

Respiratory System and Performance

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Introduction

The efficiency of the respiratory system, which is considered one of the important criteria in determining individuals' work and performance capacity, also holds significant importance in athletic performance. As the oxygen requirement of tissues increases during physical activity, the amount of oxygen delivered from the respiratory system to the body must also increase. The rising demand of tissues necessitates that the respiratory system functions regularly and adequately to tolerate the excess carbon dioxide produced and the metabolic heat generated (Fox, et al., 2012). The primary function of the respiratory system is to maintain the partial pressures of oxygen (O_2) and carbon dioxide (CO_2) in arterial blood. During exercise, there is an increased O_2 consumption (need to be protect) and an increased CO_2 (need to be eliminate) production by the working muscles that must be managed. Therefore, the primary reason for the increased ventilation during exercise is to enhance alveolar ventilation in proportion to O_2 consumption and CO_2 production, while maintaining acid-base homeostasis. The respiratory system achieves this with remarkable precision and minimal energy cost to the body through the coordination of lung parenchyma, airways, respiratory control systems, and respiratory muscles (Mills, 2013).

Aim of The Study

The aim of this study is to summarize the effects of respiratory system on athletic performance.

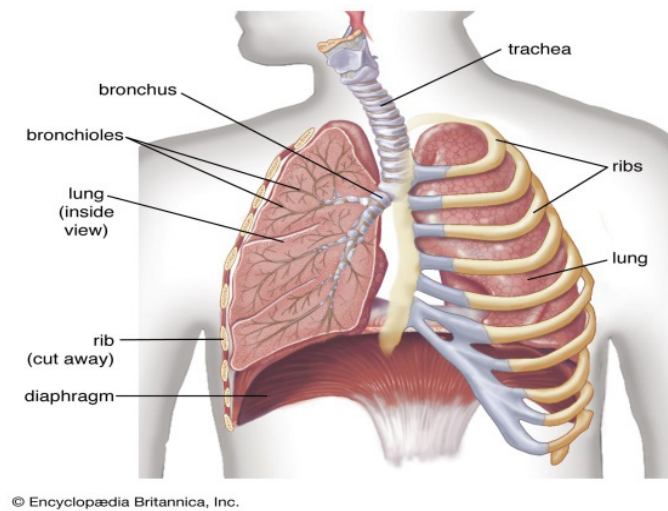
Respiratory System Organs

The air we breathe passes through a series of airways before reaching the millions of tiny sacs deep inside the lungs. The respiratory system consists of the nose, nasal cavity, pharynx, larynx, trachea, bronchi and lungs. This system is usually divided into the upper respiratory system (nose, nasal cavity, pharynx), which includes structures in the head and neck, and the lower respiratory system (larynx, trachea, bronchi and lungs), which consists of structures in the thorax (Marieb, 2008; Tate, 2011; Saladin ve ark., 2018). Solunum sistemi bireyin günlük yaşamı, iş performansı ve sportif performans kapasitesi açısından oldukça önemlidir (Vural, Özdal and Pancar, 2019). Within lung tissue, there are numerous small air sacs (alveoli) where respiration occurs. The thorax, pleura, and respiratory muscles allow for the expansion and contraction of the lungs, facilitating the process of breathing. The lungs do not have the ability to move actively; their movements are provided by the rib cage and respiratory muscles. One structural feature of the respiratory organs is that many of them have a cartilaginous framework in their walls. Therefore, they do not have the ability to constrict and always contain air within them. (Demirel & Koşar, 2002).

Additionally, through the respiratory organs:

- Foreign particles in the inhaled air are filtered out.
- Along with the CO_2 produced from the combustion of carbon, water vapor and heat are also generated. This heat helps maintain body temperature between $36.5\text{-}37.5^\circ\text{C}$.
- Sounds are produced as a result of the vibrations of the air passing through the respiratory pathways.
- The sense of smell is facilitated, and blood pH is regulated.
- Gas exchange between air and blood in the lungs is ensured (Akgün, 1975; Aktümsek, 2001).

