A 12-month longitudinal study of aerobic vs. anaerobic training: effects on body composition and athletic performance

Un estudio longitudinal de 12 meses sobre el entrenamiento aeróbico versus anaeróbico: efectos en la composición corporal y el rendimiento atlético

Authors

Md. Shahariar Kabir [1]
Ilham Ilham [2]
Sunita Yadav [1]
Vlad Adrian Geantă [3]

[1] Nims University Rajasthan (India)
[2] Universitas Negeri Padang (Indonesia)
[3] Aurel Vlaicu University of Arad (Romania)

Corresponding author:
Ilham Ilham
ilhamf@fik.unp.ac.id

How to cite in APA

Kabir, M. S., Ilham, I., Yadav, S., & Geantă, V. A. (2025). A 12-month longitudinal study of aerobic vs. anaerobic training: effects on body composition and athletic performance. *Retos*, *68*, 905–916. https://doi.org/10.47197/retos.v68.110454

Abstract

Introduction: Aerobic and anaerobic training yield distinct physiological adaptations, yet their long-term comparative effects remain underexplored.
Objective: To evaluate and compare the 12-month impact of aerobic and anaerobic training on body composition, cardiovascular fitness, and athletic performance in healthy adults aged 18–35.
Methodology: A randomized controlled trial (n = 120; 60 males, 60 females) assigned participants to aerobic (AT) or anaerobic (ANT) training. Assessments at 0, 3, 6, and 12 months included DXA-derived body composition, VO_2 max, and performance metrics (strength, power, endurance). 108 participants completed the study.
Results: AT significantly reduced body fat percentage (-4.6%, p < .001) and increased VO_2 max (+6.8 mL·kg^{-1}·min^{-1}, p < .001), reflecting improved cardiovascular fitness and fat loss. ANT led to greater gains in lean body mass (+3.2 kg, p < .001), muscular strength (+22.7 kg bench press, p < .001), and anaerobic power (+423 W, p < .001). Both groups showed improvements aligned with training specificity.
Discussion: Findings confirm divergent, goal-specific adaptations: aerobic training is optimal for fat reduction and cardiovascular enhancement, while anaerobic training promotes hypertrophy, strength, and power. These results support strategic exercise prescription based on individualized goals.
Conclusions: Aerobic and anaerobic training confer distinct yet complementary benefits. Program design should consider long-term modality-specific adaptations to optimize individual performance and health outcomes.

Keywords

Aerobic training; anaerobic training; athletic performance; body composition; long-term adaptation.

Resumen

Introducción: El entrenamiento aeróbico y anaeróbico induce adaptaciones fisiológicas específicas, pero sus efectos comparativos a largo plazo aún no se comprenden completamente.
Objetivo: Evaluar y comparar los efectos de 12 meses de entrenamiento aeróbico y anaeróbico sobre la composición corporal, la condición cardiovascular y el rendimiento atlético en adultos sanos de 18 a 35 años.
Metodología: Ensayo controlado aleatorizado (n = 120; 60 hombres, 60 mujeres), con asignación a un grupo de entrenamiento aeróbico (AT) o anaeróbico (ANT). Se realizaron evaluaciones a los 0, 3, 6 y 12 meses, incluyendo composición corporal (DXA), VO_2 máx y métricas de rendimiento (fuerza, potencia, resistencia). Completaron el estudio 108 participantes.
Resultados: El grupo AT redujo significativamente el porcentaje de grasa corporal (-4,6%, p < .001) y mejoró el VO_2 máx (+6,8 mL·kg^{-1}·min^{-1}, p < .001), reflejando mejoras cardiovasculares y en pérdida de grasa. El grupo ANT mostró mayores aumentos en masa magra (+3,2 kg, p < .001), fuerza muscular (+22,7 kg en press de banca, p < .001) y potencia anaeróbica (+423 W, p < .001). Ambos grupos mejoraron según la especificidad del entrenamiento.
Discusión: Los resultados confirman adaptaciones divergentes y orientadas a objetivos: el entrenamiento aeróbico optimiza la reducción de grasa y la capacidad cardiovascular, mientras que el anaeróbico favorece la fuerza, potencia y masa muscular.
Conclusiones: El entrenamiento aeróbico y anaeróbico ofrece beneficios distintos y complementarios. La programación debe adaptarse a objetivos individuales para maximizar resultados a largo plazo.

Palabras clave

Adaptación a largo plazo; composición corporal; entrenamiento aeróbico; entrenamiento anaeróbico; rendimiento atlético

Introduction

The relationship between aerobic and anaerobic exercise and their respective effects on body composition and athletic performance has long been a central topic in sports science and exercise physiology (Martín-Rodríguez et al., 2024; Latino et al., 2024; Martins & Loureiro, 2023; Anderson & Drust, 2023; Saadati, 2023). Recent studies emphasize the importance of individualized training programs, acknowledging that both modalities contribute differently depending on specific goals and physiological traits (Kabir et al., 2025; Lasso Quilindo & Chalapud Narváez, 2024; Sánchez Benavides, et al., 2024; Ahsan, Ali & Al-Zahrani, 2023; McWeeny et al., 2020; Gillen et al., 2016).

Both training types play vital roles in enhancing general health and athletic capacity, yet they elicit distinct physiological adaptations (Furrer, Hawley & Handschin, 2023; Moscatelli et al., 2023; Kraemer, 2020). Adaptations arise from the cumulative effect of structured, repeated exposure to physical stress (Hughes, Ellefsen & Baar, 2018). Understanding these long-term adaptations is essential for optimizing performance and achieving tailored training goals (Kraemer, Ratamess & Newman, 2024; Bucher Sandbakk et al., 2023; Wackerhage & Schoenfeld, 2021; Coffey & Hawley, 2007). Coaches must integrate these parameters to maximize athlete outcomes (Ahsan, Ali & Al-Zahrani, 2023).

Aerobic training, characterized by prolonged, moderate-intensity activity such as running, swimming, or cycling (Tyshchenko et al., 2023), is widely recognized for improving cardiovascular fitness, metabolic health, and brain plasticity (Susiono et al., 2025; Isath et al., 2023; Moscatelli et al., 2023; de Barcelos et al., 2022; Franklin et al., 2022; Moscatelli et al., 2020; Hawley, 2002). Physiological adaptations include increased VO2max, improved cardiac output, enhanced mitochondrial density, and capillarization (Barbosa et al., 2024; Stamford, Loprinzi & Maskalick, 2023; Erdem Eyuboglu, 2023; Ferguson et al., 2021; Saghiv & SaBagiv, 2020; Lundby, Montero & Joyner, 2017; Joyner & Coyle, 2008; Holloszy & Coyle, 1984; Bassett & Howley, 2000).

