LITHUANIAN SPORTS UNIVERSITY

INTERNATIONAL MASTER OF PERFORMANCE ANALYSIS IN SPORT

DEIVIDAS SAVEIKIS

DO RESPIRATORY MUSCLES EXHIBIT SIMILAR ADAPTIVE PROPERTIES TO LOWER LIMB MUSCLES IN RESPONSE TO CHRONIC TRAINING? A CROSS-SECTIONAL COMPARISON BETWEEN BASKETBALL PLAYERS AND CYCLISTS

FINAL MASTER ‘S THESIS

Scientific Supervisor: Leonardo Cesanelli

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1. Has been carried out by myself;
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Table of Contents

ABSTRACT

Repeated exposure to specific exercise training can alter the structure of the muscles leading to specific functional adaptations. The main goal of the study was to investigate whether different types of chronic training, can induce not only specific adaptations in the lower limb but in the structural and functional characteristics of the respiratory muscles also. Thirty-two male athletes [cyclists (CYC) n=16, and basketball players (BP) n=16] participated in the study. First, anthropometric parameters were measured, followed by musculoskeletal ultrasound images of specific muscles including vastus lateralis (VL), gastrocnemius medialis/lateralis (GM/GL), and diaphragm. Then participants underwent maximal voluntary isometric contractions (MVIC) and completed a respiratory muscle functions assessment, which included maximum inspiratory/expiratory tests (MIP/MEP) and spirometry. BP compared to CYC displayed significantly greater diaphragm, GM, and GL muscle thickness (MT) ($p<0.05$), and fascicle length (FL) of GM and GL. In addition, BP showed a greater peak torque (PT) and rate torque development (RTD) in plantar flexors, and a rate of inspiratory/expiratory pressure development (RIPD/REPD) ($p<0.05$). Overall, the present study confirms that differences in the muscle-tendon structure of lower limbs in experienced athletes involved in specific exercises exist. Even more, this type of study is reported for the first time, where we observe not only differences in lung capacity but also in respiratory muscle morphology. In addition, the present findings exceed our expectations and demonstrate how chronic exercise can influence not only the primary muscles directly involved in the exercise but accessory ones such as the respiratory muscles also.

Keywords: sport performance analysis, muscle architecture, respiratory muscle strength, muscle thickness.

SANTRAUKA

Chroninių ilgalaikių treniruočių poveikis gali turėti įtakos raumenų struktūrai ir sukelti specifines funkcines adaptacijas. Pagrindinis tyrimo tikslas buvo ištirti, ar kasdieninės treniruotės gali turėti įtakos ne tik raumeninės struktūros specifinėms adaptacijoms, bet ir kvėpuojamųjų raumenų struktūrinėms ir funkcinėms savybėms. Tyrime dalyvavo 32 sportininkai (dviratininkai n=16 ir krepšininkai n=16). Pirmiausia buvo paimti antropometriniai parametrai, po to paimtos raumenų ultragarso nuotraukos iš konkrečių raumenų: kelio tiesėjų, pėdos tiesėjų ir lenkėjų bei diafragmos. Po to tiriamieji atliko maksimalaus izometrinio raumens susitraukimus bei testavo savo kvėpuojamųjų raumenų funkcinį vertinimą, kurį sudarė maksimalaus įkvėpimo ir iškvėpimo testai bei spirometrija. Krepšininkai lyginant su dviratininkais pasižymėjo reikšmingai didesniu diafragmos, bei pėdos tiesėjų ir lenkėjų raumeninės skaidulos tankumu ($p<0.05$) bei pėdos raumeninės skaidulos ilgiu. Krepšininkai taip pat parodė didesnį maksimalų jėgos momentą ir momento didėjimo greitį pėdos tiesiamuosiuose raumenyse bei įkvėpimo ir iškvėpimo greitį ($p<0.05$). Apibendrinant, mūsų atliktas tyrimas patvirtina, kad egzistuoja reikšmingi skirtumai apatinių galūnių raumenų ir sausgyslių struktūroms tarp skirtingų profesionalių sporto šakų atletų, kurie atlieka chroniškus ir specifinius treniruočių pratimus. Taip pat, mūsų atliktame tyrime stebimi ne tik plaučių fizinio pajėgumo, bet ir kvėpuojamųjų raumenų morfologiniai skirtumai, tokie kaip diafragmos raumens tankumas. Išanalizuoti tyrimo rezultatai pranoksta mūsų lūkesčius ir parodo, kad chroniškas ir specifinis fizinis krūvis gali turėti įtakos ne tik pirminiams, tiesiogiai fiziologiniuose procesuose dalyvaujantiems raumenims, bet ir papildomiems, tokiems kaip kvėpuojamųjų raumenų įkvėpimo ir iškvėpimo jėga.

Raktiniai žodžiai: sportinio našumo analizė, raumenų architektūra, kvėpuojamųjų raumenų jėga, raumeninės skaidulos tankumas.

INTRODUCTION

Nowadays, many professional sports adopt specific training regimes, and strategies, which have dissimilar consequences on athletes' bodies. It is no doubt, that consistent and repeated training which occurs over a long period of time, requires gradually increased intensity and duration, which results in significant physiological and psychological changes. The relationship between chronic changes induced by specific training regimes and physical performance has been a subject of research for several decades. Various sports have different effects on the skeletal muscle system and a recent investigation by (Reeves et al. 2009) provides evidence that different disciplines (basketball vs. cycling etc.,) undergo distinct loading patterns, which leads to architectural adaptations to exercise training and may end up having specific muscle phenotypes. Among the various aspects associated with chronic training adaptations, structural remodeling of muscles and tendons is often the main area of study, while respiratory muscle performance is significant and novel, but not as a much-studied field. Consequently, it is already found that lung development and its functions are strongly affected by the type, intensity, severity, duration, and frequency of physical activity (Meylan et al., 2014). However, the respiratory system is a very complex mechanism, and it involves muscles like a diaphragm, which is a key element for optimal respiratory performance also (Tuinman et al., 2020). Additionally, a better overall understanding of respiratory muscle specificity could lead to applications beyond sports science and physical performance optimization, such as rehabilitation strategies, decision-making, and injury prevention support. Therefore, cross-sectional comparisons of different sports are a new area of research that requires further study, especially targeting musculoskeletal features, and this master's thesis addresses this gap.

The primary aim of the present study is to determine if chronic exposure to different chronic exercise training (i.e., basketball vs. cycling) can induce not only lower limb muscle adaptations but also changes in respiratory muscles' structural and functional characteristics.

The main objectives are to characterize and compare the musculoskeletal structural and functional properties of basketball players and cyclists and explore the relationships between skeletal muscle morphological parameters, contractile capacity, and respiratory functions.

The two primary study hypotheses are that chronic exposition to a high-level basketball training regime compared to cycling can determine differences in muscle architecture (i.e., greater pennation angle and lower fascicle length in cyclists compared to basketball players) and that cyclists will show similar trends in respiratory muscles' structural and functional differences (i.e., diaphragm morphology and respiratory muscles strength).

