

Post-Exercise Recovery Factors

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Introduction

Exercise encompasses physical activities performed regularly with a specific purpose in mind. It is an activity aimed at improving overall health and has well-known positive effects on various body systems, including the cardiovascular, respiratory, and musculoskeletal systems (Akgün 1989; Wilmore, Knuttgen 2003; Pancar et al., 2023; Ay et al., 2023). In addition, regular exercise leads to a reduction in body fat percentage, an increase in bone mineral density, improvements in muscle strength and endurance, and the development of neuromuscular adaptation (Lenze, Wetherell, Hickman, Sinacore 2016). Moreover, exercise is known to have both preventive and therapeutic effects on many diseases, including cancer, type II diabetes, obesity, cardiovascular diseases, hypertension, osteoporosis, and several others (Anderson et al. 2016; Santos, Elliott-Sale, Sale 2017). During exercise, skeletal muscles utilize stored glycogen, blood glucose, lactate, free fatty acids from adipose tissue or intramuscular triglyceride stores, and creatine phosphate (CP) to synthesize ATP (Powers, Howley 2017). The main factors influencing the use of these substrates are the intensity and duration of the exercise. In high-intensity and prolonged exercise, as the oxygen supply to the muscles decreases, the metabolism shifts to anaerobic energy production. The transition from the aerobic to the anaerobic energy system is referred to as the anaerobic threshold. Exercises performed below this threshold are defined as aerobic, while those performed above it are classified as anaerobic (Wilmore, Knuttgen 2003).

Aim of The Study

The aim of this study was to examine the factors affecting the recovery protocols applied to support the improvement of sportive performance after exercise.

Aerobic Exercise

Aerobic exercise refers to activities performed with rhythmic movements over an extended period, requiring less force and without causing oxygen debt (Kitzman et al. 2016). These exercises improve the cardiovascular system, enhance respiratory parameters, and increase both the oxygen-carrying capacity to muscles and the muscles' capacity to store oxygen and ATP (Hsu 2016; Tuzcuoğulları et. al., 2017; Pancar et al., 2023). Aerobic exercise significantly increases the amount of oxygen delivered to active muscles. Long-term aerobic exercises lead to an increase in the number of blood vessels through angiogenesis in active muscles, an increase in myoglobin content, and consequently, an enhancement in ATP storage capacity (Hall 2015). At the time to peak torque, the contraction speed is at the forefront and its unit is the second. This refers to the time to reach peak torque. It is used in evaluating athletes that require explosive

power and available condition (Vural, 2019).

Additionally, during prolonged and intense exercise, the amount of oxygen consumed increases after a certain point. This value, determined during exercise tests and representing the maximum oxygen consumption, is referred to as “maximal oxygen consumption (VO₂Max)” or “maximal aerobic capacity” (Rowell, O’Leary 1990). Aerobic capacity is a significant indicator of the capabilities of the cardiovascular, pulmonary, and neuromuscular systems, and it depends on the physiological capacity of certain hematological components, such as blood volume, red blood cell count, and hemoglobin levels, as well as the efficiency of oxidative mechanisms in muscle cells during exercise (Astrand, JB 1992; Foss, Keteyian, Fox 1998).

The higher the physiological functional capacities of these systems, the greater the maximal oxygen consumption capacity (VO₂Max) (Karamizrak, Ergen, Töre, Akgün 1994). The value of aerobic capacity over a unit of time is referred to as “aerobic power.” Aerobic power is defined as the amount of oxygen consumed per kilogram per minute and is measured in milliliters (O₂ mL/kg/min) (McArdle, Jackson 2000). Aerobic capacity is typically measured using a treadmill or cycle ergometer. During maximal or submaximal exercise tests, heart rate, ECG, and blood pressure changes are monitored. The peak torque values of knee isokinetic force measurement were taken into account by H/Q ratios, performance, and recovery after injury, training planning and such as these parameters were taken into consideration (Vural & Özdal, 2019).

In these tests, the workload is increased until the individual reaches maximal oxygen consumption or maximum heart rate. As the effort level rises, oxygen consumption increases in parallel with the increasing workload. However, once exercise intensity reaches a certain point, the oxygen intake begins to plateau, despite further increases in exercise intensity. This plateau represents the individual’s VO₂Max. At this stage, blood lactate levels should be 79-80 mg or higher, the heart rate should reach its maximum, and the respiratory exchange ratio should rise to between 1.07 and 1.15 (Foss, Keteyian, Fox 1998; McArdle, Jackson 2000; Cooper, Sowash, Taylor, Storer 2003). During exercise, heat production increases in active tissues, leading to the formation of significant amounts of acidic compounds and carbon dioxide. The increased oxygen consumption in active tissues causes a decrease in oxygen pressure. This, along with the presence of these surrounding factors, facilitates the release of oxygen from hemoglobin. In prolonged and intense exercise, the insufficient supply of oxygen and other metabolites needed for ATP synthesis through the circulatory system makes it difficult to sustain exercise. Additionally, the accumulation of byproducts under these conditions can negatively impact muscle performance (Zimmerman, Granger 1992).

However, the lack of examining the peak torque values produced by quadriceps and hamstring muscles in isokinetic measurements from joint angle and duration has created the idea that there is a deficiency in this respect in the literature. Because the joint angle at the stage of producing an athlete’s peak torque strength is actually directly related to the muscle section and the contraction capacity of the muscle and strength programs (Vural et al., 2017).

Anaerobic Exercise

Short-duration, high-intensity physical activities are classified as anaerobic exercises.

In this type of exercise, the individual's oxygen intake is insufficient, reaching maximal or supramaximal levels, which exceeds the anaerobic threshold. This lack of oxygen triggers the anaerobic energy system.