In contrast, anaerobic training emphasizes short bursts of high-intensity activity such as sprinting, weightlifting, or HIIT (Jatmiko, Kamandulis et al., 2024; Tauda, Cruzat Bravo & Suárez Rojas, 2024; Nurkholis et al., 2024; Kusnanik & Sidik, 2024; Laursen & Buchheit, 2019; Buchheit & Laursen, 2013; Lasso Quilindo & Chalapud Narváez, 2024; García-Flores et al., 2023; Franchini et al., 2020). It enhances muscular strength, power, and anaerobic capacity (Kraemer, Fleck & Evans, 1996; Gibala et al., 2006) by inducing neuromuscular adaptations like increased fiber recruitment and hypertrophy (Sale, 1988). Anaerobic exercise also elevates resting metabolic rate and contributes to lean body mass gains (Strasser & Schobersberger, 2011).

Resistance and high-intensity anaerobic training induce a range of adaptations across lean mass components muscle, bone, and connective tissues. At the muscular level, hypertrophy and increased fiber cross-sectional area enhance strength and endurance (Schoenfeld et al., 2021; Lopez et al., 2021). High-impact and weight-bearing activities improve bone mineral density, mitigating osteoporosis risk (Benedetti et al., 2018; Nebigh et al., 2023). Connective tissues such as tendons and ligaments also adapt by increasing stiffness and load-bearing capacity, supporting enhanced mechanical performance (McMahon, Comfort & Pearson, 2012; Asahara, Inui & Lotz, 2017). These multi-tissue adaptations underscor

Despite extensive research on the acute responses to aerobic and anaerobic exercise, there is limited data on their long-term (≥12 months) effects on comprehensive performance and body composition outcomes (Furrer, Hawley & Handschin, 2024; Wilson et al., 2012). Most studies are short-term (8–12 weeks) and focus on isolated parameters like hypertrophy, strength, or VO2max (Shaw et al., 2006), limiting our understanding of adaptation trajectories and potential plateaus during extended training.

Long-term adaptations particularly related to muscle growth and endurance require sustained training and may vary in timing between modalities. Effective program design must account for these trajectories and modify training variables over time (Hawley, 2009). Thus, analyzing the differential and combined effects of aerobic and anaerobic exercise across a full training year offers crucial insights for tailoring athletic programming.

While anaerobic training exerts pronounced effects on muscle hypertrophy, bone density, and connective tissue strength, its systemic impact contrasts with the cardiovascular and metabolic adaptations typically elicited by aerobic exercise. Despite their widespread application, few studies have investigated the long-term (≥12 months) adaptations induced by these modalities across multiple domains of performance and body composition.

This study aims to address this gap by examining the chronic effects of aerobic, anaerobic, and concurrent training protocols on key physiological and performance parameters. We hypothesize that anaerobic training will lead to greater improvements in muscular strength, power, and skeletal muscle mass, while aerobic training will more effectively enhance cardiovascular fitness and reduce fat mass. A secondary hypothesis posits that concurrent training will yield superior overall outcomes enhancing strength, endurance, and body composition compared to either modality alone.

By employing validated imaging and performance testing methods over a 12-month intervention, this research seeks to provide evidence-based insights to support the development of optimized, goal-specific training programs for athletes and practitioners.

Method

This study was designed as a randomized controlled trial with two parallel groups: one assigned to aerobic training (AT) and the other to anaerobic training (ANT), each consisting of 60 participants. Group allocation was performed using computer-generated random sequences to ensure allocation concealment and minimize selection bias. An independent researcher, not involved in the implementation or assessment phases, conducted the randomization. The intervention lasted 12 months, with data collected at four assessment points: baseline, 3 months, 6 months, and 12 months, allowing for a robust longitudinal evaluation of training effects.

Participants

The study recruited 120 healthy participants (n = 120), equally divided by gender (60 males and 60 females), aged 18–35 years. Inclusion criteria required participants to be recreationally active but not engaged in any formal training program for at least six months prior to the study. Individuals with musculoskeletal, metabolic, or cardiovascular conditions that could impair training performance or increase the risk of injury were excluded.

Out of the 120 volunteers, 108 participants (90%) completed the 12-month intervention (AT: n = 54; ANT: n = 54). The dropout rate was similar across both groups, primarily due to time constraints or relocation. Among the 108 participants who completed the study, 52% were male (n = 56) and 48% were female (n = 52). The gender distribution was balanced across the groups (AT: 27 males, 27 females; ANT: 29 males, 25 females), ensuring homogeneity and facilitating consistent analysis of the effects of aerobic and anaerobic training on the outcome measures.

Ethical approval for the study was obtained from the National Institute of Medical Science and Research (NIMS), Jaipur, India, Ethics Committee (approval number: NIMSUR/IEC/2023/699). All participants provided written informed consent before enrolment in the study.

Procedure

Participants were randomly assigned using RNG software to either an aerobic training group (AT) or an anaerobic training group (ANT). The intervention spanned 12 months, with evaluations at baseline, 3, 6, and 12 months.

Training protocols

The aerobic training (AT) group completed four weekly sessions of continuous aerobic exercise, such as running, cycling, or rowing, performed at 65–75% of heart rate reserve (HRR) for 45–60 minutes. Intensity was prescribed using the Karvonen formula: HRR = (220 – age – resting HR) × intensity + resting HR

To ensure sustained physiological adaptation, both training volume and intensity were progressively increased over the 12-month period.

In contrast, the anaerobic training (ANT) group followed a combined protocol of resistance training and high-intensity interval training (HIIT), with two weekly sessions of each. Resistance training targeted major muscle groups using loads of 70–80% of one-repetition maximum (1RM) for 3 sets of 8–12 repetitions, with 1RM estimated via the Epley equation: 1RM = weight lifted × (1 + 0.0333 × repetitions)

HIIT sessions involved 4–6 intervals of 30 seconds of maximal effort, interspersed with 4-minute active recovery periods.

Both modalities followed a structured progression model. In resistance training, load and volume were adjusted every 4–6 weeks based on updated 1RM values, typically increasing weight by 2.5–5% or adding sets/repetitions. HIIT progression involved increasing interval duration, intensity, or reducing rest periods. Training adaptations were monitored through periodic assessments (e.g., heart rate, RPE, and 1RM testing), ensuring individualized progression and minimizing overtraining risk.

