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Enhancing Physical Fitness and Promoting Healthy Lifestyles in Junior Tennis Players: Evaluating the Influence of "Plyospecific" Training on Youth Agility

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Abstract: Physical fitness is a crucial component of tennis performance, and improving agility and lateral movement can give young tennis players a competitive edge. By training with plyospecific exercises, which focus on explosive movements and plyometric exercises, junior players can improve their speed, power, and reaction time on the court. The paper aimed to evaluate the effects and benefits of a 10-week physical training program on the agility of junior tennis players, using the results of seven agility tests, applying statistical *t*-tests for paired and independent samples, and the difference-in-differences approach. In order to achieve this, a sample of 48 U16 male Portuguese tennis junior players was used. The empirical results indicated that the training program had a positive impact on the agility of the tennis players. Specifically, the results showed improvements in the T-test performance on both the right and left sides, as well as improvements in the Edgren test scores on the left and right sides. Additionally, there was an increase in the average number of lateral and forward movements, suggesting enhanced agility among the players. These findings highlight the effectiveness of the training program in improving agility-related skills and performance in tennis. Coaches can incorporate similar training methods and exercises to improve their players' agility, leading to better performance on the court.

Keywords: physical training; difference in difference approach; U16 junior athletes; tennis

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1. Introduction

Tennis is a physically demanding sport that requires a combination of endurance, strength, and agility. Therefore, it is essential to identify effective training strategies that can improve the physical performance of young tennis players and help them reach their full potential.

Previous research has shown that plyometric and explosive training, or "plyospecific" training, can improve physical attributes, such as strength, power, and agility. Evidence for this is presented in the studies of [1–5], supporting the claim that plyometric and explosive training can improve athletes' physical attributes, including strength, power, and agility. Plyospecific training can be defined as tennis-specific physical training that consists of short forward, backward, and sideways sprints (3–5 m) performed in combination with plyometric training for speed, strength, and agility.

However, there is limited research on the effectiveness of this type of training in junior tennis players, particularly in improving their agility [6–9]. The existing studies [6–9] have mainly focused on the effects of training interventions on other aspects of tennis performance, such as serve velocity, rather than agility.

This gap in the literature is significant because agility is a crucial component of tennis performance, and improving agility can lead to better on-court movement, faster reaction times, and improved shot accuracy [10–12].

Given the increasing competitiveness of tennis and the rising number of young athletes specializing in the sport, it is crucial to identify effective training programs that can help junior players excel (Güllich and Emrich, 2006) [13] in their performance and reduce their risk of injuries (DiFiori et al., 2014) [14].

Tennis involves technical procedures and elements of pushing the kinetic force on the ball with the racket, which requires motor and physical qualities. Different execution modes are implemented for hitting the ball, depending on the specific context. Thus, the modern tennis player must look good physically; run like an athlete; and have the elasticity of a gymnast, the footwork of a boxer, the strength of a weightlifter, the intelligence of a chess player, and the stamina of a marathon runner [15].

Performance enhancement illustrates one of the primary purposes of sports activity, and the main objective is to optimize it. The junior year is the starting point of a successful senior year [16,17]. Junior U16 tennis players first start playing in national tournaments and then in international games. The best juniors are able to occupy a good ranking after they transition to seniority [18].

It is, therefore, widely accepted that tennis players need good physical fitness to execute advanced strokes and compete effectively against elite opponents [19].

Tennis requires excellent skills and perfect physical preparation, which includes physical components such as speed, agility, strength, and metabolic pathways. Fernandez and Raid illustrated tennis as an anaerobic sport with breaks between the single points that generate high-intensity short efforts mixed with breaks or low-intensity activities that can last up to 5 h in some cases. One example is the Grand Slam matches, where men play five sets. Regarding the effort level in tennis, it has been concluded that this sport includes short, high-intensity relays with alternative accelerations and decelerations, changes in direction, and repeated strokes over short periods of different durations, with an average duration of 90 min [20]. Previous studies showed that tennis players need several physical qualities, such as power, speed, agility, and good aerobic resistance, to perform well. A study by Hassan et al. (2019) [21] showed that power was a crucial physical quality for generating racket head speed, acceleration, and force production in tennis strokes. Tennis players must cover the court quickly and efficiently, responding to opponent shots and moving into optimal positions. Speed and agility are essential for executing quick footwork, swift direction changes, and effective court coverage (Fernandez-Fernandez et al., 2016) [22]. Good aerobic endurance enables players to maintain high performance throughout matches and recover quickly between points (Gomes et al., 2018) [23]. Efficient stroke mechanics enhance shot accuracy, consistency, and the ability to generate power effectively (Reid et al., 2016) [24].

To react quickly to other players' actions, agility and acceleration are crucial for performance [19]. Agility can be defined as the capacity to change direction and start and stop as quickly as possible [25]. Besides agility, the players should also possess excellent speed and strength to reach a high pace quickly [26,27]. As per previous studies and statistics, athletes should possess explosive and multilateral movements all over the tennis court [28]. Tennis players tend to move from side to side on the baseline. This is a limiting factor, as they never achieve maximum speed [29]. Parsons and Jones [30] proved that tennis players usually move sideways (approximately 48% of the time) during a match.

Improving lateral movement can boost performance [31,32]. Linear and lateral drills performed for 15 to 20 min three times a week improve the capacity of the tennis players to react faster. The research of Kondrič et al. (2013) [31] showed that specific drills targeting lateral movements could enhance players' agility, footwork, and court coverage. The tennis players consequently accomplished this kind of exercise during the game. Ferrauti [33] stated that lateral speed improvements are suitable for developing strength.

Plyometric training is known for its advantages, such as providing coordination to the neuronal system and enhancing muscular power, especially in the lower limbs [34]. However, as far as young tennis players are concerned, there is a limited number of studies in the literature. Buchheit et al. [35] conducted one of the only studies demonstrating progress regarding neuromuscular physical qualities. Repeated sprints had a more significant impact on shuttle sprint performance.