The anaerobic glycolysis pathway involves the breakdown of glucose or glycogen to pyruvic acid. In this process, pyruvic acid is converted to lactic acid. This metabolic transformation leads to the accumulation of citric and lactic acids in the environment, as well as an increase in the levels of nicotinamide adenine dinucleotide (NADH). As a result, the pH level within the cell decreases (pH 6.4), which causes metabolic acidosis and fatigue.

As a result, the prolonged maintenance of anaerobic exercise is not feasible due to the adverse effects brought about by these metabolic changes. This situation is a significant factor that affects athletes' performance and endurance, and it is a critical point to consider during the planning and implementation of anaerobic exercises.

Lactate produced through anaerobic glycolysis is removed from the muscles via the cardiovascular system and transported to the liver and heart. This process enables the conversion of lactate into glucose or glycogen in the liver and its use for energy production in the heart. This mechanism is crucial for the sustainability of energy production (Åstrand, Rodahl, Dahl 1986; Morton et al. 2007).

However, during intense and sustained exercise, the decrease in ATP activity leads to the impairment of cellular functions. This situation results from the insufficiency of the sodium-potassium ATPase pump in the cell membrane; this deficiency causes sodium accumulation within the cell and potassium efflux outside the cell. Consequently, these events lead to intracellular water retention, triggering the formation of cellular edema.

Additionally, under these conditions, a reduction in the ability of the sarcolemma to retain creatine kinase and myoglobin has also been observed. Creatine kinase and myoglobin play significant roles in energy production and oxygen storage in muscle cells; therefore, the decrease in these proteins adversely affects muscle performance (Newham 1988; Proske, Morgan 2001). On the other hand, the time for the muscle to reach peak torque at a certain movement angle is important for performance athletes, especially in activities that require explosive power especially anaerobic power (Tahhan et al., 2018a; Tahhan et al., 2018b).

In this context, understanding the negative effects that intense and prolonged exercise can have on both energy production and cellular homeostasis is critically important for planning exercise programs aimed at optimizing athletes' performance and preventing injuries.

The work capacity generated by muscles through the anaerobic energy system during maximal or submaximal physical activities is defined as “anaerobic capacity.” This definition refers to the total amount of work performed by the muscles utilizing the anaerobic energy system over a specific period. The value of this work per unit of time is termed “anaerobic power,” which is typically measured in kilograms per second (kg/s), kilograms per minute (kg/min), or watts.

Anaerobic power is a concept that defines the expression of explosive strength and encompasses workloads above the anaerobic threshold. These types of physical activities are typically associated with short-duration, high-intensity exercises and demonstrate a

parallel interaction with fatigue. Although anaerobic power cannot be precisely measured, it can be partially determined using various tests and indirect measurement methods.

Determining anaerobic power is critically important for assessing sports performance and optimizing training programs. This is because anaerobic capacity is a significant factor affecting athletes' endurance, power output, and overall performance. Therefore, deepening research in this area holds a significant place in the literature of sports sciences. These applications encompass laboratory and field tests. Additionally, blood lactate levels are considered an important indicator of anaerobic power. Therefore, it is recommended that studies measure blood lactate levels before and after exercise (McArdle, Jackson 2000; Myers, Ashley 1997). In short-duration, high-intensity sports activities, high-energy phosphates (creatine phosphate) serve as an immediate energy source for the muscles. In this system, energy is provided anaerobically while preventing lactic acid formation. Creatine phosphate produces ATP by phosphorylating ADP. This reaction is reversible in nature and is catalyzed by creatine kinase (Powers, Howley 2014).

Sports Performance

During a physical activity, the bodily, physiological, and psychological efficiency required by that activity is defined as “sports performance.” Additionally, sports performance is also known as the actions and work accomplished during competition or training. However, when this concept is approached from a competitive perspective, it can also be related to athletes' abilities to effectively showcase their current conditioning. Therefore, the success in achieving this efficiency is an important factor that determines the performance level of an athlete (Cadegiani and Kater, 2019).

In this context, developing training programs and strategies to enhance athletes' performance levels is critically important for improving efficiency. It should also be noted that sports require not only physical skills but also mental resilience.

The determinants of sports performance encompass various components and differing levels of importance specific to different sports. Each sport has its unique dynamics, requirements, and performance criteria, which means that athletes must be able to cope with adverse factors they may encounter during training or competition.

In addition to individual factors such as the athlete's conditioning level, nutrition habits, and health status, environmental factors such as the condition of the playing surface and weather conditions also significantly impact sports performance. For example, when an athlete maintains a healthy nutrition regimen and achieves an adequate level of conditioning, their performance will improve; however, adverse environmental conditions or health issues may diminish this performance.

In this context, in order to optimize athletes' performance, it is essential to consider not only training programs but also nutrition plans and environmental conditions. Adopting a multidimensional approach for the sustainability of performance is critically important for enhancing athletes' achievements (Venhorst et al., 2018).

Factors Affecting Sports Performance

Enhancing sports performance is undoubtedly one of the most emphasized topics for

athletes and coaches. Improving performance directly impacts not only competition results but also the overall development of athletes. The various actions an athlete takes before, during, and after training or competition are among the factors that can positively or negatively influence their performance. In this context, one of the primary goals of athletes is to identify the factors that affect performance and manage them in a way that contributes positively. For example, elements such as structuring the training program, reviewing nutrition habits, and mental preparation are among the factors that directly influence performance.

When examining the factors affecting athletes' performance, it becomes evident that not only physical conditioning and technical skills but also psychological factors, environmental conditions, and social support systems play significant roles. Therefore, efforts to enhance performance require a multidimensional approach (Weinberg and Gould, 2007). This multifaceted examination allows coaches to develop effective strategies in the development processes of athletes, ultimately contributing to achieving higher performance levels.

The Impact Of Internal And External Factors On Sports Performance

Factors affecting sports performance can be generally classified into two main groups: internal and external factors. Each of these factors plays a significant role in determining the performance levels of athletes.

