

Effects of lower limb power, aerobic capacity and hand grip strength on the technical efficiency of young tennis players

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Technical efficiency of young tennis players.

Abstract

Introduction: Tennis is a sport with no time limit. This can result in matches lasting less than an hour or up to five hours. This variability requires that high-competition tennis athletes be trained both at an anaerobic level for better performance, and at an aerobic level, to help with recovery between points, during the game. **Methods:** This cross-sectional study intended to analyse how lower limb power, aerobic capacity and hand grip strength influences the technical efficiency of tennis players. Training among young tennis players provides a positive and crucial role in building technique effectiveness, so early but convenient and adapted preparations through training play an essential role in helping these young players to improve their skills in this game. Twenty-six athletes, aged between 8 and 16 ($M=11.26\pm 2.25$), 18 males (69.2%) and 8 females (30.8%) were included. They performed the Hand-Grip strength test, the aerobic capacity was tested via one-mile (1609 meters) test. For technical efficiency, they performed 50 right and 50 left shots, checking which ones reached the area inside and outside the tennis court and the leg power capacity through the Chronojump system. Non-parametric tests were applied, Mann-Whitney, Wilcoxon and Kruskal-Wallis and also Rho Spearman correlations between variables. **Results:** Comparisons between level of training ($p\leq 0.02$) and years of practice ($p\leq 0.04$) revealed that all the variables had a direct and positive influence on the technical efficiency of these tennis players. As for correlation results, all independent variables have a strong correlation with tennis technical efficiency (0.480 to 0.736). **Conclusions:** Findings suggest that higher physical fitness capacities are associated with greater technical efficiency.

Keywords: Tennis, children, lower limb power, aerobic capacity, hand-grip strength, technical efficiency, national circuit.

Introduction

Long-term sports training can be defined as the ability to specifically plan a player's career about their growth and development stages (Crespo, Reid, Miley & Atienza, 2023). The development of technical, tactical, physical and psychological skills essential for playing tennis at a high level can be developed from early ages and there must be proper attention to each of the stages of development (Reid, Crespo, Lay & Berry, 2007). All these factors related to tennis players, are important in long-term planning, where the physiological and psychological ages, levels of motivation and neurological development of the player stand out, in addition to the sensitive phases and critical periods that are more favorable for training these more specific aspects (Reid et al., 2007). Although training control in tennis is well documented, with many scientific articles on both physical and physiological control and evaluation, there is little research in technical efficiency in young players (Cortes, 2010). This means that these fundamental aspects of training in junior tennis are still left to the subjectivity of the coach and their knowledge of training in these areas. Without controlling these aspects, it is not easily detectable which aspects of training should be adjusted to allow for its evolution.

Technical efficiency is understood as the number of successful shots achieved, as a proportion, of the total number of actions performed according to a sports skill (Moreira et al, 2003).

An understanding of the most opportune periods for improving different skills and capabilities, as well as knowledge about the fundamental characteristics of growth, development and maturity of human beings becomes essential. To help and motivate young tennis players to practice this sport and be developed and promoted to their maximum potential, it is crucial to understand the implications of such changes. According to the available research, tennis is characterized by fast and precise movements, accelerations and speed slowdowns, and often lasts quite a long time. A tennis match involves a combination of periods with low and high intensities, and can be considered an intermittent anaerobic sport, with an aerobic recovery phase (Fernandez, Mendez.Villanueva & Pluim, 2006). In tennis matches there is a general tendency for oxygen consumption (VO_2) and heart rate to increase as the game continues, with a decrease during rest periods between points, matches and changing courts (Kovacs, 2006). The characterization of the physical effort applied to tennis has aroused interest [5], but opinions on this subject differ (Kovacs, 2006; Durmus, Odemis & Sogut, 2023). The physiological characterization of tennis, at different competitive levels, is still delicate and contradictory, but it is a factor of great interest to be studied. The evaluation and analysis of physical effort in tennis has as its main objective the creation of specific physical tests applications. It's intended to be predictable and accurately, the components involved in training and competition, with correct application of training methods with greater rigor and precision (fig. 1). However, to develop a battery of tennis-specific tests, it is necessary to know the nature of the game and identify the most relevant physiological parameters for performance (Durmus et al., 2023).

Tennis is also characterized by intermittent efforts, with short breaks between periods of effective play, as well as some periods of rest. Athletes have a stopping time between each point that can reach 30 seconds and between every two games a regulatory stopping period that can reach 1 minute and 25 seconds (Bergeron, Maresh & Kraemer, 1992). The best way to identify the specific physical needs of the sport is through observation of the competitive situation, particularly in terms of the statistical interpretation of a tennis match. According to the same author, matches that last 3 sets identify 20 to 30% as effective and useful playing time, and the remaining 70 to 80% is time for rest or field changes. It has also been reported that, at each point, the distance covered can vary on average between 8 and 12 meters (Pereira, Nakamura, Jesus, Vieira, Misuta, Barros & Moura, 2016). This fact leads us to believe that movement and reaction speed are motor skills of great demand in tennis matches, directed related with leg power capacity (Hoppe, Baumgart, Bornefeld, Sperlich, Freiwald &

Holmberg, 2015). Tennis is still considered an anaerobic sport that requires high levels of aerobic capacity to avoid fatigue (Waldzinski, Waldzinska & Durzynska, 2024). The aerobic physical state of players often determines a large part of their ability to maintain high-intensity exercise during the game, and can influence the player's technical and tactical performance, allowing him/her to better manage fatigue (Comelas & Viñaspre, 2001).

