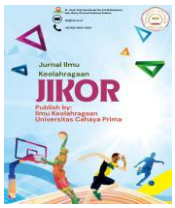

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The Effectiveness of HIIT Exercise on Aerobic Energy System Adaptation in Athletes: A Literature Review

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ABSTRACT

High-Intensity Interval Training (HIIT) is an effective training method for enhancing athletic performance through physiological adaptations in the body's energy systems. This literature review aims to analyze the effectiveness of HIIT in promoting aerobic energy system adaptations in athletes based on current scientific evidence. Articles were retrieved from the Scopus, DOAJ, and Google Scholar databases using the keywords "High-Intensity Interval Training," "HIIT," "aerobic," "VO_2max," "energy system adaptation," and "athlete," covering publications from 2020–2025. Based on inclusion and exclusion criteria, five articles were analyzed in depth using the annotated bibliography method. The findings indicate that HIIT consistently improves VO_2max, aerobic capacity, energy metabolism efficiency, and athletes' cardiovascular endurance. HIIT protocols with an intensity of 80–95% HRmax and training duration of 3–8 weeks have been shown to effectively produce significant physiological adaptations. Moreover, adjusting work–rest intervals according to the characteristics of each sport has a positive impact on competitive performance enhancement. This review confirms that HIIT is an efficient and evidence-based training strategy for improving athletes' aerobic capacity. However, further large-scale experimental research is needed to strengthen the generalization of these findings.

INTRODUCTION

Physical exercise is a crucial component in enhancing athletic performance, particularly through the physiological adaptations that occur within the body's energy systems (Atiq et al., 2022). One training method that has gained increasing popularity in recent years is High-Intensity Interval Training (HIIT), a high-intensity exercise performed in specific intervals interspersed with short recovery periods (Herlan & Komarudin, 2020). HIIT is well known for its effectiveness in improving cardiovascular capacity, aerobic fitness, energy metabolism efficiency, and athletes' ability to repeatedly perform high-intensity physical activities (Atakan et al., 2021).

The aerobic energy system is the primary system that supplies energy for moderate to high-intensity continuous physical activity (Sandi, 2019). Adaptations to aerobic training involve an increase in muscle oxidative capacity, improved oxygen utilization efficiency, and the body's enhanced ability to produce sustained energy (Tanzila & Hafiz, 2019). For athletes, these adaptations are essential to support performance, endurance, and recovery during both training and competition (Yue et al., 2025).

Several studies have investigated the effects of HIIT on aerobic energy system adaptations; however, the results vary depending on factors such as training intensity, duration, frequency, and subject characteristics. This literature review aims to examine existing scientific evidence regarding the effectiveness of HIIT in improving aerobic energy system adaptations in athletes, thereby providing a scientific foundation for designing more effective and sport-specific training programs to enhance athletic performance (Yang et al., 2025).

Based on previous research, further in-depth analysis is needed to evaluate the effectiveness of HIIT in promoting aerobic energy system adaptations among athletes. This literature review will examine various HIIT protocols, as well as variations in training duration, intensity, frequency, and participant characteristics used in prior studies. The objective of this review is to determine the impact of HIIT on aerobic energy system adaptations in athletes based on the available scientific evidence.

METHODS

The article search strategy in this literature review employed the PICOT method. Keywords used for the search included the phrases "High-Intensity Interval Training," "HIIT," "aerobic," "VO_2max," "energy system adaptation," and "athlete." Searches were conducted using journal database tools from both national and international sources, namely Scopus, DOAJ, and Google Scholar.

Inclusion and exclusion criteria were applied to determine which articles would be used in this literature study. The inclusion criteria were as follows: (1) articles focused on HIIT and aerobic energy system adaptation in athletes; (2) publication years within the last five years (2020–2025); (3) written in English; (4) available in full-text format; and (5) experimental or training intervention study design. The exclusion criteria were: (1) articles not focused on HIIT and aerobic energy system adaptation in athletes; (2) published outside the 2020–2025 range; (3) not written in English; (4) unavailable in full-text format; and (5) studies with observational or review-only designs.