Internal Factors

1. **Physical Structure:** The genetic makeup, age, skill level, and gender of athletes are intrinsic components that directly affect performance. Genetic makeup determines an individual's physical abilities, while age is critically important for development and conditioning.
2. **Psychological Variables:** Psychological factors such as stress, anxiety, worry, tension, and aggression can influence athletes' mental states, thereby shaping their performance. Such psychological elements can directly affect an athlete's concentration and motivation.
3. **Physiological Characteristics:** Energy metabolism, cardiovascular, and respiratory system performance play a determining role in athletes' endurance and efficiency during physical activities. Maintaining these characteristics at an optimal level contributes to improved performance.
4. **Bio-motor Characteristics:** Attributes such as strength, speed, endurance, flexibility, and coordination are fundamental components of athletes' physical abilities. The development of these characteristics has the potential to enhance athletes' effectiveness and performance (Walker and Nordin, 2010; Bali, 2015).

External Factors

1. **Nutrition Habits:** The dietary patterns of athletes have a direct impact on their energy levels and overall health. Adequate and balanced nutrition is crucial for sustaining performance.
2. **Family-related Issues:** Financial constraints and familial problems can adversely affect athletes' psychological states and motivation. Such circumstances can create additional pressure on the athlete.
3. **Coaching and Management Factors:** The experience, education, and management skills of coaches play a decisive role in the development of athletes and the enhancement of their performance levels. Effective coaching can unlock an athlete's potential.
4. **Equipment Quality:** The inadequacy or poor quality of equipment stands out as an

external factor that negatively impacts athletes' performance. The use of appropriate and high-quality gear can enhance athletes' effectiveness.

5. Environmental Factors: Elements such as climate, weather conditions, altitude, surface conditions, and spectators directly influence athletes' performances. The suitability of these factors can positively affect performance.

6. Bad Habits: Negative habits such as alcohol, smoking, and drug use can adversely affect athletes' physical and mental health, thereby diminishing their performance.

7. Sleep Patterns: Adequate sleep significantly influences the physical and mental performance of athletes. Regular and quality sleep can accelerate recovery processes and enhance performance (Wilmore et al., 2008; Siegel and Laursen, 2012).

In conclusion, the interaction between internal and external factors affecting athletic performance plays a critical role in determining the success of athletes. Careful examination and management of these factors can assist athletes in maximizing their potential and enhancing their performance.

Performance Variability In High-Intensity Exercises

High-intensity physical activities can lead to significant changes in both the physical and psychological states of athletes. These changes are considered important factors that affect the overall performance of athletes. Below are the key parameters that are regarded as indicators of performance decline in athletes.

1. Decrease in Running Duration and Speed
2. Shortening of Walking and Running Distances
3. Reduction in Bio-motoric Characteristics
4. Deterioration in Reaction Time
5. Increase in Perceived Difficulty.
6. Increase in Blood Pressure
7. Delayed Decrease in Heart Rate
8. Increase in Body Temperature

These factors are defined in the literature as elements leading to a decline in athletes' performance and represent critical criteria that must be considered in performance monitoring (Enoka & Duchateau, 2016; Jones et al., 2017). It is essential for athletes to optimize their training programs by taking these variables into account, as this can significantly enhance their performance.

Fatigue

Fatigue is defined as the inability to continue performing at the same intensity due to physical exertion, resulting in a decline in performance (Coutts et al., 2007). According to another definition, fatigue is considered one of the important factors affecting performance and is expressed as a reduction in maximal effort (Knicker et al., 2011). Sogaard (2008) describes fatigue as a phenomenon characterized by a gradual decrease in muscle force capacity or a measurable reduction that signifies the endpoint of sustained activity. In this context, it can be stated that fatigue is directly proportional to the intensity of exercise (Sogaard et al., 2016).

Fatigue: Causes And Contributing Factors

Fatigue is a critical aspect in many contexts, presenting a complex structure that is studied across various scientific disciplines (Coutts et al., 2007). Therefore, it can be stated that fatigue is a fundamental element to be considered in the management of

training and performance for athletes. The factors that lead to fatigue and contribute to its development can be classified as follows, in direct correlation with the intensity of exercise.

Table 1.

Factors Contributing to Fatigue (Enoka & Duchateau, 2016)

NERVOUS-MUSCLE ACTIVATION	PHYSIOLOGICAL INDICATORS	PSYCHOLOGICAL
Changes in strength capacity	Decrease in glycogen stores	Decrease in focus
Decrease in muscle contractions	Increase in metabolic acidosis	Impaired decision-making ability
Motor neurons	Decrease in blood sugar levels	Motivation
Afferent feedback	Increase in body temperature	Sleep quality

Factors Influencing Fatigue

- * Individual's age and gender differences
- * Fitness level
- * Dietary habits and the types of consumed foods
- * Adequate and quality sleep
- * Circadian rhythm
- * Psychological factors
- * Social quality of life
- * Current health status (Finsterer & Mahjoub, 2014).

It can be emphasized that fatigue is influenced by a specific set of factors, each playing a significant role in an individual's overall performance and health. Given that fatigue is affected by individual differences such as age, gender, fitness level, and dietary habits, as well as external factors like circadian rhythm and psychological state, it is evident that athletes and individuals need to develop strategies for managing fatigue. Moreover, classifying fatigue could contribute to the development of more effective assessment and intervention methods in sports sciences and health fields (Fatigoni et al., 2015).

Classification of Fatigue

Fatigue, being a multifactorial symptom with both biological and psychosocial characteristics, can be classified into different types based on various aspects (Fatigoni et al., 2015).

Table 2.