Outcome Measures

Body Composition

Body composition, including total body mass, fat mass, lean body mass, and body fat percentage, was assessed using dual-energy X-ray absorptiometry (DXA). Measurements were performed with a GE Lunar iDXA system, a validated and widely used device for body composition analysis. The system employs low-dose X-rays at two energy levels to determine the distribution of fat and lean mass within the body.

Certified technicians conducted the scans in accordance with the manufacturer's protocols, ensuring accuracy and consistency. Participants were instructed to remain motionless during the procedure to minimize variability. Body composition measurements were collected at baseline and at 3, 6, and 12 months to monitor longitudinal changes.

Cardiovascular Fitness

Cardiovascular fitness was evaluated through maximal oxygen uptake (VO_2 max) testing, conducted using a graded exercise protocol on a treadmill. Gas exchange measurements were performed with the Parvo Medics TrueOne 2400 Metabolic Measurement System, a validated and reliable tool for indirect calorimetry. This system measures oxygen and carbon dioxide exchange during exercise to accurately calculate VO_2 max. Participants performed the test on a Woodway Pro XL treadmill, which provides a stable and controlled environment for exercise testing. The protocol involved progressive increases in treadmill speed and incline until the participant reached volitional exhaustion. Heart rate and respiratory gas exchange were continuously monitored throughout the test to determine peak oxygen uptake.

Muscular Strength

Muscular strength was assessed using the one-repetition maximum (1RM) test for the bench press (upper body) and back squat (lower body). Participants began each test with a standardized warm-up involving light weights. Load increments were systematically increased by 5–10% for the bench press and 10–20% for the back squat until participants reached the maximum weight they could lift for one complete repetition with proper form. Adequate rest intervals (3–5 minutes) were provided between attempts to prevent fatigue. The highest successfully lifted weight was recorded as the 1RM, a widely accepted measure of maximal strength.

Muscular Power

Muscular power was assessed through vertical jump height and peak power output, measured using a Kistler 9281CA force plate, which provides precise measurements of ground reaction forces during jumping. Participants performed countermovement jumps, and peak power output was calculated using the Sayers equation, a reliable method for evaluating lower-body explosive power (Sayers et al., 1999).

Muscular Endurance

Muscular endurance was measured using push-up and sit-up tests based on standardized protocols frequently employed in physical fitness research (Adams et al., 2022). These tests assess the participant's ability to perform repeated contractions against resistance over a specified duration, providing a reliable measure of endurance for upper and core musculature.

Anaerobic capacity

Anaerobic capacity was assessed using the Wingate Anaerobic Test (WAnT), conducted on a Monark 894E. The protocol involved a 30-second all-out effort, where participants cycled at maximum intensity against a predetermined resistance. The resistance was set at a specific value for the entire duration of the test. Peak power output (PPO) and anaerobic capacity were recorded, with PPO representing the highest power achieved in the first 5 seconds of the test, and anaerobic capacity calculated from the total work performed during the 30-second period (Bar-Or, 1987).

Sport-Specific Performance

Sport-specific tests included the 40-yard sprint, agility T-test, and the 5-10-5 pro agility test. The 40-yard sprint is commonly used to assess acceleration and speed in various sports, particularly in American football. The test is based on protocols commonly used in athletic performance evaluations, such as those outlined in studies of sprinting and speed assessments in athletes (D'Isanto et al., 2019). It typically measures the time it takes an athlete to cover 40 yards (36.58 meters) in a straight line from a standing start. The agility T-test assesses an athlete's agility and ability to change directions quickly, which is critical in many sports like basketball, soccer, and tennis. The protocol follows standardized methods often referenced in research, such as Sayers et al. (1999) and others focusing on agility training and testing. The 5-10-5 Pro Agility Test also known as the "Pro Shuttle", this test evaluates an athlete's ability to change direction quickly over a short distance. It's widely used in football, basketball, and soccer and follows protocols that are based on established norms for measuring agility and quickness, as discussed in sports performance literature (Forster et al., 2022).

Data analysis

Statistical analyses were performed using IBM SPSS Statistics v26. Normality was assessed with the Shapiro-Wilk test. A 2 x 4 (group x time) mixed-model ANOVA was performed to evaluate the effects of training modality and time on all outcome measures. Post hoc comparisons were conducted using Bonferroni correction to control for multiple comparisons, ensuring statistical rigor. Statistical significance was defined as $p < 0.05$.

Results

Over the 12-month intervention, both groups experienced significant changes in body composition. A mixed-model ANOVA revealed significant main effects of time for total body mass, fat mass, lean body mass, and body fat percentage ($p < 0.001$ for all variables).

Table 1. Baseline characteristics of participants (mean ± SD).

Characteristics	AT Group (n = 54)	ANT Group (n = 54)
Age (years)	26.3 ± 4.7	25.9 ± 4.5
Height (cm)	172.5 ± 9.2	173.1 ± 8.8
Body mass (kg)	71.8 ± 12.3	72.4 ± 11.9
Body fat (%)	22.7 ± 6.8	22.3 ± 7.1
VO2max (ml/kg/min)	42.6 ± 6.4	43.1 ± 6.2

Note: AT = Aerobic training group, ANT = Anaerobic training group

Additionally, significant group × time interactions were observed for all body composition metrics ($p < 0.01$), indicating distinct patterns of change between the AT and ANT groups.

Table 2. Changes in Body Composition, Strength, Anaerobic Capacity, and VO2max over 12 Months for Five Groups

Variable	Group	Baseline	3-Month Change	6-Month Change	12-Month Change	Total Change (12 Months)	p-value
Total Body Mass (kg)	AT	71.8 ± 12.3	-1.0 ± 0.9	-1.5 ± 1.2	-2.7 ± 1.8	-2.7 ± 1.8	p < 0.001
	ANT	72.4 ± 11.9	+0.3 ± 0.8	+0.8 ± 1.0	+1.4 ± 1.2	+1.4 ± 1.2	p < 0.05
Body Fat Percentage (%)	AT	22.7 ± 6.8	-1.5 ± 0.9	-3.0 ± 1.4	-4.6 ± 1.9	-4.6 ± 1.9	p < 0.001
	ANT	22.3 ± 7.1	-1.0 ± 0.7	-2.0 ± 1.2	-2.8 ± 1.5	-2.8 ± 1.5	p < 0.01
Fat Mass (kg)	AT	16.3 ± 7.3	-1.2 ± 1.0	-1.8 ± 1.4	-2.9 ± 2.3	-2.9 ± 2.3	p < 0.001