Furthermore, the results of the article search and selection process were presented using the PRISMA flow diagram, which consisted of four stages of data collection: (1) Identification, (2) Screening, (3) Eligibility, and (4) Inclusion (see Figure 1).

Population and Sample

The population in this study consisted of articles published in international journals discussing the effects of HIIT on aerobic energy system adaptation in athletes. The sample was selected from articles published between 2020 and 2025, written in English, and meeting the established inclusion and exclusion criteria.

Data Analysis

The researcher employed an annotated bibliography analysis method, which involved the following steps: (1) Identifying the sources cited; (2) Evaluating the authors' qualifications and objectives; (3) Summarizing the main content of each article; (4) Assessing the relevance and significance of each source in addressing the research problem.

The initial search using the relevant keywords on the selected databases yielded 285 articles. After filtering by publication year (2020–2025), English language, and full-text availability, 21 articles remained. These articles were then further screened for topic relevance,

specifically, whether they examined the effects of HIIT on aerobic energy systems in athletes, resulting in 10 articles. After removing 5 duplicate articles, the final sample consisted of 5 articles that were analyzed in this literature review. The PRISMA flow diagram illustrating this selection process is shown in Figure 1.

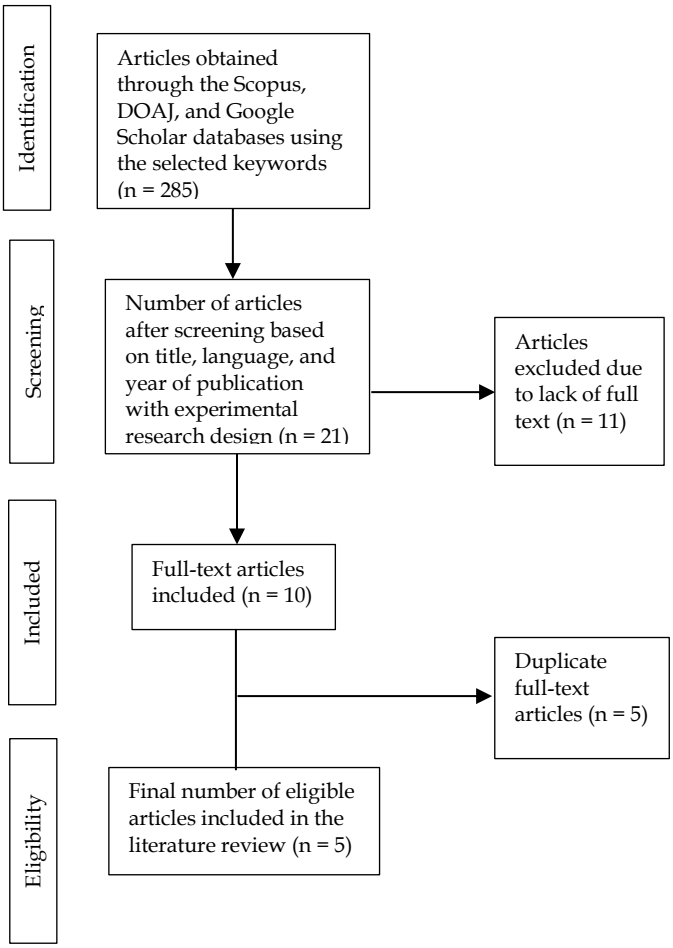

Figure 1. PRISMA Flow Diagram Used in the Literature Search

RESULTS

In the past five years (2020–2025), several international studies have demonstrated that High-Intensity Interval Training (HIIT) has a significant effect on the adaptation of the aerobic energy system in athletes. The five articles analyzed in this literature review (Table 1 and Table 2) indicate that HIIT can enhance VO_2max, stroke volume, and overall aerobic capacity across various sports disciplines (Atakan et al., 2021; Lasso-Quilindo et al., 2025; Wang & Wang, 2024; Yang et al., 2025; Yue et al., 2025).

