Vol. XXVII, Issue 1/ 2026

G Y M N A S I U M

Scientific Journal of Education, Sports, and Health

Original Article

Optimizing the Performance of Junior Middle-Distance Swimmers: Interactions Between Metabolic Conditioning, Respiratory Training, and Sports Recovery

Potec Camelia [1*]
Vasile Lucia [2]
[1,2]*National University of Physical Education and Sport in Bucharest, Constantin Noica Street, No. 140, Bucharest, 060057, Romania*

DOI: 10.29081/gsjesh.2026.27.1.4

Keywords: *junior swimmers, middle distance, metabolic training, respiratory training, sports recovery*

Abstract

The rapid evolution of international performances and methodological transformations in sports science require reconsidering traditional training models, predominantly oriented towards the development of aerobic capacity, adapted to the current requirements of the competition. This paper analyzes the theoretical and applicative foundations of an innovative methodological model, intended for junior swimmers specializing in 200 and 400 m events, based on the harmonization of mixed metabolic training, with respiratory muscle training and modern sports recovery strategies. The analysis of the specialized literature highlights the determining role of VO_2max, anaerobic threshold, lactate tolerance, ventilatory efficiency and post-exertional recovery, in optimizing sports performance. The absence of unitary experimental models that integrate these components into a coherent training strategy for junior middle-distance swimmers is identified. Therefore, this paper proposes an interdisciplinary perspective on contemporary swimming training, which is oriented towards the development of superior metabolic adaptations, increasing functional efficiency and the sports recovery process.

1. Introduction

Sports Science and Physical Education is an interdisciplinary field, which integrates the theory and methodology of sports training, effort management, physiology, ergophysiology, anatomy, biomechanics, psychology, and other related disciplines, in order to gain a deeper understanding of all the mechanisms of optimizing human athletic performance. Additionally, it advances strategies for training and recovery of athletes who are tired or exhausted after training or

* *E-mail*: lucielav05gmail.com

competitions. In this context, through scientific study, complex methodologies are developed that can contribute to ensuring excellence, regardless of the branch of sport practiced.

Swimming performance requires tenacity, determination, respect for the opponent, but above all, intense effort, carried out during the many hours of training both in the swimming pool and on land. High performance in sports, and therefore also in swimming, is achieved through the coach's understanding of the complexity of each component of training. This requires the assumption of the permanent integration of everything that, at a given time, represents innovation in physical, technical, tactical, theoretical, psychological training, respectively in the recovery process. This is where the knowledge regarding the results of scientific studies, which are validated, practically applied, and disseminated, must intervene.

Swimming is one of the sports disciplines carried out in a non-specific setting – water, with the most complex practical-methodological structural profile. The specific effect of hydrodynamic resistance on forward speed, buoyancy control, by maintaining balance on an unstable surface, and coordination of movements in a non-specific environment, in which sensations change significantly, give swimming a particular character, with distinct methodological requirements in relation to the sports branches practiced without water.

The conceptualization of swimming sports training based on new principles can be achieved by referring to the notional structures present in the dedicated literature, where performance results from the improvement of physical (speed, strength, endurance, mobility), physiological (dominantly cardiorespiratory and muscular-oxidative), coordinative (skill-related - kinesthetic discrimination, reaction speed, spatial-temporal orientation, etc.), cognitive-motor (anticipation and prompt and adequate motor response), and mental components (motivation, volition, prosexic capacity, regulation of activation level). This multidimensional model supports the need for an integrative approach to training, in line with the new methodological directions in world swimming, which includes sports preparation, but also the complex component of recovery.

Moreover, the performance of elite swimmers can only be guaranteed through an operational complex process of choosing the most efficient stimulus-effort, the most valuable planning, the most efficient methods and means of recovery, interventions based on recent data, taken from rigorous sources. We therefore consider that the sporting result depends on the quality of preparation and the valences of the trophotropic recovery process. The manner in which this answer is generated represents an open path, dedicated to scientific research, the development of the theory and methodology of the swimming discipline and innovation in the reference field.

These considerations bring about the need to restructure the methodological frameworks proposed to coaches (for cadets, juniors, seniors - mixed, long-distance or middle-distance swimmers) and interdisciplinary teams, which, through science, join performance swimmers and guarantee them the achievement of valuable, repeatable sporting results over time.

Starting from these premises, we propose to delve deeper into recent scientific studies regarding metabolic training of junior performance swimmers, development of respiratory muscles and highlighting the role of new methods or techniques of sports recovery, in the desire to develop a new, unified methodological line for these middle-distance swimmers.

In the last three decades, swimming training has undergone significant transformations, and the development of concepts related to training forms has opened vast directions of investigation. We will propose scientific research aimed at validating an innovative training and recovery methodology, intended for junior middle-distance swimmers. This will be based on interventions on mixed metabolic mechanisms (aerobic-anaerobic), pulmonary function, and the post-exercise recovery process.

Motivation for choosing the topic

Sports performance is determined by extremely small differences between competitors. Optimizing swimmers' performance through any sports training method is a fundamental objective of sports science research, imposed by the proliferation of high-value international competitions and the increasing demands on specific (in water) and non-specific (on land) training.

Traditional training, focused mainly on the development of aerobic capacity (70%), with limited contribution to the development of the anaerobic pathway (30%), no longer meets the current competitive requirements of high-performance swimming in middle-distance events. In this context, the research topic becomes relevant because it proposes to investigate how the two sports training directions – aerobic-anaerobic (mixed) and through controlled hypobaric exposure – can be associated with the trophotropic recovery process, in a unitary training model, capable of generating superior adaptations ("hyperfunctions").