1. LITERATURE REVIEW

1.1 Basketball sport and its considerations

The sport of basketball requires very specific skills that have to be done under fast-changing and dynamic conditions. In most cases, athletes' abilities are examined while moving at a high speed or changing directions, which results, that successful basketball players need to possess high strength, power, and agility while at the same time maintaining good body composition. On the court, the demands and characteristics of the athletes differ by position, but they are not as drastically different as in other team sports. What is more, basketball training typically contains a strong emphasis on developing jumping ability, whereas plyometric jumps commonly incorporate among training practices, due to its high translatability to game scenarios (Simenz, Dugan, and Ebben 2005). Indeed, plyometric jumps capitalizes on the stretch-shortening cycle (SSC) where muscle tendon units (MTU's) are eccentrically stretched during the loading or impact phase before being concentrically shortened in the push-off or take-off phase (Taube, Leukel, and Gollhofer 2012). Therefore, jump exercises that utilize the SSC seem to be more effective at improving not only physical fitness attributes like sprinting, jumping or change of direction, but physiological and biomechanical adaptations also (e.g. increased motor unit recruitment and rate of force development). In addition, strength, speed, and agility highly corelates with players' athletic performance, and lower-limb muscles play an important role during training (Ostojic et al., 2006).

Some other performance parameters are not less important, such as sprint velocity, squat jump height, and absolute leg force. It seems that they are positively correlated with leg and thigh total muscle volumes, so therefore to perceive stronger and bigger lower-limb muscles, athletes have to obtain huge workloads (Chelly et al., 2010). Exploring muscle contractile properties of lower limb muscles, some researchers state that the volume of the quadriceps femoris muscle group is strongly correlated with peak power even at various angular velocities for knee extensions. In addition, it is common, that lower-body strength exercises often focus on this specific muscle group training, which tends to help improve basketball player performance (O'Brien et al., 2009). Another important aspect to take into account is that professional basketball players tend to have between ten to twelve physically active training per week, so chronic exposure to specific energy systems (aerobic and anaerobic) is an integral part of an athlete's everyday routines. What is more, basketball is characterized by frequent starts, stops, and changes of direction which are all maintained over a short period, and most of the work is performed at a high intensity, and a certain level of endurance is important to meet game demands throughout the season. For instance, in comparison to other team sports, the aerobic demand in basketball is less than in soccer but more than in baseball or volleyball, so even if the anaerobic system is dominant, aerobic capacity is also important (Taylor, John MS., 2004). On the other hand, the rules of the game allow great substitution and provide rest periods during the breaks, which helps to boost the ability of the aerobic energy system to replenish the anaerobic system for sustained-high intensity efforts over the game. The intermittent activity pattern during the basketball game demands chronic physical respiratory system adaptations so that players can sufficiently sustain repeated short bouts of very high-intensity exercise, alternated by relatively long periods of rest.

1.2 Cycling sport and its considerations

Physical activity like cycling nowadays remains one of the major ways of transportation in many countries all around the world. It is known as a recreational and competitive activity, and it continues to grow while remaining very popular around different ages and physical capabilities of people. Furthermore, during the last decade, cycling experienced exponential growth in popularity, especially around major cities, basically because of the exponential growth of cars and horrible traffic conditions. Even though cycling continues in expanding as a recreational activity, the competitive nature of the sport is increasing, especially among youth. Just one of many examples of competitive cycling is off-road or in other term mountain trail biking (MTB), which requires certain driving skills and a good base of cardiovascular endurance. The necessity to use both aerobic and anaerobic power occurs because cyclists need to possess the ability to generate a relatively high but short power output during the mass start, steep climbing, and at the race finish (Impellizzeri and Marcora, 2007).

On the contrary, road cycling is a form of endurance exercise that involves sustained physical effort over a prolonged period, and by its premature physiological context, is closer to chronic exercise modality than others. What is more, this type of exercise incorporates mainly concentric compared to eccentric (i.e., running) muscle contractions. The long distances that cyclists achieve, correlates to greater stresses on the body, resulting in a change in structural characteristics of muscle tissues due sustained demand severe substrate depletion (metabolic damage vs. mechanical damage) (Córdova-Martínez et al. 2022). Furthermore, during different types of competition, exercise movements are a combination of concentric and eccentric muscle contractions. Even though in road cycling, the predominant component is concentric action, eccentric phase appears during intensive sprints or very demanding step climbs. Therefore, cycling by nature is an activity which sometimes requires negligible eccentric contractions, as in contrary to running, where repeated eccentric contractions are dominant (Córdova Martínez et al. 2015).

Another thing to mention, is that engaging in road cycling, breathing rate, and depth increases, in order to accommodate oxygen demand of working muscles, especially lower limbs. This mechanism tends to increase the ventilation rate (Ve) leading to improved oxygen delivery to muscles and an increased ability to remove carbon dioxide (CO_2). Consequently, regular road cycling over time can lead to improvements in pulmonary function, including increased lung capacity and better gas exchange efficiency. What is more, cycling strengthens the respiratory muscles involved in breathing, such as the diaphragm and intercostal muscles, which can lead to increased lung volume and improved respiratory mechanics. For instance, some researchers show that professional cyclists pose very high $\dot{V}O_2max$ values (~74 mL/kg/min) and other pulmonary function parameters, which are considerably high compared to other individual or team sports (Fernandez-Garcia et al., 2000). However, it is important to note that road cycling can also expose athletes to air pollutants and allergens, which can have some negative effects on pulmonary functions, so it is important to minimize training in areas near heavy traffic or places with higher levels of pollution.

No matter which type of cycling an athlete prefers, it is clear that respiratory system endurance plays a major role in physiological performance. There is some data, which suggests the cyclist’s breathing pattern appears to influence performance no less than other factors. In theory, professional cyclists exhibit a unique breathing pattern at high workloads characterized by increased ventilatory exposure through higher tidal volume versus breathing frequency (Luca et al., 1999). Consequently, not sufficient breathing during heavy exercise compromises leg blood flow to working limb muscles, and even if cyclists use more efficient breathing patterns, it may not always help to reduce blood flow to the working muscles (Harms, 2000). In consensus, it raises some questions, about how strongly respiratory function strength affects lower limb muscle parameters. Some states, that respiratory system strength has correlations with the lower limb, whereas they already observed a decrease in maximum inspiratory flow rate after both a 20km and a 40km cycling time trial (Romer et al., 2002), and due to this, inspiratory muscle fatigue slows the relaxation rate needed for muscle recovery. It potentially helps to understand, why lower limb muscles are so dependent on an athlete's respiratory system strength (maximum inspiratory flow), adaptation (can enhance efficiency and metabolic cost of breathing), and endurance (Romer et al., 2002).

1.3 Musculoskeletal characteristics of lower limbs in athletes

The human body is an extremely adaptable creature, and various sports have different effects on the skeletal muscle system. A recent investigation by (Reeves et al. 2009) provides evidence that different disciplines (basketball vs. cycling etc.,) undergo distinct loading patterns, which consequently leads to architectural adaptations to exercise training and by that different sports may end up having certain muscle phenotypes. For instance, basketball tends to use eccentric training more, which leads to a marked increase in fascicle length with no significant change in pennation angle. On the contrary, cycling primarily use concentric action, which induces an increase in pennation angle, with little change in fascicle length also (Franchi et al. 2014). In addition, it may be said, that exposure to particular training can induce various adaptations in lower limb musculature (Franchi et al., 2014), while chronic mechanical stimuli can aid to select distinct muscle phenotypes, particularly in the lower limb musculature. For instance, muscle size, architecture, and MTUs' passive mechanical properties appear to be extremely responsive to usage and inactivity (De Boer et al., 2007).