Table 2. Changes in Body Composition, Strength, Anaerobic Capacity, and VO2max over 12 Months for Five Groups

Variable	Group	Baseline	3-Month Change	6-Month Change	12-Month Change	Total Change (12 Months)	p-value
	ANT	16.1 ± 7.0	-0.6 ± 0.9	-1.2 ± 1.0	-1.7 ± 1.3	-1.7 ± 1.3	p < 0.001
Lean Body Mass (kg)	AT	55.5 ± 7.4	+0.1 ± 0.2	+0.2 ± 0.5	+0.3 ± 0.9	+0.3 ± 0.9	p > 0.05
	ANT	55.3 ± 7.9	+0.8 ± 0.4	+2.1 ± 0.9	+3.2 ± 1.4	+3.2 ± 1.4	p < 0.001
VO2max (ml/kg/min)	AT	42.6 ± 6.4	+2.3 ± 1.2	+4.5 ± 2.1	+6.8 ± 2.3	+6.8 ± 2.3	p = 0.001
	ANT	43.1 ± 6.2	+1.2 ± 0.8	+2.1 ± 1.2	+2.9 ± 1.7	+2.9 ± 1.7	p < 0.001

Over the 12-month intervention, significant differences were observed between the aerobic training (AT) and anaerobic training (ANT) groups across all measured variables, demonstrating distinct physiological adaptations driven by the two modalities. The AT group experienced a statistically significant reduction in total body mass ($M = -2.7 \pm 1.8$ kg, $p < .001$), whereas the ANT group showed a modest but significant increase ($M = +1.4 \pm 1.2$ kg, $p < .05$). A significant group × time interaction effect ($p < .01$) further supports the divergent trajectories in body mass change between the two groups, highlighting the catabolic nature of aerobic training and the anabolic effects of anaerobic training.

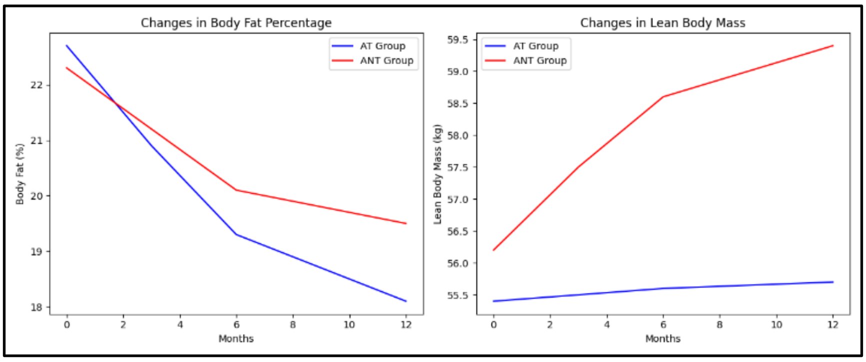
Aerobic training excelled in reducing total body mass, body fat percentage, and fat mass while driving substantial improvements in cardiovascular fitness (VO_2 max). Both groups demonstrated significant reductions in body fat percentage over time ($p < .001$). However, the AT group achieved a more pronounced decrease ($M = -4.6 \pm 1.9\%$) compared to the ANT group ($M = -2.8 \pm 1.5\%$), as confirmed by a significant group × time interaction effect ($p < .01$). These results underscore the superior fat-reducing potential of aerobic training, likely attributable to sustained energy expenditure and enhanced fat oxidation. In line with reductions in body fat percentage, fat mass also decreased significantly in both groups ($p < .001$). The AT group exhibited a larger decline ($M = -2.9 \pm 2.3$ kg) compared to the ANT group ($M = -1.7 \pm 1.3$ kg). The significant group × time interaction effect ($p < .01$) reinforces the greater efficacy of aerobic training in promoting fat loss.

Anaerobic training was superior for promoting hypertrophic adaptations, as evidenced by significant gains in lean body mass, reflecting the anabolic effects of resistance and high-intensity interval training. The response of lean body mass differed markedly between the two groups. The ANT group displayed a substantial and statistically significant increase ($M = +3.2 \pm 1.4$ kg, $p < .001$), while the AT group showed minimal, non-significant changes ($M = +0.3 \pm 0.9$ kg, $p > .05$). The significant group × time interaction effect ($p < .001$) confirms the pronounced hypertrophic response associated with anaerobic training, likely driven by the mechanical load and anabolic stimulus of resistance exercises.

Both groups showed significant improvements in VO_2 max, but the magnitude of change was notably greater in the AT group ($M = +6.8 \pm 2.3$ mL·kg^{-1}·min^{-1}, $p = .001$) compared to the ANT group ($M = +2.9 \pm 1.7$ mL·kg^{-1}·min^{-1}, $p < .001$). A significant group × time interaction effect ($p < .001$) highlights the superior cardiovascular adaptations elicited by aerobic training, consistent with increased oxygen uptake capacity and enhanced cardiac efficiency.

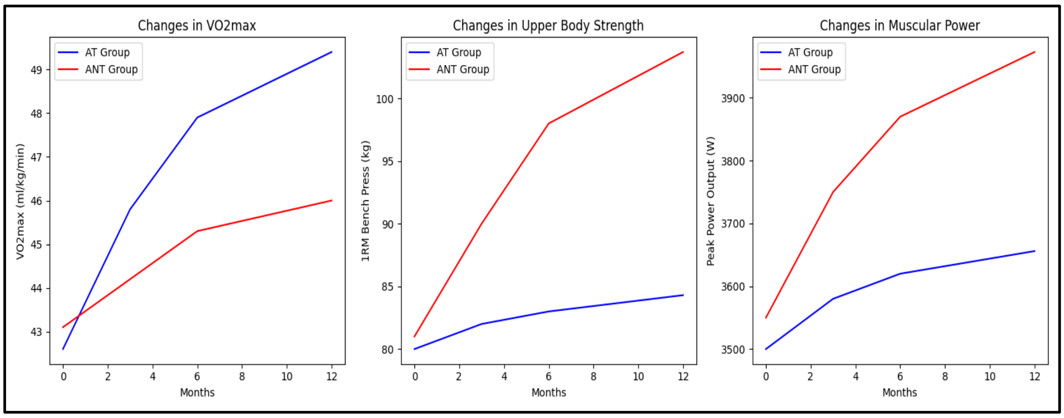
The observed group × time interaction effects across variables demonstrate that training modality plays a critical role in shaping long-term physiological outcomes. These findings underscore the importance of selecting training strategies aligned with individual fitness goals, whether prioritizing fat loss, cardiovascular fitness, or muscle hypertrophy.

