reflect aspects of aerobic exercise physiology, but their relationship requires careful interpretation. During submaximal running, an athlete with a higher VO_2max may perform at a lower percentage of maximal aerobic capacity than an athlete with a lower VO_2max, provided that both have the same absolute oxygen requirement at that speed. This can reduce the relative physiological strain associated with maintaining a particular pace. Nevertheless, the oxygen cost of running itself does not necessarily decrease when VO_2max increases. For example, two runners may consume similar amounts of oxygen while running at the same speed even though one has a substantially higher VO_2max. In this situation, the runner with greater aerobic capacity is exercising at a lower relative intensity, but the two runners have similar running economy. This distinction is fundamental to evaluating whether VO_2max is associated with RE or whether both variables independently contribute to endurance performance.

Recent empirical findings provide evidence of an association between VO_2max and running economy in certain populations, although the direction and consistency of that relationship remain uncertain. Bayissa et al. (2025) examined 53 high-level Ethiopian distance runners, including 30 men and 23 women, training

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at an altitude of approximately 2,400 m. The researchers identified statistically significant correlations between VO_2max and oxygen cost at selected running speeds. In women, a significant association was reported at 14 $km \cdot h^{-1}$, whereas in men, significant associations were observed at 12 and 14 $km \cdot h^{-1}$. The reported correlation coefficients ranged from 0.513 to 0.550. However, these findings do not establish that higher VO_2max consistently produces better running economy. The study also emphasized the potential contribution of exceptional running economy to successful endurance performance despite comparatively moderate VO_2max values. Furthermore, its high-level Ethiopian sample limits direct generalization to recreational runners.

Evidence from recreational runners also challenges the assumption that higher VO_2max necessarily corresponds to greater running efficiency. Domingos et al. (2026) investigated 61 female recreational distance runners aged 20–60 years and examined several potential predictors of running economy. The researchers found no statistically significant correlation between VO_2max and energy cost of running ($r = -0.200$, $p = .121$). In contrast, body fat percentage was positively associated with energy cost ($r = 0.629$, $p < .001$), while lean mass was negatively associated with energy cost ($r = -0.330$, $p = .009$). The findings indicate that body composition may explain relevant differences in running economy even when maximal aerobic capacity does not show a significant relationship with energy cost. Nevertheless, the study focused exclusively on female recreational runners, meaning that its findings cannot automatically be generalized to male runners or populations with different training characteristics.

Differences in the measurement and interpretation of running economy further complicate comparisons between studies. As discussed by Lee et al. (2024), the conventional practice of expressing oxygen uptake relative to body mass assumes a proportional relationship between body mass and oxygen consumption. However, this assumption may not adequately represent the relationship across individuals with different body sizes. Their systematic review and meta-analysis examined the allometric scaling of oxygen uptake and highlighted the importance

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of appropriate normalization when comparing running economy. Inconsistencies in testing speed, measurement protocols, participant characteristics, and the expression of oxygen or energy cost may therefore contribute to differences in reported associations between VO_2max and RE. Such methodological considerations are particularly important when synthesizing research involving heterogeneous recreational running populations.

The available evidence indicates that VO_2max should be considered a potentially relevant correlate of running economy rather than a direct or universally reliable determinant of it. Studies conducted among high-level distance runners have identified associations between the variables at particular running speeds, whereas research involving female recreational runners has found no statistically significant relationship between VO_2max and energy cost. Meanwhile, evidence from larger, mixed-ability athletic populations demonstrates that VO_2max and exercise economy make distinct contributions to endurance performance (Bayissa et al., 2025; Domingos et al., 2026; Mougin et al., 2026). These differences suggest that the relationship may depend on training status, sex, body composition, running speed, measurement methodology, and other physiological characteristics. They also indicate the need to distinguish a direct association between VO_2max and RE from the combined contribution of these variables to running performance.

Therefore, a systematic literature review is warranted to critically evaluate the relationship between VO_2max and running economy among recreational athletes. The review should identify and synthesize relevant empirical studies, compare their findings, and examine how participant characteristics, study design, and measurement protocols influence the reported relationship. Particular attention should be given to whether higher VO_2max values are consistently associated with lower oxygen or energy costs at standardized running speeds, whether the relationship differs according to sex or training status, and whether other physiological or anthropometric factors account for the observed associations. By addressing these questions, the review will clarify the current evidence concerning the relationship between maximal aerobic capacity and running economy, identify

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limitations and gaps in the literature, and inform future research and exercise-prescription strategies for recreational runners.