The training stage of young tennis players can be characterized by the development and application of activities aimed at a complete game on the entire court. A varied set of right and left shots should be encouraged and promoted, with the recommendation to perform on all floor surfaces where tennis can be played, a complete and varied game (Genevois, 2019). The comprehensive and continuous training of young tennis players should be the main objective of coaches (Wang, 2023). Success in the technical-sport training of tennis players fundamentally depends on training that includes varied and diverse range of movements that contribute to the integral and complete development of tennis players with a view to specialization and competition (Weiss, Weiss & Amorose, 2020). Right from basic stages, the tennis player must be encouraged to specialize technically, through exercise plays and drills. His/her technical qualities must serve as leverage and impulse to obtain results in younger phases, as the ages and stages are higher, the game speed increases exponentially and the difficulties are more visible, so, it becomes more demanding to neutralize the opponent's actions. Therefore, mastering advanced tennis techniques is the main characteristic of adult tennis players who are successful in international competitions (Balbinotti, Balbinotti, Marques & Gaya, 2003). However, to avoid specialized technical-sports training early on, it is not recommended that specific exercises be removed from training, as these exercises are necessary from the first stages of development in young tennis players' careers (Fuentes, Bergerom, Pluim & Weber, 2001). Based on these considerations, the study intended to analyse how lower limb power, aerobic capacity and hand grip strength influences the technical efficiency of tennis players.

Therefore, the present study aimed to examine the associations between lower-limb power, aerobic capacity, and hand-grip strength with technical efficiency in youth tennis players. It was hypothesized that higher physical fitness capacities would be positively associated with technical efficiency.

Tennis and lower limb power

Muscular power can be defined as the ability of a muscle to contract quickly (Balbinotti, 2003). In tennis it is necessary to generate great power, applying it with a racket, which in turn must affect another that often has an enormous amount of ball movement. This combination of muscular force applied to a small ball with maximum speed is called explosive strength. The study of Pereira et al. (2016) aimed to evaluate the levels of explosive strength of the lower limbs, in a group made up of young high-performance tennis players, with international classification, correlating with displacement speeds and serve, it was found that the levels of explosive strength seem to contribute significantly to the speed of displacement and that its elastic component is important to generate high ball speeds at the time of the serving. Still, according to the same author, the explosive strength of the lower limbs can be considered as a measure of performance in tennis. According to the same study (Pereira et al., 2016) muscular power is one of the most crucial factors to consider in tennis. In agreement with what was mentioned before, it is highly important to develop muscular power for the types of demands imposed on the lower limbs, whether in movements or in the execution of technical gestures (Balbinotti, 2003; Kovacs, 2007; Taylor et al., 2010).

During a tennis match there can be a total average of one thousand executions of technical actions per game, providing a displacement of approximately 3 km when performing these type of actions (Souza, Bonette, Souza-Junior, Carmargo & Mascarenhas, 2017). However, tennis players needs efficient preparation of the predominant variables that influence improved performance, including

lower limb power and speed. It is therefore essential to train fundamental skills for the development of lower limb power, which can be developed through the inclusion of vertical and horizontal jumping exercises with high intensity of execution and range of movement. A study from Durling et al. (2013) reported the positive effects of strength training programs for tennis players on changes in body composition, increases in anaerobic power, improvements in speed and agility, as well as in strength levels during the execution of movements, serve speed, right and left shots (Mendonça, 2012). This capacity must be present in all technical actions, being responsible for the ease, speed and economy with which the tennis player executes his movements in the basic fundamentals, such as: forehand (shot holding the racket with the palm of the hand facing forward), backhand (shot holding the racket with the palm facing backwards), serving (shot that starts the point) and smashing (higher power shot cutting the ball from top to bottom) (Salanikidis & Zafeiridis, 2008).

Tennis and aerobic capacity

The aerobic capacity of athletes plays a decisive role in the recovery phase, that is, the better the athlete's aerobic capacity is, the more delayed the anaerobic threshold and the appearance of lactic acid will be, as well as the faster energy sources are restored. Tennis, from a physiological point of view, is considered as a sport with alternating aerobic – anaerobic activity (Skoromodova, 1998; Saladinikis & Zafeiridis, 2008). A study developed by Cormi, Mcguigan & Newton (2011) to conduct a physiological and metabolic characterization and correlate it with the technical level, mentioned the importance of each of the energy systems in this sport. According to the literature (Pereira et al., 2016) the importance of training aerobic resistance in tennis players is related to direct intervention in effective game activities, with the need for the tennis player to recover between efforts, thus delaying fatigue and improving performance. With respect to cardiovascular resistance (Balbinotti et al., 2003), the athlete uses the anaerobic part much more than the aerobic part in the disputes for each point; however the physiological demand can change when we consider the game as a whole, which can last two long periods; therefore, cardiovascular resistance training has shown that there were improvements in relation to the athlete's ability to withstand fatigue and improvements in oxygen volume. Oxygen consumption increases during the first few minutes of activity and then remains stable throughout the effort. During the first minutes there is an unstable component that only increases, but after three and four minutes the value of oxygen consumption reaches a steady-state, which reflects a balance between the energy required for active muscles and the production of ATP in the aerobic metabolism (Nouailhetas, 2009). To understand the influence that aerobic capacity has on the development of performance in a match, it is necessary to carry out tests, which will help us to better observe and program the prescription and monitoring of athletes (Baiget et al., 2014; Reilly et al. 2014; Adegboye et al. 2011). Quantifying the intensity and energy used in a game, to form the basis of training, will help coaches analyse the training load required for each player, allowing the necessary adjustments to achieve each athlete's individual goals (Smekal, 2011; Vretaros, 2008).