Classification of Fatigue by Type (Zwarts et al., 2008)

Based on Structure	Based on Duration	Based on Pathophysiology
- Physiological: central and peripheral, - Perceived: physical and psychological	- Acute, - Subacute, - Chronic	- Pathophysiological: primary and secondary, - Non-pathophysiological

Exercise And The Endocrine System

Hormonal changes during exercise are initiated by the influence of the central nervous system. In this process, the secretion of growth hormone (GH), adrenocorticotrophic hormone (ACTH), prolactin (PRL), antidiuretic hormone (ADH), and thyroid-stimulating hormone (TSH) increases. Additionally, while insulin secretion is suppressed, the release of renin, angiotensin, ADH, pancreatic polypeptide (PD), glucagon, parathyroid hormone (PTH), and gastrin is stimulated. ACTH, in particular, influences the adrenal cortex to promote hormone release (Astrand, 1992). The intensity of the hormonal response depends on the individual's pre-exercise state and capacity (Astrand, 1992; Foss, Keteyian, & Fox, 1998).

Hormones are synthesized in very small amounts by endocrine glands on a daily basis and are released into the bloodstream, where they act as biocatalysts, exerting specific effects on target tissues. Despite their low concentrations in the blood, these hormones are measured in micrograms, nanograms, or picograms (Rowell & O'Leary, 1990; McArdle & Jackson, 2000).

In this context, monitoring hormonal changes during exercise is crucial for evaluating performance and enhancing individuals' physical capacities. Hormones play a significant role in post-exercise recovery, energy metabolism, and overall health. Therefore, the secretion and effects of hormones are key factors to consider when aiming to optimize athletic performance.

At the onset of physical activity or exercise, a disruption occurs in the body's internal conditions, leading to an imbalance in homeostasis. In response, the body activates autonomic systems that help maintain stable internal conditions. One of the primary mechanisms engaged to restore balance when homeostasis is disturbed is the endocrine system. By responding to stress, the endocrine system triggers a series of hormonal changes throughout the body. In this context, the balanced functioning of organs and body systems is regulated by hormones produced in specific areas of the body (Kraemer & Rogol, 2005; Meriç et al., 2014).

As exercise intensity increases, there is a rise in serum levels of various hormones, including catecholamines such as epinephrine, norepinephrine, and dopamine, as well as growth hormone, prolactin, testosterone, cortisol, ACTH, and endorphins (Anthony, 2006). It is particularly noted that after high-intensity exercises, these hormones help reduce fatigue during the recovery process by regulating blood flow, fluid balance, heart rate, and respiratory rate.

After the cessation of exercise, as the stress on the body decreases, hormones like epinephrine and norepinephrine quickly return to resting levels. However, hormones that indicate physiological stress, such as cortisol, ACTH, CRH, and endorphins, take longer to return to baseline levels (Ünal et al., 2001; Mori et al., 2004; Manoogian & Panda, 2017). It is believed that the rapid clearance or reduction of these elevated hormones following high-intensity exercise could contribute to faster recovery for athletes. This evaluation highlights the importance of hormonal responses in the recovery process after intense exercise and suggests that these processes are critical for improving performance.

Physiological Recovery After Exercise

After exercise, the increase in metabolic rate continues for a while, during which phosphagen and carbohydrate stores are replenished, myoglobin becomes saturated with oxygen, and lactic acid accumulated in the tissues is removed. This period is known as "recovery." The sustained energy consumption following exercise is essential for the recovery process (Cochrane, 2004; Özdemir, 2006). To better explain the metabolic

recovery process, it is important to focus on the following four key areas (Ergen, 1992; Wilmore & Costill, 1999):

1. Restoration of resting oxygen levels
2. Replenishment of energy sources
3. Removal of lactic acid
4. Renewal of oxygen reserves

These points detail how the body restores its energy and oxygen balance after exercise, explaining the biological foundations of the recovery process.

Restoration of Resting Oxygen Levels

During high-intensity exercise, the total oxygen content in venous blood, supported by myoglobin in the muscles, is approximately 600 ml. In trained athletes, the values defined as “oxygen debt” can reach up to 30 liters. This suggests that the amount of oxygen in the body is not sufficient to create such a large debt when compared to oxygen consumption post-exercise (Özdemir, 2006; Fox, 1999). After training, as the body is no longer engaged in exercise, its energy requirements decrease. However, oxygen consumption remains elevated for a period following exercise. This increased oxygen consumption, which exceeds the amount typically consumed at rest, is referred to as “excess post-exercise oxygen consumption” (EPOC). EPOC encompasses processes such as the replenishment of energy stores and the removal of lactic acid that accumulates during training, ultimately facilitating the body’s return to its pre-exercise state (Özdemir, 2006; Muratlı, 2005). This phenomenon underscores the significance of the recovery process after exercise and elucidates how oxygen contributes to the body’s energy balance.

Replenishment of Energy Sources

The resynthesis of muscle glycogen lost during exercise is described as a two-phase process. The first phase, termed the “fast phase,” occurs within the first 30 to 60 minutes following exercise, during which muscle glycogen is rapidly replenished. This swift glycogen synthesis occurs through an insulin-independent mechanism, arising from the sudden decrease in energy demand after exercise, which directs glucose toward glycogen synthesis rather than glycolysis. In the second phase, referred to as the “slow phase,” glycogen synthesis continues due to the increased insulin sensitivity of muscle tissue. This phase progresses at a markedly slower rate compared to the fast phase, and the process slows further as muscle glycogen stores become replenished (Özdemir, 2006).