Figure 1. Changes in body fat percentage and lean body mass over the 12-month intervention period for the aerobic training (AT) and anaerobic training (AT) groups



A significant main effect of time was observed for VO2max ($p = 0.001$), with the AT group showing a greater improvement compared to the ANT group. The AT group had a mean increase of 6.8 ± 2.3 ml/kg/min, whereas the ANT group showed a smaller but still significant increase of 2.9 ± 1.7 ml/kg/min. The group × time interaction was also significant ($p < 0.001$), confirming greater cardiovascular adaptations in the AT group.

Figure 2. Changes in VO2max, upper body strength (1RM bench press), and muscular power (peak power output) over the 12-month intervention period for the aerobic training (AT) and anaerobic training (ANT) groups.



Both groups demonstrated statistically significant improvements in upper and lower body strength over the 12-month period ($p < 0.001$). However, the anaerobic training (ANT) group exhibited significantly greater gains, as confirmed by a robust group × time interaction ($p < 0.001$). In particular, 1RM bench press strength increased by +22.7 ± 5.8 kg in the ANT group, markedly higher than the +4.3 ± 2.9 kg improvement observed in the aerobic training (AT) group ($p < 0.001$). Similarly, 1RM back squat strength improved by +41.5 ± 9.3 kg in the ANT group versus +8.7 ± 4.2 kg in the AT group ($p < 0.001$), reinforcing the superiority of resistance-based protocols for strength development.

Regarding muscular power, significant main effects of time were detected for both vertical jump height and peak power output ($p < 0.001$), with the ANT group achieving more pronounced improvements in both metrics. Vertical jump performance increased by +7.8 ± 2.4 cm in the ANT group, compared to +2.1 ± 1.6 cm in the AT group, while peak power output rose by +423 ± 98 W and +156 ± 72 W, respectively ($p < 0.001$ for interaction).

Anaerobic capacity, as assessed via the Wingate Anaerobic Test, also improved significantly in both groups ($p < 0.001$), though the ANT group achieved notably greater enhancements. Peak anaerobic power increased by +138 ± 42 W in the ANT group versus +52 ± 28 W in the AT group, and total anaerobic capacity improved by +0.89 ± 0.24 W/kg compared to +0.31 ± 0.18 W/kg ($p < 0.001$ for interaction).

Discussion

The study demonstrates that both aerobic and anaerobic training positively influence body composition through different physiological mechanisms. Specifically, the AT group exhibits a more pronounced reduction in body fat percentage and total body mass, likely due to elevated energy expenditure and enhanced fat oxidation associated with prolonged aerobic exercise (Barbosa et al., 2024; McWeeny et al., 2020). These findings align with evidence positioning aerobic exercise as a highly effective strategy for fat loss (Franklin et al., 2022). In contrast, participants in the ANT group experience modest reductions in fat mass but significant increases in lean body mass, reflecting the hypertrophic effects of resistance training (Kraemer, Ratamess, & Newman, 2024) and the muscle-building potential of high-intensity interval training (HIIT) (Kamandulis et al., 2024). Therefore, aerobic training appears more suitable for individuals prioritizing fat reduction, whereas anaerobic training proves more effective for promoting muscle growth.

Regarding cardiovascular fitness, the AT group achieves greater improvements, as evidenced by significant increases in VO_2max compared to the ANT group. This outcome aligns with the principle of training specificity, which posits that endurance training facilitates adaptations such as enhanced stroke volume and increased capillarization, thereby improving oxygen uptake and aerobic capacity (Lundby, Montero, & Joyner, 2017; Jones & Carter, 2000). Although the ANT group also shows improvements in VO_2max, these gains remain less substantial, indicating that while anaerobic training can induce cardiovascular adaptations, it is less effective than aerobic training in optimizing VO_2max (Bucher Sandbakk et al., 2023).

The study further highlights the divergent effects of these training modalities on muscular strength. The ANT group exhibits superior gains in both upper and lower body strength, consistent with neuromuscular adaptations associated with resistance training, such as enhanced motor unit recruitment, increased muscle cross-sectional area, and the development of fast-twitch muscle fibers (Schoenfeld et al., 2021; Kamandulis et al., 2024). Conversely, the AT group also demonstrates improvements in muscular strength, but these gains are notably smaller. This finding underscores the critical role of anaerobic training in programs designed to enhance strength and power, particularly for athletes requiring explosive capabilities (Dolci et al., 2020).

Anaerobic capacity, assessed via the Wingate test, further illustrates the superior performance of the ANT group in anaerobic power and capacity. These results stem from specific metabolic adaptations induced by HIIT and resistance training, including increased glycolytic enzyme activity and elevated phosphocreatine stores (Furrer, Hawley, & Handschin, 2023). Moreover, the ANT group outperforms the AT group in sport-specific performance metrics such as the 40-yard sprint and agility tests. These findings emphasize the relevance of anaerobic training for enhancing speed, agility, and explosive movements, particularly in sports requiring rapid and powerful actions (Jatmiko et al., 2024).

Conclusions

This study demonstrated distinct long-term adaptations to aerobic and anaerobic training, offering evidence-based insights for optimizing training programs based on specific performance goals. Aerobic training was more effective for improving cardiovascular fitness and reducing body fat, while anaerobic training led to greater gains in muscular strength, power, lean body mass, and anaerobic capacity.

The findings confirmed the fulfillment of the study's objectives by revealing modality-specific physiological adaptations and highlighting the complementary roles of aerobic and anaerobic exercise. Our work contributed to the field by addressing a gap in longitudinal training research, particularly over a 12-month period, and by providing practical guidance for personalized program design.

For individuals aiming to improve overall fitness, a combination of both modalities appeared beneficial, given their distinct contributions to performance. Future research should examine the effects of concurrent aerobic and anaerobic training, investigate potential sex-specific adaptations, and explore the molecular mechanisms underlying these long-term responses.

Acknowledgements

We express our gratitude to all the participants who committed their time and effort to this 12-month longitudinal study. Special thanks to the research staff and technicians at the National Institute of Medical Science and Research (NIMS), India, for their invaluable assistance with data collection and analysis. Finally, we appreciate the support from colleagues and reviewers who provided feedback and expertise during the development of this study, as well as the chairman and chancellor of NIMS for their unconditional support for the study.