Previous studies revealed that experienced athletes who were repeatedly exposed to different training modalities from various disciplines had morphological and mechanical characteristics that were defined by specific traits (Cesanelli et al., 2022; May et al., 2021; Brughelli et al., 2010). Furthermore, changes in the muscle dimension, architecture, and MTUs' passive mechanical properties, influence physical performance and muscle contractility (e.g., force-length relationship, explosive and maximal strength) (Cesanelli et al., 2022; Brughelli et al., 2010). Therefore, it can be stated, that chronic exposure to a specific exercise training stimulus can alter the MTUs' structure and consequently characterize its functions (Narici et al., 2016). Correlations between different chronic sports regimes in lower limb muscle features are widely researched by many authors in this specific field. In this sense, it has been described how Australian football players had greater vastus lateralis fascicle length but lower pennation angle than competitive cyclists, and that the force-length relationship of knee extensors and flexors muscles differed between the two groups (Brughelli et al., 2010). Comparable differences in muscle thickness and pennation angle between elite-level runners and cyclists were also seen in the vastus lateralis muscle, which affected maximal and explosive isometric strength between the athletes. (Cesanelli et al., 2022). Another important aspect refers to the necessity to understand why the rate of force or pressure development, is important in variables to compare. The rate of force development (RFD) is the ability to rapidly increase muscle force during a voluntary contraction. (Rodríguez-Rosell et al., 2018) RFD is crucial when performing explosive or ballistic tasks and daily activities (e.g., while balancing the body) and was proposed as more descriptive than the maximum force of neuromuscular properties. (Maffiuletti et al., 2016) The time course of RFD has been divided into an early (up to 75−100 ms) and a late phase (between 100 and 250 ms) that can be respectively ascribed to neural and muscular factors. While the neural factors encompass the motor unit synchronization and the ability to rapidly activate the motor units, the muscular factors are associated with muscle morphology, muscle-tendon complex stiffness, muscle size, and architecture (Dideriksen et al., 2020).

1.4 Diaphragm muscle characteristics

The diaphragm is no less important to review, especially as it represents the primary breathing muscle. From a physiological view, it is a small muscle with a dome-like form that is located between the chest and belly and is the main muscle used for inspiration. The diaphragm supplies 60–80% of the human body's breathing demands as the most significant respiratory muscle. However, there are other inspiratory muscles that contribute to ventilation in addition to the diaphragm. The parasternal intercostal muscles, external intercostal muscles, scalene muscles, and sternocleidomastoid muscles are some of the auxiliary inspiratory muscles that are called upon to help in inspiration when the stress on the diaphragm rises (Tuinman et al., 2020). Consequently, our goal was to check the diaphragm thickness and its functionality as it serves as the primary muscle for breathing. In addition to that, the sonographic evaluation of the diaphragm thickness was considered one of the best tools to evaluate the change between different breathing phases. Due to the accessibility to obtain clear images where both diaphragm excursion and thickness can be seen (Sarwal et al., 2014), while the evaluation process is possible in a considerably short amount of time. For instance, there are studies that already tried to establish reference values for diaphragm ultrasound in healthy adults, but unfortunately, it has been limited by a small sample size, so a lack of validation against volitional measures of respiratory muscle strength, or a limited range of parameters evaluated. (Spiesshoefer et al., 2020)

1.5 Respiratory system parameters

Understanding more about an athlete's pulmonary capabilities, usually, it is brought by respiratory muscles' overall functionality. Different techniques, which are based on different measurement protocols, can be utilized for the evaluation of respiratory muscle strength, which can be assessed using pressure measurement either from the mouth or from the nostril during quasi-static breathing. In evaluation, performing lung function tests is one approach to continuously register an athlete's respiratory system, and therefore both qualitative and quantitative measurements of pulmonary function are significant in determining an individual's degree of fitness (Hagberg et al., 1988) Spirometry, another possible test, which in simple terms, gauges how much air a person can inhale or exhale in a specific amount of time. Generally speaking, it is recognized as the gold standard by sports physicians, and during the evaluation process of the athlete's respiratory system performance, this pulmonary function test is most frequently used. (Laszlo, 2006) There are some physiology-based theories for why certain athletes have larger lung contents than others, this topic is still debatable because studies on athletes' respiratory capabilities are very restricted or have been evaluated on a small number of participants, especially in individual sports (Cordain and colleagues, 1990). As a result, past studies could not reach a firm consensus on how prolonged aerobic or anaerobic training exposure affects respiratory muscle system outcomes at different levels of athletes. On the other hand (Illi et al., 2012) in their systematic review of respiratory muscle training effect on exercise performance, suggests that amateurs and professional athletes, who perform more intermittent types of exercise (soccer, basketball, handball, etc.), might benefit from respiratory muscle training similarly, as athletes who perform more endurance type of sports like cycling or running. These findings were partly supported by another author, who in his study shows a reduction in recovery duration between anaerobic bouts of exercise, which was attributed to a decreased perception of respiratory effort (Romer et al., 2002). However, the respiratory system is a very complex mechanism, and it involves other important muscles like a diaphragm, which is a key element for optimal respiratory performance. Furthermore, other anatomical areas and musculature systems like abdominal wall, pectoralis group, and core stabilization muscles play a huge role and strongly influence pulmonary function. Indeed, because respiratory muscles and diaphragm adaptability to sense aerobic or anaerobic training demands is novel field, interest of sports researchers is growing (Tuinman et al., 2020).

Even though respiratory muscles and diaphragm morphology has been mostly an object of clinical research, fast-changing physical demands in sports involve sports scientist to find alternative ways, how to improve respiratory muscle performance. In this context, it was found that lung development, and consequently its functions are strongly affected by the type, intensity, severity, duration, and frequency of physical activity (Meylan et al., 2014). Hackett in his research also notes that strength-trained athletes had stronger respiratory muscles than endurance-trained athletes (i.e., maximal inspiratory and expiratory pressure, [MIP and MEP]). However, the author acknowledges that it is unclear what variables have contributed to higher respiratory muscle endurance, which raises further issues about how to explain adaptations of both - accessory muscles and muscles directly participating in the exercise (Hackett, 2020).