On the other hand, sprint-specific plyometric training methodology can improve acceleration and physical performance [32]. In one case, a combination of tennis-specific drills with sprint-specific plyometric exercises enhanced performance and improved acceleration [13]. Thus, by adapting to the demands of tennis-specific movements through a combination of drills and plyometric exercises, players can enhance their performance and accelerate more effectively (Struzik et al., 2021) [36].

Acceleration is considered an essential component in many sports. Especially in tennis, the quickness of the first step, reaction time, speed over short distances, ability to change direction, and lateral movement are vital determinants of performance [37].

A high velocity of side steps within 4–5 m is essential in returning balls, quickly returning to the starting point, and preparing for the next stroke. According to Parsons and Jones [30], lateral movement is critical when reacting and changing direction for the player to hit the ball at the right moment. Thus, it is not surprising that tennis associations have included lateral movements in testing protocols to assess the stability levels of tennis players [38]. According to Ferrauti [39], lateral movements are included in tennis and evaluation training programs. Linear and lateral sprints for 15–20 min 2–3 times a week improve players' ability to react and improve their speed, which supports the concepts of movement specificity and speed accommodation [40]. Like players of other team sports, tennis players must move laterally, forward, and backward [22]. They must move with great speed, agility, and leaping abilities to carry out their primary duties [41]. Significant emphasis has been placed on plyometric speed training as a training methodology [42]. Plyometric speed training is considered a valuable method for developing the explosiveness and speed required for high-intensity activities and sports performance [42].

This type of training is of particular interest since it enhances performance and lowers the injury risk for the athlete [43]. Plyometric training increases strength and explosiveness through exercises involving the neuromuscular system's conditioning that allow faster direction changes [44]. Plyometrics involves the rapid stretching of a muscle (eccentric contraction) before shortening it (concentric contraction) to gain maximum strength [45].

A study by Miller [45] proved the effects of plyometric training, especially on agility, highlighting that the most influential runs in tennis have the following components: starting, stopping, and changing direction [25]. In addition, Markovic [46] revealed a statistically significant impact of plyometric training.

Many plyometric workouts are limited to one main training plan. Thus, the ladder is a popular form of plyometrics that requires the athlete to move across a two-dimensional flat surface on the ground [47]. The workout can consist of lateral and forward movements; most ladder programs are structured with forward and backward movements [47].

Weineck [48] suggested that agility combined with quickness and speed are tennis and football players' most effective motor skills, and increasing quickness and agility may have a positive effect on speed [47]. However, Little and Williams [49] stated that speed, agility, and quickness should be viewed as independent motor skills with a limited influence on each other. Chimera et al. [50] evaluated the effects of plyometric training on muscle activation strategies and lower extremity performance during jumping exercises for female athletes, revealing that plyometric exercises should be incorporated into the training regimens of female athletes and may reduce the risk of injury by enhancing functional joint stability in the lower extremities.

Sibenaller et al. [51] investigated the relationship between balance and agility among collegiate athletes. Forty-four athletes from a division II collegiate athletic program in the southeastern United States were recruited as subjects in this study, which used the T-test, Edgren sidestep test, and a 30 m zigzag drill (ZZD) as agility tests and highlighted that balance and agility were not strongly related.

Hachana et al. [52] assessed the reliability and criterion-related validity of the Illinois change of direction (COD) Illinois agility test (IAGT), revealing that this test was reliable and valid and that performance was significantly related to speed rather than acceleration and leg power. Considering the test's high reliability and adequate level of utility, these results support the Illinois change of direction test as a standard measure for quantifying agility.

In addition, significant results were reported in a study by Kuroda et al. [53], which proved that agility was the physical component that most influenced junior tennis players' competitive level. Among the junior tennis players, the top-level tennis player group had a significantly better time than the middle-level group.

The studies of Booth and Orr [54] and Miller et al. [45] revealed relevant results regarding the impact of plyometric training on sports performance. Following plyometric training, improvements of 0.5–0.7 were observed in both the T-test and the Illinois test [54], while Miller et al. [45] proved that plyometric training could be an effective training technique for improving an athlete's agility.

Some recent studies from the past few years have addressed this topic [5,6,55] and have suggested that plyometric and explosive training can positively impact various physical attributes in junior tennis players, such as serve performance and agility, and contribute to improved overall tennis performance. However, further research is still needed to examine the effects of this type of training on junior tennis players' agility.

In this context, the paper aimed to evaluate the effects and benefits of a 10-week physical training program called plyospecific training on the agility of junior tennis players, leading to an improvement in the physical performance of young players.

The paper's central hypothesis was that plyospecific training would improve the agility of U16 junior players.

The paper is structured as follows. The introduction section introduces the reader to the literature on the physical performance of junior tennis players with a focus on the agility component, highlighting the main aim of the paper, the main hypothesis, and the paper's contribution to the literature. The next section, Materials and Methods, describes the data and methodology, while the third section provides valuable information about the main empirical results. The last two sections are dedicated to the main discussion and conclusions.

2. Materials and Methods

2.1. Research Design and Data Collection

The principal aim of this research was to examine and analyze the effects of plyospecific training, which includes sprints specific to tennis (forwards, backward, and sideways) performed in combination with plyometric training (speed, strength, and agility) on the agility of tennis players in the under-16 category.

To assess this, the research relied on an experiment that took place in Porto, Portugal at three sports clubs, namely: Da Maia Tennis School, Guimaraes Sports Club, and Porto Sports Club, during the period of July–August 2019 using a sample of 48 U16 junior Portuguese tennis players.