Removal of Lactic Acid

The removal of lactic acid requires additional energy after exertion, which is most effectively provided through aerobic metabolism. Lactic acid can be converted into glucose, glycogen, and protein, and it can also be metabolized into water and carbon dioxide. The heart and skeletal muscles possess the ability to utilize lactic acid as an energy source. Evidence suggests that post-exercise cooling methods can reduce the time required for lactic acid removal following exercise. Determining the recovery time after intense exercise is critical for trainers. Engaging in training before the body’s recovery processes are completed and energy stores are replenished may not only fail to promote development but can also lead to harm (Özdemir, 2006; Ergen, 1992). The most important point in winning or losing is to work and make an effort. Afterwards, success often comes naturally. However, it should also be known that working and making efforts will not always produce successful results. When the result fails despite the team’s best efforts; It should be accepted and accepted that the entire Team in front of you deserves

to win more than you. In other words, it should be accepted that the other team made fewer mistakes and the luck factor was on the side of this team (Erdoğan, 2023; Erdoğan, 2022).

Replenishment of Oxygen Sources

Myoglobin, a protein that facilitates the transport of oxygen to muscle cells, shares a structure similar to that of hemoglobin and is found in higher concentrations particularly in red muscle fibers. Research indicates that the amount of oxygen bound to myoglobin in the body is approximately 11 ml per kilogram of muscle mass, totaling around 300-350 ml overall (Cochrane, 2004). During exercise, myoglobin plays a crucial role in supplying oxygen to tissues prior to the activation of the oxygen transport system. While mitochondria are critical for energy production within muscle fibers, they also play significant roles in the diffusion of oxygen from hemoglobin in capillaries. The capacity of myoglobin to bind oxygen is directly related to the partial pressure of oxygen in the surrounding environment. In this context, myoglobin exhibits a greater affinity for oxygen at low partial pressures, whereas higher partial pressures promote the release of oxygen. Therefore, the transport and utilization of oxygen in muscle tissue are determined by the effective interaction between mitochondrial functions and oxygen diffusion in capillaries (Özdemir, 2006; Ergen, 1992).

Physical Recovery

The human organism is structured to maintain the internal balance necessary for life, enabling the organs and body systems to work together in a coordinated manner. This functional operation is achieved through the varying levels of activity of certain organs. In contemporary sports that involve high exercise intensity, athletes often engage in multiple training sessions throughout the day and are subjected to demanding workloads (Amann et al., 2015). Such continuous loads or competitions can lead to a decline in athletic performance. In this context, repeated workloads without a fully effective physical recovery process can result in increased fatigue, sports injuries, and decreased performance (Taylor et al., 2016).

In the field of sports science, the concept of recovery plays a crucial role in describing the process of alleviating fatigue that occurs after training or competition. As emphasized by Barnett (2006), the physical, physiological, and mental reconstitution of athletes is considered a critical necessity for the sustainability of maximal performance. Recovery encompasses the effective removal of metabolic waste accumulated in the body after high-intensity workloads, as well as the physical and mental rejuvenation processes that allow athletes to return to their previous states. In this context, the systematic integration of effective recovery strategies into athletes' daily lives is essential for performance enhancement. Thus, it can be concluded that the implementation of regular and effective recovery methods is necessary for athletes to maintain optimal performance levels.

The general purpose of respiratory muscle exercises is to improve the functions of the respiratory muscles to increase the risk of shortness of breath and to prevent shortness of breath during exercise. It is based on improving performance. For this reason, rehabilitation is often while used for purposes²⁴, recently it has been used by sports scientists for athletes, frequently used acutely and chronically in order to increase performance is being implemented (Bilgiç, Özdal and Vural, 2022).

The physical recovery phase is a critical process that enables athletes to recover from

fatigue experienced after training or competition and facilitates the replenishment of their energy metabolism (Bishop et al., 2008). Energy expenditure during exercise varies depending on the intensity of the activity, and accordingly, the energy sources utilized by the body also differ. Following the completion of training, the organism begins to repair the damage incurred during exercise based on the energy sources used. Continued energy consumption after exercise emerges as an essential stage for the healthy progression of the recovery process. In this context, the reconstitution of energy metabolism is vital for the sustainability of athletes' physical performance.

To explain the metabolic aspects of the recovery process, certain key criteria must be considered. Among the prominent criteria highlighted in the literature are:

- O₂-myoglobin oxygenation,
 - The return of energy sources to resting levels,
 - The removal of lactic acid as a waste product from the blood and muscle,
- along with the clearance of the oxygen debt (Günay et al., 2013; Murray et al., 2018). These criteria are critical for understanding and optimizing athletes' recovery processes.

Objectives of Physical Recovery

The primary goal of the recovery process is to heal the damage incurred during training or competition and to minimize fatigue, effectively eliminating it. The fundamental objectives of an effective recovery process include:

- Restoring the basic functions of the organism,
- Re-establishing the body's internal balance to resting levels,
- Replenishing energy stores depleted as a result of high-intensity activities,
- Returning enzyme functions to normal levels.

Effective recovery can provide the following benefits:

- Acceleration of local or general blood flow,
- Removal of accumulated waste products from the blood and muscles,
- Reduction of inflammation and edema resulting from trauma,
- Decrease in muscle stiffness and pain thresholds,
- Increase in muscle flexibility,
- Faster recovery of physical conditioning,
- Enhancement of the recovery process by reducing the onset of delayed muscle soreness.

These parameters emerge as significant factors that determine the efficiency of the recovery process (Bishop et al., 2008; Cochrane, 2004).

Factors Influencing the Physical Recovery Process

Factors that affect the recovery process can be classified as follows:

- Biological age, gender, and the individual's experience,
- Current health status and whether a sports injury or disability is ongoing,
- Maximal oxygen consumption capacity,
- Genetic factors (e.g., distribution of muscle fibers),
- Energy metabolism of actively performed activities,
- Requirements and characteristics of the sport being practiced,
- Similar studies related to overtraining,
- The individual's dietary habits and disruptions in fluid-electrolyte balance due to fluid loss,

- Environmental factors (temperature, altitude, climate, field and surface conditions),
 - Psychological factors (anxiety, fear, stress, motivation),
 - Personal lifestyle (sleep patterns, alcohol and tobacco use, social environment),
 - Jet lag effects, referring to changes and differences that occur in the body due to shifts in time zones as a result of travel.
- These factors significantly influence the effectiveness of the recovery process (Jemni et al., 2003).