Tennis e handgrip strength

The use of muscle groups in the upper limbs involves the shoulder kinetic chain, the elbow flexors and extensors and the muscles that participate and activate the handgrip strength that acts in handling the racket (Pereira et al. 2011). The dynamometer test has been presented as one of the most efficient methods for measuring handgrip. The assessment of handgrip strength (HGS) in tennis players who perform competitions must be carried out, (Fett et al. 2020) as training with the racket can produce a neuromuscular adaptation that consequently increases the HGS of the dominant hand, leading to an asymmetry in grip strength, that the player can suffer between limbs. For an optimization of sports technique (Kraemer et al. 2003), it is necessary not only to correctly execute the motor gesture, but also to know how to perform it at high performance and in the different circumstances of the game. Young tennis players aged between 13 and 16 years must have technical training in order to acquire

and consolidate the different shots. This type of training considers different moves. Unilateral differences in the strength of the dominant and non-dominant limbs of athletes from different disciplines may arise over the years, due to the specificity of systematic training, which may reflect gains or decreases in sports performance (Reid & Schneiker, 2008). In this sense, grip strength is not simply a measure of hand strength or is even limited to the assessment of the upper limb. It has many different clinical applications, for example, it is used as an indicator of total body strength, and it is used in physical fitness tests (Vretaros, 2008). Another study from Pereira et al. (2011) concluded that the strength of the dominant and non-dominant hand tends to evolve with age proportionally for both genders. For these authors, biological maturation, among other factors, seems to act to separate the strength of the dominant hand from that of the non-dominant hand. An approximation of values in the pre-pubertal period was also verified, which was possibly induced by greater development of the non-dominant hand in both genders. However, evidence supports that velocity of strokes are very important for the success in a tennis match (Rezende et al., 2012). So, improving a player's stroke efficiency is of interest to tennis players' performance, especially when anthropometric factors, such as upper-body strength, power, body height and arm span are associated with good stroke velocity in young tennis players (Moraes & Raimundo, 2009).

There are several ways of grabbing the racket (Godoy et al. 2009) according to existing tennis techniques, which correspond to better development of the athlete in tennis strokes, preventing important injuries to the wrist and upper limbs. The wrist and hand are responsible for using the upper extremity. Among the multiple purposes, the hand provides prehensile strength (Moreira et al. 2003). Anatomical and kinesiological characteristics of the wrist and hand serve as a basis for understanding the functional mechanism of the handgrips. The hand can be used in many postures and movements that in most cases involve both the thumb and the other fingers. There is a description of two basic postures of the human hand: the "power grip" and the "precision grip". The power grip involves holding an object between partially flexed fingers and palm while the thumb applies counter pressure. The precision grabbing requires greater motor coordination since the object is pinched between the flexor surfaces of one or more fingers and the thumb in opposition. The grip strength directly supports the assessment of the functionality of the upper limbs, being one of the components for research for hand control skills (Moreira et al., 2003; Bandura, 1997; Moreno et al., 2006).

Tennis Technical Efficiency

This component is an excellent parameter for identifying athletes' competitive performance, allowing a more detailed analysis of their weaknesses and strengths (Moreira et al, 2003). The assessment of technical efficiency appears to be a method with scientific validity in several investigations (Burns et al., 2016; Pereira et al., 2011; Jeb et al., 2000). This value is obtained from the percentage of balls placed in the target zone during the physiological and technical tests, on the basis of precision and power criteria (Dias, 2022).

There are trends toward increased efficiency as a function of success in the available task. This component is intended to be an excellent parameter for identifying athletes' competitive performance, which can provide more detailed analysis of their weaknesses and strengths (Maetinez-Gallego et al., 2019). Also, perceptions of efficiency may influence experienced feelings as a function of an exercise stimulus. As such, authors were interested not only in estimating feelings at a single point in time, but also in determining how efficiency expectations were related to these responses throughout the exercise period. For example, a strong hypothesis is that if efficiency is related to more positive subjective responses, then those subjects with high efficiency would be expected to demonstrate significantly greater increases from pre-exercise through on-task measurement. for the post-task assessment. Tennis specificity in terms of technical skills is a pre-dominant factor (Dias, 2022). The perfect execution of technical gestures and effective competition against opponents requires much more advanced levels of physical, technical, tactical and mental fitness (Kobal et al., 2017).