Figure 1
Thoracic Cage



Respiratory Mechanics

The lungs and the rib cage that encase them are elastic structures. In reality, there are no structures connecting the lungs to the walls of the rib cage. The force that pulls the lungs toward the rib cage and prevents them from separating from the chest wall is the fluid and negative pressure present between the two pleural layers. (Faller & Schuenke, 2000). The negative pressure between the pleural layers prevents the lungs from separating further from the rib cage during exhalation (expiration) and pulls the lungs back toward the chest wall. If, for any reason (such as injuries, lung diseases, or rib fractures), air enters between these two layers (pneumothorax), it causes the lungs to collapse. The entry of air eliminates the negative pressure in the pleural space. (Decramer, 1999). Respiration consists of inspiration (inhaling) and expiration (exhaling). For inspiration to occur, the intrapulmonary pressure must be lower than the atmospheric pressure. Conversely, expiration requires a pressure change in the opposite direction. (Guyton & Hall, 2013).

Respiratory Muscles

The respiratory muscles are anatomically classified as skeletal muscle type. However, they differ from skeletal muscles due to their specialized functions. While skeletal muscles are designed to generate movement against mobility, respiratory muscles are specialized to overcome resistance and elastic load (Eston & Reilly, 2001). Skeletal muscles contract rhythmically only during movement, while respiratory muscles contract rhythmically continuously (Edwards & Faulkner, 1995). Respiratory muscles

are vital for life, and for this reason, they are resistant to fatigue, have a high oxidative capacity, a dense capillary network, and high blood flow (Decramer, 1999). Slow fibers (Type I), which have a high oxidative potential, are particularly suited for prolonged aerobic activities and are more resistant to fatigue. Fast fibers (Type II), on the other hand, are less sensitive to fatigue and are less efficient in oxygen use, making them beneficial for high-intensity, short-duration anaerobic exercise (Qaisar, Bhaskaran, & Van Remmen, 2016). The composition of respiratory muscles, with the presence of fast and slow fibers, reflects the type of task these muscles need to perform; that is, slow fibers are predominantly used during normal inspiration. However, when the respiratory rate increases, fast fibers are recruited. This change in muscle fiber recruitment has been clearly demonstrated in animal studies. (Cretterio et al., 1982; Sekiguchi et al., 2018).

Muscles Involved in Respiration

Respiration mechanically consists of inspiration and expiration. Inspiration is an active process that occurs with the help of respiratory muscles. Expiration, on the other hand, is a passive process that occurs due to the elastic properties of the chest wall and lungs. (Bartter, et al., 2003; Guyton and Hall, 2013). During inspiration and expiration, the rib cage and lungs expand or contract with the upward and downward movement of the diaphragm. The elevation and depression of the ribs also increase or decrease the anteroposterior diameter of the rib cage. Normal quiet breathing primarily involves this mechanism, facilitated by diaphragm movement. During inspiration, the contraction of the diaphragm pulls the lower parts of the lungs downward, resulting in lung expansion. In expiration, the diaphragm relaxes, and the elastic recoil forces of the lungs and chest wall, along with the compression from abdominal structures during forceful expiration, cause the lungs to shrink and air to be expelled. (Fox, et al., 2012; Hall, 2016). The diaphragm muscle performs two-thirds of the respiratory pump work. Its convex surface faces the rib cage, while its concave surface faces the abdominal cavity. The edges of the diaphragm are muscular, while the center is tendinous; upon contraction, its dome shape decreases and increases the vertical diameter of the thoracic cavity. The lungs expand downward, resulting in inspiration. Meanwhile, as the diaphragm is pushed downward, intra-abdominal pressure increases, pushing abdominal organs backward, relaxing the abdominal muscles, and causing the abdominal wall to expand outward. Respiration that occurs due to the movement of the diaphragm is referred to as diaphragmatic or abdominal breathing (Arıncı & Elhan, 1997; Bartter, Pratter, & Irwin, 2003). All the muscles that elevate the rib cage are classified as inspiratory muscles, while all the muscles that pull it downward are classified as expiratory muscles. The most important muscle of inspiration is the diaphragm (m. diaphragma). The key muscle that elevates the rib cage is the external intercostal muscle (m. intercostales externi). Additionally, the sternocleidomastoid muscle (m. sternocleidomastoideus), the serratus anterior muscle (m. serratus anterior), which lifts several ribs, and the scalene muscles (m. scaleni), which elevate the first two ribs, assist in inspiration. (Guyton and Hall, 2013). During maximal exercise, the trapezius muscle and the extensors of the neck and back are also thought to assist in inspiration. (Fox, et al., 2012). The most important muscles of expiration are the internal intercostal muscles (m. intercostales interni) and the rectus abdominis muscle (m. rectus abdominis). (Guyton and Hall, 2013). These muscles not only pull the rib cage downward but also work with other abdominal muscles to compress the abdominal organs toward the diaphragm. In another study examining the morphology and muscle fiber type of respiratory muscles in human cadavers, it was noted that 60% of the internal and external intercostal muscles consist of Type I fibers, while 49% of the diaphragm is