References

Adams, M. M., Hatch, S. A., Winsor, E. G., & Parmelee, C. (2022). Development of a Standard Push-up Scale for College-Aged Females. *International journal of exercise science*, *15*(4), 820–833. https://doi.org/10.70252/XIJI4089

Ahsan, M., Ali, M. F., & Al-Zahrani, A. (2023). Impact of a pre-competition aerobic and anaerobic training on the maximal aerobic capacity, anaerobic power, dynamic balance, and visual-motor coordination of rugby and soccer players. *Physical Activity Review*, *11*(2). https://doi.org/10.16926/par.2023.11.25

Anderson, L., & Drust, B. (2023). Aerobic and anaerobic training. In: Williams, M. Ford, P., R. & Drust, B. (Eds). Science and Soccer Developing Elite Perfomers, 4th ed, 34-51. Routledge.

Asahara, H., Inui, M., & Lotz, M. K. (2017). Tendons and Ligaments: Connecting Developmental Biology to Musculoskeletal Disease Pathogenesis. Journal of bone and mineral research: the official journal of the American Society for Bone and Mineral Research, 32(9), 1773–1782. https://doi.org/10.1002/jbmr.3199

Bassett, D. R., Jr, & Howley, E. T. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. Medicine and science in sports and exercise, 32(1), 70–84. https://doi.org/10.1097/00005768-200001000-00012

Barbosa, R. R., Melo, R. J. P., de Brito Gomes, J. L., Guimarães, F. J. D. S. P., & da Cunha Costa, M. (2024). Effect of aerobic training volume on VO2max and time trial of runners: A systematic review. *Journal of Human Sport and Exercise*, *19*(4), 1139-1150. https://doi.org/10.55860/90apnb26

Bar-Or, O. (1987). The Wingate Anaerobic Test: An update on methodology, reliability, and validity. *Sports Medicine, 4*(6), 381–394. https://doi.org/10.2165/00007256-198704060-00001

Buchheit, M., & Laursen, P. B. (2013). High-intensity interval training, solutions to the programming puzzle. *Sports Medicine, 43*(5), 313-338. https://doi.org/10.1007/s40279-013-0029-x

Bucher Sandbakk, S., Walther, J., Solli, G. S., Tønnessen, E., & Haugen, T. (2023). Training Quality-What Is It and How Can We Improve It?. *International journal of sports physiology and performance*, *18*(5), 557–560. https://doi.org/10.1123/ijspp.2022-0484

Benedetti, M. G., Furlini, G., Zati, A., & Letizia Mauro, G. (2018). The Effectiveness of Physical Exercise on Bone Density in Osteoporotic Patients. BioMed research international, 2018, 4840531. https://doi.org/10.1155/2018/4840531

Coffey, V. G., & Hawley, J. A. (2007). The molecular bases of training adaptation. *Sports Medicine, 37*(9), 737–763. https://doi.org/10.2165/00007256-200737090-00001

de Barcelos, G. T., Heberle, I., Coneglian, J. C., Vieira, B. A., Delevatti, R. S., & Gerage, A. M. (2022). Effects of Aerobic Training Progression on Blood Pressure in Individuals with Hypertension: A Systematic Review With Meta-Analysis and Meta-Regression. *Frontiers in sports and active living*, *4*, 719063. https://doi.org/10.3389/fspor.2022.719063

D'Isanto, T., D'Elia, F., Raiola, G., & Altavilla, G. (2019). Assessment of sport performance: theoretical aspects and practical indications. Sport Mont, 17(1), 79-82. doi: 10.26773/smj.190214

Dolci, F., Kilding, A. E., Chivers, P., Piggott, B., & Hart, N. H. (2020). High-intensity interval training shock microcycle for enhancing sport performance: A brief review. *Journal of Strength and Conditioning Research, 34*(4), 1188-1196. https://doi.org/10.1519/JSC.0000000000003405

Erdem Eyuboglu, F. (2023). Circulatory System and Its Adaptation to Exercise. In: Kaya Utlu, D. (Eds) *Functional Exercise Anatomy and Physiology for Physiotherapists* (pp. 447-471). Springer Cham. https://doi.org/10.1007/978-3-031-27184-7_22

Ferguson, R. A., Mitchell, E. A., Taylor, C. W., Bishop, D. J., & Christiansen, D. (2021). Blood-flow-restricted exercise: Strategies for enhancing muscle adaptation and performance in the endurance-trained athlete. *Experimental physiology*, *106*(4), 837–860. https://doi.org/10.1113/EP089280

Franchini E. (2020). High-Intensity Interval Training Prescription for Combat-Sport Athletes. *International journal of sports physiology and performance*, *15*(6), 767–776. https://doi.org/10.1123/ijspp.2020-0289

Franklin, B. A., Eijsvogels, T. M. H., Pandey, A., Quindry, J., & Toth, P. P. (2022). Physical activity, cardiorespiratory fitness, and cardiovascular health: A clinical practice statement of the American Society for Preventive Cardiology Part II: Physical activity, cardiorespiratory fitness, minimum and goal intensities for exercise training, prescriptive methods, and special patient populations. *American journal of preventive cardiology*, *12*, 100425. https://doi.org/10.1016/j.ajpc.2022.100425

Forster, J. W. D., Uthoff, A. M., Rumpf, M. C., & Cronin, J. B. (2022). Pro-agility unpacked: Variability, comparability and diagnostic value. International Journal of Sports Science & Coaching, 17(5), 1225-1240. https://doi.org/10.1177/17479541211069338

Furrer, R., Hawley, J. A., & Handschin, C. (2023). The molecular athlete: exercise physiology from mechanisms to medals. *Physiological reviews*, *103*(3), 1693–1787. https://doi.org/10.1152/physrev.00017.2022

García-Flores, I., Hernández-Lepe, M. A., Aburto-Corona, J. A., Ortiz-Ortiz, M., Naranjo-Orellana, J., & Gómez-Miranda, L. M. (2023). Effect of high intensity Interval training on the autonomic nervous system. *Retos*, *47*, 847–852. https://doi.org/10.47197/retos.v47.91199

Gibala, M. J., Little, J. P., van Essen, M., Wilkin, G. P., Burgomaster, K. A., Safdar, A., Tarnopolsky, M. A., &

Gillen, Z. M., Wyatt, F. B., Winchester, J. B., Smith, D. A., & Ghetia, V. (2016). The Relationship Between Aerobic and Anaerobic Performance in Recreational Runners. *International journal of exercise science*, *9*(5), 625–634.