The final research was conducted over 12 weeks, of which the first and last weeks included physical testing. The training program (intervention) lasted ten weeks, with three workouts per week. The process started on 6 July and ended on 26 September 2020, twelve weeks later. The experiment took place over a ten-week period (13 July–20 September), during which the athletes followed the proposed plyospecific training plan, and at the end of it, the final physical tests were performed.

For the experimental group, players from the following clubs were taken into consideration: Guimaraes Tennis Club (Porto) and Da Maia Tennis School. For the control group, the players from Porto Tennis Club were taken into consideration. These sports clubs were considered similar, as they are in the same area, and the study included only one assessment.

The subjects in the experiment (n = 48) were divided into two groups: an experimental group (n = 25 subjects) and a control group (n = 23 subjects).

The subjects in the experimental group performed plyospecific training, consisting of plyometric training (ladder exercises and plyometric jumps) and training involving repeated sprints specific to tennis, whereas the subjects in the control group played tennis for 90 min without preparing physically.

Regarding the sample size, forty-eight male subjects aged 14 to 16 participated in the experiment; with 23 in the control group and 25 in the treatment or experimental group that received the intervention (plyospecific training).

The participants involved had approximately 4 years of experience playing tennis and a minimum of 2 years of experience participating in Portuguese national tournaments. Some of the participants had also attended international tournaments. Previously, all the twenty-five participants in the experimental group had taken part in similar activities, in which they performed similar activities, such as jumping or running.

At the beginning of the experiment, all participants were healthy, and there were no injuries during the process. Informed consent was obtained from all the participants and their parents, as they entered voluntarily with full information. Furthermore, the procedures were explained to the coaches and athletes. To be included, the tennis players had to participate in a minimum of 85% of the total training sessions and needed a minimum experience of 2 years in tournaments. In addition, the athletes did not execute training programs or strength-related exercises for 3 weeks before starting the tests and training. At the start, the athletes were familiarized with the exercises used. The Portuguese tennis players completed their usual tennis training five times per week, and additionally, they added plyospecific training three times per week. The plyospecific training was built out of two parts: tennis-specific training and plyometric training. It lasted between 60 and 90 min, three times per/week—Monday, Wednesday, and Friday—from 12:00 to 13:30. The control group trained specifically, meaning they just played tennis, five times a week.

In the research, eleven specific tests, which have been used in other scientific studies, were applied to evaluate the players' level of preparation and physical condition before and after the proposed training (plyospecific training). The athletes were tested before and after they accomplished the training sessions, called plyospecific sessions.

They performed the following physical tests:

1. **Added step test—**This test measured the velocity of the lateral run and the ability to stop and change direction. The subject began in a standing position near the service line. Then, after the start, he performed a lateral run between the two double lines on the field. First, the subject started at the middle line and reached the first line on the left or right, depending on which side he chose. He continued until he reached the other side and then returned to the starting point in the middle of the field.
2. **Spider run—**The objective of this test was to measure the specific court run, start, changes of direction, and stops. The athlete stood in front of the baseline holding his tennis racket. At the start signal, he started running to the right or left side, and then to each corner of the field, always returning to the starting point. There were, in total, five points marked on the field that the subject needed to reach with the feet.

Regarding this physical test, it was demonstrated that top-level junior tennis players had a significantly better time than the middle-level group ($p = 0.0011$) in the spider test (Figure 1).

3. **Illinois Agility Test**

The objective of the Illinois Agility Test (IAT) is to determine the athlete's ability to accelerate, decelerate, and change direction (Figure 2).

The athlete began in a prone position with the chin touching the surface of the starting line. On the researcher's start command, the stopwatch was started, and the participant stood up as quickly as possible and ran along the course while trying to avoid contact with cones placed on the ground. Then, the participant ran toward the middle cone at the starting line, following the zigzag course forward and then backward, sprinted toward the last cone on the side of the starting line, and then ran toward the last cone and finished at the finish line. At the finish line, the time was stopped and recorded. Subjects completed a maximum of two attempts with at least two minutes of rest between trials. The best time was considered, and it was recorded in seconds [37].

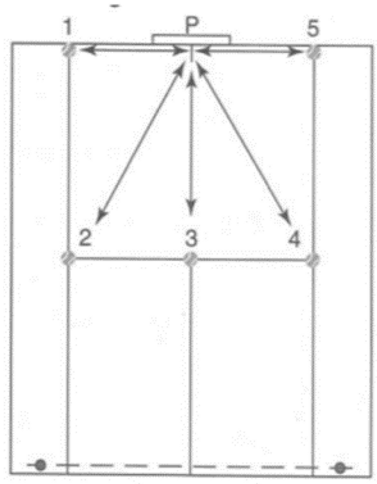

Figure 1. The Spider test.

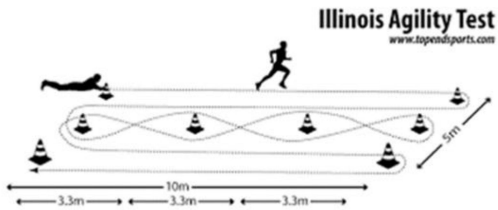

Figure 2. Illinois agility test.

4. **Edgren Sidestep Test**

The starting point was the middle cone, facing the net. After the start command was given, the subject ran toward the right side until the right foot passed the cone. The subject performed the sidesteps facing the net. Afterward, he went to the left side until his foot reached the outside of the cone. This process continued for 10 s. In the evaluation of the test, the number of times that the subject passed the outside cone was counted and taken into account (Figure 3).

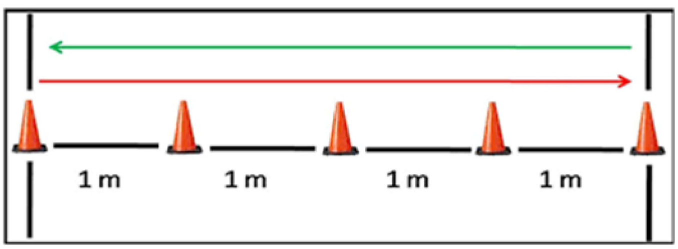

Figure 3. Edgren's sidestep test.