At the same time, the complex association of mixed metabolic and respiratory training in a normoxic hypobaric regime, with a trophotropic recovery process corresponding to the previous effort, may represent an advanced strategy in the training of junior swimmers, which currently has no scientific basis in specialized studies.

The motivation for choosing the theme also derives from an obvious practical requirement: swimming specialists are constantly concerned with identifying and applying efficient, scientifically substantiated methods and means that would allow them to align with the dynamics of world-class performances. In this context, the proposed approach is convergent with the objectives of the federal staff in Romania and, in general, of coaches at national and international level, all of whom are concerned with optimizing sports results. The exceptional performances obtained by athletes such as David Popovici, Robert Glință, Răzvan Florea, Dragoș Coman, Beatrice Coadă-Câșlaru, and Camelia Potec in the middle-distance events arouse great interest among specialists, especially regarding the particularities and structure of the training process that was the basis of these results.

Topic relevance

The literature review reveals that, although there are numerous studies on each training method separately, there is no research that integrates them into a unitary experimental design. The absence of a comprehensive model thus justifies the originality, timeliness and importance of the proposed research, as it can align with competitive demands and inter- and multidisciplinary integration trends in sports science.

The research topic is currently of great interest and aligns with the evolution of world swimming: it is based on contemporary scientific directions, fills a gap in the specialized literature and proposes an innovative methodological model, with high application potential. The topicality of the work is based on recent guidelines in the field of sports science, on the methodological transformations that have occurred in world swimming and on the need to identify structured training models in as many complementary directions as possible. We consider contextually that the integration of aerobic-anaerobic training, of inspiratory muscle training through controlled exposure to the hypobaric regime, but also of a new formula for sports recovery in the training of junior middle-distance swimmers, may represent a valuable methodological proposal.

Current literature confirms a strong trend towards understanding mixed energy mechanisms, which support intense effort in the middle distance. Longitudinal studies conducted on adolescent swimmers demonstrate that the gradual development of mixed, aerobic-anaerobic sustained effort capacity has positive effects on energy expenditure and metabolic performance (Kuberski et al., 2025; Lätt et al., 2010).

During periods of growth and development of the body, the energy needed to sustain the effort must come predominantly from oxidative metabolism, which confirms the importance of solid development of the aerobic system. In this context, the need to optimize sports performance also requires the improvement of the anaerobic supplier, required by the intense effort regime of competitive races. The need to increase the VLamax (anaerobic index of glycolytic power) in the high-interest events of junior middle-distance swimmers, who must be trained not only towards the "aerobic energy ceiling" (VO2max), but also on the complementary "anaerobic floor" (VLamax). This can guarantee the explosive sprint, developed in an acceleration of the swim course for tactical purposes, or an intense finish.

Another essential aspect, which underlines the topicality of the topic addressed, is the interest in recent years in the development of respiratory muscles, considered a major determinant of performance in predominantly aerobic disciplines.

Unlike land sports, the act of breathing in swimming requires correct synchronization with the movements of the upper limbs and is performed in an environment characterized by increased hydrodynamic pressure on the torso, generated by the kinetic energy of the water flow. These particularities justify the need to implement respiratory exercise programs, and recent studies reveal an important difference in favor of athletes who performed this type of exercise, with a significant improvement for every 50 m swam. The data support the current value of including the method of developing respiratory muscles (Respiratory Muscle Training- RMT) in swimmer training (Chang et al., 2021). Recently, however, there has been discussion about the use of the hypobaric tunnel as technical equipment for effective respiratory training, which ensures natural, physiological conditions for pulmonary training in a normoxic regime.

The study by Park & Lim (2017) on competitive swimmers revealed significant improvements in aerobic capacity, anaerobic power, and 50 and 400 m performance after just 6 weeks of hypoxic-hypobaric exposure at 526 mmHg. This finding explains how the low-pressure swim tunnel environment can be a valuable solution for stimulating aerobic as well as anaerobic adaptations, essential for middle-distance swimmers.

A final important milestone is represented by the need to reconsider the complex process of recovery for swimmers. Studies on the recovery of swimmers directly in the water, through various relaxing, compensatory exercises, reveal that the atypical environment (water), in which this complementary process to sports training is carried out, directly influences the heart rate and the ability of athletes to repeat intense sprints. Casuso et al. (2014) demonstrated that recovery in water, characterized by a decrease in maximum heart rate and optimization of blood flow, contributes to reducing speed losses in repeated series of 100 m, compared to recovery on dry land.

These results are important because a complex training program must integrate not only components of stress and sports training, but also strategies for rebalancing homeostasis, compensation, and regeneration, which maximize the adaptations induced by the effort stimulus - the recovery component.

2. Material and methods

Research Design

The present paper is conceived as a theoretical and conceptual review focused on the optimization of performance in junior middle-distance swimmers through the integration of mixed metabolic training, respiratory muscle training, and modern recovery strategies. The study adopts an interdisciplinary approach, combining perspectives from exercise physiology, sports training theory, swimming methodology, respiratory physiology, and sports recovery science.

The review was conducted in order to identify, analyze, and synthesize the main scientific evidence regarding the determinants of performance in 200 and 400 m swimming events and to formulate an integrative methodological model applicable to junior athletes.

Literature Search Strategy

The scientific literature was identified through systematic searches conducted in the following electronic databases: PubMed, Web of Science, Scopus, Google Scholar.

The search process focused on studies with particular emphasis on recent investigations addressing contemporary swimming training methodologies.