Parallel to the information above, other researchers have suggested that trained individuals exhibit stronger resilience to respiratory muscle exhaustion than untrained individuals, indicating that respiratory muscle strength is increased by whole-body training (Coast et al., 1990). Taken together, the evidence suggests that physical training, rather than genetic predisposition, has a greater influence on the morphology and functional aspects of respiratory muscles (Martin & Chen, 1982). Furthermore, it implies that the level of athletic fitness is not the sole predictor of respiratory muscle strength, but alternatively, it is more likely that the endurance of the respiratory muscles is determined not only by the amount of training but also by its particular sports specifics (Jurić et al., 2019). That's why, it is crucial to compare athletes who have undergone different types of chronic training (high vs. lower intensity) and different types of respiratory muscle workloads (e.g., varied operating lengths and working frequency) to better understand respiratory muscle strength aspects. In addition, Pereira and colleagues examined the variations in respiratory muscle strength and its relationships with physical performance in professional wheelchair basketball players who were affected by various physical limitations and, consequently, constrained in various playing positions. (Pereira et al., 2016) Considering respiratory muscle strength and aerobic capacity, the authors described clear positive connections between them. Moreover, variations in the chronic "work" of the respiratory muscles at certain operating lengths and under various loadings (strength and frequency of the breath cycles) may theoretically result in the formation of a different morphological and mechanical profile of the respiratory muscles. However, further research is needed to support this claim, particularly if we want to compare 1) athlete populations subjected to various chronic sports activities and 2) compare respiratory muscles to lower limb muscles that are primarily used for exercise demands. When combined, chronic and specific exercise training can identify unusual morphological and mechanical properties, much as it has been proven to accomplish for limb muscles, and if the same is true for respiratory muscle characteristics, it remains to be proved. Accordingly, the impact of specific and chronic exercise training on respiratory muscle structure and functions represents a significant and novel field of study, consequently, more research in this field is needed to clarify such aspects.

2. RESEARCH METHODOLOGY AND ORGANIZATION

2.1 Research aim, object, and hypothesis

The primary aim of the present study is to explore if chronic exposure to different exercise training regimes (i.e., basketball vs. cycling) is able to induce similar structural adaptations of the diaphragm muscle as expectable for lower limb muscles and the impact on functional characteristics.

The main objectives of the present study are

1. To characterize and compare the musculoskeletal structural and functional properties of professional basketball players and cyclists.
2. To explore the relationships between skeletal muscle morphological parameters, contractile capacity, and respiratory functions of professional basketball players and cyclists.

In addition, the main study hypothesis is that chronic exposition of basketball compared to cycling can determine differences in muscle architecture (i.e., greater pennation angle and lower fascicle length in cyclists compared to basketball players) and contractile capacity (i.e., peak torque production and rate of torque development) Moreover, as an exploratory research, it was raised the question whether diaphragm muscle and in consequence respiratory functions may also differ in similar way as hypothesised for lower limb muscles.

2.2 Research design

In this observational, cross-sectional comparison between elite cyclists (high-level amateurs) and competitive basketball players (different basketball clubs), certain data on the dominant athlete's leg was taken, including vastus lateralis, lateral and medial heads of the gastrocnemius muscle architecture, patellar tendon dimensions, and diaphragm muscle morphology parameters. Continuously, respiratory system variables like maximal inspiratory and expiratory muscle strength and rate of pressure development, as well as athlete's dominant leg knee extensors'-flexors' isometric torque production (MVIC) have been evaluated and analyzed.

2.3 Study participants and research organization

Totaly thirty-two well-trained athletes (23 ± 3.9 years; 83.7 ± 9.5 kg; 188.8 ± 6.3 cm) were tested in this cross-sectional comparison, (n=16) competitive basketball players (BP) and (n=16) elite/sub-elite cyclists (CYC). All study subjects voluntarily participated after signing an informed consent declaration. ("World Medical Association Declaration of Helsinki," 2013) In addition, this cross-sectional study was designed and approved following requirements by the local institutional review board (Lithuanian Sports University, NR. MNL-SVA (M)-2023-556).

2.4 Sample size and inclusion criteria

Elite or sub-elite cyclists, as well as competitive basketball players who meet at least two of Jeukendrup's criteria for "well-trained athletes" and who haven't suffered a recent or prior injury (affecting the lower limbs), have been selected as appropriate research subjects (Jeukendrup et al., 2000). Other exclusion criteria were persistent joint pain and the absence of apparent cardiovascular, pulmonary, or metabolic disorders. What is more, the study's ideal sample size was calculated following the previous studies involving similar populations and with similar research aims, thus it is represented by 16 well-trained cyclists and 16 well-trained basketball players (May et al., 2021).

2.5 Research methodology

2.5.1 Participants' testing protocol

Each individual of the different groups (BP and CY) performed all the testing procedures in one single day (figure 1). As the first step of the protocol, body mass and anthropometric measurements have been taken, which include athlete height, upper body, and lower limb circumferences [chest, abdomen, thighs': proximal; medial and distal; upper thighs' (gluteal) and calves' girths)]. Continuously, skinfold thickness analysis of muscles (triceps, biceps, mid-axillary, chest, subscapular, abdominal, supra iliac, thigh, and calf) have been measured in order to acquire information on athletes' body composition. The procedures have been carried out following the guidelines of the National Health and Nutrition Examination Survey (NHANES): (Anthropometry Procedure Manual, 2007). Following the anthropometric measurements, resting quiet and forced breathing ultrasound images of the diaphragm muscle (Tuinman et al., 2020) (Fayssoil et al., 2018) and the vastus lateralis muscle (Cesanelli et al., 2022) have been acquired. Afterward, the subjects performed a low-intensity warm-up (5' cycling on a cyclo-ergometer at 100 W) and performed the tests in this order 1) a maximal inspiratory and expiratory (MIP and MAP) pressure test (Pereira et al., 2016) 2) a maximal voluntary isometric contraction (MVC) test for knee extensors and plantar flexor muscles. (Turpin et al., 2014) Three to five days before the testing each participant was invited to get familiarised with the testing protocol and to fill out an informed consent form. A summary of the study procedures is represented in (Figure 1).

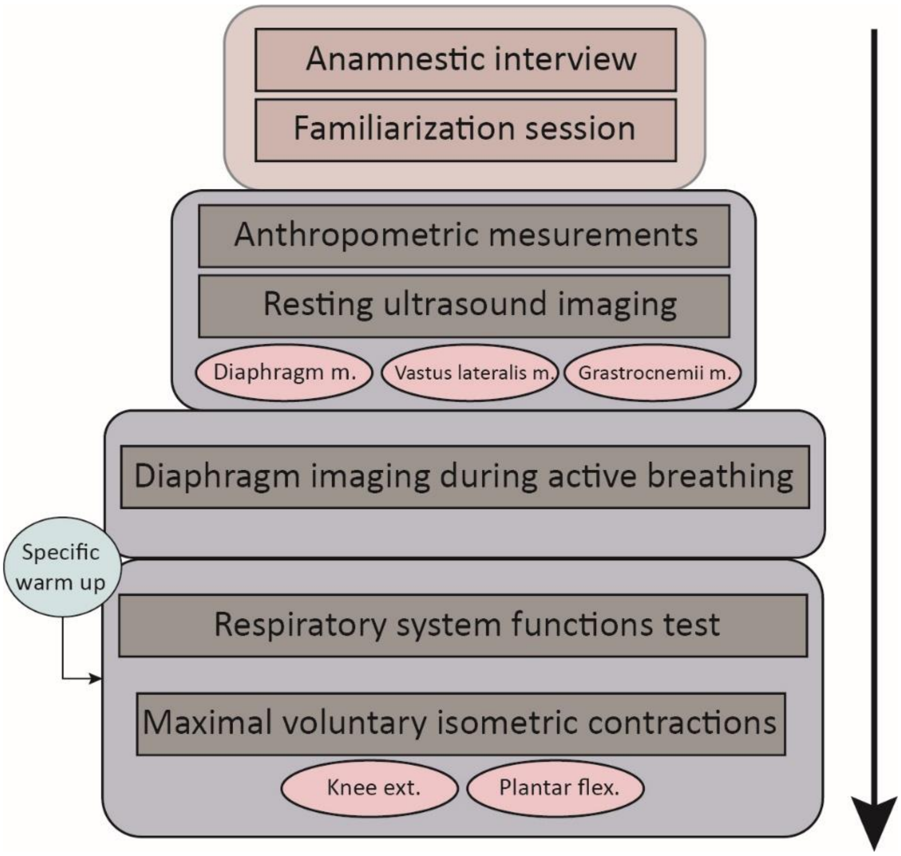

Figure 1. From top to bottom, an overview of the study protocol.