5. **T-test**

Four cones were arranged in a T-shape. The athlete needed to touch each cone with their hand during the test and moved with quick sidesteps in order to finish as fast as possible. Three cones were placed in a line 5 m apart from each other. The fourth cone was 10 m away from the middle cone. The four cones needed to build the shape of a T (Figure 4).

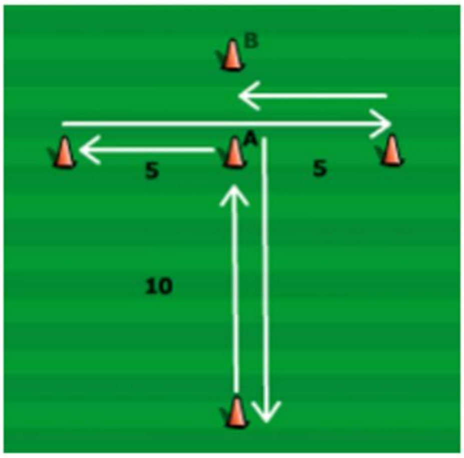

Figure 4. T-test.

At the start command, the subject ran to the middle cone (B), then moved to the A cone, returned to the opposite side (to the C cone), and then returned to the middle cone (B).

6. **Average number of lateral movements**

This indicator was calculated from the total number of lateral moves in 5 trials.

7. **Average number of forward movements**

This indicator was calculated from the total number of forward moves in 5 trials.

Prerequisites: verification of equivalence between the two groups (experimental and control) in tennis movement performance before completing the training program. In addition, the players were identified according to sports club membership, age, and height, which were considered as the variables in the process of evaluating the impact of plyospecific training.

Within the experimental research, the impact of the plyospecific training was assessed in several categories of performance dimensions, among which were agility indicators, speed indicators, speed indicators in endurance mode, mobility indicators, strength indicators, and synthetic performance indicators. From all these dimensions, our focus in this paper was to assess the agility indicators highlighted by:

- Added step test
- Spider test
- Illinois agility test
- Edgren sidestep test
- T-test
- Average number of lateral movements
- Average number of forward movements.

For the agility indicators, the added step test, spider test, Egdren lateral step test, and T-test, as well as lateral and forward movement, were also evaluated on both sides (dominant and non-dominant).

The average number of lateral movements/forward movements was calculated from the total number of movements in 5 trials. The design of the intervention (plyospecific training) is presented in Figure 5. A detailed description of the plyospecific physical training plan is provided in the Supplementary Materials.

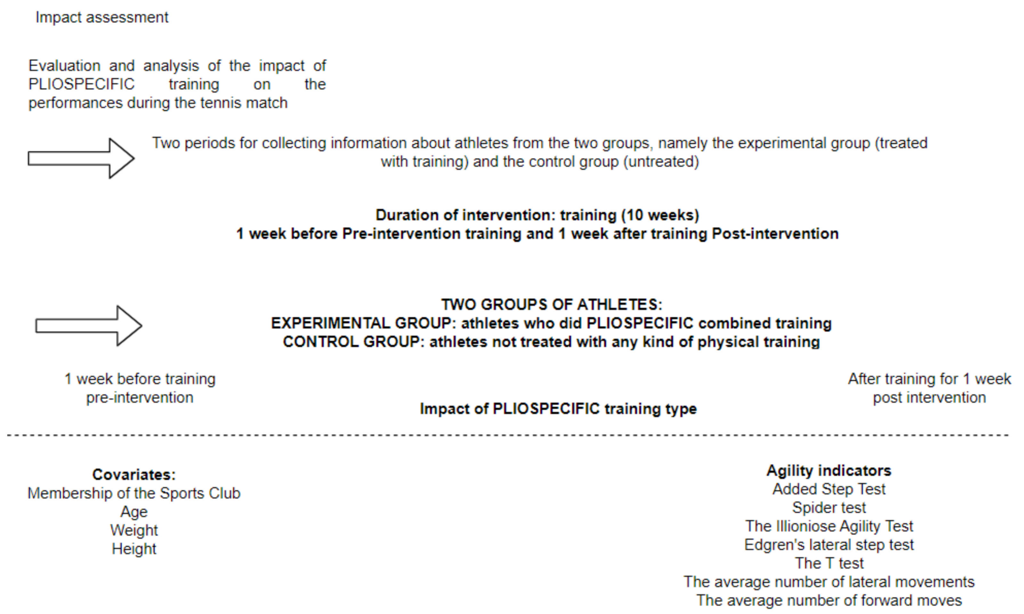

Figure 5. Intervention design (plyospecific training).

2.2. Research Methodology

To evaluate the impact of the plyospecific training program, seven agility indicators were used as dependent variables: the added step test, the spider test, the Illinois agility test, the Edgren sidestep test, the T-test, the average number of lateral movements, and the average number of forward movements; the independent variables were time (pre-training and post-training) and training group (control and plyospecific); and the covariates were age, sports club membership, quality of rest, and active recovery. The average number of lateral movements/forward movements was calculated from the total number of movements in five trials.

Descriptive statistics for both control and treatment (experimental) groups were used to highlight the main characteristics of both groups. The paired samples *t*-test for means and the independent samples *t*-test were used to highlight the existence of statistically significant differences between each group before and after the training, as well as to capture statistically significant differences in the agility indicators between the experimental and control groups after the training.

