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Physical Fitness Profiling in Tunisian Junior Tennis Players: A 1-Year Longitudinal Study

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Abstract

Background: Tennis, a sport demanding high levels of physical fitness, combines various aspects of athleticism such as agility, endurance, strength, and speed. The development of these attributes in junior players is crucial for their progress in the sport. Understanding the impact of structured tennis training on the physical fitness of junior players can provide valuable insights into the effectiveness of training programs and guide future coaching strategies.

Objective: This study aimed to assess the effects of 1-year of tennis practice on the physical fitness of Tunisian junior players.

Methods: Sixty-two healthy participants were enrolled, divided into two groups, tennis players (TP) (n = 36) and controls, where the participants sedentary, (n = 26), each group was divided into two subgroups U14 and U16 age-groups. Physical fitness tests were conducted at baseline (T0) and after one-year (T1), including standing long jump, countermovement jump, medicine ball throw (MBT), 5m, 10m, and 20m sprints, sideways shuffle, Zigzag, spider drill, 20m shuttle run, and sit and reach (SAR) tests.

Results: Jump performances increased significantly for TP in U14 and U16 compared to controls at T0 and T1. In both age-groups, MBT performance increased significantly for TP, with U16 for both groups were higher at T0 and T1 ($p<0.05$). The 5m and 10m sprints increased significantly for TP in both age-groups, though controls decreased in the 5m sprint in U14 ($p<0.05$). The 20m sprint increased significantly for TP in U14 and U16 ($p<0.05$), with U16 outperforming U14 at T0 and T1 ($p<0.05$). Sideway shuffle and spider drill performances significantly improved for TP ($p<0.05$), while decreased in controls ($p<0.05$). The Zigzag test and the maximum oxygen intake increased significantly for TP across both age-groups at T0 and T1, whereas controls' performance decreased in U14 ($p<0.05$).

Conclusion: TP's SAR was significantly better than controls ($p<0.05$). In conclusion, tennis training enhances young athletes' physical fitness, improving agility, sprinting, jumping, and endurance compared to controls, reporting better results in U16 compared to U14 for most of tests.

Keywords: *Physical performance, Tennis, Age, Training, Adolescent*

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1. Introduction

Tennis has experienced substantial evolution in recent times, transforming from a predominantly technical sport focused on specific skills like racket handling and ball control, to a more dynamic and explosive game characterized by greater hitting power and speed. This shift has led to a remarkable increase in physical demands compared to traditional play styles (1). Consequently, achieving high performance in tennis requires exceptional physical fitness encompassing various components such as speed, agility, strength, and power (2, 3). The assessment of these physical attributes is considered crucial in both professional and youth tennis, providing coaches and players with essential information for decision-making, training, and competition planning (4-7). Additionally, this evaluation plays a vital role in talent selection, injury prevention, and the maintenance of motivation (8-11).

Physical characteristics such as morphology, body composition, and general fitness can change due to factors such as growth, biological age, diet, and physical exertion (12). During adolescence, individuals experience rapid and significant changes in morphological and physiological attributes that can significantly influence physical performance (13). Notably, young people in advanced stages of maturity tend to exhibit better results in motor, physical, and functional evaluations compared to their peers of the same chronological age (14). Although these maturation-related functional differences are slightly transient, they tend to reduce and regularly disappear as late-maturing athletes reach higher levels of maturity in late adolescence or early adulthood (13, 15). This period of adolescence can offer advantages in terms of gains in body size, strength, and muscle power; but it can also have negative effects on aspects such as body composition, coordination, and agility, particularly due to rapid increases in body size and weight (15-20).

Understanding the interplay between body size, physical performance, and the various physical attributes associated with tennis performance, such as speed, power, agility, flexibility, and muscular strength of the upper and lower extremities, can provide valuable insights into the relative importance of these measures (4, 21). Furthermore, this knowledge can offer crucial inputs for designing training programs that optimize athletic performance and improve player development.

In the context of tennis, physical fitness is divided into power, speed, and agility, all of which strongly correlates with tennis performance (7, 22). Power, which is a combination of strength and velocity, is essential for executing fast shots using the upper body and making explosive movements on the court using the lower body (23, 24). Speed and agility are equally important for quickly positioning oneself on the court to respond to shots. Measuring power, speed, and agility through functional tests is considered the most useful approach for assessing the physical fitness of junior tennis players (3, 24). Moreover, the role of maturity during this phase is important, as it affects physical fitness development differently between boys and girls and across different age categories (25, 26). Understanding the improvement of these physical attributes is crucial for coaches to enhance the overall tennis performance, aid in talent identification, and design tailored training programs. Several studies have used a longitudinal design in order to follow anthropometric and physical performance changes (3, 22, 27, 28), and showed a significant improvement in both anthropometric and physical performance after the intervention period.

While previous study have highlighted the importance of power, speed, and agility for tennis performance in heterogeneous groups of players (8), there is a need for longitudinal research to understand how these physical attributes develop and impact the performance level among junior tennis players. Otherwise, none of the latter studies (3, 27, 28) used a control group to compare the development of tennis players compared to sedentary participants. In our knowledge, the effects of practicing tennis on growing players have not been studied. This longitudinal study investigated the effects of 1-year of tennis practice on the lower and upper limb strength, sprint, agility, endurance, and flexibility performance among adolescent tennis players (U14 and U16) *vs.* non-physically active adolescents. We hypothesized that physical performance would increase in tennis players more than non-physically active participants in both age-groups. Also, we hypothesized that U16 would outperform U14 in both groups.