made up of Type I fibers, with the vastus lateralis having a similar fiber type to that of the diaphragm (Mizuno and Secher, 1989). Therefore, it has been expressed that the superior oxidative capacity of the diaphragm, which is the primary muscle of respiration, is related not only to muscle fiber type but also to various enzyme activities, vascular systems, and mitochondrial density. (Emchrc et al., 2019; Nair et al., 2019). 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). These additional morphological adaptations are not present in the accessory respiratory muscles. This situation can be explained by the fact that the primary functions of these muscles are merely to provide stability and facilitate the movement of the thorax. (Hodges et al., 2001; Mills et al., 2015; Ratnovsky et al., 2008). Another feature that distinguishes respiratory muscles from skeletal muscles is their unique characteristics that make them less sensitive to fatigue. (Sheel ve Romer, 2012). A large number of vascular sources nourish the respiratory muscles. (Dempsey et al., 2006). While skeletal muscles receive blood from a single artery, the diaphragm is supplied by multiple sources. (Dempsey and Smith, 2014). Although the accessory respiratory muscles and diaphragm have similar muscle fibers, the ratio of capillaries to muscle fibers in the diaphragm is higher. (McConnell, 2013). This helps reduce the volume of diaphragm muscle fibers, thereby decreasing the diffusion distance. All these physiological mechanisms contribute to enhancing tolerance to the increased respiratory demands during exercise. (Sheel and Romer, 2012).

Viscoelastic Properties of Respiratory Muscles

The general viscoelastic properties of muscle include stress relaxation, creep, and static elasticity. içerir (Wang, et al., 2016). Viscoelasticity is determined by the mechanical properties of intracellular and extracellular proteins. An important feature of the viscoelastic structure is hysteresis in the stress-strain relationship, meaning that at any muscle length, the tension generated during passive stretching exceeds the tension during passive shortening. (Jannapureddy, et al., 2003; Patel, et al., 2003). In hysteresis, both viscous and elastic forces resist passive elongation, with the elastic response leading to passive shortening, which is countered by viscous forces. Thus, energy is lost during the stretching-shortening cycles (Campbell, et al., 2000; Sieck et al., 2013). Respiratory muscles exhibit hysteresis that depends on the initial muscle length, strain, and direction of tension. (Kumar, et al., 2004; Patel, et al., 2003). If the stretching-shortening cycles begin in a long position, the viscous and elastic forces of the diaphragm increase. (Syme, 1990). The viscous resistance to the tension applied along the long axis of the diaphragm and abdominal muscle fibers is greater than that to the tension applied transversely. (Jannapureddy, et al., 2003). Considering that the diaphragm muscle is similar to skeletal muscles, the short-range elastic component of diaphragm muscle fibers will contribute to the hysteresis of the stretching-shortening cycles and will affect respiratory mechanics. At the end of expiration, lung volume increases above or below functional residual capacity following respiratory effort. (Homma and Hagbarth, 2000; Izumizaki, et al., 2006; Izumizaki, et al., 2004). These changes have been associated with transient impairments in the mechanics of respiratory muscle cells following movement. (Izumizaki, et al., 2006). The hysteretic properties of respiratory muscles are physiologically very important. (Faffe & Zin, 2009). The rates of elongation of these

muscles are significant determinants of their viscoelastic properties. Rapid stretchings in research, when outside the physiological range of elongation-shortening speeds, result in excessive energy loss due to viscous resistance, which reduces the contribution of thixotropy to the viscoelastic properties. (Sieck, et al., 2013). Therefore, it is expected that the viscous resistance of respiratory muscles increases inversely with body size during respiration. beklenir (Isaza, et al., 2003; Koo, et al., 2010). Another factor affecting viscoelastic properties is temperature. When temperature increases, the viscosity and elasticity of a material decrease, and this concept also applies to skeletal muscles (Behm, 2018).