Finally, the counterfactual impact evaluation method of the difference-in-differences approach was applied [56–63] to capture the net impact of the program through the average treatment effect (ATE). The effect is calculated by measuring the change over time in the experimental and control groups and then considering the difference between these two differences. Thus, the difference-in-differences analysis compared the change in youth agility for those who participated in plyospecific training with the change over time for those who did not participate. It requires two groups and two periods of time, as follows [39–41]:

- Before (Pre = 0) and after training (Post = 1) (Pre = 0 and Post = 1, respectively);
- The experimental group (*Ti* = 1) and the control group (*Ti* = 1 and *Ti* = 0, respectively)

The potential impact of plyospecific training on youth agility was captured through 11 specifications of the following regression model based on several agility indicators:

$$Y_i = \beta_0 + \beta_1 * T_i + \beta_2 * t_i + \beta_3 * t * T_i + covariates_i + e_i \quad (1)$$

where:

Y_i is the dependent variable representing the agility indicators of a tennis player i, $Y_i(1)$ is the outcome of the agility of a tennis player under the plyospecific training, and $Y_i(0)$ is a tennis player's agility resulting from not participating in the plyospecific training;

β_0 is the baseline average, β_1 is the difference between the two groups in pre-training, β_2 is the time trend in the control group, and β_3 is the difference in the change over time. The variable t_i is the time variable reflecting the periods in the analysis: before the plyospecific training $t = 0$ (pre-intervention) and after the plyospecific training (post-intervention) $t = 1$; T_i is the pliospecific training dummy variable, taking a value of 1 if the player participated in the plyospecific training or 0 if the player was not a participant in the training. The interaction term $(t * T_i)$ captures the effect of the plyospecific training on the agility indicators. The statistical significance of the β_3 coefficient is fundamental to prove the impact of such training on the agility of tennis players.

Several variables were included as covariates: age, sports club membership, quality of rest, and active recovery. The quality of rest was evaluated by the number of hours of sleep: 8, 9, or 10. The active recovery was based on a maximum of 1 h of massage and 2 h of swimming divided into two sessions.

All data were analyzed using the Statistical Package for Social Sciences (version 24.0; SPSS Inc., Chicago, IL, USA) for Microsoft Windows and STATA software (version 15.0).

3. Results

3.1. The Profile of the Experimental and Control Group

The experimental group (n = 25 players) and the control group (n = 23 players) were very similar. The average age was almost 15 years, with an average weight of 59.36 kg and a mean height of 1.68 m in the experimental group and an average weight of 57.60 kg and a mean height of 1.66 m in the control group. The average ranking position was 62 for the experimental group, while for the control group, it was 96 (see Tables 1 and 2).

Table 1. Profile of the experimental group.

Variable	Obs.	Media	Std. Dev.	Min.	Max.
Age	25	14.88	0.83	14	16
Total Ranking	25	62.08	68.32	1	288
Weight (kg)	25	59.36	7.89	45	72
Height	25	1.68	0.07	1.54	1.81

Table 2. Profile of the control group.

Variable	Obs.	Media	Std. Dev.	Min.	Max.
Age	23	14.52	0.841	14	16
Total Ranking	23	96.21	67.10	7	288
Weight (kg)	23	57.60	3.99	48	72
Height	23	1.66	0.085	1.41	1.81

3.2. Exploring Time Differences in the Agility of Tennis Players for Both Groups

The empirical results of paired samples *t*-test exploring the statistically significant differences before and after training revealed, in the case of the experimental group, statistically significant differences for all tests at a 1% significance level, proving the effectiveness of plyospecific training (Appendix A, Tables A1 and A2). Therefore, in the added step test (left and right side), spider test (left and right side), T-test (left and right sides), and Illinois test, the time after training improved. In the case of the Edgren sidestep test (left and right sides), the average number of lateral and forward movements showed a negative difference, so after training, the number of movements increased, which also highlights the effectiveness of the training.

For the control group, the results of paired samples *t*-test for added step test, spider test, Illinois test, and Edgren sidestep test showed significant differences between the pre-and post-training values at different significance thresholds of 1%, 5%, or 10%. The difference in means between the two paired samples for all agility tests was negative and statistically significant, empirically demonstrating that the average time before training (IP) was better than that after training (DP), proving players' decreased performance in the control group. The results were also similar in lateral and forward movements, leading to the conclusion that the players performed better before training than after, which means that the athletes were not as agile after the training in which they only performed tennis-specific training.

3.3. Exploring Differences in the Agility of Tennis Players from Both Groups after Pliospecific Training

Furthermore, statistical differences were explored in the agility of tennis players using the independent samples *t*-test comparing the experimental and control group results after the plyospecific training. The empirical results showed no significant differences for both the left and right added step test and spider test, with the probability exceeding the maximum significance threshold of 10% in both scenarios assuming both equal and unequal dispersion between the two samples.

On the other hand, significant differences were highlighted in the case of the Illinois test, T-test, and Edgren test, as well as for the average number of lateral and forward movements, with probabilities smaller than the 5% threshold (Appendix B, Table A3).

3.4. Shedding Light on the Impact of Pliospecific Training on Agility Indicators Using the Difference in Difference Approach

The difference-in-differences approach was applied to evaluate the effects of plyospecific training on the agility of young players.

The empirical results (Table 3) revealed significant differences in the right- and left-side T-test, the right- and left-side Edgren test, the mean number of lateral movements, and the mean number of forward movements since the estimator of the DID approach (inter) showed statistical significance at 10% significance level. Therefore, the plyospecific training improved the results of junior players.

Table 3. The empirical results of counterfactual impact evaluation analysis.