2. Methods and Materials

2.1. Participants

G*power software (version 3.1.9.6; Kiel University, Kiel, Germany) was used to calculate the minimum required sample size. A sample size of 52 participants would be sufficient to detect significant differences (effect size f = 0.3, $\alpha = 0.05$) with an actual power of 95.08%. Sixty-two healthy participants volunteered to participate in this study. All participants were divided into two groups based on their physical activity patterns. The tennis players (TP) group comprised 36 tennis players (including 29 boys and 7 girls) who belonged to the same team and had a minimum of two years of experience in tennis. The other 26 were assigned to the control group (including 21 boys and 5 girls) who only had physical education at school and did not participate in any kind of sport during the previous 6 yr. Both the TP and control groups were further divided into two age-groups: U14 and U16. None of the participants exhibited any observable symptoms of dysfunction in their musculoskeletal or cardio-pulmonary systems. Prior to their inclusion in the study, all participants received comprehensive verbal and written instructions that explained the procedures and potential risks involved. They were also informed of their right to withdraw from the trial at any point. This study was approved by the committee of the ISSEPS, University of Sfax (Ref: 016/2021) and was conducted in accordance with the recommendations of the World Healt Organization outlined in the Helsinki Declaration. Prior to participation, participant's parents were provided with an informed consent document, which they were asked to read and sign.

2.2. Training Load

The TP engaged in a comprehensive training regimen that spanned a minimum of two years, averaging 2.5 ± 0.5 years. Apart from participating in two weekly 50-minute physical education sessions at school, the players dedicated themselves to five weekly tennis training sessions, each lasting approximately 90 minutes.

During these tennis training sessions, a structured approach was adopted. The players commenced with a 90-minute session, which included a 15–20 minute warm-up comprising low-intensity games and stretching exercises to prepare them physically. Following this, they spent 10–25 minutes on technical tennis exercises, focusing on refining their groundstrokes, footwork, volleys, and serves. These exercises involved dynamic actions such as lateral movements, cone drills, and varied serve practices.

Furthermore, the players allocated approximately 20–30 minutes to engage in match play or mini-matches, providing a realistic context to apply their skills and work on strategic decision-making. The sessions concluded with 10 minutes of active recovery exercises designed to cool down and prevent muscle stiffness, incorporating static stretches and light conditioning drills. Throughout this comprehensive training routine, the coach actively provided feedback and guidance to enhance the players' overall performance.

2.3. Study Design

The present study employed a longitudinal design to examine changes in the measured variables over a 1-year period, which begins at the beginning of a sport period (1st September) and ends at the beginning of the next sport period (12 months later). The study involved two measurement points: the baseline measurement (T0) on the first day of the 1-year period and the follow-up measurement (T1) at the end of the 1-year period.

2.4. Testing procedures

2.4.1. Anthropometrics:

Height and body mass were determined using a portable stadiometer (Seca Model 225, Hanover, MD) and a digital scale (Tanita, Tokyo, Japan). Participants were measured in stocking feet and underwear, with height rounded to the nearest 5 mm and body mass to the nearest 100 g. The body mass index (BMI) was determined by dividing the body mass by the square of the height.

2.4.2. Jump performance

Participants performed the countermovement-jump (CMJ) using an infrared jump system (Optojump Microgate—Italy) connected to a computer. They stood between two infrared sensor bars and executed a rapid downward movement, followed by an upward jump, keeping their hands on their iliac crests. Three trials were performed with a 2min rest period, and the highest jump was used for analysis.

2.4.3. Medicine Ball Throw (MBT)

As described by Sayers and Bishop (29), Participants performed the overhead medicine ball throw by standing behind a designated line. They used a 1-kg or 2-kg medicine ball, depending on their assigned group. The ball was brought back behind the head using both hands and then released as far as possible without any foot movement or crossing the line. The distance from the starting line to the ball's landing point was measured. Each participant completed two repetitions, and the best performance was recorded.

2.4.4. Sprint Tests

Running performance was evaluated over a 20 m distance, with intermediate phases at 0-5 m and 0-10 m. After a standardized warm-up period, participants performed two maximal sprints with a 3 min rest interval. The best time from the two sprints was used for analysis. The sprints were timed using three infrared photoelectric cells (Cell Kit Speed Brower, USA) placed at 0.4 meters above the ground at the start line and at 5, 10, and 20m marks.

2.4.5. Sideway shuffle test

For the sideway shuffle test, participants shuffled along the center service line at the T, starting with one foot on each side of the line and facing the net. They shuffled to touch the doubles sideline and then shuffled to the opposite doubles sideline before returning to the center. Crossover steps were not allowed. The trial time was recorded using a stopwatch.

2.4.6. Zigzag test

Concerning the Zigzag test, participants performed the Zigzag sprint, starting from point A and finishing at point F (Figure 1). They were instructed to complete the test as quickly as possible, cutting around markers without running over them. Sprint times were recorded using two infrared photoelectric cells (Cell Kit Speed Brower, USA) placed at 0.4 meters above the ground at the start point (A) and the finish point (F).