2.5.2 Participants' testing measurements

Musculoskeletal ultrasound imaging

Musculoskeletal ultrasound images were obtained using a grayscale B-mode ultrasonography linear array transducer (10–15 MHz transducer, Echoblaster 128, UAB; Telemed, Vilnius, Lithuania). The settings of the ultrasound system were standardized for all participants, kept identical for all measurements, and recorded using EchoWave II video-based software (Telemed). For the diaphragm muscle images, the subjects were seated on a chair, head, and trunk aligned vertically and with hips and knees flexed at 90°. The trunk angle, i.e., the angle between the trunk and the horizontal axis through the trochanter, was fixed around 90°. Diaphragm thickness (measured perpendicular to its fiber direction between the pleural and peritoneal membrane) and thickening fraction [calculated from B-mode or M-mode images and as the percentage inspiratory increase in diaphragm thickness relative to end-expiratory thickness during tidal breaths (TFdi) or maximal inspiratory efforts (TFdimax)], measured at the mid-axillary intercostal approach at the zone of apposition, have been described as reliable indicators of diaphragm muscle morphology and functions. (Tuinman et al., 2020; Patel et al., 2022)

For the vastus lateralis muscle, each subject was asked to lie in the supine resting position on a physiotherapy bed with the probe applied to the midpoint of the vastus lateralis (Cesanelli et al., 2022), at 50% of the femur length from the knee joint space to the greater trochanter. (Foure et al., 2009) Parallel fascicle alignment has been presumed when the transducer orientation produced an image in which the aponeuroses and the fascicle perimysium trajectory were identified clearly, with no visible fascicle distortion at the image edges. The images were used to calculate the muscle thickness, and the pennation angle to estimate the fascicle length of the muscles. Three images of each muscle were acquired, analyzed, and averaged (coefficient of variation and intra-class correlation were checked).

Respiratory muscle strength

Respiratory muscles strength assessment: maximum inspiratory and expiratory pressures (MIP and MEP) as indicators of respiratory muscle strength were measured through a digital mouth pressure meter (± 300 cm H2O) (RP Check, MD Diagnostic LTD), in accordance with a protocol widely described by previous studies [e.g., (Pereira et al., 2016)]. More in detail, the subjects were asked to be in a seated position and by wearing a nose clip, to perform MIP and MEP tests, as reserve volume and total lung capacity respectively, through a sterile flanged mouthpiece with a small leak (2 mm internal diameter) as a help to prevent glottic closure during the maneuver. Continuously, the participants were instructed to exert maximal inspiratory after slow exhalation and maximum expiratory after a deep inhalation. All tested participants were encouraged by the investigator to “inspire harder” or “expire harder” during each MIP and MEP maneuver which lasts about 2 seconds. If any participant failed to reach the amount of time required for evaluation, he had to repeat it, until three significant trials were made, and the best value was taken for future examination.

Maximal voluntary contraction

Maximal voluntary isometric contraction test: as previously described, the subjects after a proper warm-up had performed a maximal voluntary contraction test. The test includes 2x3s contractions with 2 min recovery between each contraction. With the subject firmly strapped into the dynamometer and the joint angle set, the maximal knee extension and plantar flexion contractions were performed with the intent to produce knee extensors and plantar flexors’ muscles force as fast and hard as possible. Data were sampled at 1000 Hz through a Biopac 12-bit analog-to-digital converter system (EL254S; Biopac Systems, Santa Barbara, CA, USA) and AcqKnowledge software (version 4.1, Biopac Systems). After data collection, the maximal voluntary torque (MVT) was defined as the peak isometric torque (Nm) exerted within the entire contraction phase. In accordance with the procedures described by Maffiuletti et al., the contractile rate of torque development (RTD) has been calculated as the average slope of the torque–time curve (Nm s^{-1}) in the early contraction phase time intervals (0–100 ms) and late contraction phase time intervals (0–300 ms). The onset of contraction was defined as the time point when the knee extensor torque exceeded 2.5% of the difference in the baseline relative to the peak isometric torque (Maffiuletti et al., 2016). MVT and $RTD_{0–100}$, and $RTD_{0–300}$ data from the best voluntary contraction were used for the analyses. All the RTD calculations were performed using a customized Excel spreadsheet whereas the raw data were exported from the AcqKnowledge software.

2.6 Research data and statistical analysis

JAMOVI (2021) computer software (version 2.2) was used for all data analysis. For each variable, descriptive statistics (mean SD) were computed, and data were divided by field of sport (cycling vs. basketball). The Shapiro-Wilk test was used to determine the normality of the sample distribution, which led to the selection of parametric or non-parametric tests. As a result, an independent t-test was used to compare cyclists and basketball players for parameters like (FL, PA, MT, and muscle contraction performance variables (MVIC, RTD0-300). Cohen's d effect size (ES), calculated by dividing the mean difference between the two groups by the pooled standard deviation, was computed using the following criteria: 0 to 0.19, trivial; 0.20 to 0.59, small; 0.6 to 1.19, moderate; 1.20 to 1.99, large; >2.0 very large (Hopkins et al., 2009). Pearson correlation analysis with linear regression was then used to assess the potential correlations between the criteria morphological factors and neuromuscular performance variables in the two groups (cycling and basketball). To evaluate the size of correlations between measured variables, the following criteria were used: 0.09, trivial; 0.10 to 0.29, minor; 0.30 to 0.49, moderate; 0.50 to 0.69, big; 0.70 to 0.89, very large; and >0.90, virtually perfect (Ferguson, 2009). The statistical significance was determined using an alpha threshold of $p<0.05$.

3. RESEARCH FINDINGS

3.1 Anthropometric data characterization

In the following section, mean and standard deviation were used as descriptive statistics. Additionally, athletes' anthropometric measurements and sport discipline were used as the independent and dependent variables, respectively. Shapiro-Wilks test was used to assess the normality of the data revealing that all analyzed variables had normal distribution, except participants' age and tibia length.

Table 1. Research subjects' characteristics (*mean* ± *SD*) and significance between two different groups.