	Model I	**Model II**	**Model III**	**Model IV**	**Model V**	**Model VI**	**Model VII**	**Model VIII**	**Model IX**	**Model X**	**Model XI**
Dep./indep. variables	Added Step Test, Right Side	Added Step Test, Left side	Spider Test, Right Side	Spider Test, Left Side	Illinois Agility Test	T-Test, Right Side	T-Test, Left Side	Edgren Step Test, Right Side	Edgren Step Test, Left Side	The average number of lateral movements	The average number of forward movements
Plyospecific training (ref = not participating in training), participating in training	−0.570 ***	−0.554 ***	−0.834 ***	−0.795 ***	−1.548 ***	−0.223 *	−0.333 *	0.332 *	0.488 *	7.29 *	2.89 *
PRE_POST (ref = before training), after training	0.033	−0.037	0.067	0.017	0.022	0.079	0.022	0.011	0.413 **	7.81 *	2.61 *
DID estimator (inter)	−0.148	−0.149	−0.533	−0.508	−0.279	−0.772 **	−0.582 *	0.983 ***	0.524 **	18.76 ***	6.20 **
Covariates											
Age (ref = 14 years old) 15 years old	−0.544 ***	−0.534 ***	−0.405 *	−0.397 *	−0.963 ***	−0.06	−0.101	0.176	0.063	6.89 **	1.609

Table 3. *Cont.*

	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII	Model VIII	Model IX	Model X	Model XI
Age (ref = 14 years old) 16 years old	−0.396 ***	−0.401 ***	−0.097	−0.119	−0.756	−0.140 **	−0.094 *	0.286 *	0.314 *	16.62 ***	2.65 *
Sports club (ref = club 1), club 2	0.672 ***	0.660 ***	1.155 ***	1.159 ***	1.252 ***	0.257	−0.444 ***	0.034	0.27	1.516	4.51 *
Quality of rest	−0.178 *	−0.181 *	−0.683 ***	−0.644 ***	−0.326 *	−0.429 **	−0.323 *	0.294 *	0.163 *	5.01 **	0.877 *
Active recovery	−0.045	−0.047	−0.323 *	−0.290 *	−0.016	−0.256 *	−0.176	0.126	0.016	2.99 *	0.075 *
Intercept	7.58 ***	7.62 ***	24.74 ***	24.50 ***	22.25 ***	14.50 ***	13.74 ***	4.23 ***	4.78 ***	44.02 ***	23.21 ***
No of obs.	96	96	96	96	96	96	96	96	96	96	96
F-stat	5.23 ***	5.21 ***	5.55 ***	5.88 ***	7.09 ***	4.36 ***	5.70 ***	7.90 ***	7.71 ***	6.73 ***	11.29 ***

Note: *, **, *** means statistically significant at 10%, 5% and 1%.

It is worth mentioning that for all agility indicators, improvements in results were observed for players participating in the plyospecific training compared with those not trained with this type of training. On the contrary, significant differences were observed post-training compared with pre-training only for the Edgren test (left side) and lateral and forward movements, revealing better results after training.

Age led to an improvement in agility, leading to better results. Thus, tennis players who were 16 years old showed better results in most agility tests than the 14-year-old players.

Interestingly, players from Sports Club 1 (Guimaraes Tennis Club) had better results in the added step test, spider test, and Illinois test than those from Sports Club 2 (Tennis School da Maia), while players from Club 2 performed better in the forward movements.

The quality of rest improved tennis players' agility, showing statistical significance in all models. At the same time, active recovery, even if it had the expected impact, did not show statistical significance.

Both control variables, quality of rest and the active recovery, considerably improved the quality of the estimated models, with the degree of determination R^2 ranging between 40% and 50%. All estimated models were statistically valid in terms of the Fisher test.

Therefore, the plyospecific training partially contributed to the agility indicators, as shown by the significant results of the right- and left-side T-test, right- and left-side Edgren test, average number of lateral movements, and average number of forward movements.

4. Discussion

The main objective of this research was to evaluate the effects and benefits of a 10-week physical training program that involved tennis-specific sprints (forward, backward, and sideways) performed in conjunction with plyometric training (speed, strength, and agility) on the agility of under-16 tennis players, with the central hypothesis that plyospecific training improves the agility of U16 junior players.

The empirical results were only partially able to prove this hypothesis. The empirical results of statistical tests highlighted that the plyospecific training improved the right- and left-side T-test and the number of lateral movements in the Edgren test (right and left side) and increased the average number of lateral and forward movements during a match.

Furthermore, the difference-in-differences empirical results revealed a statistically significant impact of plyospecific training on the agility of players, optimizing the T-test results for both sides, improving the number of lateral movements in the Edgren test (right and left side), and increasing the number of lateral and forward movements during a match.

Therefore, for the group of athletes trained with this program, plyospecific training partially contributed to improving youth agility, proving its effectiveness in four of the seven agility indicators and partially validating the core hypothesis of the research. The results are in line with those of other studies from the literature that have revealed a significant impact of the training program on the agility of tennis players [27,45,51–54].

Plyometric training increases strength and explosiveness through exercises involving neuromuscular system conditioning that allow faster direction changes [44]. Plyometrics involves the rapid stretching of a muscle (eccentric contraction) before shortening it (concentric contraction) to gain maximum strength [45].

A particularly relevant study that also supports our results is the study of Miller [45], which proved the effectiveness of plyometric training, especially on agility, highlighting that the most influential runs in tennis have the following components: starting, stopping, and changing direction. The authors discovered that their technique significantly improved the subjects' agility in the experimental group compared with the control group, particularly when examining the impacts on agility. On the other hand, Markovic [46] revealed a statistically significant impact of plyometrics training. The study of Little and Williams [49] stated that speed, agility, and quickness should be viewed as independent motor skills with limited influence on each other.

The findings of Raya et al. [27] also support the results of our research, which suggested that the Edgren sidestep test, T-test, and Illinois agility test are valid measures of agility that uniquely assess movement in different planes, thus providing a comprehensive assessment of high-level mobility.

Hachana et al. [52] assessed the reliability and criterion-related validity of the Illinois change of direction (COD) Illinois agility test (IAGT), revealing that this test is a reliable and valid test whose performance is significantly related to speed rather than acceleration and leg power. Considering the test's high reliability and adequate level of utility, these results support using the Illinois change of direction test as a standard measure for quantifying agility, thus partially confirming our results.