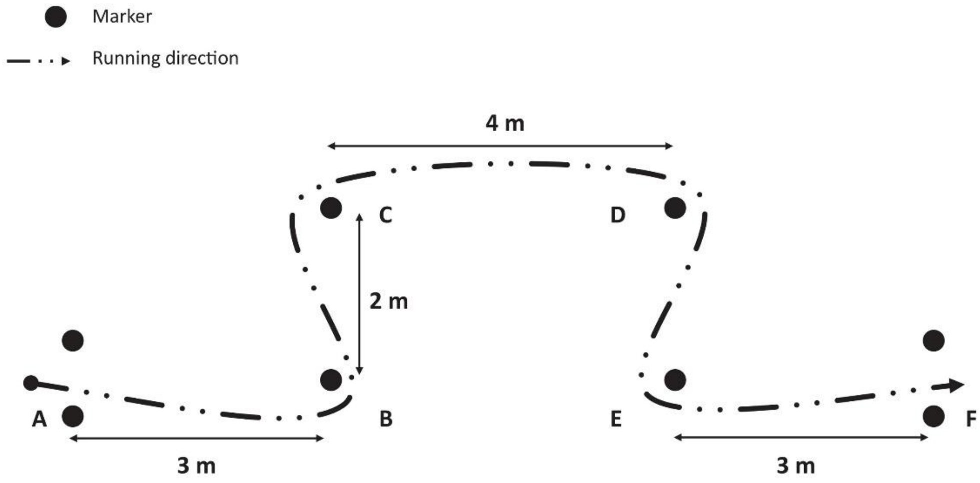

Figure 1. Schematic of the Zigzag Test.

2.4.7. Spider drill test:

For the spider drill test, participants broke the beam of the timing gates to officially start the assessment. They performed sprints in a specific pattern, starting with a sprint to the right and progressing anticlockwise. The distances covered varied for each sprint. After completing the last sprint, participants turned right 90° and sprinted through the timing gates to finish the test. Sprint times were recorded using an infrared photoelectric cell (Cell Kit Speed Brower, USA) placed 0.4 m above the ground at the start line.

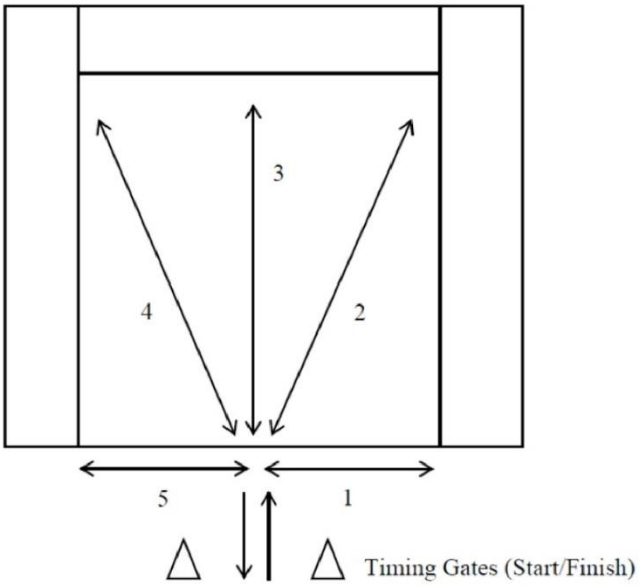

Figure 2. Schematic of the Spider Drill Test.

2.4.8. Aerobic maximal power

The maximum oxygen intake (VO_{2max}) was estimated through the 20m shuttle run test (20mSRT) (29). Participants begin with an initial speed of 8.5 km/h, which is then increased by 0.5 km/h every minute (with each minute considered as one stage). The subjects run in a linear path, pivoting at the end of each shuttle, and adjust their pace according to audio cues. The test concludes either when the subjects voluntarily stop or when they fail to reach the designated end lines in sync with the audio signals on two consecutive occasions.

2.4.9. Flexibility

The sit and reach test (SAR) was performed according to Ayala, de Baranda (30) procedures, participants sat on the floor with their legs together, knees extended, and soles of the feet against the edge of the box. With arms extended forward and palms down, they reached as far as possible along the measuring scale without bending their knees. The position of the heel and knee extension was monitored throughout the test.

2.5. Statistical analyses

Descriptive statistics were presented as Mean ± standard deviation (SD). The normality of data sets was confirmed using the Shapiro Wilk test. The sphericity was checked using the Mauchly test. The three-way analysis of variance (ANOVA) (Group [TP vs. CG] × age-group [U14 vs. U16] × time [T0 vs. T1]) was performed using the "afex" package (version 1.3-0). When a significant difference was found, post-hoc pairwise comparisons with the Bonferroni adjustment were conducted using the "rstatix" package (version 0.7.2). The magnitude of difference between age-groups was evaluated using the effect size statistic ($\eta p2$). The criteria used to determine the effect sizes were as follows: 0.01 denoted a small effect size, 0.06 represented a moderate effect size, and 0.14 indicated a large effect size. Significance was accepted for all analyses at a p-value threshold of less than 0.05 ($P < 0.05$). All statistical analysis was performed using R programming language (version 4.3.1, R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1. Anthropometric parameters

General characteristics and anthropometric measurement of participants for TP and controls in both U14 and U16 at T0 and T1 are presented in Table 1.

Table 1. Anthropometric characteristics of tennis players in U14 and U16 age groups for tennis players (TP) and controls (values were presented as Mean ± SD).