Materials & Methods

The study has a descriptive, observational and cross-sectional design. Twenty-six athletes participated in this study, with ages between 8 and 16 years ($M=11,26\pm 2.25$), 18 males and 8 females participated in this study. All of them are registered in the Portuguese Tennis Federation competing in the national circuit. They train 3 to 4 times a week, lasting between 60 and 90 minutes per sessions, with matches on the weekend. Participants were chosen from the club that agreed to participate in the study according to the ages groups intended for this study. They were informed about the methodology and objectives of the study. The inclusion criteria were: i) athletes that only participate in tennis; ii) not present any physical or psychological disabilities or any type of injury at the time of the evaluations or in the last 6 months. The exclusion criteria were: i) no player included had injuries during the study. After providing consent, they filled out a form with their data regarding age, competition level in the club, sex and years of practice. Informed consent requests were given to their parents for authorization to participate in the study. The investigation was approved by the Review Board of the Sports Department Scientific Committee, respecting all ethical standards in accordance with the Declaration of Helsinki, the Belmont Report and the Ethics Standards in Research in Sport and Exercise Sciences. The participant has the right to withdraw from the research at any time for any reason.

Instruments and procedures

All players were properly equipped in terms of clothes and sneakers, using professional rackets and balls. Researchers did not interfere in the training sessions and only instructed the coaches on how the tests should be executed. The coaches involved held the official and necessary qualifications and all exercises and tests were performed under supervision. Before each test, players were instructed regarding the protocol and verbally encouraged to give their best performance. All tests were performed for two weeks. The first tests conducted were the anthropometric measurements (weight and height). After a physiological warm-up period of 20 minutes, before the training began, the vertical jump was assessed (De Blas, Padullés, Guerra-Balic, 2012). After all the players finished this test, the second test was the one mile test (Welk et al., 2011), which was performed under the same conditions. The third test was the recording of the technical efficiency of the tennis players, whereas the last test was the hand-grip strength test (Pereira et al., 2011). These two last tests were performed in other different days. The evaluations took place on a synthetic tennis court in the afternoon registering a climatic temperature between 18 and 22 degrees.

Anthropometric assessments

Height was measured using a stadiometer with a standard protocol: the distance from the vertex (top point of the head) to the ground, with the player barefoot. For the weight measure, it was distributed over both feet, with the head oriented horizontally according to the Frankfort plan, using a Tanita R-604 bio-impedance scale (Jeb et al., 2000). Players wore only shorts and a T-shirt and no other accessories, climbed onto the scale slowly and remained still, with their heads erect, their eyes fixed straight ahead and their arms extended alongside their bodies with the palms hands facing inwards and their feet in a parallel position.

Lower Limb Power

A Chronojump Boscossystem mat rigid format (60X42cm) from Creative Commons Reconocimiento-Compartir (REF 3.0) was used. In this test, the athletes were asked to perform three vertical jumps, with a 30 second rest period between each jump. The best jump was validated and recorded in Watts. For this test the player is initially in an erect position with their hands on the waist, then a brief flexion of the knees is performed (approximately 90°) followed by a vertical jump, with the hands always kept on the waist (De Blas et al., 2012). The player is instructed to start and end the jump while keeping the

feet inside the contact mat area with their knees extended during the jump. This type of test has been commonly used for this purpose and has been validated (De Blas et al., 2012) with ICC values varying between 0,821 and 0,950 and 0,821 with an average difference of 1,38% and a deviation of 1.11.

Aerobic assessment

The one-mile test was applied. The athletes were instructed to cover the distance corresponding to one mile (1609 meters), at the minimum possible time, this test was conducted around the tennis court. The test was developed and is used as a submaximal effort test to estimate the maximum oxygen uptake (VO₂ max) (Burns et al., 2016; Welk, et al., 2014). The objective of this test involves the athlete running a mile as quickly as possible. If the athlete is not able to cover the entire distance running, he/she can walk in the shortest possible time. Athletes begin the test with the “Ready, Go” voice. As they cross the finish line they are informed of their split race time. To calculate VO₂ max (ml/kg/min) an equation was used based on the total time (T) spent in minutes: $VO_2 \text{ max} = 100.311 - (9.602) \times T + (0.287) \times T^2$ [44].

Technical evaluation

The third test recorded the athlete’s technical efficiency where they performed 50 right and 50 left shots, alternated from each side in the field, checking which shots reached the area inside and outside the tennis court. To collect data, right and left shots were performed in equal situations for all athletes, during training exercises. To analyse this variable, a model was used (Baiget et al., 2014) as a reference, which validated a procedure for evaluating specific resistance in tennis. This method combines performance, physiological and technical efficiency parameters, and was also used in another investigation (Adegboye et al., 2011; Smekal, 2011). Two criteria were observed, precision and power. The accuracy criterion consisted of recording how many balls the athlete hit within the field target and the power criterion analysed the number of balls that, after jumping on the target, passed the power line (presented on figure 1), without hitting the ground once again. Our study focused only on the accuracy criterion. The ball machine model used was a Slinger Bag. Figure 1 presents the tennis technical efficiency model used in this study. The performance recording was carried out by two investigators, who underwent visualization training with 20 performance actions each, with the aim of assessing the coding process inherent in the efficiency recording method. The data recorded for each of the players obtained agreement from these two investigators.