In addition, significant results were reflected by the study of Kuroda et al. [53]. This study proved that agility was the physical component that most influenced junior tennis players' competitive level. Among the junior tennis players, the top-level tennis player group had a significantly better time than the middle-level group.

Relevant results of plyometric training on sports performance have been revealed by the studies of Booth and Orr (2016) [54] and Miller et al. [45]. Following plyometric training, improvements of 0.5–0.7 were observed in both the T-test and the Illinois test [64], while Miller et al. [45] proved that plyometric training could be an effective training technique for improving an athlete's agility. Therefore, these studies confirmed the same benefits of this training program for youth agility from another perspective.

The transfer of the effect of plyometric training to the improvement of field sports performance is more about improving speed and agility rather than the ability to jump. This is probably because the sport rarely involves jumping throughout the competition. Young athletes showed improvements in several agility tests (−9.6%) [64]. Similar effects were also observed in senior athletes (−0.29 s) for the T-test and (−0.26 s) the Illinois agility test [65].

Therefore, the proposed plyospecific training can lead to the improvement of the U16 junior players' agility through the improvement of the results for the T-test (right and left side), Edgren test (left and right side), and the average number of lateral and forward movements. Better agility on the field means better movement during the game.

In summary, the results highlight the positive impact of plyospecific training on various aspects of agility, including quick directional changes, lateral movements, and overall mobility. By improving these agility measures, plyospecific training can enhance players' performance, responsiveness, and versatility in sports that demand agility as a critical component. Coaches and trainers can utilize these findings to design effective training programs aimed at developing and optimizing players' agility skills.

Revealing a statistically significant impact of plyospecific training on the agility of players could have several important implications for coaches, trainers, and athletes. Firstly, it would suggest that plyospecific training can be an effective tool for improving agility among players. This finding could be used to inform training programs and strategies aimed at enhancing players' performance on the field. The optimized T-test results on both sides indicate that plyospecific training can have a balanced impact on agility for both the right and left sides of the body. This is important because agility is essential for performing quick movements in any direction, and having balanced agility can prevent injuries and improve overall performance. Improving the number of lateral movements in the Edgren test (right and left side) and increasing the number of lateral and forward movements during a match indicates that plyospecific training can improve players' ability to make quick movements in different directions, which is critical for performing well in various game situations.

These implications suggest that incorporating plyospecific training into athletes' training programs could help improve their agility and overall performance on the field, potentially leading to greater success in competitions.

According to the findings of the study, several potential future directions for research could build on these results, such as:

1. Investigating the optimal frequency and duration of plyospecific training for improving agility. This study did not explore the optimal training frequency or duration necessary to improve agility significantly. Future research could explore these factors in greater detail to identify the most effective training protocols.
2. Examining the long-term impact of plyospecific training on agility. This study only examined the impact of plyospecific training on agility over a relatively short period. Future research could investigate the long-term effects of this training on agility and other performance indicators, such as injury rates and overall player health.
3. Comparing the effectiveness of plyospecific training to other training methods. While this study found that plyospecific training was effective for improving agility, future research could explore how it compares to other training methods, such as strength training or aerobic exercise, in terms of enhancing agility and other performance measures.
4. Investigating the effects of plyospecific training in different populations: The study focused on young players, so future research could explore whether plyospecific training effectively improves agility among other populations, such as female players.
5. Exploring the impact of plyospecific training on other aspects of physical performance. While this study focused on agility, future research could investigate whether plyospecific training impacts other performance indicators, such as speed and strength.

Among the study's main limitations, the relatively small sample size, short study duration, lack of blinding, and limited evaluation of other physical or mental factors can be highlighted. The study included a small number of participants, which limits the generalizability of the results. The findings may not represent the broader population of junior tennis players. It only lasted six weeks, which may not have been long enough to see the full impact of plyospecific training on agility or other performance measures. Longer-term studies would be necessary to determine the lasting effects of this type of training. The researchers who conducted the study were not blinded to the participants' group assignments, which may have introduced bias into the study. In addition, the study only evaluated the impact of plyospecific training on agility. It did not measure other physical or mental factors impacting athletic performance, such as strength, endurance, and confidence.

5. Conclusions

With the primary objective of the evaluation of the benefits of a 10-week plyospecific program on U16 junior players' agility, the empirical results highlighted the importance of this training program on young athletes' agility through the progress registered in four for seven agility indicators—the T-test (right and left side), Edgren test (left and right side), average number of lateral movements, and average number of forward movements—partially validating the core hypothesis of the research. Thus, the proposed plyospecific training led to the progress of the U16 junior players' agility through the improvement of the results for the T-test (right and left side) and Edgren test (left and right side), as well as through the improvement in the average number of lateral and forward movements.

Consequently, the implementation of plyospecific training demonstrated several significant implications. Firstly, it resulted in notable advancements in the agility of U16 junior players. This was evidenced by the improvement in the T-test results on both the right and left sides, indicating enhanced lateral agility. Similarly, the Edgren test scores exhibited improvement on both the left and right sides, suggesting enhanced multidirectional agility. Moreover, the average number of lateral and forward movements increased, indicating an overall enhancement in agility and mobility. These findings collectively demonstrate the positive impact of plyospecific training on U16 junior players' agility and underscore its effectiveness as a training method.

Thus, coaches and trainers can optimize the benefits of plyospecific training, leading to further advancements in U16 junior players' agility and overall performance on the field.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15139925/s1. The description of the plyospecific physical training plan.

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Data Availability Statement: Our analysis dataset is available from the corresponding author upon request.

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Appendix A

Table A1. Paired samples *t*-test results for agility indicators in the experimental group.