Table 1. Overview of the Research Findings

Category	n
Year of Publication	
2020	0
2021	1
2022	0
2023	0
2024	1
2025	3

Study Design	n
Ekperimen dengan pre-test and post-test group design	2
Randomized controlled trial	2
Quasi-experimental	1
Type of Sport	**n**
Cycling athletes	1
Swimming athletes	1
Soccer athletes	1
Martial arts athletes	1
General athletes (multi-sport)	1

Table 2. Summary of Literature Review on the Effectiveness of HIIT in Aerobic Energy System Adaptation among Athletes

Source	Research Design	Sample	HIIT Protocol	Duration & Exercise Intensity	Research Findings
(Lasso-Quilindo et al., 2025)	Quasi-experimental	3 paracycling athletes with cerebral palsy (2 class T1, 1 class T2))	Long HIIT: 2 sets × 5 reps of 3-min work, 3-min rest; Short HIIT: 1 set × 10 reps of 30-sec work, 1-min rest	4 weeks, 2 sessions per week; work intensity: Long HIIT at 85% Wmax (incremental test), Short HIIT at 100% Wmax (WAnT30s test)	VO_2max increased in Athletes A & C (7%, 9.4%); maximal and average anaerobic power increased in all athletes (max power: +31% A, +15% B, +9% C); time trial completion time decreased (A: –6.7%, B: –3.7%, C: –3.6%)
(Wang & Wang, 2024)	Randomized controlled trial	24 swimmers	6 intervals of 2-min work, 2-min rest	8 weeks, intensity 80–90% HRmax	HIIT was more effective in improving VO_2max than MICT; MICT improved anaerobic threshold faster
(Yang et al., 2025)	Eksperimen pre-test & post-test	18 soccer players	140-sec work, 165-sec rest	3–6 weeks, intensity 85–95% HRmax	HIIT protocol significantly improved VO_2max
(Yue et al., 2025)	Randomized controlled trial	16 martial arts athletes	HIIT adjusted to sport-specific characteristics	6 weeks, high intensity	Increased both aerobic and anaerobic capacities supporting competitive performance
(Atakan et al., 2021)	Eksperimen pre-test & post-test	22 multi-sport athletes	30-sec sprint, 90-sec rest	4 weeks, intensity 90% HRmax	Improved metabolic energy efficiency, aerobic capacity, and endurance

Several HIIT protocols have been shown to effectively improve aerobic energy system adaptation in athletes. These include: Long HIIT consisting of 2 sets × 5 repetitions of 3-minute work with 3-minute rest and Short HIIT consisting of 1 set × 10 repetitions of 30-second work with 1-minute rest in paracycling athletes with cerebral palsy (Lasso-Quilindo et al., 2025); six 2-minute work intervals with 2-minute rest per session in swimmers (Wang & Wang, 2024); 140-second work intervals followed by 165 seconds of rest in soccer players (Yang et al., 2025); sport-specific HIIT protocols in martial arts athletes (Yue et al., 2025); and 30-second sprint intervals with 90-second rest, repeated multiple times per session, in multi-sport athletes (Atakan et al., 2021).

HIIT and VO_2max Improvement

Several studies demonstrate that specific HIIT protocols can significantly enhance VO_2max and athletes' physiological capacity. Lasso-Quilindo et al. (2025) reported that Long HIIT (2 sets × 5 repetitions of 3-minute work followed by 3-minute rest) and Short HIIT (1 set × 10 repetitions of 30-second work with 1-minute rest) performed for 4 weeks by three paracycling athletes with cerebral palsy increased VO_2max by 7% and 9.4% in Athletes A and

C, respectively. Moreover, this training improved maximal and mean anaerobic power across all athletes and reduced time trial completion time.

Comparison Between HIIT and Moderate-Intensity Continuous Training (MICT)

Wang & Wang (2024) compared HIIT and MICT in 24 swimmers. The HIIT group performed six 2-minute work intervals with 2-minute rest for 8 weeks at 80–90% HRmax. Results showed that HIIT was more effective in increasing VO_2max, while MICT led to a faster improvement in the anaerobic threshold.