The main keywords and combinations of terms used in the search process included: *junior swimmers, middle distance, metabolic training, respiratory training, sports recovery.*

Inclusion and Exclusion Criteria

The inclusion criteria for the selected literature were:

- original research articles, systematic reviews, and meta-analyses;
- studies focused on swimming performance, particularly middle-distance events;
- investigations involving adolescent or junior athletes;
- studies examining metabolic conditioning, respiratory function, hypoxic/hypobaric interventions, or recovery strategies;
- articles published in peer-reviewed scientific journals;
- publications written in English.

The exclusion criteria included:

- studies unrelated to competitive swimming;
- articles focused exclusively on technical biomechanics without physiological relevance;
- non-peer-reviewed publications;
- duplicate studies or articles with insufficient methodological clarity.
- Data Analysis and Synthesis

The information extracted from the literature was comparatively interpreted and integrated into a conceptual framework designed to support the development of an innovative methodological model for junior middle-distance swimmers.

The study follows a theoretical-integrative methodological perspective. Rather than quantitatively aggregating data, the review aims to critically synthesize current scientific knowledge and identify conceptual relationships between the major determinants of performance in middle-distance swimming.

Theoretical and physiological foundations of middle-distance swimming performance

Sports performance is the result of the complex interaction between multiple biological mechanisms, which allow the human body to respond appropriately to physical exertion.

In swimming, this performance is determined by the athlete's ability to optimally utilize energy resources, under the conditions of a particular environment. Water determines hydrodynamic resistance to forward movement, the difficulty of the coordination task, especially balancing on the unstable surface, and numerous other specific motor or psychomotor demands. For these reasons, swimming is classified as one of the most complex sports disciplines. It intensely demands the cardiorespiratory and neuromuscular systems, based on the morpho-functional and multimodal specialization of the analyzers involved in movement (proprioceptive, visual, acoustic, vestibular and tactile - for calibrating water pressures), as afferent-efferent systems of primary knowledge in an environment different from the terrestrial one.

Buoyancy control ("finding support"), managing water resistance during movement, synchronizing breathing with propulsive movements, and reducing sensory-perceptual errors are just a few elements that differentiate swimming from other sports practiced in the past. In this context, the swimmer's performance derives from the simultaneous optimization of several fundamental components: aerobic capacity, anaerobic power, functional efficiency (respiratory, cardiovascular, muscular), acute sensory discrimination.

Within the general framework of the discipline, the middle-distance events in swimming are represented by distances of 200 and 400 m. From this perspective, middle distance swimmers' performance depends mainly on mixed metabolic pathway, respiratory capacity, recovery capacity after exertion. Other determinants can be discussed contextually: anaerobic threshold, tolerance capacity to metabolite accumulation, maximal oxygen consumption (VO_2max), techmique, motor skills, cognitive strategies, etc. (Figure 1).

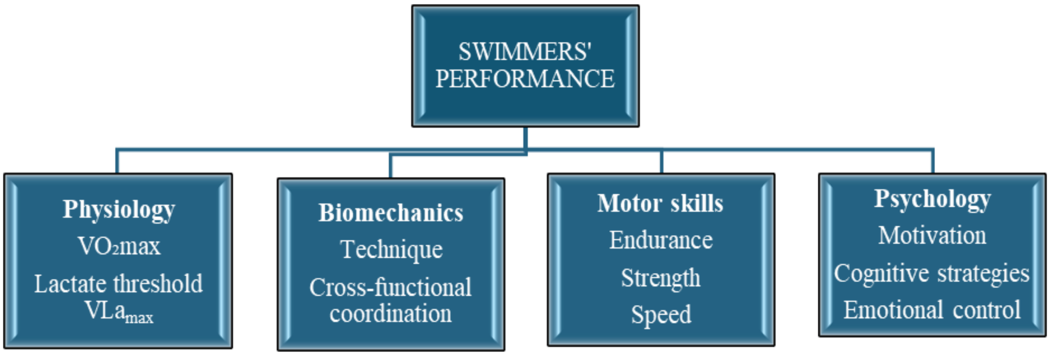

Figure 1. *The conceptual model of factors determining swimming performance*

Metabolic pathways. The 200 and 400 m races have a mixed bioenergetic profile, in which the contribution of the energy systems is made in a variable proportion, depending on the duration and intensity of the effort. These events demand both the body's ability to produce energy through oxidative metabolism and its power to rapidly generate energy through anaerobic mechanisms, especially in the acceleration phases and at the end of the swim.

In the analysis of the specific effort in the middle distance, the maximum oxygen consumption must be constantly reconsidered. VO2max is one of the most relevant indicators of exercise capacity, illustrating the combined efficiency of the respiratory system - supplier of O2, cardiovascular system - with the function of transporting O2 to the active muscles, and muscular system - user of the vital gas in restoring the energy substrate.

In this intense effort, excessive post-exercise oxygen consumption (Excess Post-exercise Oxygen Consumption - EPOC) reflects the intensity of the physiological processes involved in the body's recovery after aerobic-superior and mixed effort. EPOC represents the set of physiological processes for restoring post-exercise balance, which supports the restoration of energy reserves, the elimination of secondary metabolic products and the restoration of body functions, all of which are essential for optimal sports performance and the athlete's recovery.

The oxygen debt, typically paid for by excessive post-exercise oxygen consumption, highlights the need for an increased rate of oxygen intake after intense physical activity. The body's energy demand can now exceed the oxygen available, resulting in a partial reliance on anaerobic metabolism. After exercise, oxygen consumption remains elevated to return the body to its pre-exercise state and to replenish energy reserves (Børsheim & Bahr, 2003).