Respiratory System and Exercise

Adaptation of the Respiratory System to Exercise

As the oxygen (O_2) requirement of tissues increases during physical activity, it is essential for the amount of O_2 delivered from the respiratory system to the body to also increase. The heightened demand from tissues, along with the excess carbon dioxide (CO_2) produced and the need to manage metabolic heat, requires both the circulatory and respiratory systems to work effectively. Minute ventilation increases in response to the rising levels of CO_2 produced and O_2 consumed by the muscles. Minute ventilation does not limit the capacity of the cardiorespiratory system (Fox, et al., 2012). During exercise, accessory respiratory muscles become active during inspiration. Specifically, muscles that elevate the chest cavity assist with inspiration. Expiration occurs through the pressure generated by the intercostal muscles and abdominal muscles. The strength of the accessory respiratory muscles ensures that ventilatory airflow reaches its maximum level (Ergen et al., 2002).

During exercise, there is an increase in both respiratory volume and frequency to meet the body's oxygen (O_2) demands. At maximal exertion, the amount of air exchanged in one minute can reach levels as high as 200 liters, achieved through increases in both tidal volume and breathing frequency. (Fox, et al., 2012). The minute ventilation, which can vary based on respiratory muscle strength, can reach 200 liters per minute during high-intensity physical activities, while in individuals not engaged in any physical activity, this number is estimated to be around 100 liters per minute. During maximal exercise, minute ventilation is regulated more by carbon dioxide (CO_2) production than by oxygen (O_2) consumption. In exercise, increases in the depth and frequency of breathing lead to significant increases in minute ventilation. In severe exercise, the respiratory rate in adult males has been reported to reach between 35-45 breaths per minute in some sources (Ergen et al., 2002) and 40-50 (McConnell, 2011) in others. For Olympic athletes, this number can rise to between 60-76 during maximal exercise (Ergen et al., 2002). Tidal volume during intense exercise can increase to 3-4 liters, resulting in minute ventilation approaching 120-160 liters. In Olympic athletes, tidal volume can reach around 5 liters, with minute ventilation rising to approximately 250-300 liters. (McConnell, 2011).

As an athlete's maximal oxygen uptake ($MaxVO_2$) increases, minute ventilation also rises. A rapid increase occurs within the first few seconds after the onset of exercise. After a certain period, this increase continues gradually. The rise in ventilation is driven by stimuli received by the nervous system from joint receptors. The duration of this increase is directly proportional to the intensity of the exercise. (Fox, et al., 2012). In moderate-intensity exercises, the increase in ventilation is primarily due to the rise in respiratory volume. This increase in ventilation is closely related to oxygen (O_2) consumption (Günay, 1998). Such an increase can even be observed in excited individuals just before exertion. At the same time, at the beginning of exercise, the respiratory volume increases more than the respiratory frequency. However, if the intensity of the exercise reaches a level that induces metabolic acidosis, the increase in respiratory frequency is greater.

This is a key indicator of metabolic acidosis (Akgün, 1989). During exercise, maximal oxygen uptake (MaxVO_2) and the amount of carbon dioxide (CO_2) expelled from the lungs per unit of time (pulmonary carbon dioxide output, VCO_2) increase linearly up to about 60% of the athlete's maximal work capacity. The respiratory rate during exercise can reach 30 breaths per minute or even higher. (Guyton and Hall, 2013).