Hawley, J. A. (2002). Adaptations of skeletal muscle to prolonged intense endurance training. *Clinical and Experimental Pharmacology and Physiology*, *29* (3), 218–222.

Hawley, J. A. (2009). Molecular responses to strength and endurance training: Are they incompatible? *Applied Physiology, Nutrition, and Metabolism, 34*(3), 355–361. https://doi.org/10.1139/H09-023

Holloszy, J. O., & Coyle, E. F. (1984). Adaptations of skeletal muscle to endurance exercise and their metabolic consequences. *Journal of Applied Physiology, 56*(4), 831–838.

Hughes, D. C., Ellefsen, S., & Baar, K. (2018). Adaptations to Endurance and Strength Training. *Cold Spring Harbor perspectives in medicine*, *8*(6), a029769. https://doi.org/10.1101/cshperspect.a029769

Isath, A., Koziol, K. J., Martinez, M. W., Garber, C. E., Martinez, M. N., Emery, M. S., Baggish, A. L., Naidu, S. S., Lavie, C. J., Arena, R., & Krittanawong, C. (2023). Exercise and cardiovascular health: A state-of-the-art review. *Progress in cardiovascular diseases*, *79*, 44–52. https://doi.org/10.1016/j.pcad.2023.04.008

Jatmiko, T., Kusnanik, N. W., & Sidik, R. M. (2024). High-Intensity Interval Training (HIIT) Progressive Sprint-Release Model: Its Effect in Increasing Speed, Aerobic Capacity, and Anaerobic Capacity of Athletes. *Retos*, *57*, 318–323. https://doi.org/10.47197/retos.v57.104857

Jones, A. M., & Carter, H. (2000). The effect of endurance training on parameters of aerobic fitness. *Sports Medicine, 29*(6), 373-386. https://doi.org/10.2165/00007256-200029060-00001

Joyner, M. J., & Coyle, E. F. (2008). Endurance exercise performance: the physiology of champions. *The Journal of physiology*, *586*(1), 35–44. https://doi.org/10.1113/jphysiol.2007.143834

Kabir, Md. S., Yadav, S., Biswas, S., Pradhan, A., & Geantă, V. A. (2025). Aerobic vs anaerobic exercise on body composition and hormonal adaptations in athletes and non-athletes: A Randomized controlled trial. *Journal of Coaching and Sports Science, 4*(1), 52-65. https://doi.org/10.58524/jcss.v4i1.553

Kamandulis, S., Dudėnienė, L., Snieckus, A., Kniubaite, A., Mickevicius, M., Lukonaitiene, I., Venckunas, T., Stasiule, L., & Stasiulis, A. (2024). Impact of Anaerobic Exercise Integrated Into Regular Training on Experienced Judo Athletes: Running Vs. Repetitive Throws. *Journal of strength and conditioning research*, *38*(9), e489–e495. https://doi.org/10.1519/JSC.0000000000004829

Ketelhut, S., & Ketelhut, R. G. (2020). Type of Exercise Training and Training Methods. *Advances in experimental medicine and biology*, *1228*, 25–43. https://doi.org/10.1007/978-981-15-1792-1_2

Kraemer, W. J., Ratamess, N. A., & Newman, T. (2024). *Developing the Athlete: An Applied Sport Science Roadmap for Optimizing Performance*. Human Kinetics.

Kraemer A. (2020). An Overview of the Beneficial Effects of Exercise on Health and Performance. *Advances in experimental medicine and biology*, *1228*, 3–22. https://doi.org/10.1007/978-981-15-1792-1_1

Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: Progression and exercise prescription. *Medicine and Science in Sports and Exercise, 36*(4), 674–688. https://doi.org/10.1249/01.MSS.0000121945.36635.61

Kraemer, W. J., Fleck, S. J., & Evans, W. J. (1996). Strength and power training: physiological mechanisms of adaptation. *Exercise and sport sciences reviews*, *24*, 363–397.

Latino, F., Martinez-Roig, R., Setyawan, H., Susanto, N. ., Anam, K. ., Saraiello, E., & Tafuri, F. (2024). Physiological Responses of Wheelchair Basketball Athletes to a Combined Aerobic and Anaerobic Training Program. *Retos*, *57*, 800–808. https://doi.org/10.47197/retos.v57.107483

Lasso Quilindo, C. A., & Chalapud Narváez, L. M. (2024). High Intensity Interval Training (HIIT) in Paralympic Athletes. A narrative review. *Retos*, *51*, 1431–1441. https://doi.org/10.47197/retos.v51.101379

Lopez, P., Radaelli, R., Taaffe, D. R., Newton, R. U., Galvão, D. A., Trajano, G. S., Teodoro, J. L., Kraemer, W. J., Häkkinen, K., & Pinto, R. S. (2021). Resistance Training Load Effects on Muscle Hypertrophy and Strength Gain: Systematic Review and Network Meta-analysis. *Medicine and science in sports and exercise*, *53*(6), 1206–1216. https://doi.org/10.1249/MSS.0000000000002585

Lundby, C., Montero, D., & Joyner, M. (2017). Biology of VO_2 max: looking under the physiology lamp. *Acta physiologica (Oxford, England)*, *220*(2), 218–228. https://doi.org/10.1111/apha.12827

Martín-Rodríguez, A., Belinchón-deMiguel, P., Rubio-Zarapuz, A., Tornero-Aguilera, J. F., Martínez-Guardado, I., Villanueva-Tobaldo, C. V., & Clemente-Suárez, V. J. (2024). Advances in Understanding the Interplay between Dietary Practices, Body Composition, and Sports Performance in Athletes. *Nutrients*, *16*(4), 571. https://doi.org/10.3390/nu16040571

Martins, R., & Loureiro, N. . (2023). Effects of 6 Weeks of Low-Volume Combined Training on Muscle Power, Muscular Strength, and Aerobic Power in Active Young Adults. *Retos*, *50*, 478–486. https://doi.org/10.47197/retos.v50.99698

McMahon, J. J., Comfort, P., & Pearson, S. (2012). Lower limb stiffness: Effect on performance and training considerations. *Strength & Conditioning Journal*, *34*(6), 94-101. https://doi.org/10.1519/SSC.0b013e3182781b4e

McWeeny, D. K., Boule, N. G., Neto, J. H. F., & Kennedy, M. D. (2020). Effect of high intensity functional training and traditional resistance training on aerobic, anaerobic, and musculoskeletal fitness improvement. *Journal of Physical Education and Sport, 20*(4), 1791-1802. https://doi.org/10.7752/jpes.2020.04243