	Controls				Tennis players			
	U14 (n = 13)		U16 (n = 13)		U14 (n = 20)		U16 (n = 16)	
	T0	T1	T0	T1	T0	T1	T0	T1
Age (years)	13.12 ± 0.32	14.12 ± 0.32	15.36 ± 0.32	16.36 ± 0.32	13.59 ± 0.58	14.59 ± 0.58	15.54 ± 0.62	16.54 ± 0.62
Height (m)	1.56 ± 0.09	1.59 ± 0.09 ¤¤¤¤	1.7 ± 0.1 ‡‡	1.72 ± 0.1 ¤¤¤¤ ‡‡	1.53 ± 0.09	1.57 ± 0.09 ¤¤¤¤	1.69 ± 0.09 ‡‡‡‡	1.74 ± 0.09 ¤¤¤¤ ‡‡‡‡
Weight (kg)	44.86 ± 12.48	48.94 ± 12.84 ¤¤¤¤	59.33 ± 8.45 ‡‡	63.18 ± 8.35 ¤¤¤¤ ‡‡	46.16 ± 10.38	49.61 ± 10.87 ¤¤¤¤	56.28 ± 7.49 ‡‡	59.47 ± 8.13 ¤¤¤¤ ‡‡
BMI (kg/m^{2})	18.06 ± 3.6	19.16 ± 3.36 ¤¤¤¤	20.46 ± 1.64	21.2 ± 1.7 ¤¤¤¤	19.61 ± 3.08	20.06 ± 3.11 ¤¤	19.78 ± 2.01	19.52 ± 2.1 ‡*

BMI: Body mass index. T0: Baseline measurement; T1: After 1-year measurement; * ($p < 0.05$): significantly different compared to controls; ¤¤ ($p < 0.01$), ¤¤¤¤ ($p < 0.0001$): significantly different compared to T0; ‡‡ ($p < 0.01$), ‡‡‡‡ ($p < 0.0001$): Significantly different compared to U14.

The three-way ANOVA on the height revealed significant main effects for age-group ($F(1,58) = 42.15$; $p < 0.001$; $\eta_p^2 = 0.421$) and time ($F(1,58) = 372.78$; $p < 0.001$; $\eta_p^2 = 0.865$). There was a significant group × time ($F(1,58) = 11.85$; $p < 0.01$; $\eta_p^2 = 0.17$) and age-group × time ($F(1,58) = 15.12$; $p < 0.001$; $\eta_p^2 = 0.207$) interactions. The pairwise comparisons showed that the height significantly increased in U14 and U16 for both TP and controls ($p < 0.01$). Additionally, U16 was taller than U14 at T0 and T1 in both controls ($p < 0.01$) and TP ($p < 0.0001$).

For body mass, there was a significant main effects for age-group ($F(1,58) = 200.43$; $p < 0.001$; $\eta_p^2 = 0.277$) and time ($F(1,58) = 537.19$; $p < 0.001$; $\eta_p^2 = 0.903$). Also, a significant group × time interaction was found ($F(1,58) = 4.15$; $p < 0.05$; $\eta_p^2 = 0.067$). However, the body mass in both TP and controls significantly increased in U14 and U16 ($p < 0.0001$). Additionally, in both TP and controls, U16 was heavier than U14 at T0 and T1 ($p < 0.01$).

Concerning BMI, there is a significant main effect for time ($F(1.58 = 53.92$; $p < 0.001$; $\eta_p^2 = 0.482$) as well as significant group × time ($F(1,58) = 35.69$; $p < 0.001$; $\eta_p^2 = 0.381$) and age-group × time ($F(1,58) = 14.71$; $p < 0.001$; $\eta_p^2 = 0.202$) interaction were found. The BMI for controls significantly increased in both U14 and U16 ($p < 0.0001$), but only in U14 for TP ($p < 0.01$). Moreover, BMI for TP was lower compared to controls in U16 at T1 ($p < 0.05$). Also, U16 showed higher BMI compared to U14 for controls at T0 ($p < 0.05$).

3.2. *Jump performance*

The three-way ANOVA on CMJ revealed a significant main effects for group ($F(1,58) = 68.91$; $p < 0.001$; $\eta_p^2 = 0.542$), age-group ($F(1,58) = 40.05$; $p < 0.001$; $\eta_p^2 = 0.408$), and time ($F(1,58) = 289$; $p < 0.001$; $\eta_p^2 = 0.833$). There was a significant interactions of group × age-group ($F(1,58) = 9.94$; $p < 0.01$; $\eta_p^2 = 0.146$) and group × time ($F(1,58) = 35.77$; $p < 0.001$; $\eta_p^2 = 0.381$). CMJ performance showed a significant increase in U14 and U16 ($p < 0.0001$) for TP. Additionally, TP has better performance in CMJ than controls in both U14 and U16 at T0 ($p < 0.001$) and T1 ($p < 0.0001$). Also, CMJ was significantly better in U16 compared to U14 for TP ($p < 0.0001$) and controls ($p = 0.02$) at T0 and T1.

3.3. *Medicine ball throw test*

Concerning MBT, our results showed significant main effects for group ($F(1,58) = 23.96$; $p < 0.001$; $\eta_p^2 = 0.292$), age-group ($F(1,58) = 90.57$; $p < 0.001$; $\eta_p^2 = 0.610$), and time ($F(1,58) = 172.32$; $p < 0.001$; $\eta_p^2 = 0.748$). Also, there are significant group × age-group ($F(1,58) = 23.96$; $p < 0.001$; $\eta_p^2 = 0.292$) and group × time ($F(1,58) = 169.36$; $p < 0.001$; $\eta_p^2 = 0.745$) interactions. MBT showed a significant increase in U14 and U16 for TP ($p < 0.0001$). MBT was significantly better for TP in U14 at T0 and T1 ($p < 0.0001$). Additionally, U16 was significantly better than U14 for TP ($p < 0.01$) and controls ($p < 0.0001$) at T0 and T1.