HIIT in Sport-Specific Contexts

In soccer, Yang et al. (2025) found that HIIT consisting of 140-second work and 165-second rest intervals for 3–6 weeks at 85–95% HRmax significantly improved VO_2max. Similarly, Yue et al. (2025) observed that sport-specific HIIT performed for 6 weeks at high intensity in martial arts athletes enhanced both aerobic and anaerobic capacities, contributing to improved competitive performance.

HIIT and Metabolic Energy Efficiency

Atakan et al. (2021), demonstrated that performing 30-second sprints with 90-second rest intervals for 4 weeks at 90% HRmax improved metabolic energy efficiency, aerobic capacity, and endurance among multi-sport athletes. These findings emphasize that HIIT not only enhances cardiovascular capacity but also optimizes energy utilization efficiency during high-intensity physical activities.

DISCUSSION

The results of this literature review indicate that High-Intensity Interval Training (HIIT) has a significant impact on the adaptation of the aerobic energy system across various sports. In general, the five analyzed studies demonstrate that implementing HIIT with high intensity and structured work-rest intervals enhances aerobic capacity, energy metabolism efficiency, and overall physiological performance in athletes.

HIIT and Aerobic Energy System Adaptation Mechanisms

The adaptation of the aerobic energy system resulting from HIIT generally involves an increase in muscle oxidative capacity, oxygen transport efficiency, and mitochondrial enzyme activity. These mechanisms are associated with improvements in stroke volume, cardiac output, and the muscles' ability to utilize oxygen efficiently (Yang et al., 2025). HIIT also stimulates increased capillary density and mitochondrial biogenesis, which directly contribute to higher VO_2 max(Atakan et al., 2021).

Recent literature supports these findings. A meta-analysis on *VO_2max (VO_2peak) in elite athletes under high-intensity interval training* revealed that HIIT significantly improves VO_2max compared to conventional training, particularly when the recovery phase is ≥ 2 minutes and the recovery intensity is ≤ 40% of maximal intensity (Ma et al., 2023). Other studies reported that HIIT enhances citrate synthase activity and mitochondrial OXPHOS capacity, which are biochemical markers of aerobic adaptation in skeletal muscle (Yang et al., 2025).

Comparison Between HIIT and Moderate-Intensity Continuous Training (MICT)

Studi Wang & Wang (2024), demonstrated that HIIT is more effective than moderate-intensity continuous training (MICT) in improving VO_2max. This aligns with the theory that high-intensity bouts stimulate stronger cardiovascular and pulmonary adaptations, accelerating aerobic capacity development. Meanwhile, MICT primarily enhances the anaerobic

threshold due to its steady and continuous stimulus. Therefore, combining HIIT and MICT could be an ideal training strategy — HIIT for rapid aerobic capacity gains and MICT for sustaining long-term endurance. Additionally, the meta-analysis by Ma et al. (2023) confirmed that HIIT protocols with recovery ≥ 2 minutes produce greater improvements than MICT in elite athletes.

Variations in HIIT Protocols and Their Effects

Differences in outcomes across studies indicate that variations in duration, intensity, and frequency of HIIT intervals influence the level of physiological adaptation achieved. For instance, the Long HIIT protocol (3-minute work, 3-minute rest at 85% VO_2max) proved effective in paracycling athletes, increasing VO_2max by up to 9.4% (Lasso-Quilindo et al., 2025). Meanwhile, the Short HIIT sprint protocol (30-second work, 90-second rest) was particularly effective in improving metabolic efficiency and anaerobic endurance (Atakan et al., 2021).

A recent *network meta-analysis* comparing different interval training methods found that work intervals around 140 seconds with recovery of approximately 165 seconds produced optimal VO_2max improvements in athletes (Yang et al., 2025). Similarly, the study *Effectiveness of High-Intensity and Sprint Interval Training on Metabolic Biomarkers…* in adolescents reported that both Sprint Interval Training (SIT) and HIIT yielded significant improvements in metabolism and cardiorespiratory fitness, though specific effects varied based on duration and frequency (González-Gálvez et al., 2024).