Classification of Physical Recovery

In general terms, recovery can be categorized into three main types based on duration. This classification is important for effectively managing recovery and enhancing individuals' performance.

Quick Recovery Time

The type of recovery that occurs between repeated activities in short intervals plays a significant role, especially in dynamic sports such as walking competitions. This process can be defined as the recovery that takes place between each step. The aim during this phase is to replenish ATP energy in the muscles and remove metabolic waste products. This recovery process enables walking athletes to take quicker steps and complete competition distances in better times, facilitated by recovery in the lower extremities. Therefore, quick recovery is critical for enhancing performance in such training and competitions (Bishop et al., 2008).

Short-Term Physical Recovery

Short-term recovery refers to the rest periods between sets during repeated speed or strength exercises. This process allows the individual to rest after performing a movement, enabling subsequent performance to continue without loss. Effective recovery during high-intensity activities permits continuation of the activity without any degradation in performance. For instance, a scenario in which an athlete lifts a 50 kg weight, takes a short rest to renew energy metabolism, and then lifts the same weight again exemplifies this situation (Gümüşdağ et al., 2015).

In a study conducted to investigate the effectiveness of this recovery process, similar activities were performed with varying recovery durations. The results indicated that recovery times of 15 and 30 seconds negatively affected performance compared to recovery durations of 60 and 120 seconds (Gümüşdağ et al., 2015). These findings provide significant insight into determining the effectiveness of short-term recovery.

Long-Term Physical Recovery

This type of recovery is characterized by the ongoing process that occurs between two training sessions or competitions and is defined as complete recovery. Athletes in various sports may experience significant fatigue when participating in multiple training sessions or competitions within the same week or even on the same day. This situation clearly underscores the critical importance of the post-exercise recovery process (Bishop et al., 2008).

For instance, insufficient rest following a low-intensity exercise can negatively impact

subsequent performance. It is recommended to allow a rest period of at least 8 to 24 hours after completing aerobic activities. Complete recovery typically requires at least 24 hours or more. Additionally, the replenishment of depleted energy stores emerges as a significant factor influencing this process (Sporer and Wenger, 2003; Burke et al., 2006).

Physical Recovery Methods

To enable athletes to achieve efficient physical recovery, coaches, researchers, and sports scientists have long conducted various studies to identify the most effective recovery methods. Understanding the effects of implemented recovery methods and the underlying principles behind them is of great importance. In recent years, a variety of methods have been employed to ensure effective physical recovery and expedite this process, especially after intense training or competition (Haff and Triplett, 2015).

Currently, the following recovery methods are commonly used and considered effective: Commonly Used Recovery Methods

- Traditional Recovery: Activities such as exercise, jogging, stretching, walking, and low-intensity running.
- Massage: Classic massage, sports massage, and ice massage.
- Cryotherapy: Cold applications and cold water immersion.
- Hydrotherapy: Water-based therapies.
- Contrast Applications: Alternating use of cold and hot treatments.
- Nutrition: Fluid intake and the use of ergogenic aids.
- Acupuncture
- Ultrasound
- Compression Garments
- Use of Anti-inflammatory and Analgesic Medications
- Hyperbaric Oxygen Therapy
- Electromyostimulation: Electrical stimulation of muscle tissue.
- Psychological Relaxation Therapy
- Lifestyle Improvement
- Combined Recovery Methods

These methods are frequently employed to enhance athletes' recovery processes and improve their performance (Wilcock et al., 2006; Tessitore et al., 2007).

Impact of Recovery on Metabolic Response

Lactic acid is produced when the intensity of exercise exceeds metabolic thresholds and glucose utilization accelerates. The accumulation of lactic acid leads to a decrease in pH levels, negatively affecting muscle contractions and inhibiting the enzyme phosphofructokinase. Consequently, energy and metabolite levels decline due to the slowing of the glycolysis process. The buildup of lactic acid in the muscles and blood causes fatigue, thereby decreasing performance. Therefore, the removal of lactic acid from the body during rest is crucial (Kerstholt, 2015; Stupnicki et al., 2010).

Post-exercise recovery occurs through the resynthesis of energy substrates, removal of metabolic waste, increased oxygen consumption, reduction of body temperature, and maintenance of fluid-electrolyte balance (Fox, 1998). Restoring the organism to its pre-exercise state and allowing for recovery are fundamental goals of post-exercise recovery. This process reduces fatigue, minimizes the risk of injury, and accelerates recovery time between training sessions. The removal of lactic acid from the body initiates the recovery and rest process.

The process of removing lactic acid from the body after maximal training or competitions takes approximately 2 hours with passive rest and about 1 hour with active recovery (Brent, 1994). This process is characterized by an increase in cardiac output and blood flow, accompanied by a rise in systolic blood pressure, pulse rate, and heart rate, while diastolic pressure decreases (Chidakel et al., 2005).

Furthermore, the absorption of glucose and increased glucose uptake in cells lead to a rise in insulin resistance, stimulating carbohydrate metabolism (Güllü et al., 2004). While findings indicate that training can enhance thyroid metabolism in sedentary individuals, there is insufficient reporting to suggest that athletes fall within this risk group (Sterling, 1978; Akkoyunlu et al., 2002). This situation highlights the importance of evaluating athletes' metabolic adaptation processes and training programs.

The metabolic response of lactate during recovery, regardless of gender, remains consistent in substrate metabolism and active recovery (Horton et al., 2002). Hormonal fluctuations do not significantly impact the changes in fuel metabolism affecting the rate of lactate removal from the blood and muscles. Comparatively, during and after recovery in the lactate fast phase (LF), a higher rate of lactate elimination has been observed when contrasted with the moderate intensity phase (MF) (Jurkowski et al., 1981; Güneş, 1995).