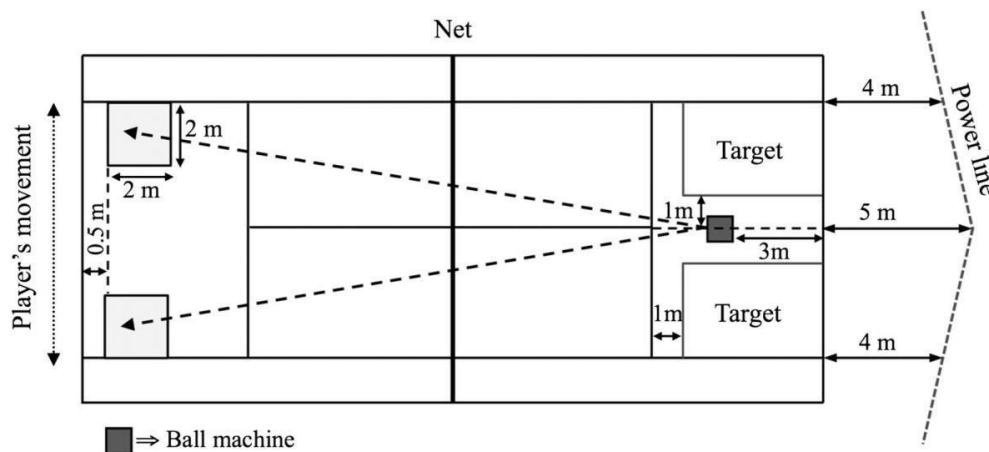


Figure 1 – Tennis technical efficiency model (Baiget et al. 2014).

Hand-Grip strength

The last test was the **Hand-grip** strength test. This equipment provides reliable and accurate data ($Rho = ,8764 p < .001$), Godoy et al (2004). The type of test conducted to determine handgrip strength using a dynamometer was the maximum voluntary strength test, which includes the measurement of the absolute strength of the handgrip movement (Pereira et al., 2011). To measure handgrip strength, a bulb dynamometer (Saehan 5008), with a capacity in kilograms (Kg) was used. A first recording included the determination of the student's dominant hand, the athlete was asked to identify which hand he usually holds the racket with, and by this it was considered his/her dominant hand. Subsequently, measurements were taken on the dominant hand and opposite hand of each subject, in the orthostatic position, keeping the arms extended at the sides of the body. While holding, it was not permitted to rest the equipment on the body. The one-repetition test requires maximum dynamic grip contraction in a single movement. Athletes were instructed to squeeze the manual dynamometer to 100% of their maximum force for 3 seconds, enough time to collect data on the dynamometer. The maximum force was established by the highest value generated in two attempts.

Statistical procedures

In this study, therefore, we want to know if using larger samples leads to statistics that better approximate parameters by assessing the correlation between sample size and the sample mean and median, and their respective SD. It's hoped that this study will contribute to knowledge on whether or not larger samples support the estimation of sample parameters by using a more robust technique. We also attempted to provide the empirical rationale for using representative samples. Statistical inference and descriptive statistics are the essence of all quantitative research.

For the statistical procedures descriptive techniques were applied to estimate the central tendency and dispersion measures of the variables under study (minimum and maximum values, means and standard deviations). **For the inferential statistics tests, non-parametric tests were applied, since the assumption of normality was not met through the Shapiro-Wilk test, namely the Mann-Whitney, Wilcoxon and Kruskal-Wallis (King & Eckersley, 2019). The effect size was also calculated using Partial Eta-squared, which was evaluated according to Cohen's d values, performing the inference method based on the magnitude of the effects. The variation intervals for classifying the magnitude of the effects (Cohen's d) were as follows: 0-0.2, trivial; 0.21-0.6, small; 0.61-1.2, moderate; 1.21-2.0, large; > 2.0, very large (Hopkins, 2009).** Rho Spearman correlations (Schober et al., 2018) were also computed to determine the relationship of the variables under study with the technical efficiency of tennis players. **The results presented focus on exploratory comparisons.** It was used the Statistical Package for Social Sciences (SPSS 22.0) for data entry and statistical analysis. **Alpha was set at 0.05 for all analyses.**

Results

The following tables show the results obtained in terms of inferential and descriptive statistics. Table 1 presents the absolute and relative values for each of the independent variables analysed in this study.

Table 1. Descriptive statistics of the independent variables.

Variables		Frequency (n)	Percentage (%)
Sex	Male	18	69.2
	Female	8	30.8
Competition level	Under-10	8	30.8
	Under-12	9	34.6
	Under-14	4	15.4
	Under-16	5	19.2
Dominant hand	Right hand	21	80.8
	Left hand	5	19.2
Years of tennis practice	Between 1 and 3	7	26.9
	Between 3 and 6	7	26.9
	More than 6	12	46.2
Total		26	100

According to table 1, in terms of gender, the tennis athletes included eighteen males and eight females; for the competition level eight athletes were Under-10, nine athlete's Under-12, four athlete's Under-14 and five athlete's Under-16. Twenty-one athletes who played with their right hand and five were left-handed. In terms of athlete's years of practice, most play for more than six years, and the others are between one and three years or three and six years. Table 2 presents the descriptive statistics for all dependent variables.

Table 2. Descriptive statistics of all dependent variables.