METHOD

his study will use a systematic literature review (SLR) to examine the relationship between maximal oxygen uptake (VO_2max) and running economy (RE) among recreational runners and recreational athletes. The review will follow the PRISMA 2020 guidelines to ensure transparent reporting of the identification, screening, eligibility, and inclusion processes (Page et al., 2021a, 2021b).

Eligibility criteria

The inclusion and exclusion criteria will follow the Population, Intervention/Exposure, Comparator, Outcome, and Study Design (PICOS) framework.

Table 1. Eligibility criteria

Element	Inclusion criteria	Exclusion criteria
Population	Recreational runners or athletes aged 18–50 years.	Elite/professional athletes, individuals outside the specified age range, or populations with injuries or chronic diseases.
Exposure	VO_2max measured using a validated laboratory or field test.	Studies without a clear VO_2max measurement.
Comparator	Different VO_2max levels or analyses examining the relationship between VO_2max and RE.	Studies without relevant comparisons or association data.
Outcome	Running economy assessed through submaximal oxygen consumption, oxygen cost, or energy expenditure during running.	Studies that do not measure RE.
Study design	Peer-reviewed experimental and observational studies published between October 27, 2016, and October 27, 2026.	Reviews, editorials, opinion articles, qualitative studies, and conference abstracts without accessible full text.

Studies involving mixed populations will be included only when data for eligible recreational participants can be identified separately. A separate control group will not be required if the association between VO_2max and RE can be assessed directly.

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Database Search Strategy

The literature search will be conducted using PubMed, Scopus, ScienceDirect, and Google Scholar. Keywords will be combined using the Boolean operators AND and OR to identify relevant publications.

The main search terms will include "VO2max," "maximal oxygen uptake," "aerobic capacity," "running economy," "running efficiency," "recreational runners," "recreational athletes," and "amateur runners."

Study Selection PRISMA Flow

Study selection will follow four PRISMA stages. During identification, records from all databases will be collected and duplicates removed. During screening, titles and abstracts will be assessed against the eligibility criteria. During eligibility assessment, the full texts of potentially relevant studies will be examined, and exclusion reasons will be documented. Finally, studies meeting all criteria will be included in the qualitative synthesis.

Two reviewers will independently conduct screening and full-text assessment. Disagreements will be resolved through discussion or consultation with a third reviewer. The PRISMA flow diagram will report the number of records identified, duplicates removed, records screened, full-text reports assessed, reports excluded with reasons, and studies included in the final synthesis (Page et al., 2021b). Actual counts will be entered after the search and screening processes are completed; they will not be estimated.

Data Extraction

Data will be extracted using a standardized form. The following information will be collected: author and publication year, country, study design, sample size, participant age and sex, recreational status, VO_2max measurement method and values, running-economy assessment protocol, running speed, outcome units, statistical associations, and relevant confounding factors.

Quality Assessment

The methodological quality and risk of bias of included studies will be assessed using appropriate Joanna Briggs Institute (JBI) critical appraisal checklists

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according to study design. Two reviewers will independently assess relevant domains, including participant selection, validity of VO_2max and RE measurements, confounding factors, completeness of data, and appropriateness of statistical analysis. Disagreements will be resolved through discussion. (Cuschieri, 2019).

Data Synthesis

Findings will be synthesized narratively to describe the direction, strength, and consistency of the relationship between VO_2max and RE. Results will be compared according to participant characteristics, measurement methods, running speeds, and Study design.

A meta-analysis will be considered if sufficient studies report comparable populations, outcomes, and effect estimates. Otherwise, a narrative synthesis will be presented. The interpretation will distinguish statistical associations from causal effects, recognizing that higher VO_2max does not necessarily indicate better running economy.

RESULT AND DISCUSSION

A preliminary literature search identified four potentially relevant original research studies published between 2017 and 2026. The studies investigated the relationship between physiological determinants of endurance performance, sex-related differences in running economy, methods of measuring running economy, and physiological adaptations following high-intensity interval training.

However, the formal identification and screening process across PubMed, Scopus, ScienceDirect, and Google Scholar remains to be completed. Therefore, the total number of records identified, duplicates removed, full-text articles assessed, and studies meeting all inclusion criteria will be reported after the systematic screening process is finalized.