The recovery period after intense exercise involves several physiological processes that require additional oxygen. These processes include the restoration of phosphocreatine (PCr) in the muscles, the replenishment of O2 stores in hemoglobin (fixed to the heme groups) and myoglobin, and the elimination or conversion of accumulated lactate to glycogen via the Cori cycle in the liver cytosol. In addition, the increase in body temperature, increased heart rate, and increased hormonal activity during recovery also contribute to increased metabolic rate and oxygen consumption (Gaesser & Brooks, 1984).

EPOC has two components: a fast and a slow one. The fast component occurs immediately after intense exercise and involves the replenishment of ATP and phosphocreatine stores, as well as oxygenation of the blood and muscle tissues. The slow component can last from a few minutes to a few hours, depending not only on the intensity but also on the duration of the exercise. The level of training also influences the restoration of effort parameters, so trained athletes may experience a shorter duration of excess oxygen consumption (Short & Sedlock, 1997). In EPOC, physiological processes such as lactate removal, glycogen resynthesis and thermoregulation continue to require additional oxygen (Laforgia, Withers, & Gore, 2006). In conclusion, EPOC occurs following excessive carbohydrate consumption and, thus, a metabolic imbalance, oxidative damage to the cell membrane and the accumulation of serum lactate (Huang et al., 2025).

Another indicator of middle-distance performance is the *anaerobic threshold*, defined as the swimming intensity at which lactate production begins to exceed the body's ability to eliminate this catabolite. The anaerobic threshold marks the transition from moderate aerobics to higher oxidative metabolism at 4 mmol lactate/L blood and is an important indicator of an individual's ability to sustain moderate to high intensity exercise. Athletes with a high anaerobic threshold can maintain high speeds for longer periods of time, which is an important advantage in middle-distance races.

The ability to tolerate high lactate levels is also important. This can be developed by constant intensification of the upper aerobic muscle metabolism, bordering on the anaerobic one, "learning pain". Massive accumulations of catabolites are generated and, as a consequence, compensatory mechanisms are created - buffer solutions (bicarbonate-phosphate-protein), alkaline substances increase in quantitywhich prevent a decrease in muscle pH. Gradually, “unresponsiveness to pain, which accompanies severe fatigue" develops (Platonov, 2015), new blood capillaries open, the number of functional pulmonary alveoli and the intensity of energy-generating reactions increase by enzymatic activity (e.g., lactate permease, a transport enzyme for residual metabolites, increases quantitatively).

Ventilatory capacity. Aquatic breathing depends mainly on the strength of the diaphragmatic and intercostal muscles, but also on the resistance of the pulmonary system, which, together with the cardiovascular and muscular systems, ensure the metabolic patterns in which middle-distance races take place. Swimmers must demonstrate *cardiovascular, respiratory and muscular resistance* in order to cope with the rigors of training or stressful competitive situations in terms of duration (Vasile, 2023). Thus, if myocardial (aerobic) resistance results in pumping a large amount of nutritious blood to the tissues, and muscular (anaerobic) resistance is directly related to muscle fatigue, its installation determining a decrease in maximum tension or contractile force, *the respiratory resistance* ensures: acceleration of gas exchange at the pulmonary level (by intensifying pulmonary hematosis) and at the muscular level, breathing control by increasing the possibilities to accelerate (polypnea), reduce (bradypnea) or temporarily stop (apnea) the respiratory rate, increase respiratory flow and quickly restore respiratory rate after exercise.

Swimmers' ability to recover after exertion presents numerous particularities, and the metabolic and functional-respiratory processes, greatly intensified in middle-distance races, require an appropriate process, which allows for the coherent restoration of energy reserves, the elimination of lactate and other catabolites resulting from anaerobic glycolysis, and then gradually the establishment of homeostasis. In the context of contemporary sports training, efficient management of recovery processes is also an essential element for optimizing performance and preventing overstraining of the body.

In recent years, specialized literature has frequently highlighted the importance of several methodological directions integration in the training of performance swimmers. We therefore consider that, for middle-distance swimmers, these guidelines should include the association of mixed metabolic training with respiratory training and the corresponding recovery component. This innovative direction can ensure the simultaneous development of aerobic and anaerobic capacities, the development of inspiratory muscles and the restoration of the body according to the specific demands of the middle-distance. This approach may reflect the current trend of interdisciplinary integration in sports science, in which exercise physiology, biomechanics, psychology and sports training theory allow the development of complex methodological models.

In this context, the issue addressed in this research aims to optimize the training process for junior swimmers specializing in middle distance events, by integrating modern training and recovery directions.

The conceptual delineation of all the aspects previously specified represents the theoretical foundation of the research. It constitutes the starting point for the critical analysis of specialized literature and for the development of an integrative methodological model.

3. Results and Discussions

Reflection of the topic in specialized literature

In recent scientific literature, numerous studies have analyzed the determinants of performance in middle-distance swimming events, highlighting the role of the interaction between the aerobic and anaerobic energy systems, respiratory function and, less significantly, post-exertional recovery processes. These research directions, however, constitute important benchmarks for the development and experimental validation of modern methodological models for training performance swimmers.

In this context, the first area of interest is represented by studies on the development of bioenergetic capacity in specific efforts of the middle distance. Research conducted on adolescent swimmers has demonstrated that the progressive development of mixed effort capacity determines the improvement of metabolic efficiency and, thus, ensures the improvement of sports performance.

Longitudinal studies highlight that the development of aerobic endurance during junior years is the foundation of later performance, contributing to increased maximal oxygen consumption and improved endurance in middle-distance events (Kuberski et al., 2025; Lätt et al., 2010). At the same time, recent research emphasizes the importance of developing anaerobic power, expressed by the glycolytic power indicator VLamax, which contributes to tactical accelerations and the final sprint of the race.