Sport-Specific HIIT Applications

Yue et al. (2025) emphasized the importance of sport-specific HIIT protocols tailored to the movement characteristics of each sport. For example, martial arts athletes improved both aerobic and anaerobic capacity with sport-adapted HIIT, supporting the *specificity of training* principle that physiological adaptations are optimized when the training stimulus mimics the sport's movement patterns. Similarly, Yang et al. (2025) found that soccer players performing 140-second work and 165-second rest intervals significantly improved VO_2max, as this pattern closely mirrors the work-rest dynamics of actual gameplay.

Meta-analytic evidence Ma et al. (2023) further suggests that HIIT protocols with recovery ≥ 2 minutes provide more consistent effects among elite athletes, whose training demands continuous high-intensity efforts with short recovery phases. A systematic review and meta-analysis by Engel et al. (2018) on young athletes found that while the VO_2peak effects of HIIT may range from small to moderate, protocols resembling sport-specific work-rest patterns yield greater performance improvements.

Metabolic Efficiency and Energy Adaptation

Beyond improving aerobic capacity, HIIT enhances metabolic energy efficiency by increasing the body's ability to utilize oxygen more effectively for ATP production. Atakan et al. (2021) reported that 30-second sprints with 90-second recovery intervals improved endurance and metabolic efficiency. These adaptations not only enhance aerobic performance but also strengthen muscular resistance to fatigue during high-intensity activities.

The 8-week study *Effectiveness of High-Intensity and Sprint Interval Training on Metabolic Biomarkers, Body Composition, and Physical Fitness in Adolescents* found that both SIT and HIIT reduced fat mass, improved body composition, and enhanced cardiorespiratory fitness indicating that metabolic adaptations occur not only at the oxidative level but also in substrate utilization and muscle performance otot (González-Gálvez et al., 2024). The meta-analysis by

Ma et al. (2023) also supported that HIIT with low-intensity recovery and adequate rest periods enhances metabolic efficiency.

Practical Implications for Coaches and Athletes

Based on this review and supporting evidence, HIIT can serve as an effective strategy for improving aerobic capacity and endurance across various sports disciplines. However, the intensity and duration of intervals should be tailored to the athlete's fitness level and sport characteristics. The ideal training frequency ranges from 2–3 sessions per week for 4–8 weeks to achieve significant physiological adaptations. Coaches are encouraged to conduct regular evaluations of VO_2max and maximum heart rate to adjust training loads accordingly.

A meta-analysis comparing HIIT and MICT on endurance performance parameters found that training durations of 6–9 weeks were most effective for improving VO_2max compared to shorter or longer durations without protocol variation (Wang & Wang, 2024). Furthermore, *Home-based HIIT Improves Cardiorespiratory Fitness* (Tsuji et al., 2023) demonstrated that HIIT remains effective even outside laboratory settings, highlighting its practicality in real-world athletic training environments.

This review has several limitations. First, the number of studies analyzed was relatively small (only five), limiting generalizability. Second, some studies had small sample sizes and varied training durations. Moreover, most did not differentiate HIIT effects based on athlete performance level (amateur vs. elite). Therefore, future large-scale randomized controlled trials are needed to confirm the broader effectiveness of HIIT. Nonetheless, overall findings affirm that HIIT is an effective training method for improving aerobic energy system adaptation in athletes. The observed increases in VO_2max, metabolic efficiency, and aerobic capacity highlight the strong potential of HIIT in supporting modern sports performance that demands high levels of speed, endurance, and energy efficiency.

CONCLUSION

This literature review concludes that High-Intensity Interval Training (HIIT) effectively enhances aerobic energy system adaptations in athletes. Implementing HIIT 2–3 times per week for 3–8 weeks at high intensity (80–95% HRmax) has been proven to increase VO_2max, aerobic capacity, energy metabolism efficiency, and cardiorespiratory endurance. Adapting HIIT protocols to the specific demands of each sport further enhances competitive performance. However, this review is limited by the small number of studies and the variability in research designs. Future studies should include larger samples, cover more sports disciplines, and explore the long-term effects of HIIT on physiological.

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