		Paired Differences			t	Sig. (Two-Tailed)
		Mean	Std. Deviation	Std. Error Mean		
Pair 2	T1_added_step_IP_LF-T2_added_step_DP_LF	0.09	0.09	0.02	5.03	**0.00**
Pair 3	T1_spider_test _IP_R-T2_spider_test _DP_R	0.41	0.34	0.07	6.00	**0.00**
Pair 4	T1_spider_test _IP_LF-T2_spider_test _DP_LF	0.44	0.34	0.07	6.51	**0.00**
Pair 5	T1_Illinois_test_IP-T2_Illinois_test_DP	0.22	0.16	0.03	6.63	**0.00**
Pair 6	T1_T_Test_IP_R-T2_T_Test_DP_R	0.66	0.71	0.14	4.70	**0.00**

Table A1. *Cont.*

		Paired Differences			t	Sig. (Two-Tailed)
		Mean	Std. Deviation	Std. Error Mean		
Pair 7	T1_T_Test_IP_LF-T2_T_Test_DP_LF	0.54	0.63	0.13	4.27	**0.00**
Pair 8	T1_Edgren_side_step_IP_R-T2_Edgren_side_step_DP_R	−0.96	0.35	0.07	−13.66	**0.00**
Pair 9	T1_Edgren_side_step_IP_LF-T2_Edgren_side_step_DP_LF	−0.92	0.49	0.10	−9.33	**0.00**
Pair 10	Average number lateral movements IP-Average number lateral movements DP	−10.59	3.86	0.77	−13.72	**0.00**
Pair 11	Average number_forwardmovements IP-Average number forward movements DP	−3.69	1.48	0.30	−12.43	**0.00**

Note: IP, before training; DP, after training; R, right side; LF, left side.

Table A2. The empirical results of the paired samples *t*-test for agility indicators in the control group.

		Paired Differences			t	Sig. (Two-Tailed)
		Mean	Std. Deviation	Std. Error Mean		
Pair 1	T1_added_step_IP_R-T2_added_step_DP_R	−0.05	0.06	0.01	−3.71	**0.001**
Pair 2	T1_added_step_IP_LF-T2_added_step_DP_LF	−0.05	0.06	0.01	−3.79	**0.001**
Pair 3	T1_SpiderTest_IP_R-T2_SpidetTest_DP_R	−0.06	0.12	0.03	−2.37	0.027
Pair 4	T1_SpiderTest_IP_LF-T2_SpiderTest_DP_LF	−0.02	0.02	0.01	−3.01	**0.007**
Pair 5	T1_Illinois_test_IP-T2_Illinois_test_DP	−0.09	0.23	0.05	−1.81	0.083
Pair 6	T1_T_Test_IP_DR-T2_T_Test_DP_R	−0.05	0.12	0.03	−2.11	0.047
Pair 7	T1_T_Test_IP_LF-T2_T_Test_DP_LF	−0.01	0.03	0.01	−1.79	0.088
Pair 9	T1_Edgren_side_step_IP_LF – T2_Edgren_side_step_DP_LF	−0.39	0.58	0.12	−3.22	**0.004**
Pair 10	Average number of lateral movements IP-Average number lateral movements DP	7.51	3.83	0.80	9.42	**0.00**
Pair 11	Average number foreword movements IP-Average number foreword movements DP	2.50	1.46	0.30	8.21	**0.00**

Appendix B

Table A3. The empirical results of the independent samples *t*-test for agility indicators for the experimental vs. control group (Levene's test for equality of variances).

		F	Sig.	t	Sig. (Two-Tailed)	Mean Difference	Std. Error Difference
T2_added_steps_DP_R	Equal variances assumed	0.38	0.54	−1.61	0.11	−0.29	0.18
	Equal variances not assumed			−1.61	0.12	−0.29	0.18
T2_added_steps_DP_LF	Equal variances assumed	0.41	0.52	−1.57	0.12	−0.28	0.18
	Equal variances not assumed			−1.56	0.13	−0.28	0.18
T2_SpiderTest_DP_R	Equal variances assumed	0.82	0.37	−1.37	0.18	−0.39	0.29
	Equal variances not assumed			−1.35	0.19	−0.39	0.29
T2_SpiderTest_DP_LF	Equal variances assumed	0.50	0.48	−1.19	0.24	−0.33	0.28
	Equal variances not assumed			−1.18	0.24	−0.33	0.28
T2_Illinois_test_DP	Equal variances assumed	0.30	0.59	−2.98	**0.01**	−0.99	0.33
	Equal variances not assumed			−2.98	**0.01**	−0.99	0.33
T2_T_Test_DP_R	Equal variances assumed	0.34	0.56	−2.55	**0.01**	−0.68	0.27
	Equal variances not assumed			−2.56	**0.01**	−0.68	0.27
T2_T_Test_DP_LF	Equal variances assumed	0.00	0.96	−2.00	**0.05**	−0.52	0.26
	Equal variances not assumed			−2.00	**0.05**	−0.52	0.26

Table A3. *Cont.*

		F	Sig.	t	Sig. (Two-Tailed)	Mean Difference	Std. Error Difference
T2_Edgren_side_step _DP_R	Equal variances assumed	0.17	0.68	6.34	**0.00**	1.34	0.21
	Equal variances not assumed			6.33	**0.00**	1.34	0.21
T2_Edgren_side_step _DP_LF	Equal variances assumed	0.43	0.52	3.85	**0.00**	0.78	0.20
	Equal variances not assumed			3.83	**0.00**	0.78	0.20
Average number lateral movements DP	Equal variances assumed	0.31	0.58	5.79	**0.00**	28.97	5.01
	Equal variances not assumed			5.85	**0.00**	28.97	4.95
Averagenumber_foreword -movements _DP	Equal variances assumed	6.43	0.02	6.59	**0.00**	12.77	1.94
	Equal variances not assumed			6.75	**0.00**	12.77	1.89

Note: IP, before training; DP, after training; R, right side; LF, left side.

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