	Cyclists (n=16)	Basketball players (n=16)	P value
Age	24.8 ± 3.94	21.3 ± 3.15	0.011*
Body mass (kg)	80.6 ± 6.92	86.8 ± 10.9	0.033*
Body fat (%)	8.58 ± 4.01	8.58 ± 4.01	0.720
Height (cm)	184 ± 3.41	193 ± 5.43	< .001**
Femur (cm)	45.9 ± 3.05	48 ± 2.68	0.047*
Tibia (cm)	43.2 ± 2.39	45.8 ± 1.81	0.008**
Chest (cm)	100 ± 6.91	101 ± 6.11	0.940
Waist (cm)	84.1 ± 5.72	87.2 ± 7.45	0.136
Quad(cm)	54.5 ± 3.08	54.2 ± 3.5	0.851
Calf (cm)	8.48 ± 2.43	8.58 ± 4.01	0.978

*Notes: *: p≤0.05; **: p≤0.01*

The independent t-test indicates a significantly greater age difference, with mean values of [*p*=0.011; mean difference: -3.5 y; 95%CI: 0.19 to 1.74; ES: 0.98; moderate], but significantly lower body mass [*p*=0.003; mean difference: 6.2 kg; 95%CI: -1.406 to 0.061; ES: 0.44; small]. In addition, cyclists' height [*p*<0.01; mean difference: 9 cm; 95%CI: -2.91 to -0.95; ES: -1.94; moderate] was significantly lower compared to basketball players as well as tibia length [*p*=0.002; mean difference: 2.6 cm; 95%CI: -2.01 to -0.37; ES: 1.20; large] and femur length [*p*=0.047; mean difference: 2.1 cm; 95%CI: -1.46 to 0.01; ES: 0.73; moderate] No significant differences were found for body fat, chest, waist, quad, and calf muscles width between different groups.

3.2 Differences in the musculoskeletal morphological parameters

The following tables characterize morphological parameters of upper and lower limb muscles, including muscle thickness of the diaphragm in three different phases (end expiration and end inspiration, quiet maximum), muscle thickness of vastus lateralis, gastrocnemius lateralis, and medialis.

Table 2. Descriptive statistics (*mean* ± *SD*) and significance of three different phases of diaphragm muscle compared in different groups.

	Cyclists (n=16)	Basketball players (n=16)	P value
MT DIA ee (mm)	2.65 ± 0.23	3.17 ± 0.47	<0.001
MT DIA ei quiet (mm)	3.56 ± 0.32	4.37 ± 0.68	<0.001
MT DIA ei maximum (mm)	5.66 ± 0.59	6.44 ± 1.01	0.001

Notes: MT, muscle thickness; DIA, diaphragm; ee, end-expiration; ei, end inspiration.

The independent t-test shows significantly lower diaphragm MT at the end-expiration with mean values of [p<0.001; mean difference: 0.52mm; 95%CI: -2.23 to -0.53; ES: 1.40; large] in BP group. Continuously, results indicate that diaphragm MT during end inspiration (quiet and maximum) has significantly greater values [p<0.001; mean difference: 0.81 mm; 95%CI: -2.38 to -2.38; ES: 1.52; large] and [p=0.001; mean difference: 0.78 mm; 95%CI: -1.70 to-0.16; ES: 0.94; moderate] in the BP compared to CYC.

Table 3. Descriptive statistics (*mean* ± *SD*) and significance of three different lower limb muscles' thickness compared in different groups.

	Cyclists (n=16)	Basketball players (n=16)	P value
VL MT (mm)	28.2 ± 1.84	26.7 ± 2.6	0.074
GL MT (mm)	15.9 ± 1.3	17.4 ± 1.18	0.002
GM MT (mm)	19.2 ± 1.63	20.7 ± 1.11	0.005

Notes: MT, muscle thickness; VL, vastus lateralis; GL, gastrocnemius lateralis; GM, gastrocnemius medialis.

As it is shown in Table 3, statistically significant differences appear in the lower part of limb muscles, whereas gastrocnemius lateralis [p=0.002; mean difference: 1.5 mm; 95%CI: -2.00 to -0.37; ES: 1.20; large] and gastrocnemius medialis [p=0.005; mean difference: 1.5 mm; 95%CI: -1.83 to -0.25; ES: 1.06; moderate] had a lower MT value in BP group. On the contrary, no significance was seen in vastus lateralis MT between the groups [p=0.074; mean difference: -1.5 mm; 95%CI: -0.08 to 1.37; ES: 0.65; moderate].

Table 4. Descriptive statistics (*mean* ± *SD*) and significance of lower limb muscles' fascicle length compared in different groups.

	Cyclists (n=16)	Basketball players (n=16)	P value
VL FL (mm)	79.8± 7.30	83.7 ± 5.23	0.088
GL FL (mm)	59.5 ± 4.04	65.5± 5.13	<0.001
GM FL (mm)	56.2 ± 4.49	64.9 ± 6.55	<0.001

Notes: VL, vastus lateralis; GL, gastrocnemius lateralis; GM, gastrocnemius medialis; FL, fascicle length.

As it is presented in Table 4, statistically, significant differences appear in the lower part of limb muscles, whereas gastrocnemius lateralis [*p*<0.001; mean difference: 6 mm; 95%CI: -2.11 to -0.45; ES: 1.30; large] and gastrocnemius medialis [*p*<0.001; mean difference: 8.7 mm; 95%CI: -2.41 to -0.64; ES: 1.54; large] where CYC had a lower value of fascicle length. Additionally, no significance was observed in the vastus lateralis muscle between the groups [*p*=0.088; mean difference: 3.9 mm; 95%CI: -1.34 to 0.11; ES: 0.62; moderate].

3.3 Differences in contractile properties of lower limb muscles

Table 5. Descriptive statistics (*mean* ± *SD*) and significance of knee extensors and plantar flexors' peak torque compared in different groups.

	Cyclists (n=16)	Basketball players (n=16)	P value
PT KE (Nm)	380 ± 81.9	378 ± 92.2	0.956
PT PF (Nm)	213 ± 56.5	233 ± 59.9	0.35

Notes: PK, peak torque; KE, knee extensors; PF, plantar flexors.

As it's presented in Table 5, statistical analysis reveals no significant difference between CYC and BP in peak torque of knee extensors [*p*=0.956; mean difference: -2 (Nm); 95%CI: -0.67 to 0.71; ES: 0.015; trivial]. Furthermore, there was no significance between the groups in peak torque of plantar flexors, with mean values of [*p=0.35*; mean difference: 20 (Nm); 95%CI: -1.03 to 0.37; ES: 0.33; small].

	Cyclists (n=16)	Basketball players (n=16)	P value
early RTD KE (Nm*s-1)	2241 ± 396	2282 ± 489	0.925
late RTD KE (Nm*s-1)	1414 ± 217	1687 ± 378	0.018

early RTD PF (Nm*s-1)	793 ± 174	1037 ± 245	0.003
late RTD PF (Nm*s-1)	506 ± 119	839 ± 215	<0.001

Table 6. Descriptive statistics (*mean* ± *SD*) and significance of knee extensors and plantar flexors' rate of torque development compared in different groups

Notes: RTD, rate torque development; KE, knee extensors, PF, plantar flexors.

As it's presented in Table 6, no significant difference was found between the groups in early RTD of knee extensors [*p*=0.925; mean difference: 41 (Nm*s-1); 95%CI: -0.78 to 0.60; ES: 0.02; trivial]. On the contrary, there was a significant difference in late RTD of knee extensors, whereas BP showed greater values compared to CYC [*p=0.018*; mean difference: 273 (Nm*s-1); 95%CI: -1.63 to -0.11; ES: 0.88; moderate]. In addition, BP also had significance in early [*p*=0.003; mean difference: 244 (Nm*s-1); 95%CI: -1.93 to -0.32; ES: 1.14; moderate] and late [*p*<0.001; mean difference: 333 (Nm*s-1); 95%CI: -2.86 to -0.92; ES: 1.91; large] RTD of plantar flexors compared to CYC.