3.4. *Sprint performance*

The three-way ANOVA on 5mS, showed significant main effects for group ($F(1,58) = 12.05$; $p < 0.001$; $\eta p2 = 0.172$), age-group ($F(1,58) = 9.01$; $p < 0.01$; $\eta p2 = 0.134$), and time ($F(1,58) = 12.1$; $p < 0.001$; $\eta p2 = 0.173$). Also, there was a significant group × time interaction ($F(1,58) = 19.46$; $p < 0.001$; $\eta p2 = 0.251$). The 5mS significantly increased in U14 and U16 ($p < 0.01$) for TP and decreased in U14 for controls ($p < 0.05$). At T1, TP has significantly better 5mS performance compared to controls in U14 ($p = 0.002$) and U16 ($p < 0.001$). Moreover, U16 was significantly better than U14 in TP at T0 ($p < 0.0$) and T1 ($p < 0.0001$).

Regarding 10mS, there was significant main effects for group ($F(1,58) = 12.68$; $p < 0.001$; $\eta p2 = 0.179$) and time ($F(1,58) = 35.25$; $p < 0.001$; $\eta p2 = 0.378$). Additionally, significant group × age-group ($F(1,58) = 25.43$; $p < 0.001$; $\eta p2 = 0.305$) and group × time ($F(1,58) = 43.55$; $p < 0.001$; $\eta p2 = 0.429$) interactions was observed. 10mS performance increased significantly for TP in U14 ($p < 0.0001$) and U16 ($p < 0.001$). Additionally, TP has significant higher 10mS performance compared to controls in U16 ($p < 0.01$) and U14 ($p < 0.05$) at T0, and only in U16 at T1 ($p < 0.0001$). However, 10mS for both TP and controls was significantly higher in U16 compared to U14 at both T0 and T1 ($p < 0.01$).

For 20mS, significant main effects for group ($F(1,58) = 24.75$; $p < 0.001$; $\eta p2 = 0.299$), age-group ($F(1,58) = 13.77$; $p < 0.001$; $\eta p2 = 0.192$), and time ($F(1,58) = 67.58$; $p < 0.001$; $\eta p2 = 0.538$) were found. As well as there was a significant group × age-group ($F(1,58) = 9.17$; $p < 0.01$; $\eta p2 = 0.137$) and group × time ($F(1,58) = 63.14$; $p < 0.001$; $\eta p2 = 0.521$) interactions. The pairwise comparisons revealed significant increases in 20mS performance for TP in U14 ($p < 0.00001$) and U16 ($p < 0.001$). Furthermore, 20mS for TP was significantly higher than controls in U16 at T0 ($p < 0.01$) and in U14 ($p < 0.01$) and U16 ($p < 0.0001$) at T1. Lastly, 20mS performance in U16 was significantly better than U14 for TP at both measure points ($p < 0.0001$).