Mishra, P., Pandey, C. M., Singh, U., Gupta, A., Sahu, C., & Keshri, A. (2019). Descriptive statistics and normality tests for statistical data. *Annals of cardiac anesthesia*, *22*(1), 67–72. https://doi.org/10.4103/aca.ACA_157_18

Moscatelli, F., Messina, G., Polito, R., Porro, C., Monda, V., Monda, M., Scarinci, A., Dipace, A., Cibelli, G., Messina, A., & Valenzano, A. (2023). Aerobic and Anaerobic Effect of CrossFit Training: A Narrative Review. *Sport Mont, 21*(1), 123-128. https://doi.org/10.26773/smj.230220

Moscatelli, F., Messina, G., Valenzano, A., Triggiani, A. I., Sessa, F., Carotenuto, M., Tartaglia, N., Ambrosi, A., Cibelli, G., & Monda, V. (2020). Effects of twelve weeks' aerobic training on motor cortex excitability. *The Journal of sports medicine and physical fitness*, *60*(10), 1383–1389. https://doi.org/10.23736/S0022-4707.20.10677-7

Nebigh, A., Touhami, I., Chtara, M., Govindasamy, K., Surech, C., Hage, R. E., Saeidi, A., Boullosa, D., Clark, C. C. T., Granacher, U., & Zouhal, H. (2023). The Impact of Sport-discipline and Sex on Physical

Fitness and Bone Markers in Athletes. *International journal of sports medicine*, *44*(10), 736–743. https://doi.org/10.1055/a-2038-3040
Nurkholis, N., Suyoko, A., Subagio, I., Phanpheng, Y., Kusuma, I. D. M. A. W., & Pranoto, A. (2024). The Effect of Anaerobic Interval Air Rowing Training (AIART) on Increasing Strength and Endurance of Upper Body Muscles in Rowing Athletes. *Retos*, *61*, 1025–1030. https://doi.org/10.47197/retos.v61.109793
Saadati, S. A. (2023). Recent Innovations in Sports Physiology: Shaping the Future of Athletic Performance. *Health Nexus*, *1*(2), 15-27. https://doi.org/10.61838/kman.hn.1.2.3
Sánchez Benavides, C. L. ., Galindo-Perdomo, F. ., & Monterrosa Quintero, A. (2024). Analysis of Two Training Methods for Jump Development in Elite Young Cheerleaders. *Retos*, *55*, 266–273. https://doi.org/10.47197/retos.v55.102262
Sale, D. G. (1988). Neural adaptation to resistance training. *Medicine and Science in Sports and Exercise, 20*(5 Suppl), S135–S145. https://doi.org/10.1249/00005768-198810001-00009
Saghiv, M., S. & Sagiv M. S. (2020). Oxygen uptake and anaerobic performances. *Basic Exercise Physiology: Clinical and Laboratory Perspectives*, 149-205.
Sayers, S. P., Harackiewicz, D. V., Harman, E. A., Frykman, P. N., & Rosenstein, M. T. (1999). Cross-validation of three jump power equations. *Medicine and science in sports and exercise*, *31*(4), 572–577. https://doi.org/10.1097/00005768-199904000-00013
Shaw, K., Gennat, H., O'Rourke, P., & Del Mar, C. (2006). Exercise for overweight or obesity. *Cochrane Database of Systematic Reviews, 2006*(4), CD003817. https://doi.org/10.1002/14651858.CD003817.pub3
Schoenfeld, B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. *Journal of Strength and Conditioning Research, 24*(10), 2857-2872. https://doi.org/10.1519/JSC.0b013e3181e840f3
Schoenfeld, B. J., Grgic, J., Van Every, D. W., & Plotkin, D. L. (2021). Loading recommendations for muscle strength, hypertrophy, and local endurance: A re-examination of the repetition continuum. *Sports, 9*(2), 32. https://doi.org/10.3390/sports9020032
Stamford, B. A., Loprinzi, P. D., & Maskalick, S. (2023). Exercise Physiology. In: Placzek, J., D. & Boyce, D. A. (Eds). *Orthopaedic Physical Therapy Secrets-E-Book: Orthopaedic Physical Therapy Secrets-E-Book*, 38-47
Strasser, B., & Schobersberger, W. (2011). Evidence for resistance training as a treatment therapy in obesity. *Journal of Obesity, 2011*, Article ID 482564. https://doi.org/10.1155/2011/482564
Susiono, R. ., Sugiyanto, F. ., Lumintuarso, R. ., & Tomoliyus, T. (2025). Effect of High-Intensity Interval Training and unification training on Aerobic Capacity and Muscle Strength in Intermediate Distance Runners- a systematic review. *Retos*, *63*, 698–712. https://doi.org/10.47197/retos.v63.111191
Tauda, M., Cruzat Bravo , E. J. ., & Suárez Rojas, F. I. (2024). Metabolic and cardiac adaptations during a strength protocol at the anaerobic threshold over 8 weeks. *Retos*, *54*, 406–416. https://doi.org/10.47197/retos.v54.103654
Tyshchenko, V., Tovsiopiatko, F., Sokolova, L., & Budnikov, O. (2023). Improving the aerobic possibilities of qualified athletes. *Scientific Journal of the Dragomanov Ukrainian State University*, (9(169), 139-142. https://doi.org/10.31392/NPU-nc.series15.2023.9(169).30
Wackerhage, H., & Schoenfeld, B. J. (2021). Personalized, Evidence-Informed Training Plans and Exercise Prescriptions for Performance, Fitness and Health. *Sports medicine (Auckland, N.Z.)*, *51*(9), 1805–1813. https://doi.org/10.1007/s40279-021-01495-w
Wilson, J. M., Marin, P. J., Rhea, M. R., Wilson, S. M. C., Loenneke, J. P., & Anderson, J. C. (2012). Concurrent training: A meta-analysis examining interference of aerobic and resistance exercises. *Journal of Strength and Conditioning Research, 26*(8), 2293–2307. https://doi.org/10.1519/JSC.0b013e31823a3e2d

Authors and translators' details:

Md. Shahariar Kabir	shariear9999@gmail.com	Author
Ilham Ilham	ilhamf@fik.unp.ac.id	Author
Sunita Yadav	Sunita.Yadav.27@gmail.com	Author
Vlad Adrian Geantă	vladu.geanta@gmail.com	Author/Translator