The Effect of Respiratory Mechanics on Performance

During exercise, maximal oxygen uptake (MaxVO_2) and the amount of carbon dioxide (CO_2) expelled from the lungs, known as pulmonary carbon dioxide output, indicate that there is an increase in MaxVO_2 of approximately 60% of the athlete's maximal work capacity. (Guyton and Hall, 2013). With the cessation of exercise, there is a rapid decline in ventilation. This decrease is attributed to the cessation of motor activity as sensed by muscle and joint receptors. The higher the intensity of the exercise, the longer it takes for ventilation to return to resting levels (Özdal, 2015). Athletes breathe heavily during exercise, and just like skeletal muscles, the respiratory muscles require sufficient levels of oxygen to function effectively. During high-intensity exercise, the respiratory muscles work significantly harder than at rest. Therefore, a high level of metabolic activity is needed to sustain respiration. (Sheel, 2002). In response to this metabolic stress, the respiratory muscles also adapt. Generally, muscles undergo structural changes to accommodate training, leading to alterations in muscle function. It has been noted that the positive effects of exercise on the respiratory system will also yield positive results on overall performance (Boutellier, et al., 1992). Studies have shown that there is a direct relationship between respiratory muscle strength and endurance and exercise capacity. This is because delaying fatigue in the respiratory muscles ensures that blood flow is sufficiently directed to these muscles. As a result, the respiratory muscles can perform their functions more easily. (Gigliotti, et al., 2006). During exercise, there is an increase in both the rate and depth of breathing to allow the respiratory muscles to contract more forcefully and rapidly. At rest, the expiratory muscles are relaxed, and respiration is primarily driven by the mechanical effect of the inspiratory muscles. However, during exercise, the expiratory muscles also actively participate in breathing to enhance the increase in tidal volume and expiratory airflow. Considering that the respiratory muscles utilize about 16% of the oxygen consumed during high-intensity exercise, it is clear that effective respiratory muscle strength is crucial for meeting the demands of exercise. (McConnell, 2011).

Respiratory Muscle Training

Inspiratory Muscle Training

The onset of fatigue in the respiratory muscles leads to a decrease in their contraction strength. As a result of fatigue in the respiratory muscles, alveolar ventilation decreases, causing an increase in arterial carbon dioxide (CO_2) levels. When this increase reaches a peak level, respiratory function can no longer be maintained. (Macklem et al., 1979). As the exercise intensity increases, the respiratory load also rises. As a result of this increase, athletes may experience not only fatigue in the respiratory muscles but also insufficient oxygen delivery to the tissues, leading to a decline in performance. This fatigue can result in an energy loss of up to 15% for the athlete. (St Croix, et al., 2000; Lomax and McConnell, 2003). To reduce energy loss, proper breathing exercises and diaphragm muscle development mechanisms should be practiced. In a study on respiratory muscles, it was found that diaphragm-oriented correct respiratory muscle training can improve respiratory muscle strength and function more positively than standard training (Vural,

et al., 2024). Respiratory muscle exercises can be performed with or without equipment; however, after the POWERBreathe device was observed to have therapeutic benefits for patients with respiratory difficulties such as chronic obstructive pulmonary disease (COPD), dyspnea, and asthma, sonra (Lacasse, et al.; Gosselink et al., 2011) researchers in sports science began to investigate its potential contributions to athletes (Fernández-Lázaro et al., 2021).

Respiratory Muscle Stretching Exercise

Effective respiratory mechanics depend on chest mobility, healthy respiratory muscles that can generate lung volumes, and the ability to move to ensure adequate pulmonary ventilation simultaneously. (Sonehara, et al., 2011). Disruptions in respiratory mechanics are generally caused by the shortening of the respiratory muscle system (De Sa et al., 2017). The main reasons for such shortening include psychoneural factors (stress), respiratory diseases, muscle weakness, aging, and insufficient physical activity. (Moreno et al., 2007; Tumasian et al., 2021) As a result of these factors, there is a decrease in the movement of the spinal, costal, and sternal joints associated with hypertonicity of the respiratory muscles. (O'Donnell and Laveneziana, 2007) Changes in the shape and structure of the chest wall, particularly, can lead to a shortening of respiratory muscle fibers by 30% to 40%. This imbalance in the tension-length relationship results in reduced expansion of the lower thoracic cage and decreased costal mobility, thereby diminishing pulmonary function. (De Troyer, 2012; Duiverman et al.). It is believed that respiratory muscle stretching exercises can help reduce this negative mechanism. These exercises are effective in directly stretching muscle fibers and increasing thoracic mobility. (Ashwini, et al., 2017; Mohamed, et al., 2021). Respiratory muscle stretching exercises improve the parasympathetic activation of the diaphragm and respiratory muscles by regulating the autonomic nervous system, leading to an increase in pulmonary function and a reduction in fatigue and dyspnea (Fernández-López et al., 2021) These exercises promote an increase in the length of the muscle-tendon unit of the respiratory muscles. By increasing the distance between the origin and insertion of the diaphragm, they reduce the tension caused by fiber shortening, making muscle contractions more effective (Page, 2012). The respiratory muscle stretching technique causes sensory modulation and potential reflex changes due to the static load on the connective tissue, resulting in improved viscoelastic properties. In this context, it has been noted that respiratory muscle stretching exercises have a positive effect on both muscle and joint mobility. (Fernández-López et al., 2021; Rattes et al., 2018).