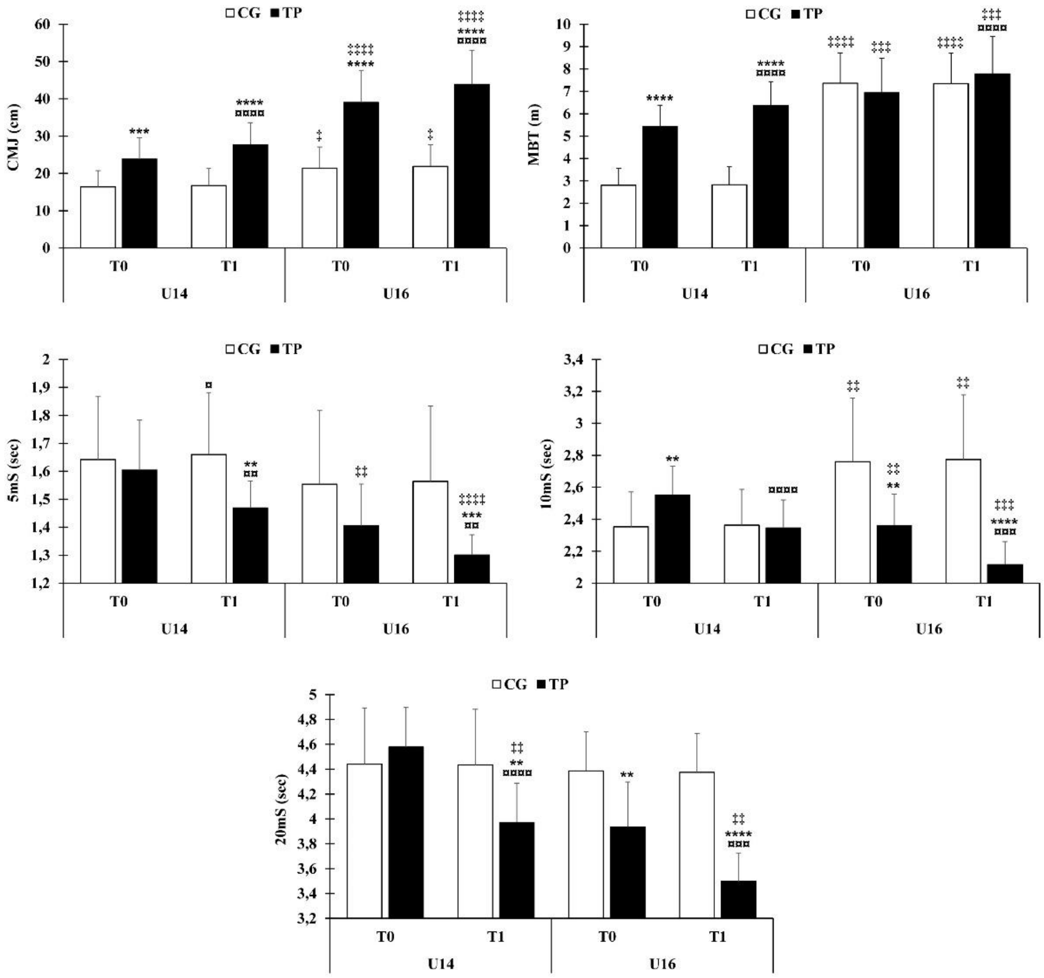

Figure 3. Jump performance, medicine ball throw, and 5m, 10m, and 20m sprint tests results for tennis players (TP) and controls (CG) in U14 and U16 recorded at T0 and T1 (Values were presented as Mean ± SD). ¤ ($p < 0.05$), ¤¤¤¤ ($p < 0.0001$): significantly different compared to T0; * ($p < 0.05$), ** ($p < 0.01$), *** ($p < 0.001$), **** ($p < 0.0001$): significantly different compared to controls (CG); ‡ ($p < 0.05$), ‡‡ ($p < 0.01$), ‡‡‡ ($p < 0.001$), ‡‡‡‡ ($p < 0.0001$): significantly different compared to U14.

3.5. *Agility performance*

Concerning the sideway shuffle test, there was significant main effects for group ($F(1,58) = 225.16$; $p < 0.001$; $\eta p2 = 0.795$) and time ($F(1,58) = 118.25$; $p < 0.001$; $\eta p2 = 0.671$). Also, significant group × age-group ($F(1,58) = 17.61$; $p < 0.001$; $\eta p2 = 0.233$), group × time ($F(1,58) = 112.7$; $p < 0.001$; $\eta p2 = 0.66$), and age-group × time ($F(1,58) = 5.81$; $p < 0.05$; $\eta p2 = 0.091$) were recorded. The pairwise comparisons showed that the sideway shuffle performance significantly increased for TP in U14 and U16 ($p < 0.0001$) and decreased for controls in U16 only ($p < 0.05$). Additionally, the sideway shuffle performance for TP was significantly better than controls in U14 and U16 at both measure points ($p < 0.0001$). Moreover, U16 showed significant higher performance than U14 for controls at T0 ($p < 0.05$) and T1 ($p < 0.0001$), and for TP at T0 ($p < 0.01$).

The three-way ANOVA on the spider drill test revealed a significant group × age-group × time interaction ($F(1,58) = 9.28$; $p = 0.003$; $\eta p2 = 0.138$), where the performance significantly increased in U14 and U16 for TP ($p < 0.0001$) and decreased for controls ($p < 0.01$). As well as the spider drill performance in TP was significantly better than controls in U16 at T0 ($p < 0.001$) and in U14 ($p < 0.001$) and U16 ($p < 0.0001$) at T1. Moreover, U16 for TP presented a significantly higher performance than U14 at T0 ($p < 0.0001$) and T1 ($p < 0.01$).

The Zigzag test showed a significant main effect for group ($F(1,58) = 127.90$; $p < 0.001$; $\eta p2 = 0.688$) and time ($F(1,58) = 192.67$; $p < 0.001$; $\eta p2 = 0.769$). Also, significant group × age-group ($F(1,58) = 5.64$; $p < 0.05$; $\eta p2 = 0.089$)

and group × time ($F(1,58) = 202.49$; $p < 0.001$; ηp2 = 0.777) interactions were observed. For controls, the Zigzag performance significantly decreased in U14 ($p < 0.05$). However, the performance increased significantly for TP in both U14 and U16 ($p < 0.0001$). Indeed, TP presented a significant higher performance than controls in U14 at T0 ($p < 0.05$) and T1 ($p < 0.001$) as well as in U16 at both T0 and T1 ($p < 0.0001$). Additionally, U16 in TP was significantly better than U16 at T0 ($p < 0.01$).

3.6. Aerobic maximal power

The three-way ANOVA reported significant main effects of group ($F(1,58) = 200.58$; $p < 0.001$; ηp2 = 0.776) and time ($F(1,58) = 103.86$; $p < 0.001$; ηp2 = 0.642), and significant group × time interaction ($F(1,58) = 128.55$; $p < 0.001$; ηp2 = 0.689). VO2max increased significantly in U14 and U16 ($p < 0.0001$) for TP. Furthermore, VO2max for TP was significantly higher than controls in U14 and U16 at T0 and T1 ($p < 0.0001$).

3.7. Flexibility

The three-way ANOVA on SAR revealed a significant main effect for group ($F(1,58) = 89.19$; $p = 0.003$, ηp2 = 0.114). However, no significant main effect for age-group, time, or interactions were observed. SAR was significantly better for TP than controls at T0 in U14 ($p < 0.05$) and U16 ($p < 0.05$), also in U14 only at T1 ($p < 0.05$).