Variables	Minimum	Maximum	Mean±SD
Right hand-grip ¹	7	24	14.73±5.22
Left hand-grip ¹	7	23	13.62±4.75
Aerobic capacity ²	32.31	52.23	42.2±5.0
Lower limb power ³	250.80	766.60	462.68±150.27
Right technical efficiency ⁴	37	46	41.88±2.5
Left technical efficiency ⁴	34	48	40.35±3.1
Total technical efficiency ⁴	71	93	82.23±5.45

Units: ¹ kgf; ² ml/kg/min; ³ watts; ⁴ number of precision shots

This table shows that, according to the hand-grip test there are similar values between right and left-handed athletes, with a lightly greater values for the right-hand strength. For the aerobic capacity, the mean value for this variable is considered very good at these ages, as is the lower limb power, with a mean value of 462.68 watts. Regarding technical efficiency, for the right and left shots, the mean values are higher when considering the 50 left and right shots, which indicates a very high mean of total efficiency (82.23), when considering a total of 100 shots.

Table 3 presents the gender differences in the dependent variables considered in this study.

Table 3. Descriptive analysis of the variables under study and statistical significance between gender.

Gender		Right hand- grip ¹	Left hand- grip ¹	Aerobic capacity ²	Lower limb power ³	Right technical efficiency ⁴	Left technical efficiency ⁴	Total technical efficiency ⁴
Male	N	18	18	18	18	18	18	18
	M±SD	14.61±5.57	13.50±4.92	42.11±5.61	456.15±160.65	41.89±2.80	40.33±3.74	82.22±6.21
Female	N	8	8	8	8	8	8	8
	M±SD	15.00±4.66	13.88±4.67	42.52±3.57	477.37±131.41	41.88±2.23	40.38±1.59	82.25±3.53
	<i>Sig.</i>	0.871	0.849	0.978	0.644	0.892	0.935	0.935
	<i>d Choen</i>	0.142	0.087	0.022	0.197	0.065	0.044	0.033

*Sig. $\alpha \leq 0.05$ Units: ¹ kgf; ² ml/kg/min; ³ watts; ⁴ number of precision shots

The results in table 3 show no significant differences in hand-grip strength, aerobic capacity, lower limb power and technical efficiency, when comparing male and female athletes. According to the effect size, a trivial effect is presented in all variables.

Table 4 presents the comparison of the dependent variables by competition levels.

Table 4. Descriptive analysis of the variables under study and statistical significance between competition levels.

Competition level		Right hand- grip ¹	Left hand- grip ¹	Aerobic capacity ²	Lower limb power ³	Right technical efficiency ⁴	Left technical efficiency ⁴	Total technical efficiency ⁴
U-10	N	8	8	8	8	8	8	8
	M±SD	9.13±1.24	8.88±1.12	38.22±2.74	327.17±55.37	41.38±2.72	39.25±2.31	80.62±4.98
U-12	N	9	9	9	9	9	9	9
	M±SD	14.33±2.64	12.78±2.81	41.40±3.72	398.68±57.14	41.22±2.53	38.56±2.45	79.78±4.49
U-14	N	4	4	4	4	4	4	4
	M±SD	17.00±2.16	16.75±0.5	44.05±3.79	596.92±43.99	43.50±1.29	43.00±0.81	86.50±1.91
U-16	N	5	5	5	5	5	5	5
	M±SD	22.60±2.07	20.20±3.56	48.70±3.97	687.31±46.89	42.60±3.20	43.20±3.89	85.80±6.88
	<i>Sig.</i>	0.001*	0.001*	0.002*	0.001*	0.223	0.013*	0.029*
	<i>d Choen</i>	4.364	3.2	2.071	3.943	0.517	1.491	1.232

*Sig. $\alpha \leq 0.05$ Units: ¹ kgf; ² ml/kg/min; ³ watts; ⁴ number of precision shots

The results in table 4 show significant differences in all variables between competition levels, except for right technical efficiency. In general, results indicate that as competition levels increases, the values obtained for each variable also increase, suggesting that older athletes demonstrate greater overall physical development. Considering the statistical differences identified between groups through the Wilcoxon test, in the analyzed variables except for the right technical efficiency, the Mann-Whitney test was applied, between pairs, to verify specific statistical differences between athletes' competition levels. Pairwise comparisons indicated significant differences ($p < 0.05$) between all groups, in all variables, except: right hand-grip (U12 vs. U14), left-hand grip (U14 vs. U16), aerobic capacity (U12 vs. U14 and U14 vs. U16), left technical efficiency (U10 vs. U12 and U14 vs. U16), and total technical efficiency (U10 vs. U12, U10 vs. U16, and U14 vs. U16). According to the effect size, it was found a small effect size on right technical efficiency, a large effect size on left and total technical efficiency and all the other variables with a very large effect size.

Table 5 presents the comparison of the dependent variables by years of practice.

Table 5. Descriptive analysis of the variables under study and statistical significance between years of practice.