Delayed Onset Muscle Soreness (DOMS)

The term Delayed Onset Muscle Soreness (DOMS) was first defined by Hough as a syndrome experienced by individuals after exercise, typically felt about 8 to 10 hours post-exercise. This condition not only contributes to fatigue but also leads to various other effects. Since then, research has continued to investigate the physiological mechanisms underlying this distressing condition following exercise (Böning, 1995).

During high-intensity exercises, excessive strain can cause micro-tears in the weak myofibrils of muscle fibers, leading to the sensation of delayed muscle soreness. These tears result in circulatory disturbances within the muscle tissue and subsequent edema. As a result of ongoing reactions, ion imbalances that trigger pain in the muscle tissue are observed (Gulick & Kimura, 1996).

DOMS varies depending on the type of exercise, as well as its intensity and duration (Armstrong, 1990). This variability is an important factor for optimizing athletes' training programs and recovery processes.

Delayed Onset Muscle Soreness (DOMS) begins to be felt approximately 8 to 10 hours after activity or exercise, reaching its peak pain level within 24 to 48 hours, and its effects can last for 5 to 7 days post-exercise (Hody et al., 2013; Finsterer, 2012). Muscle fatigue is defined as a reversible decrease in performance during exercise, showing a significant reduction in the initial hours of recovery. In contrast, while muscle damage indicates a decline in performance, the recovery process from muscle damage is generally slower compared to muscle fatigue. The key distinction between muscle fatigue and muscle damage lies in the fact that muscle fatigue is shorter in duration and does not cause structural damage to myofibrils (Clarkson & Sayers, 1999).

Assessment of Delayed Onset Muscle Soreness (DOMS)

The evaluation of DOMS post-exercise involves the following parameters:

- a) Range of Motion (ROM)
 - b) Muscle Function and Strength Decline
 - c) Perceived Pain Level
 - d) Elevations of Specific Muscle Proteins in Blood (McHugh et al., 1999).
- These assessments provide critical insights into the effects of DOMS and inform strategies for its management.

The Relationship Between Recovery And Exercise

Recovery is defined as the process by which the organism returns to its normal state after exercise. During periods of competition or training, the optimal reduction of fatigue levels caused by intense exertion is expressed as psychological and physical rejuvenation aimed at restoring athletes' mental and physical conditions to their previous levels (Bishop et al., 2008). The primary goal of post-exercise recovery is to help athletes return to their pre-exercise conditions and to rest all muscle groups and bodily systems (Juel, 1998). In this context, the recovery process is viewed as a mechanism for restoring the muscles and entire body systems to their pre-exercise state (Fox et al., 2011). This process is crucial for ensuring performance continuity and reducing the risk of injury among athletes.

Effective recovery is a critical period following training or competition, vital for replenishing lost energy reserves and alleviating fatigue. Insufficient recovery can lead to muscle injuries and chronic fatigue among athletes, which may result in them being sidelined from their sports for a certain period. It is known that athletes in various sports engage in demanding training sessions at least 2-3 times a day (Bompa & Gregory, 2000). Such intense training, when combined with psychological and physiological stress, exceeding three hours of daily training, and factors such as repeated overloads, deficiencies in training systems, lack of variety in training loads, and insufficient rest days, further elevates stress levels (Alemdaroğlu & Koz, 2011). Therefore, it is critical for athletes to effectively manage their recovery processes to sustain their performance and reduce the risk of injury.

Professional athletes in league competitions may participate in international tournaments, leagues, or national events within the same week. The journeys undertaken after these competitions also constitute a separate source of stress. These factors can lead to temporary declines in athletic performance (Reilly & Ekblom, 2005; Waterhouse et al., 2003; Barnett, 2006). If complete recovery is not achieved following intense workloads, fatigue can become chronic, potentially resulting in injuries (Silva, 1990). Therefore, it is crucial for professional athletes to optimize their recovery processes following training and competitions in order to maintain their performance levels and ensure their long-term health. The psychological and physiological recovery of athletes should be considered an integral part of training. To achieve optimum performance, it is essential to avoid excessive training methods (Alemdaroğlu & Koz, 2011). Sports scientists and coaches have long conducted research to ensure that athletes achieve complete recovery (Bompa & Gregory, 2000).

To better prepare athletes for their next competition and enhance their performance, systematic recovery programs must be developed and implemented. The optimal balance between loading and recovery plays a critical role in improving athletes' performance. In this context, various activities such as immersion in water at different temperatures,

massage, stretching, showering, aerobic running, contrast baths, and walking in a pool have the potential to accelerate the recovery process (Burke, Loucks, & Broad, 2006). The effective integration of such activities promotes muscle relaxation while enhancing blood flow, thereby accelerating the elimination of metabolic waste. Additionally, these methods provide not only physical recovery but also psychological relaxation, thus supporting the overall well-being of athletes. Therefore, the implementation of an effective recovery strategy is vital for the sustainability of athletes' performance and the reduction of injury risk (Burke, Loucks, & Broad, 2006).

Respiratory Physiology During Rest and Exercise

The healthy functioning of the respiratory system depends on the coordination of lung mechanics, respiratory muscles, and chest wall movements (McConnell, 2011; Tukanova et al., 2020). At rest, pressure fluctuations descend into the abdominal cavity, increasing volume and creating negative pressure in the thoracic cavity. This process occurs due to the autonomic contractions of the diaphragm (West, 2000). When the diaphragm contracts, the volume of the thoracic cavity increases while the air pressure in the alveoli decreases, facilitating airflow. This mechanism plays a critical role in meeting the energy needs of the body at rest by facilitating the transfer of oxygen from the alveoli into the bloodstream. During exercise, however, the respiratory muscles must exhibit increased activity, leading to enhanced respiratory rate and depth. Consequently, these processes induce significant physiological changes aimed at meeting the body's oxygen demand and increasing carbon dioxide elimination. Therefore, respiratory physiology is a fundamental component that affects athletes' performance.