3.4 Differences in respiratory muscles functions and lungs capacity

Table 7. Descriptive statistics (*mean* ± *SD*) and significance of respiratory function parameters compared in different groups

Notes: FVC, forced vital capacity; FICV, forced inspiratory vital capacity; PIF, peak inspiratory flow; MIP/MEP, maximum inspiratory/expiratory pressure; RIPD/REPD, rate inspiratory/expiratory pressure development.

As it's presented in Table 7, no significant differences were observed in FVC [p=0.604;

	Cyclists (n=16)	Basketball players (n=16)	P value
FVC (L)	6.68± 1.01	6.50±0.39	0.604
FIVC (L)	5.01± 0.95	5.04± 0.30	0.843
PIF (L/s)	7.19 ± 1.12	7.68 ± 1.41	0.220
MIP (cmH20)	149 ± 14.8	157 ± 19.2	0.184
MEP (cmH20)	188 ± 25.7	209 ± 15.5	0.009
RIPD (cmH20*s-1)	1442 ± 261	1795 ± 222	<0.001
REPD (cmH20*s-1)	2227 ± 261	2531 ± 199	<0.001

mean difference: -0.18 (L); 95%CI: -0.51 to 0.88; ES: 0.18; small] and FIVC [p=0.843; mean difference: 0.03 (L); 95%CI: -0.76 to 0.62; ES: 0.07; trivial] between the tested groups. PIF revealed similar, non-significant value [*p*=0.220; mean difference: 0.49 (L/s); 95%CI: -1.08 to

0.32; ES: 0.38; small] as well as MIP [*p*=0.184; mean difference: 8 (cmH20); 95%CI: -1.18 to 0.24; ES: 0.48; small]. On the contrary, statistical analysis showed that BP had a significantly greater MEP [*p*=0.009; mean difference: 21 (cmH20); 95%CI: -1.75 to -0.20; ES: 0.99; moderate] compared to cyclists. In addition, BP seems to have a significantly higher rate of inspiratory [*p*<0.001; mean difference: 353 (cmH20*s-1); 95%CI: -2.30 to -0.57; ES: 1.45; large] and expiratory [*p*<0.001; mean difference: 304 (cmH20*s-1); 95%CI: -2.12 to -0.46; ES: 1.31; large] pressure development, compared to cyclists.

4. CONSIDERATIONS

The present cross-sectional comparison aimed to determine if chronic exposure to different chronic exercise training (i.e., basketball vs. cycling) can induce not only lower limb muscle-specific adaptations but also changes in respiratory muscles' structural and functional characteristics. Furthermore, after some research in the literature, we presumed that chronic exposition to a high-level basketball training regime compared to cycling can determine differences in muscle architecture (i.e., greater pennation angle and lower fascicle length) between the different groups. In addition, we also expected that cyclists would show similar trends in respiratory muscles' structural and functional differences (i.e., diaphragm morphology and respiratory muscles strength) compared to elite basketball players.

As it is shown in the results, the contractile properties of KE did not differ significantly between the two groups, except for the late RTD that was greater in BP. In parallel to this, no differences in VL MT emerged, supporting the notion by which, muscle contractile capacity, and more in detail, maximal strength, is strictly related to muscle quality and size (Pinto et al. 2014). In this sense, another study reaffirms our findings, where it states that MT, is an indirect measure of force-generating capacity (Muraki et al., 2013), and its correlation with the power-generating ability was observed in master cyclists also (Ocana et al., 2021). Thus, we confirm that both disciplines are able to induce considerable hypertrophy of knee extensor muscles, accompanied by high torque-generating capacity.

Nevertheless, to explain the significantly higher value in late RFD of the BP, variable RFD needs to be simplified. As anticipated before, RFD is dispensed to neural (which is the early phase) and muscular (late phase) factors (Maffiuletti et al., 2016). While the neural factors encompass the motor unit synchronization and the ability to rapidly activate the motor units (Del Vecchio et al., 2019), the muscular factors (late phase) are associated with muscle size and morphology, as well as muscle architecture (Maffiuletti et al., 2016). Even though our findings show that VL MT and quad size weren't significantly different, the possible explanation for differences could be from

Zaras and colleagues (Zaras et al., 2016), who found that longer muscle fascicles were correlated with greater RFD, even though the authors did not distinguish the early from the late phase. Additionally, BP compared to CYC does have a longer FL of VL, and it reaffirms the idea that muscle architecture plays a role in the RFD late (not early phase). Concluding, a possible explanation for the differences in late RTD could be linked to the architectural differences in FL in BP VL compared to CYC, which has been associated with the speed of contraction.

The present experiment also revealed differences in contractile properties of ankle joint muscles, where BP compared to CYC had higher, but not significant PT of PF muscles. As previously mentioned, recent studies have found that certain architectural characteristics relate to advantages in physical performance. For instance, some state that a greater pennation angle allows a greater amount of contractile tissue to attach to a given area of tendon or aponeurosis within a cross-sectional area and predicts the maximal capacity for force production (Blazevich & Sharp, 2005). On the contrary, our findings show that BP had lower values of pennation angle for both gastrocnemius muscles, so the question arises which other factor influenced greater PT of PF? Another possible explanation, underlined in the previous subchapter, could be that BP shows significantly greater GL and GM muscle thickness compared to CYC, which directly correlates to muscle cross-sectional area and additionally influences maximal force production (Narici et al., 2016). These observations could potentially explain why BP has higher values in MVIC of the PF muscle group.

Another important aspect that needs to be discussed, is the early and late RFD of PF, whereas BP had significantly higher values in comparison to CYC. These observations revealed that the lower part of limb muscles is strongly affected due to chronic training factors and physiological body adaptations. As some researchers state, RFD is derived from the earlier phase of the contraction (≤100 ms) and seems to be largely influenced by neural mechanisms, which mainly concern motor unit behavior (Del Vecchio et al., 2019). In addition, since PT of PF did not have any significant difference between the groups, physiological features of RFD could explain why it has been more sensitive to neural mechanisms and potentially does not have similar referring values compared to MVIC. Indeed, our research support other authors' findings that early RFD is poorly correlated to MVIC (Andersen and Aagaard, 2006) and is largely dependent on motor unit recruitment speed and maximal discharge rate (Del Vecchio et al., 2019). On the other hand, some researchers state that late RFD strongly correlates to MVIC and therefore seems to depend more on structural variables and muscle architecture (Andersen et al., 2010; Folland et al., 2014).

In summary, both aspects are believed to contribute, and the analysis of our tested athlete's morphological parameters revealed, that both GL and GM fascicle lengths, were significantly higher in BP compared to CYC, reaffirming, the findings mentioned before. What is more, greater BP PF MT could be explained by another author's findings (Lee et al., 2021), where he discusses how MT of GM was significantly greater in male sprint cyclists (GM: 20.9±4.1mm) compared to endurance cyclists (GM: 15.9 ± 3.2mm) and that this was correlated to cycling power over 20 s. Continuously, the fact that BP physical demands during the game are intermittent and at a high intensity (~10% of movements are short sprints up to 20m) (McInnes et al., 1995), with sprints and jumps as prevalent gestures, the significantly greater MT values in GM could be the result of that. Furthermore, our findings could be also explained by a similar study by (Abe et al., 2000), where he revealed that increased MT correlates to greater power output in the GM muscle in sprinters.