The Relationship Between Respiratory Muscle Training and Performance

There may be several possible mechanisms to explain the finding that respiratory muscle training (RMT) improves performance. Research suggests that improvements in performance are likely due to the moderate cardiovascular demands placed on the entire body during respiratory muscle training (Markov et al., 2001; McConnell and Jones, 2002). In some studies, the mechanisms underlying performance improvements have been explained as enhanced oxygen kinetics kinetiği (Bailey et al., 2010), reduced respiratory effort and fatigue perception (Griffiths & McConnell, 2007), weakened respiratory muscle metaboreflex (McConnell and Lomax, 2006), and decreased respiratory muscle fatigue during exercise (Verges et al., 2007). Physiological adaptations have been observed following respiratory muscle training (RMT). In patients with chronic obstructive pulmonary disease (COPD), a study showed that after 5 weeks of RMT, there was an increase in type I fiber size by 38% and type II fiber size by 21% in the external

intercostal muscles (measured via biopsy). (). Potentially, this increase in respiratory muscle capacity could reduce the frequency of breathing during exercise. Similarly, a study that utilized the difference between VO_2 during exercise and voluntary hyperpnea at rest reported that after 6 weeks of respiratory muscle training (RMT), the VO_2 of the respiratory muscles decreased by 3.4% at $\text{VO}_{2\text{max}}$. (Taylor et al., 2012). These results suggest that respiratory muscle training (RMT) may reduce the oxygen cost of breathing. Additionally, it can be inferred that the decrease in the oxygen cost of breathing following RMT is likely associated with changes in respiratory muscle improvement models during hyperpnea. Improvements in oxygen transport have also been reported after RMT. Following 4 weeks of pressure threshold RMT, the $\dot{V}_{\text{O}_2}$ component was found to decrease during high-intensity (from 0.60 to 0.53 $\text{L}\cdot\text{min}^{-1}$) and maximal cycling exercise (from 0.28 to 0.18 $\text{L}\cdot\text{min}^{-1}$) to voluntary tolerance limits. RMT has also reduced the intensity of respiratory muscle fatigue as measured by maximal inspiratory pressure (MIP) (Bailey et al., 2010). Many studies have shown that respiratory muscle training (RMT) improves performance during exercise below the threshold of diaphragm fatigue and respiratory muscle metaboreflex. For example, it has been demonstrated that RMT enhances performance in time trial events of 20 and 40 km, where the average power output is approximately 75% of maximum (Romer, et al., 2002). Therefore, it is likely that other potential mechanisms support the observed performance improvements at submaximal exercise intensities.

The Impact of Respiratory Muscle Training on Aerobic Power and Capacity

Aerobic power refers to the capacity to produce aerobic energy during intense exercise, and this capacity is determined by maximal oxygen uptake ($\text{VO}_{2\text{max}}$). Aerobic capacity is defined as the ability to sustain exercise for prolonged periods and is often used synonymously with endurance. Athletes with good aerobic training capacity are more likely to maintain training intensity until the end of a game compared to those with lower aerobic capacity and power. Additionally, athletes with higher aerobic capacity tend to recover more quickly during active rest periods immediately following intense training sessions. (Reilly et al., 2000).

Most of the studies covered in this systematic review used maximal inspiratory pressure (MIP) measures to determine effort intensity during IMW, given that these measures are a reference in the assessment of global inspiratory-muscle strength enabling correct individual measurement and guidance on the inspiratory intervention load (Avci, Özdal and Vural, 2021).