Characteristics of the Identified Studies

The preliminary evidence includes cross-sectional studies, longitudinal assessments, and an exercise-training intervention. The sample sizes ranged from

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11 to 80 participants, although some studies included mixed populations or recreationally active individuals rather than exclusively recreational runners.

Table 2. Characteristics and principal findings of potentially relevant studies

Author and year	Participants and design	Principal findings
Takayama et al. (2017)	11 adult recreational runners; pre- and seven-day post-marathon assessments.	VO_2max and running economy showed no clear deterioration seven days after marathon running. Oxygen cost changed from 221.0 to 221.2 $mL \cdot kg^{-1} \cdot km^{-1}$, with no statistically significant difference ($p = .919$).
Takayama et al. (2018)	39 recreational runners; treadmill-based physiological assessment.	VO_2max, fractional utilization of VO_2max at the anaerobic threshold, and running economy collectively explained 94% of the variation in velocity at the anaerobic threshold.
Mendonca et al. (2020)	25 recreational runners aged 19–27 years; comparison between male and female participants.	Women exhibited lower oxygen costs of running than men despite having lower absolute VO_2max values, suggesting that aerobic capacity alone does not determine running economy.
Chen et al. (2024)	30 male recreational runners; biomechanical and metabolic assessment.	Running economy was associated with lower-limb kinematic and kinetic characteristics, indicating that movement mechanics contribute to differences in energy cost.
Lee et al. (2025)	69 recreationally active college students; laboratory assessment.	Submaximal oxygen uptake and energy cost increased with running intensity. The study highlighted the importance of allometric scaling when comparing running economy between individuals.
Lenk et al. (2025)	26 recreationally active adults; six-week HIIT intervention.	VO_2max and time to exhaustion improved, but submaximal oxygen uptake did not change significantly overall, indicating that aerobic improvements did not necessarily coincide with measurable improvements in running economy.
Öncel et al. (2026)	80 runners comprising elite and recreationally trained groups; cross-sectional physiological comparison.	Elite runners demonstrated higher VO_2max and better running economy than recreationally trained participants. Because this was a mixed-population comparison, the recreational subgroup must be evaluated separately against the eligibility criteria.
Malinen et al. (2026)	33 recreational-to-competitive endurance runners; physiological assessment before and after prolonged exercise.	The study identified changes in VO_2max and running economy during fatigue. However, the relationship between these changes was analyzed in a mixed population, limiting direct application to recreational runners alone.

Discussion

Relationship Between VO_2max and Running Economy

The findings of Takayama et al. (2018) indicate that VO_2max and running economy contribute jointly to endurance performance. In 39 recreational runners, the combination of VO_2max, fractional utilization of VO_2max at the anaerobic

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threshold, and running economy explained 94% of the variation in velocity at the anaerobic threshold. Each variable contributed significantly to the statistical model ($p < .001$). These findings support the importance of considering multiple physiological determinants when evaluating running performance. However, the percentage explained by the combined model does not establish that VO_2max directly improves running economy.

Further evidence comes from Mendonca et al. (2020), who examined 25 recreational runners aged 19–27 years. The study found that women had lower maximal oxygen uptake than men but also demonstrated lower oxygen costs of running across several treadmill speeds. This finding challenges the assumption that a higher VO_2max automatically indicates better running economy. Instead, it suggests that sex-related physiological and anthropometric characteristics may influence the relationship between aerobic capacity and the energetic cost of running.

Takayama et al. (2017) examined the recovery of aerobic fitness and running economy seven days after a marathon. Mean VO_2max decreased from 59.3 to 58.1 $mL \cdot kg^{-1} \cdot min^{-1}$, but the difference was not statistically significant ($p = .294$). Running economy, expressed as oxygen cost per kilometre, also showed no significant change ($p = .919$). Although this small longitudinal study did not directly test whether VO_2max predicts running economy, it demonstrates that both variables may follow different patterns of change during recovery.

Factors Influencing Running Economy

Studies examining recreational runners indicate that running economy is influenced by factors beyond maximal aerobic capacity. Chen et al. (2024) investigated 30 male recreational runners with a mean VO_2max of 54.61 ± 5.42 $mL \cdot kg^{-1} \cdot min^{-1}$. The researchers found associations between running economy and lower-limb biomechanics, including hip and knee movement and ground-reaction forces. These results suggest that differences in movement mechanics may contribute to the variation in oxygen or energy cost between runners with measurable aerobic capacity.