Continuously, the pulmonary function test between the groups, revealed that none of the tested respiratory function parameters had any significance. Similar findings were observed in FVC between the CYC and BP, with mean values of 6.68 +- 1.01 and 6.50+- 0.947 respectively. Consequently, a very small difference occurred in FIVC between the groups, where CYC had a value of 5.01+- 0.395 and BP 5.04 +- 0.305. However, to explain these findings, it needs to be emphasized that primarily lung function varies depending on the sport, with superior performance previously reported in endurance-trained compared to athletes involved in strength/power training (Durmic et al., 2017). Considering that CYCs predominately are endurance-type athletes, usually their functional characteristics such as FVC appear to be better than strength/power athletes (Lazovic et al., 2015). Nevertheless, the author highlights that the power group in his study (wrestling and short-distance runners), had only significantly lower lung vital capacity (LVC) above all tested pulmonary function parameters. Therefore, this concurs with our results and partly explains our findings, (i.e., respiratory function parameters, were slightly better in CYC compared to BP), in theory, numerous lung function indicators tend to favor endurance-trained athletes, compared to strength/power athletes (Hackett, 2020). On the other hand, the fact that we did not observe very significant differences may be explained because, in our study, the BP had significantly greater body height and mass, which re-confirms the study of Lazovic et al., where the authors found the highest statistical correlations between height and weight among all tested pulmonary function parameters (Lazovic et al., 2015). Nevertheless, a broader look, focusing not only on lung capacity but also on respiratory system muscles is necessary, in order to understand respiratory system functional adaptations between the different chronic sports disciplines.

Accordingly, the present study focused also on diaphragm morphology and functions assessment, as one of the most important and studied respiratory muscles. The respiratory muscle strength tests revealed that most of the parameters were significantly higher in the BP group when compared to CYC, except for MIP. Specifically, the BP group produced 10.6% greater maximal expiratory pressure (MEP) and 12.7% greater rate of pressure development (REPD) with a moderate and large effect size respectively. These findings could be explained from several points of view. First, basketball is a more multidisciplinary sport, combining different planes of motion and non-identical body moves in space. The game usually demands lots of core stabilization, fast change of direction, and rotational jumps, and BP performance combines all of that. In addition, core muscles are involved not only in the stabilization of the body, but the positioning of the jump, and execution of the upper limb also. It is already known, that during the forced expiration phase, muscles located in the thoracic (pectoralis major) and trunk (abdominals) regions actively assist in the expiratory flow and the deflation of the lungs (McKenzie, 2012), and maintaining abdominal muscle functionality is linked with preserving trunk control, which predominantly prevails during basketball training more often than in cycling. What is more, (Pereira et al., 2016) in his research reveals, that greater trunk stabilization and angular movements (flexion, extension, lateralization, and rotation) generate greater functional scores by IWBF (International Wheelchair Basketball Federation) classification, so for this reason, his tested control group MEP values exceeded the predicted ones. These considerations agree with our findings, whereas basketball discipline by itself, gives more opportunity to make an impact on thoracic and trunk muscle regions, which very actively assists in the breathing expiration phase.

On the contrary, our findings revealed a non-significant difference in maximal inspiratory pressure (MIP), whereas the BP group, had a 5.8% greater value compared to CYC. Besides that, the rate of inspiratory pressure development (RIPD) was 21.8% significantly greater also. It could be assumed that higher values are a result of the game specificity, whereas players' physical demands are much higher because of a strong relationship between body composition, aerobic fitness, and anaerobic power, within positional roles in elite basketball (Narazaki et al., 2009). This results that maintaining body weight and lean mass through the long season is the biggest issue, so proper weight training and rich nutrition are a must. In addition, it seems that greater inspiratory pressure values are a consequence of resistance training, whereas intra-abdominal pressure increases as a result of heavier loads (Blazek et al., 2019) and it’s achieved through contraction of the diaphragm. Consequently, contraction moves this inspiratory muscle inferiorly acting on the relatively incompressible abdominal contents and is aided by the coactivation of abdominal muscles (Cavaggioni et al., 2015). Therefore, the diaphragm, thoracic cage muscles, and abdominal muscles, are recruited during resistance training to assist with the elevation of intra-abdominal pressure. This mechanism proves not only why inspiratory pressure parameters are greater in BP (the diaphragm is one of the main working muscles during MIP), but why BP showed greater muscle thickness also. BP had 17% thicker diaphragm muscle, in comparison to CYC with a large effect size, calculating the average of all breathing phases. To conclude, the present findings go in line with the other author, whereas he demonstrated a significant increase in inspiratory muscle strength with greater gains shown by the high-intensity training (HIT) over the endurance training (ET) protocol. Therefore, observations of his study demonstrate that the stimulus for inducing respiratory muscle adaptations requires high-intensity work and it suggests that the observed greater inspiratory muscle strength (diaphragm strength primarily) was due to greater demand placed on the respiratory muscles with HIT over ET (Dunham and Harms, 2012). Nevertheless, when analyzing respiratory function parameters, anthropometric parameters like body height and weight should be considered also, due to high statistical correlations with pulmonary function parameters among the general population (Lazovic et al., 2015).

CONCLUSIONS

In summary, muscle architecture, and contractile functions differed between the two tested groups. In addition, our primary aim was reached since we observed differences in respiratory muscles functions, where for the first time we described not only lungs capacity but also respiratory muscle structural and functional characteristics such as maximum inspiratory and expiratory strength, associated with the morphological characterization of a primary respiratory muscle - the diaphragm. However, deeper analyses needed involving more heterogeneous populations (e.g., water sports) and focusing not only on inspiratory muscles such as the diaphragm but also on expiratory muscles, may extend the present findings and increase the relevance of investigations in this field.

Nevertheless, we accept both of our primary study hypotheses because:

1. We see differences in lower limb muscle architecture (i.e., greater pennation angle and lower fascicle length) in cyclists compared to basketball players.

2. We observe a possible trend towards similar adaptive traits for respiratory muscles in response to chronic exercise training, resembling that observed for lower limb muscles.

SUGGESTIONS AND RECOMMENDATIONS

1. Different chronic exercises like basketball and cycling induce specific adaptations to the main muscles involved in the activity, such as knee extensors and plantar flexors. This, in turn, is reflected in differences in muscle contractile capacity and therefore athlete performance remarks. The results obtained from this comparison may reveal potential benefits or detrimental effects of applying one or other form of exercise training in order to obtain very specific adaptations, supporting athletes' monitoring, performance optimization, or rehabilitation strategies.

2. In addition, different chronic exercises like basketball and cycling seem to be able to produce a positive adaptive response in terms of lung capacity, respiratory muscle strength, and morphological parameters. Although not remarkable as lower limb muscles we observed a possible trend towards specific adaptations according to the exercise training performed chronically. This may represent a relevant aspect beyond the application in sports, as rehabilitation procedures from respiratory system illnesses could involve not only specific respiratory muscles training but also activities such as aerobic training (i.e., cycling) or higher intensity exercise (i.e., basketball) whereas patients could engage more easily and for longer periods of time.

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