Metabolic efficiency is influenced by biomechanical, neuromuscular or technical factors, biochemical factors, nutrition and hydration, the age of the athletes, etc., which can determine the improvement of results, even in the absence of significant changes in VO_2max (Coyle, 1999; Ainslie et al., 2005).

A central concept in the analysis of swimming performance is thus this maximal oxygen consumption (VO_2max), considered one of the most important indicators of the superior aerobic capacity of swimmers. Studies by Coyle (1999) highlight that VO_2max reflects the capacity of the respiratory, cardiovascular, and muscular systems to take up, transport, and use oxygen and to sustain high-intensity aerobic efforts. However, subsequent research has demonstrated that performance in endurance sports does not depend exclusively on the level of VO_2max, but also on the percentage in which this capacity sustains the effort for its entire duration (Bosquet, Léger & Legros, 2002) (Figure 2).

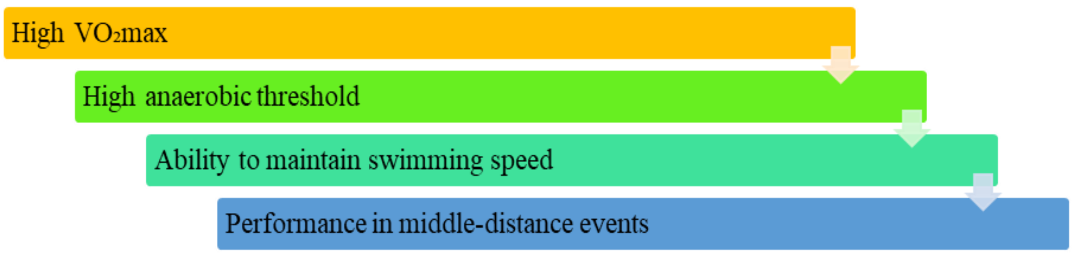

Figure 2. *The relation between aerobic capacity and athletic performance*

Theoretical explanatory models of maximum O2 consumption include two metabolic reference moments - the first and second lactate thresholds, which are exceeded during incremental exercises, in which the intensity increases from 2 to 4-5 mmol lactate/L blood. This allows us to know the level of effort at which the catabolic product in the blood begins to increase above basal values and the highest intensity at which lactate production and elimination are in balance (maximal lactate steady state – MLSS).

International literature also highlights the role of anaerobic threshold as a valid predictor of sports performance. According to Faude, Kindermann and Meyer (2009), it represents the intensity of aerobic-medium effort, at which lactate production exceeds the body's ability to eliminate it. Athletes with a higher anaerobic threshold can maintain higher speeds for longer periods of time, which constitutes a significant competitive advantage in middle-distance events. It is therefore considered that, based on a high VO2max and an anaerobic threshold recorded late in the race, an efficient transition is achieved from medium aerobic metabolism (4 mmol lactate/L blood) to swimming at maximum critical speed (VMC - 5 mmol lactate/L blood) and then, to anaerobic metabolism. Therefore, the correct evaluation of these individual parameters (VO2max and anaerobic threshold) allows the prediction of performances in middle-distance races, and, at the same time, the correct establishment of the effort zones crossed in the specific training of 200, 400, 800 or 1500 m swimmers.

The literature also presents other factors determining performance in endurance-speed (200 m) or endurance-strength (400 m) events. For example, the significant role of the resistance of oxidative muscle fibers, strongly irrigated at the mitochondrial level, but also of white glycolytic ones (Kuberski et al., 2025).

Several authors state that. athletic performance in the 200 and 400 m events is assessed by the speed that can be maintained for several minutes. This is progressively reduced by the accumulation of hydrogen ions (lactic acidosis) and heat (hyperthermia). Therefore, in laboratory simulations of performance, athletes are considered to tire when thermal stress during exercise (when esophageal temperature reaches approximately 40°C) is associated with a near-maximal heart rate and a high level of perceived exertion (Wilmore & Costill, 2004).

In recent years, research has paid increasing attention to respiratory muscle training, as the second area of interest in this paper. Respiratory Muscle Training (RMT) exercises can improve ventilatory efficiency and reduce the perception of fatigue during intense exercise. Other research highlights that the development of inspiratory muscles contributes to optimizing the redistribution of blood flow to active muscles and delaying the onset of muscle fatigue (Fernández-Lázaro et al., 2021; Fabero-Garrido et al., 2022).

More recently, respiratory muscle training (RMT) has been proposed as a strategy to improve inspiratory muscle strength and endurance. These physiological adaptations delay fatigue and, over time, attenuate lactate accumulation in anaerobic contexts (Grachan & Essick, 2019; Xavier et al., 2025). Researchers also correlate swimmer breathing with technique and highlight that variations in breathing frequency influence both muscle activity and motor coordination. In this sense, the respective studies support the idea that swimming performance cannot be fully exploited in practice without optimizing the ventilatory function. These methodological considerations transform respiratory training from an auxiliary component into a fundamental pillar of current training, with multiple valences (Amaro, 2017).

A complementary research direction is represented by studies on the effects of hypoxic training on sports performance. Methods such as Intermittent Hypoxic Training (IHT) or Repeated Sprint Training in Hypoxia (RSH) have been implemented in numerous endurance sports, including swimming. These methods aim to stimulate physiological adaptations through controlled exposure to reduced oxygen conditions. Faiss et al. (2013) highlight that training in hypoxia causes increases in VO_2max, improves lactate tolerance, and optimizes performance in high-intensity efforts.