Years of practice		Right hand-grip ¹	Left hand-grip ¹	Aerobic capacity ²	Lower limb power ³	Right technical efficiency ⁴	Left technical efficiency ⁴	Total technical efficiency ⁴
Between 1 and 3 years	N	7	7	7	7	7	7	7
	M±SD	9.71±1.97	9.00±1.29	39.60±3.03	324.88±62.34	41.29±3.45	38.00±3.36	79.29±6.60
Between 3 and 6 years	N	7	7	7	7	7	7	7
	M±SD	14.14±4.01	13.00±3.60	41.23±5.06	408.68±88.03	41.43±2.50	39.86±1.95	81.29±4.27
More than 6 years	N	12	12	12	12	12	12	12
	M±SD	18.00±4.80	16.67±4.41	44.35±5.29	574.57±131.83	42.50±2.23	42.00±2.82	84.50±4.71
	<i>Sig.</i>	0.004*	0.003*	0.114	0.003*	0.456	0.048*	0.117
	<i>d Choen</i>	1.599	1.69	0.673	1.74	0.276	0.929	0.665

*Sig. $\alpha \leq 0.05$ Units: ¹ kgf; ² ml/kg/min; ³ watts; ⁴ number of precision shots

According to the results observed in terms of years of practice, it is noted, as expected, that the players with more years of practice are the ones with higher scores on all variables analysed. All variables, except right and total technical efficiency, showed significant differences between groups of years of practice. According to the effect size, it was found again a small effect size on right technical efficiency, a moderate effect size on total technical efficiency, aerobic capacity and left efficiency. All the remaining variables present a large effect size.

Table 6 shows the association between hand grip strength, aerobic capacity, lower limb power and technical efficiency.

Table 6. Significance values of the influence/correlation of handgrip, aerobic fitness and lower limb power on the efficiency of tennis players.

		Right technical efficiency	Left technical efficiency	Total technical efficiency
Spearman's Rho	Right hand-grip	.480*	.579**	.567**
	Left hand-grip	.611**	.763**	.736**
	Aerobic capacity	.520**	.521**	.546**
	Lower limb power	.542**	.630**	.618**

*Sig. $\alpha \leq 0.05$ **Sig. $\alpha \leq 0.01$

According to correlation results, all independent variables in the study have a strong correlation with tennis technical efficiency. In terms of hand-grip strength, left-handed players are more effective in precision shots, aerobic capacity has a strong correlation with technical efficiency as well, and lower limb power has a high correlation with technical efficiency, with the highest value being observed for left technical efficiency.

4 Discussion

In this study we sought to shed new light onto the effects of lower limb power, aerobic capacity and hand grip strength on the technical efficiency of tennis players. Some results were highlighted that support and corroborate similar studies, which will contribute to the organization and intervention in the training process of young tennis players.

In terms of the results for lower limb power (LLP) variable, mean values were recorded in watts for all ages, namely, U10=327.17, U12=398.68, U14=586.92 and U16=687.31. These results are in line with normative lower limb power values identified in children of similar age as those in this study and are considered extremely positive (Balbinotti, 2003). These values suggest good levels of performance, a factor not verified in another investigation (Moreno et al., 2006) where 10 tennis players aged between 10 and 14 had weak LLP values were found, negatively affecting their motor skills. That fact was already supported by other studies where it was observed that higher LLP values reveal good performance indicators in tennis players (Pereira et al., 2016; Comelas & Viñaspre, 2001). The same situation was verified with 33 tennis players aged between 10 and 12 years, (Kovacs, 2006) where both genders presented similar levels of LLP, in this case, higher levels among male athletes between the LLP values and the specific power tennis test that was carried out. In another investigation from Taylor et al. (2010) involving 11 athletes with a mean age of 16 years, a positive relationship was found between LLP indices and speed of movement, which is considered a determining variable in the execution of motor actions in tennis athletes. In terms of the relationship and influence of this variable on the athletes' effectiveness, a positive correlation was observed between the athletes' LLP capacity and their effectiveness, whether in right or left shots in right or left-handed athletes, which corroborates a previous study from Duringan et al. (2013) with 8 tennis athletes who, after a 12-week program of strength training (including LLP), showed a positive relationship between LLP and players dominant hand, whether on the right or left side.

1.1.1 Findings on aerobic capacity, show mean values recorded in ml/kg/min for all ages, namely, U10=38.22, U12=41.40, U14=44.05 and U16=42.60 values, which was considered as ideal according to a previous study from Baiget et al. (2014) with 4500 children aged between 9 and 15 years, whose values varied between 37.4 and 46 ml/kg/min. These results differ from those of one of the studies already mentioned (Kovacs, 2007) in which, in this study, male athletes presented higher values than females did, however in the correlation of this variable with the specific efficiency test there was a positive and high value, in which is in accordance with the results found in this study. In another investigation of Bandura (1977), it was found that male and female athletes present VO₂ values higher than these values, a fact that can be justified by the higher mean age, however in references to these last two studies (Kovacs, 2007; Bandura, 1997) both showed higher values for all variables analysed in older athletes, at higher competitive levels and with longer practice in the sport, which is in line with the results of this study. In terms of the influence of this variable on the technical efficiency of tennis players, there was a positive correlation, which indicates that the better the aerobic capacity is, the better the technical effectiveness, in this specific case, in the precision of the right and left shots. The same situation was observed in a previous study (Kraemer et al., 2003) where it was found that athletes with better aerobic conditions achieved better technical efficiency with a greater number of balls falling in the precision zone due to the shots performed. This evidence was found in several studies (Pereira et al., 2016; Genevois, 2019; Fuentes et al., 2001) indicating that athletes with lower VO₂ capacity present higher fatigue values that represent a decrease in technical skills during physical effort, namely the precision factors that include right and left technical gestures. According to Corbin (2015), the biomechanical movement required for the throw demands the athlete's body to utilize its power in order to develop a powerful throw derived from a set of biomechanical and kinanthropological factors in various stages, which together complement the overall technical gesture. From the moment the athlete's body creates the balance derived from the beginning of the movement, which in turn is maintained by the body's own weight. The throw can only be achieved through a synchronized set of forces acquired by the lower limbs, the hip joint, the trunk, the shoulder joint, and finally the upper limbs. With an identical combination of efforts, each specific muscle suffers less wear and tear because it is supported by the entire body weight.