The negative pressure generated by the contraction of the diaphragm facilitates inspiration by increasing airflow into the lungs (Aliverti, 2008). Expiration during rest involves the energy expended to achieve thoracic extension, which occurs passively through the elastic properties of the respiratory system, allowing the functional residual capacity to be reached following the cessation of inspiration (Dominelli & Sheel, 2012).

This process begins with the relaxation of the diaphragm and other inspiratory muscles; as these muscles return to their anatomical positions, thoracic volume decreases relative to inspiration, leading to an increase in intrathoracic pressure. This increase facilitates the expulsion of air from the lungs, resulting in expiration. Therefore, the respiratory mechanism during rest plays a significant role in both the generation of negative pressure and energy expenditure. These processes enhance the efficiency of the respiratory system by regulating oxygen intake and carbon dioxide elimination.

The elastic structure of the respiratory mechanism refers to the energy required for the anatomical components related to respiration to deform, while resistive respiration defines the energy necessary to overcome the resistance to airflow in the airways (Dominelli & Sheel, 2012). During exercise, respiratory muscles must perform both elastic and resistive work. The expansion of the lungs and thoracic wall occurs through an elastic recoil mechanism that increases the pressure of the air entering the airways during high airflow (Sheel & Romer, 2012).

The respiratory workload during exercise is based on the principle of minimal effort. This principle indicates that the natural ventilatory response during exercise is associated with the minimum energy requirements of the respiratory muscle system. This notion is

supported by experimental data and mathematical modeling (Batzel et al., 2012). Ventilation occurs within a range of lung volumes that provides the highest total lung compliance during exercise. This refers to the pressure changes required to achieve a change in volume. The dynamics at play during exercise enhance the efficiency of the respiratory system, optimizing oxygen uptake while facilitating the expulsion of carbon dioxide.

In conclusion, the management of respiratory workload during exercise plays a critical role in enhancing athletes' performance. In this context, considering the effectiveness of respiratory mechanisms in the design of exercise programs is essential for achieving optimal performance.

The combination of increased tidal volume and respiratory frequency occurs at a level that minimizes dead space ventilation. This enhances the efficiency of the respiratory system, optimizing oxygen uptake while facilitating the expulsion of carbon dioxide (McConnell, 2011).

At the onset of exercise, alveolar ventilation is increased to meet the demand for maintaining acid-base balance close to homeostatic levels. During this process, arterial oxygen levels are expected to remain stable despite rising demand, while a decrease in venous oxygen tension is observed. Additionally, any increases in carbon dioxide production must be effectively eliminated (Des Jardins, 2012).

The changes in respiratory mechanisms that occur at the onset of exercise are associated with neural changes in the brainstem centers that actively increase oxygen intake and coordinate the respiratory muscles moving the thoracic cavity (Aliverti, 2008). These neural adaptations optimize oxygen uptake during exercise, ensuring the efficient continuation of bodily functions. Consequently, these dynamic processes play a critical role in sustaining exercise performance.

To maintain metabolic efficiency during exercise, it is essential to preserve the respiratory regulation without excessive demand on alveolar ventilation (John, 2011). Adaptations in respiratory mechanisms to meet the increased ventilation demand are reflected in changes in both tidal volume and respiratory frequency, leading to increases in minute ventilation. Minute ventilation progressively rises with the increase in exercise intensity (McConnell, 2011).

During light exercise, the increased load on inspiratory muscles and a moderate rise in respiratory frequency lead to significant changes in tidal volume. This occurs as the respiratory workload increases, resulting in an elevation in respiratory frequency to compensate for changes in tidal volume platitudes when reaching 60% of vital capacity. These dynamic mechanisms maximize oxygen uptake throughout the exercise while effectively facilitating carbon dioxide elimination. Therefore, these adaptations play a critical role in optimizing exercise performance.

Changes in tidal volume are associated with the expansion of the thoracic cavity, which allows for the utilization of both inspiratory lung volume and end-expiratory lung volume. This process occurs through the coordinated action of the respiratory muscles, enabling an effective increase in alveolar ventilation. The expansion of the thoracic cavity triggers changes in intrathoracic pressure, facilitating airflow and thereby optimizing oxygen

intake while supporting carbon dioxide expulsion. This dynamic significantly enhances the efficiency of respiratory mechanisms, playing a crucial role in exercise performance.

Determination of Respiratory Muscle Fatigue

Peripheral respiratory muscle fatigue can be assessed through non-invasive voluntary evaluation methods, such as measuring maximal inspiratory pressure (MIP), maximal expiratory pressure (MEP), maximal transdiaphragmatic pressure, or cough pressure. These measurements are utilized to detect respiratory muscle fatigue following high-intensity exercise (Bostancı et al., 2019; Romer et al., 2002; McConnell, 2011; Volianitis et al., 2001).

However, these techniques have certain limitations; results may vary based on individual effort levels and can be influenced by learning effects (ATS/ERS, 2002). Additionally, respiratory muscle fatigue can be evaluated through frequency domain analysis of electromyography (EMG) signals recorded via surface electrodes placed on the relevant muscle group or by using an electrode catheter inserted intranasally into the participant's nasal cavity to reach the lower esophagus (Luo et al., 2008). There are ongoing discussions regarding the validity of EMG power spectrum measurements. Neural or sarcolemmal events may contribute to spectral shifts associated with fatigue, and these shifts can occur independently of the processes related to excitation-contraction coupling. Consequently, a weak correlation has been observed between EMG spectral shifts and mechanical fatigue indices.

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