In international specialized literature, numerous other benefits of voluntary breathing exercises are described on: O2 absorption and CO2 emission, respiratory quotient (RQ), respiratory volume and rate, muscle perfusion, mitochondrial density, angiogenesis, and, in general, on respiratory fitness (Jin et al., 2025; Rozek et al., 2020).

Deep breathing exercises are often promoted as a method of reducing transient abdominal pain associated with intense physical activity (exercise-related transient abdominal pain - ETAP). ETAP is a common discomfort experienced during physical activity, especially during middle-distance swimming, when the steady state has not yet set in. The pain is usually acutely felt below the costal margin. Although the exact etiology of this transient manifestation is not fully elucidated, the literature mentions several possible physiological mechanisms that could explain its occurrence (Morton & Callister, 2015). A plausible hypothesis is that the pain occurs as a result of mechanical stress exerted on the diaphragm during intense exercise. The diaphragmatic muscle plays an essential role in breathing, and during high-intensity physical activity it must contract strongly to satisfy the body's increased oxygen demand. In conditions of insufficient oxygenation, the diaphragm could contribute to the occurrence of pain localized subcostally. In addition, the tension of the ligaments that support the abdominal organs during repetitive movements can favor the onset of the sensation of intense abdominal pain (Morton & Callister, 2015).

In correlation with the first two research directions regarding the sports training of swimmers - metabolic and respiratory training - the specialized literature also highlights the role of recovery processes in optimizing sports performance, thus constituting a third area of interest for our research.

In this context, recent studies emphasize that recovery in the aquatic environment can positively influence the restoration of homeostasis after intense efforts. Studies highlight the role of the fluid environment in accelerating post-exertion recovery processes through its thermality, water being a powerful stimulus for the body (Solsona et al., 2023), which favorably modulates the inflammatory response of skeletal muscle after exercise (Horgan et al. 2024).

An adequate recovery process ensures not only the restoration of the body, but also the installation of coherent functional adaptations. For example, if the inspiratory muscles were intensely stressed during the previous effort, restoring their functional potential through various techniques can improve the "second breath". Second wind is a process encountered during prolonged physical exercise, in which the athlete initially feels fatigue and breathing difficulties, only to subsequently experience a decrease in respiratory discomfort and the possibility of continuing the effort in more comfortable conditions. The second breath occurs after the first stages of demanding exercise, when the body passes from a state of oxygen deficiency to a stable, relative or absolute, metabolic state, of the steady state type (McArdle, Katch, & Katch, 2015).

In the initial phase of high-intensity exercise, the demand for O2 exceeds the available supply at the muscle level. Consequently, energy production is partially achieved through anaerobic metabolism, which causes the accumulation of metabolites and the onset of fatigue. As the effort continues at a slightly reduced intensity, physiological adjustments occur in the respiratory and cardiovascular systems, which increase the supply of oxygen to the active muscles. At this point, a steady state is established, aerobic metabolism becomes the main energy supply, and feelings of fatigue and dyspnea progressively decrease (Kenney, Wilmore, & Costill, 2020).

Recent research also highlights the need to integrate modern psychophysiological recovery strategies into the sports training process, such as mindfulness techniques, flow experiences in the aquatic environment and cognitive self-regulation strategies applied during aquatic immersions. These interventions are considered relevant not only through their effect on reducing physiological stress and avoiding "functional overreaching", but also through their contribution to optimizing the mental state, concentration and connection to competitive or training requirements (Mihajlovic et al., 2023). In the context of performance sports, such methods can support the body's recovery, favoring a faster return to an optimal functional level after intense efforts. At the same time, these interventions can improve emotional control, reduce the subjective perception of effort and increase the mental availability necessary for active involvement in subsequent training sessions. In this way, recovery is no longer just a passive stage of restoration/recovery, but an active process, with a role in maintaining the continuity of adaptations and optimizing sports performance.

The correlated analysis of all these studies highlights that performance in middle-distance swimming events can be improved through bioenergetic and functional adaptations, especially respiratory, as well as by reconsidering, on a modern basis, the post-exertional recovery process. Based on this finding, the present research aims to investigate the valences of an integrative training methodology, which combines mixed metabolic training and respiratory muscle development in hypobaric regime with modern sports recovery methods, in order to optimize the performances of junior swimmers specialized in middle-distance events (Figure 3).

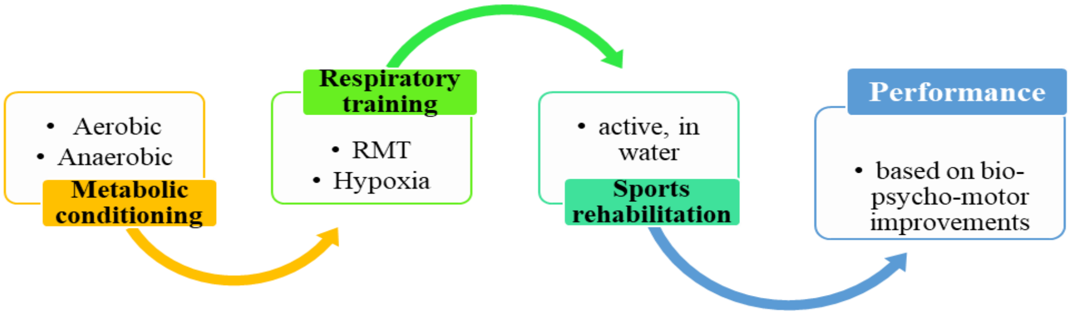

Figure 3. *An integrative training model for junior middle-distance swimmers*

Discussions

This paper proposes an integrative methodological model aimed at optimizing the performance of junior swimmers specializing in middle-distance events, starting from the premise that unidimensional approaches to sports training no longer fully meet the demands of contemporary performance. Current literature suggests that success in 200–400 m events depends on the functional interaction between aerobic capacity, anaerobic metabolism, ventilatory efficiency and post-exercise recovery processes, which supports the need for an integrated methodological approach.