Regarding the hand-grip strength (HGS) variable, already mentioned in previous studies (Duringan et al., 2013; Skoromudova, 1998; Adegboye et al., 2011) where, contrary to the results in this study, higher HGS values were found in males. Higher HGS values were also observed in athletes

at higher competitive levels as well as those with more time practicing in tennis, corroborating our results in this study. An investigation with Pereira et al. (2011) involving 93 tennis athletes aged between 10 and 18 years, found that HGS capacity increases along with practice time and age, which is accordance with the findings in this study. Another investigation (Smekal, 2001), with 30 older athletes, also analysed HGS by age, reported that older athletes tend to show significantly higher rates. With respect to practice time, the same situation occurs between these two studies, with higher HGS values being observed in athletes with longer practice time. In the research of Pereira et al. (2011), right-handed athletes have higher HGS values, as it was also observed in this study. Studies such as (Smekal, 2001; Weiss et al., 2010; Reid et al., 2008; Fett et al., 2020). report that the variables gender, time spent practicing tennis, competitive level and dominant hand are significant predictors of greater capacity in terms of HGS related to chronological and biological age which promotes neural and muscular adaptations for racket mastery in tennis athletes. One of the studies (Fett et al., 2020) also mentioned that the type of racket grip had no effect on HGS capacity. However, we cannot rule out that some of these changes may also result from maturation processes and not only from adaptations to training. Some young people exhibit biological maturation before the age of 13, possessing greater metabolic capacity and body size compared to their peers of the same chronological age with normal or late maturational rates (Ré et al., 2005), highlighting the transition of this biological phenomenon, linked to the individual growth and maturation rate.

In terms of the technical efficiency in tennis (TET), in a previously mentioned study (Bandura, 1997) comparing genders, girls were more effective in placing balls in precision zones, as was the case as in this study. In a study with 755 tennis players, aged between 13 and 16 years old, who underwent a training program to improve physical fitness, had better results in terms of ranking (Comelas & Viñaspre, 2001). It was found that all variables of hand-grip strength, aerobic capacity and lower limb power were positively related to the efficiency of tennis players (Weiss et al., 2010; Kovacs, 2007; Taylor et al., 2010; Bandura, 1977; Moreno et al., 2006; Fett et al., 2020; Rezende et al., 2012; Kraemer et al., 2003). Studies such as Cormi et al. (2011), Reilly et al. (2014) and Rezende et al. (2012) suggest that efficiency levels demonstrate excellent performance indicators for athletes in a competitive context and are associated with lower error rates. These frame findings has associations or potential contributors that warrant further longitudinal or experimental investigation and from a practical perspective, the observed associations suggest that physical conditioning may support technical performance, however, intervention studies are needed to confirm causal links.

The study has some limitations, such as: it was conducted only in twenty-six athletes, aged between 8 and 16 years old; The relationships between hand-grip strength and aerobic capacity may differ in different populations, such as males, females and in different ages groups. More study's with a considerably larger sample are needed; The correlation between sample size and standard error of the mean is even stronger; it will be interesting to develop studies that analyse psychological components in tennis training, as there are several references to studies that identify which and how psychological aspects can interfere with effectiveness; evaluate other age groups and see if the trends of the results maintain this profile.

For future studies it is suggested the use of laboratory-based assessments as they can present more precise data and maybe determine other models for evaluating efficiency in tennis, considering the frequency, intensity and volume of training, as well as assessments on other types of the playing surface.

5 Conclusions

In sum, the results of the present study show that all the variables analyzed have a positive and significant effect on the technical efficiency of tennis players, with the highest correlation being HGS. LLP was slightly greater in females than in males and increased as the competitive level and time of

practice were higher. These results suggest associations between physical fitness parameters and technical efficiency in youth tennis and support the assertion that increasing the grip strength or decreasing body mass and body fat percentage may be an appropriate strategy to increase aerobic power. In terms of AC, it was equally higher in females, and it also increases as the competitive level and practice time are higher. With respect to HGS variable, it was once again higher in females with the same evolutionary trends with regard to competitive level and practice time. Values with significant differences were recorded for the variables analysed according to the athletes' competitive level and practice time. In this context, training sessions should be encouraged for muscle strengthening tasks of the lower limbs, as well as aerobic work to increase VO₂ and specific handgrip work to develop the hand muscles that are used to manipulate the racket.

These findings provide preliminary evidence that general physical fitness capacities may contribute to technical proficiency in youth tennis players, supporting the value of integrated physical and technical development approaches.

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Author Contributions statement

Conceptualization, SH, MB, DV, YG and PS; methodology, SH and MB; software, MB, JS and JS; validation, MR and VK; formal analysis, HF and LV; investigation, DV, YG and SH; resources, PS; data curation, AS and ET.; writing—original draft preparation, SH; writing—review and editing, SH, MB, JS, HF and LV; visualization, AS, VK and ET; supervision, SH; project administration, SH, DV and YG. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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