Previous studies have shown that respiratory muscle training has a significant impact on the respiratory muscles. It has been observed that such training can lead to increased strength within a few days, and after four weeks of training, there is an improvement in the individual's performance. (Voliantis et al., 2001; Romer, McConnell, & Jones, 2002a; Romer, et al., 2002b; Lomax and McConnell, 2009; Kilding, et al., 2010).

The increase in respiratory muscle strength (MIP, MEP) following respiratory muscle training can affect athletes' performance. In a supporting study, after 6 weeks of respiratory muscle training performed by professional cyclists, the maximal inspiratory pressure (MIP) of 16 participating cyclists improved by 22% (Turner et al., 2012). As a result of increased respiratory muscle strength, the contribution of exercise hyperpnea to total body VO_2 during maximal exercise decreased from 11% to 8% (Turner et al., 2012).

Many tests conducted on basketball players have found that $\text{VO}_{2\text{max}}$ ranges between

40 (ml/kg/min) and 70 (ml/kg/min) (Matković, 2005). A study conducted on college basketball players in the United States showed that the average $\text{VO}_{2\text{max}}$ was 65 ± 6.2 (ml/kg/min) (Tavino, 1995). Additionally, research has indicated significant differences in $\text{VO}_{2\text{max}}$ among players based on their positions (Marinkovich, 2013).

Respiratory muscle training (RMT) is effective in improving athletes' ability to achieve deeper and slower breathing. It also enhances the stability of the core muscles, which helps the athlete perform movements more effectively and reduces the risk of injury. (McConnell, 2011, s. 21).

In terms of pulmonary ventilation, significant decreases in maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) have been shown to occur as a result of decreased strength and endurance in the respiratory muscles following intense aerobic and/or prolonged physical exercise (Martin & Stager, 1981). These respiratory factors limit athletes' performance; (HajGhanbari et al., 2013), therefore, it is possible to discuss the positive effects of respiratory muscle training on performance.

The Impact of Respiratory Muscle Training on Anaerobic Power and Capacity

The anaerobic energy system refers to the production of energy in the body during short-duration exercises through the ATP-CP and lactic acid systems in an oxygen-deprived environment (Dündar, 1998). Anaerobic performance encompasses an energy system that includes anaerobic power and anaerobic capacity. Anaerobic power is defined as an individual's ability to utilize the phosphagen system during short bursts of high-intensity muscle activities, while anaerobic capacity is described as the total amount of energy produced as a result of the combination of the anaerobic glycolytic and phosphagen systems. (Perrin, 1993). The energy mechanism is one of the most important topics in the field of sports. The ability of the human body to perform various movements at the desired level depends on the individual's energy capacity. Each system's ability to provide the necessary energy for exercise is dependent on the type of exercise performed. These exercises can vary from short-duration, explosive movements that require rapid energy production, such as jumping (lasting 2-3 seconds), to longer-duration activities, such as marathon running, which require slower energy production over two to three hours. Anaerobic performance is a significant factor in the success of sports that involve explosive movements (such as speed, agility, and direction changes). (Stone and Sands, 2007). Athletes are exposed to high-intensity movements during a match, and their ability to sustain these actions until the end of the game is only possible with well-developed anaerobic power. (Hoffman, 2003). In a study involving basketball players, the results of an anaerobic power test conducted after four weeks of respiratory muscle training (RMT) showed that the experimental group had increased average anaerobic power values compared to the control group. (Çevik, 2018). It was stated that there was a statistically significant difference in anaerobic power in favor of the experimental group during the anaerobic power test conducted in the 4th and 8th weeks of the respiratory muscle training (Koç, 2017). Similarly, it has been noted that a 6-week respiratory muscle training program increases anaerobic power in cyclists. (Johnson, Graham, & Peter, 2007). It has been explained that the respiratory muscle training leads to an increase in the contraction speed of the respiratory muscles. (Hajghanbari et al., 2013). Tennis is generally considered an anaerobic sport. Regular tennis training combined with respiratory muscle training may have a positive effect on athletes' anaerobic performance. (Köroğlu, 2020).

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