One of the main directions validated in the specialized literature is the development of mixed energy metabolism. Recent studies show that, although aerobic metabolism remains dominant in middle-distance events, the anaerobic contribution plays a determining role in tactical accelerations and at the end of the race (Maglischo, 2015; Kuberski et al., 2025). This observation raises questions about the effectiveness of traditional training models, focused predominantly on the development of aerobic endurance. In the current context, exclusively aerobic training may limit the athlete's ability to respond to the tactical and metabolic demands specific to modern competition.

At the same time, contemporary literature highlights that athletic performance cannot be explained exclusively by classical indicators such as VO_2max. Although maximal oxygen consumption remains an essential marker of aerobic capacity (Coyle, 1999), middle-distance performance depends equally on anaerobic threshold, tolerance to metabolite accumulation and energy economy of movement (Bosquet et al., 2002; Faude et al., 2009). From this perspective, the proposed conceptual model supports a methodological orientation closer to the real specificity of the competitive event.

A second relevant dimension of the discussion is the role of respiratory function. Traditionally, respiratory training has been treated as a secondary component in swimmer training. However, the biomechanical peculiarities of swimming – the constrained synchronization of breathing with arm movements, the hydrodynamic pressure on the chest and the increased coordination demands – justify reconsidering this factor as a major determinant of performance. Recent studies support this perspective, demonstrating that respiratory muscle training can improve ventilatory efficiency, reduce the perception of fatigue and favor the redistribution of blood flow to the active muscles (Shei et al., 2022; Fernández-Lázaro et al., 2021).

Moreover, the integration of hypoxic or hypobaric exposure into respiratory training opens up promising methodological directions. However, the practical applicability of these methods in junior athletes requires cautious analysis, given the physiological peculiarities and stage of biological development of this category.

Another important aspect is the integration of recovery strategies into the architecture of sports training. Contemporary literature increasingly supports the fact that recovery should not be viewed as a passive or complementary stage, but as an active determinant of adaptation and performance. Active recovery in the aquatic environment, psychophysiological self-regulation techniques and modern strategies for reducing physiological stress can contribute to accelerating the restoration of homeostasis and preventing overstrain (Casuso et al., 2014; Mihajlovic et al., 2023).

From a critical perspective, the main limitation identified in the current literature is the lack of integrated, experimentally validated methodological models dedicated to junior middle-distance swimmers. Most studies analyze separately the metabolic, respiratory or regenerative components, without investigating the cumulative effects of their interaction. In this sense, the conceptual contribution of the present paper consists in formulating a coherent interdisciplinary framework, which proposes the articulation of these components in a unitary methodological logic.

However, it should be emphasized that the proposed model is at this stage conceptual and requires experimental validation. The practical efficacy of integrating mixed metabolic training, respiratory training, and modern recovery strategies needs to be tested through controlled longitudinal research on relevant populations of junior athletes.

Overall, the discussion supports the idea that contemporary swimming performance requires a paradigm shift: from segmented training, focused on isolated components, to integrated, interdisciplinary models, capable of reflecting the real complexity of competitive effort.

5. Conclusions

Performance in middle-distance swimming events should be understood as the expression of a complex interaction between metabolic efficiency, ventilatory function and post-exertional recovery capacity. The analysis of specialized literature supports the need to overcome traditional training models, predominantly oriented towards the development of aerobic endurance, in favor of integrated interdisciplinary approaches, adapted to current competitive requirements. The proposed conceptual model highlights the potential of a methodology that correlates mixed metabolic training, respiratory training and modern recovery strategies, providing a relevant theoretical framework for optimizing the performance of junior swimmers specialized in middle-distance events. Experimental validation of this model remains necessary, however, to confirm its practical applicability in contemporary sports training.