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Lee et al. (2025) examined methods of quantifying running economy in 69 recreationally active college students. The study found that submaximal oxygen uptake and energy cost increased with running intensity. It also demonstrated the importance of appropriate body-mass scaling when comparing running economy. These methodological findings are relevant because inconsistent normalization procedures may affect the observed relationship between VO_2max and running economy across studies.

The results of Lenk et al. (2025) provide additional evidence from an intervention study. Following six weeks of HIIT, VO_2max improved significantly overall ($p = .004$), and time to exhaustion also increased ($p = .002$). However, submaximal oxygen uptake, used as an indicator of running economy, showed no statistically significant overall change ($p = .751$). These findings suggest that improvements in maximal aerobic capacity can occur without a corresponding, statistically detectable improvement in running economy over a relatively short training period.

Evidence from Recent Comparative Studies

Recent studies involving mixed recreational and competitive populations provide additional context but require cautious interpretation.

Öncel et al. (2026) compared 80 elite and recreationally trained runners, with 40 participants in each category. Elite runners exhibited higher VO_2max values and superior running economy compared with the recreationally trained groups. Although these findings demonstrate that higher aerobic capacity and better running economy can coexist in more highly trained runners, the cross-sectional design cannot determine whether the higher VO_2max caused the better running economy. Differences in training history, body composition, and other physiological characteristics may also contribute to the observed group differences.

Malinen et al. (2026) examined 33 recreational-to-competitive endurance runners, including 18 recreational runners and 15 competitive runners. At baseline, the groups differed in several aerobic performance measures but did not differ significantly in running economy in the non-fatigued state. During the physiological

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resilience test, VO_2max decreased by approximately 2.3%, while running economy worsened by approximately 5.0% across the combined sample. These results indicate that aerobic capacity and running economy respond to prolonged exercise, but the mixed population and fatigue-related study design prevent a direct conclusion about the relationship between baseline VO_2max and running economy among recreational runners.

Additional evidence outside the strict eligibility criteria is also informative. Domingos et al. (2026) investigated 61 female recreational runners aged 20–60 years. The study found no statistically significant correlation between VO_2max and energy cost of running ($r = -.200$, $p = .121$). In contrast, body fat percentage ($r = .629$, $p < .001$), flexibility ($r = -.388$, $p = .002$), and lean mass ($r = -.330$, $p = .009$) were significantly associated with energy cost. Because the sample included participants older than the predefined upper age limit of 50 years and age-specific subgroup results were not available, the study should not be counted in the primary synthesis unless eligible subgroup data can be obtained.

Similarly, Bayissa et al. (2025) examined 53 high-level Ethiopian distance runners rather than recreational athletes. The researchers reported associations between VO_2max and oxygen cost at selected running speeds. Because the population consisted of competitive runners, the study does not meet the predefined population criteria. Nevertheless, it illustrates why the direction of a VO_2max–running economy relationship must be interpreted according to how running economy is measured: a higher oxygen cost represents poorer, not better, economy.

CONCLUSION

This systematic literature review aims to evaluate the relationship between maximal oxygen uptake (VO_2max) and running economy among recreational runners. Based on the preliminary evidence, the relationship between these variables does not appear to be consistently positive. Although VO_2max is an important determinant of aerobic endurance performance, a higher VO_2max does not necessarily indicate better running economy. Instead, the available evidence suggests that aerobic capacity and the energetic cost of running represent

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complementary physiological characteristics that contribute to endurance performance through different mechanisms (Takayama et al., 2018).

The findings also indicate that running economy may be influenced by factors beyond maximal oxygen uptake, including sex-related physiological differences and training adaptations. Evidence from recreational runners demonstrates that differences in running economy can occur despite comparable cardiovascular fitness, while improvements in VO_2max following high-intensity interval training do not necessarily coincide with significant improvements in submaximal oxygen uptake (Mendonca et al., 2020; Lenk et al., 2025). Therefore, evaluating endurance potential should consider VO_2max and running economy together rather than relying exclusively on maximal aerobic capacity.

However, because the formal database screening and methodological quality assessment have not been completed, these conclusions should be considered preliminary rather than definitive findings of a completed systematic review. Future research should investigate the association between VO_2max and running economy using standardized testing protocols, larger recreational runner populations, and appropriate control of confounding factors such as sex, body composition, training status, and running speed. Longitudinal studies are also needed to determine whether improvements in VO_2max are associated with subsequent changes in running economy. Completing the systematic review will help establish the consistency of the available evidence and clarify the practical implications for endurance training and performance assessment among recreational runners.

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