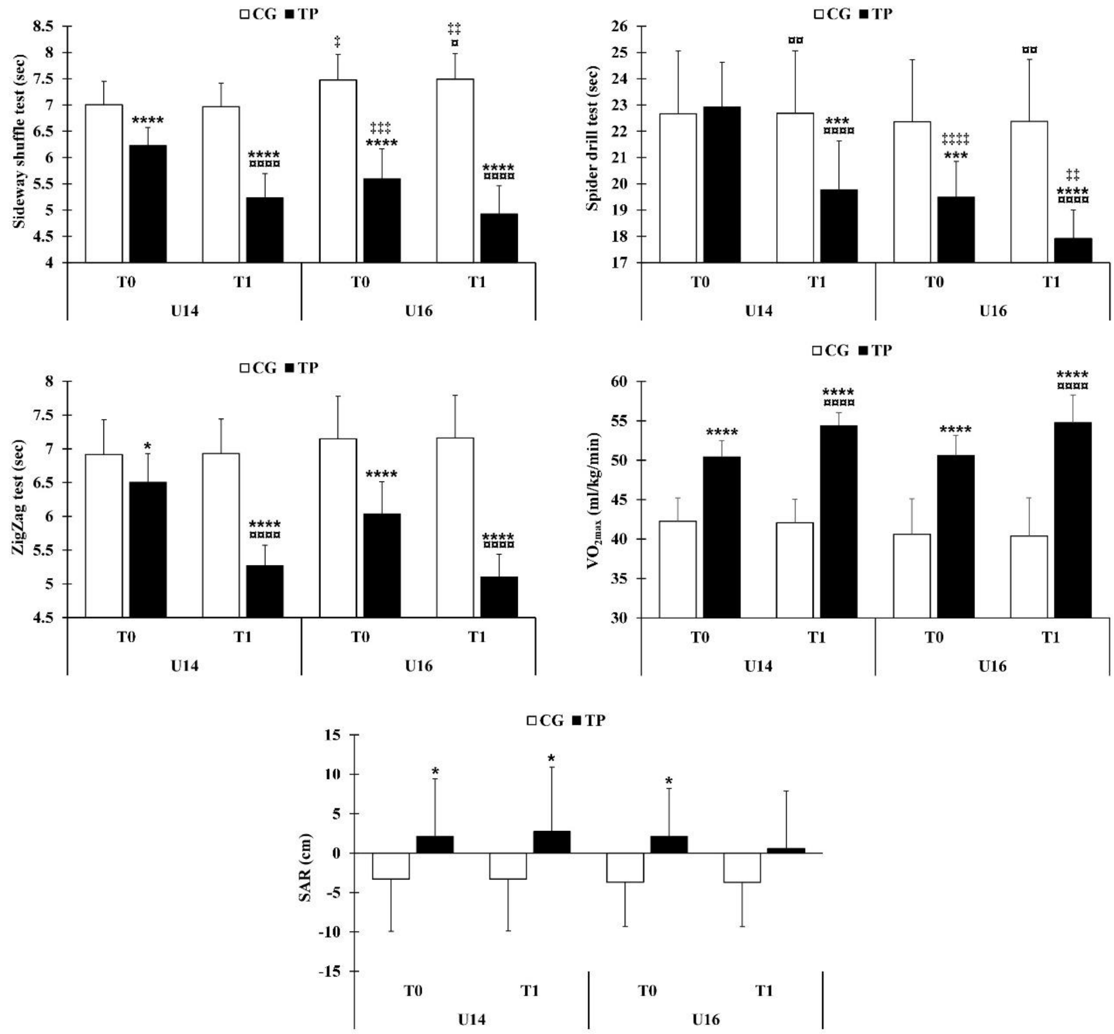

Figure 4. Agility, aerobic maximal power, and sit and reach tests results for tennis players (TP) and controls (CG) in U14 and U16 recorded at T0 and T1 (Values were presented as Mean ± SD). ¤¤ ($p < 0.01$), ¤¤¤ ($p < 0.001$), ¤¤¤¤ ($p < 0.0001$): significantly different compared to T0; ** ($p < 0.01$), *** ($p < 0.001$), **** ($p < 0.0001$): significantly different compared to controls (CG); ‡‡ ($p < 0.01$), ‡‡‡ ($p < 0.001$), ‡‡‡‡ ($p < 0.0001$): significantly different compared to U14.

4. Discussion

This study examined the effects of 1-year of tennis practice on the lower and upper limbs strength, sprint, agility, endurance, and flexibility performance among two age-groups (*i.e.*, U14 and U16) of tennis players. The main findings of the present study indicate that young tennis players have better physical performance than controls at the baseline. Additionally, TP, who practiced tennis for 4–6 hours a week, increased their upper and lower body strength, sprint, agility and aerobic abilities more than their non-physically active matched counterparts over 1-year period. Regarding anthropometric measurements, both TP and controls presented a significant increase in their height and body mass after the 1-year period, with higher values in U16 compared to U14 in both groups. However, it should be noted that while there was a significant increase in all physical performance tests for TP, flexibility did not show a significant improvement in U14 and U16 ($p < 0.05$).

Development levelled off as players aged, explained by significant contribution of the age (31). In terms of regular physical development and knowing that most of TP in U14 and U16 are boys. This may be attributed to the differing rates of physical development between boys and girls, as girls tend to reach a plateau in their physical development earlier than boys (17). Nevertheless, our study still presented a significant increase in all physical components. The study's findings align with previous studies (3, 27, 28). Malina, Bouchard and Bar-Or (17) stated that biological maturity affects the performance of motor tasks. They further explained that participants can have advantages or disadvantages in tests by being more or less mature than peers of the same chronological age (32).

Maturation tended to have an advantage in terms of upper and lower body power, which can be attributed to the influence of strength and muscle mass development (27). However, biological maturation does not always directly correspond to increased physical performance (1, 2, 7).