References

1. AINSLIE, P. N., CAMPBELL, I. T., FRAYN, K. N., HUMPHREYS, S. M., MACLAREN, D. P. M., & REILLY, T. (2005). Physiological, metabolic, and performance implications of exercise-induced dehydration. *Journal of Applied Physiology*, 98*(6)*, 2146–2153.
2. AMARO, N. M. (2017). Respiratory frequency and swimming biomechanics: Implications for performance optimization. *International Journal of Sports Physiology and Performance*, 12*(4)*, 512–519.
3. BOSQUET, L., LÉGER, L., & LEGROS, P. (2002). Methods to determine aerobic endurance. *Sports Medicine*, 32*(11)*, 675–700.
4. BØRSHEIM, E., & BAHR, R. (2003). Efectul intensității, duratei și modului exercițiului asupra consumului de oxigen după exercițiu. *Medicină sportivă*, 33*(14)*, 1037–1060. https://doi.org/10.2165/00007256-200333140-00002
5. CASUSO, R. A., PLAZA-DÍAZ, J., RUIZ-OJEDA, F. J., NORDSBORG, N. B., ARIAS, N., & MARTÍN-CARNERO, A. (2014). High-intensity high-volume swimming induces more robust signaling through PGC-1α and AMPK activation than sprint interval swimming in m. triceps brachii. PLoS ONE, 9(10), e111029.*
6. CHANG, C. K., KU, P. W., LIN, W. H., & TSAI, C. L. (2021). Effects of respiratory muscle training on swimming performance: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, 18*(13)*, 6851.
7. COCHRANE, D. J., HOUSH, T. J., SMITH, C. M., HILL, E. C., JENKINS, N. D. M., JOHNSON, G. O., & SCHMIDT, R. J. (2015). Relative contributions of strength, anthropometric, and body composition characteristics to swimming performance. *Journal of Strength and Conditioning Research*, 29*(5)*, 1310–1316.
8. COYLE, E. F. (1999). Physiological determinants of endurance exercise performance. *Journal of Science and Medicine in Sport*, 2*(3)*, 181–189.
9. FABERO-GARRIDO, R., MEDINA-CASAUBÓN, J., & ESCALONA-MARFIL, C. (2022). Inspiratory muscle training and athletic performance: Current evidence and practical implications. *Sports*, 10*(4)*, 58.
10. FAISS, R., LÉGER, B., VESIN, J. M., FOURNIER, P. E., EGGEL, Y., DÉRIAZ, O., & MILLET, G. P. (2013). Significant molecular and systemic adaptations after repeated sprint training in hypoxia. *PLoS ONE*, 8*(2)*, e56522.
11. FAUDE, O., KINDERMANN, W., & MEYER, T. (2009). Lactate threshold concepts: How valid are they? *Sports Medicine*, 39*(6)*, 469–490.
12. FERNÁNDEZ-LÁZARO, D., MIELGO-AYUSO, J., SECO-CALVO, J.,

CÓRDOVA-MARTÍNEZ, A., CABALLERO-GARCÍA, A., & FERNANDEZ-LAZARO, C. I. (2021). Respiratory muscle training enhances athletic performance: A systematic review. *Biology,* 10*(11),* 1174.

13. GAESSER, G. A., & BROOKS, G. A. (1984). Metabolic bases of excess post-exercise oxygen consumption: a review. *Medicine and science in sports and exercise*, 16*(1),* 29–43.
14. GRACHAN, J., & ESSICK, E. E. (2019). The effects of respiratory muscle resistance training on lactate threshold: A potential effort to prevent muscle fatigue during exercise. *BIOS*, 90*(4),* 263–268. https://doi.org/10.1893/0005-3155-90.4.263
15. HORGAN, B. G., WEST, N. P., TEE, N., HALSON, S. L., DRINKWATER, E. J., CHAPMAN, D. W., & HAFF, G. G. (2024). Effect of repeated post-resistance exercise cold or hot water immersion on in-season inflammatory responses in academy rugby players: a randomised controlled cross-over design. *European journal of applied physiology,* 124*(9),* 2615–2628. https://doi.org/10.1007/s00421-024-05424-3
16. HUANG, T., LIANG, Z., WANG, K., MIAO, X., & ZHENG, L. (2025). Novel insights into athlete physical recovery concerning lactate metabolism, lactate clearance and fatigue monitoring: A comprehensive review. *Frontiers in physiology*, 16, 1459717. https://doi.org/10.3389/fphys.2025.1459717
17. KENNEY, W. L., WILMORE, J. H., & COSTILL, D. L. (2020). *Physiology of sport and exercise* (7th ed.). Human Kinetics.
18. KUBERSKI, S., OLIVEIRA, R., NIKOLAIDIS, P. T., KNECHTLE, B., & ROSEMANN, T. (2025). Energy system development and performance adaptations in adolescent swimmers: A longitudinal review. *Sports Medicine*.
19. LAFORGIA, J., WITHERS, R. T., & GORE, C. J. (2006). Effects of exercise intensity and duration on the excess post-exercise oxygen consumption. *Journal of Sports Sciences,* 24*(12),* 1247–1264. https://doi.org/10.1080/02640410600552064
20. LÄTT, E., JÜRIMÄE, J., HALJASTE, K., CICCHELLA, A., PURGE, P., & JÜRIMÄE, T. (2010). Longitudinal development of physical and performance parameters during biological maturation of young male swimmers. *Perceptual and Motor Skills,* 110*(1),* 297–307.
21. MCARDLE, W. D., KATCH, F. I., & KATCH, V. L. (2015). *Exercise Physiology: Nutrition, Energy, and Human Performance (8th ed.)*. Wolters Kluwer
22. MAGLISCHO, E. W. (2015). *Swimming fastest*. Human Kinetics.
23. MIHAJLOVIC, M., STANKOVIC, M., JOVANOVIC, A., & PETROVIC, D. (2023). Mindfulness-based recovery strategies in competitive athletes: Effects on psychophysiological restoration. *Frontiers in Psychology,* 14, 1184523.
24. MORTON, D., & CALLISTER, R. (2015). Exercise-related transient abdominal pain (ETAP). *Sports medicine* (Auckland, N.Z.), 45*(1),* 23–35. https://doi.org/10.1007/s40279-014-0245-z

25. PARK, H. Y., & LIM, K. (2017). Effects of hypobaric hypoxic training on aerobic and anaerobic performance in elite swimmers. *Journal of Exercise Nutrition & Biochemistry,* 21*(3),* 29–35.
26. VASILE, L. (2023). *Teoria și metodica antrenamentului sportiv în natație.* Editura Discobolul, București
27. XAVIER, D. M., MIRANDA, J. P., FIGUEIREDO, P. H. S., & LIMA, V. P. (2025). The effectiveness of respiratory muscular training in athletes: A systematic review and meta-analysis. *Journal of bodywork and movement therapies*, 42, 777–792. https://doi.org/10.1016/j.jbmt.2025.01.010