Regarding upper body power, MBT test showed a significant increase of 14.8% and 10.79% in U14 and U16 TP, respectively. This finding is consistent with a previous study (26) and suggests that the consistent training of upper body power during tennis sessions may contribute to these improvements. However, the study also suggests that the initial high level of physical fitness among elite junior tennis players at U14 may limit further improvement in other physical components compared to players with lower initial fitness levels (26). Furthermore, Fernandez-Fernandez, Nakamura (22) showed that upper body strength (*i.e.*, Medicine ball throw and shoulder strength) increased in elite tennis players of both sexes as they change from the U13 to U15 age-groups. The increase in CMJ performance among TP indicates the influence of growth, but it is suggested that specific fitness training in tennis, such as plyometric and speed exercises, may have contributed to additional gains in jumping ability. Our findings are in the line with Sinkovic, Novak (24) who showed that jump performance was higher in older groups compared to subjects of younger biological age. Nonetheless, it is important to acknowledge the potential influence of genetic factors on superior performance (3). In terms of sprint performances, tennis players demonstrated significant improvements in sprints across all distances (U14 and U16) compared to controls. These findings are supported by Lloyd and Oliver (33), which indicated that speed development is more pronounced at age 10 compared to age 15. The development of speed at a younger age is likely influenced by biological age, increased muscle mass, improved CMJ scores, and the ability to take longer steps due to increased height. Furthermore, Kolman, Kramer (34) found that players with a higher performance level tend to have better-developed technical and tactical skills. Our findings revealed that agility test, the sideway shuffle, spider drill, and Zigzag tests performances increased significantly after the 1-year period in both U14 and U16 for TP. Kramer, Huijgen (27) supported our findings by reporting better agility performance in older TP compared to younger ones, in both sexes. Lastly, VO_{2max} in TP improved in both U14 and U16. Berdejo-del-Fresno, Vicente-Rodriguez (28) showed that young TP' VO_{2max} increased after the first 5-month but no after an 11-month period and the latter may be due to the type of training provided or the training status of the samples, where TP completed the most part of the season using the anaerobic training (28). It is recommended that tennis players have a VO_{2max} value greater than 50 mL/kg/min (35), and our TP started with > 50 mL/kg/min of VO_{2max} and this value significantly increased by 7.26 ± 2.38 and 7.25 ± 3.69% after 1-year, respectively in U14 and U16. In general, physical fitness performance increased significantly after the 1-year period. These improvements could be related to biological states. In this study, the maturation states and biological age were not measured to understand the link between physical fitness and maturation in the junior Tunisian TP. However, we used only a control group. Further studies should investigate the relationship between these two variables.

Concerning the difference between TP and controls, our results presented a significant difference between the two groups, where TP outperformed the controls in both U14 and U16 at T0 and T1 for almost in all tests. The difference between TP and controls could be due to the efficacity of training in the development of physical performance.

The findings of our study revealed a striking disparity between the TP and the control group in terms of their performance, with the TP displaying superior results across multiple metrics. These significant differences were observed in both the U14 and U16 age categories at two separate time points, T0 and T1, indicating the sustainability of the TP's enhanced physical capabilities over time. The notable outperformance of the TP can be attributed to the efficacy of the training regimen implemented in our study. Previous studies (3, 27, 28) highlighted the crucial role of targeted training programs in fostering and optimizing physical performance. By carefully designing and implementing a comprehensive training protocol, we were able to facilitate the development of various physical attributes in the TP, leading to their exceptional outcomes in the conducted tests. These may have encompassed strength, agility, endurance, flexibility, and other critical elements contributing to overall physical prowess. The success of the training intervention underscores the importance of structured and well-planned exercise routines tailored to meet the specific needs and goals of individuals. Furthermore, the positive results achieved by the TP at different age levels (U14 and U16) demonstrate the adaptability and effectiveness of the training approach across various stages of physical development. Our study's findings have significant implications, not only for sports and athletic performance but also for physical education and fitness programs in educational institutions. Incorporating evidence-based training methods, similar to the one employed in our study, may help enhance the overall physical health and performance of young individuals, leading to a more active and healthier generation.

However, it is important to acknowledge some potential limitations of the study. The lack of body composition, biological age, and maturation measurements was an important limitation in this study. Further studies should incorporate measurements of these parameters and investigate the link between maturation, biological age, body composition, and all physical fitness measurements. Additionally, the sample size was small for this study due to the dropout of participants during the 1-year period. We only mentioned the number of participants who completed the 1-year period. Having a larger sample size across different age-groups, not only U14 and U16, should be taken into consideration in future studies. Addressing these limitations in future research could further strengthen and validate the observed differences between the TP and the control Group, ultimately providing a more comprehensive understanding of the impact of targeted training on physical performance.

5. Conclusion

This study demonstrated that regular tennis practice over a 1-year period resulted in significant improvements in physical performance among young tennis players, including strength, sprinting ability, agility, and aerobic capacity. These improvements were observed in both the U14 and U16 age-groups. However, certain factors such as gender differences in physical development and genetic predispositions should be considered. From a practical point, most physical performance was better in U16, explaining the development of these capacities between the 14 and 16 years, except for flexibility. Coaches should take this consideration when constructing training programs for youths to maximize the development of physical performances in tennis players. Further research is needed to investigate the influence of technical, tactical, and other physical skills on performance levels.

Ethical Approval and Consent to Participate

dy was approved by the committee of the ISSEPS, University of Sfax (Ref: 016/2021) and was conducted in accordance with the recommendations of the World Healt Organization outlined in the Helsinki Declaration.

Consent for Publication

Not applicable.

Availability of Data and Materials

Any datasets generated during and/or analyzed during the current study are publicly available, available upon reasonable request, or if data sharing is not applicable to this article.

Competing Interests

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Authors' Contributions

All authors contributed equally to the manuscript and read and approved the final version of the manuscript.

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