IOSR Journal of Sports and Physical Education (IOSR-JSPE)
e-ISSN: 2347-6737, p-ISSN: 2347-6745, Volume 10, Issue 4, (July. – August. 2023), PP 45-53
www.iosrjournals.org

The Impact Of Six Weeks Of Plyometric Training Program On Agility, Explosive Power, And Acceleration Performance In Young Elite Tennis Players

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Abstract:
The purpose of this study aimed to examine how a six-week plyometric training regimen affected male athletes' agility, explosive power, and acceleration. Sixteen athletes consented for the study and were divided into two groups: the plyometric training group (n=8) with an average age of 16.4 ± 0.5 years and weight of 60.9 ± 7.2 kg, and the control group (n=8) with an average age of 16.4 ± 0.5 years and weight of 63.0 ± 3.4 kg. The plyometric training group participated in a combination of plyometric exercises and general tennis training, while the control group received only general tennis training. Pre- and post-testing included the T-test and 505 agility tests to assess agility, vertical jump tests for explosive power, and a short-distance acceleration test. Pre-test scores were utilized as covariates in univariate analysis of covariance (ANCOVA) to examine change scores (post-pre). In comparison to the control group, the results revealed appreciable gains in the plyometric training group for all variables that were assessed. The T-test agility measure demonstrated a significant group effect ($F_{1,13}$ = 23.75, P = 0.000). Similarly, significant group effects were observed in the 505 agility tests for both the left ($F_{1,13}$ = 37.67, P = 0.000) and right ($F_{1,13}$ = 28.22, P = 0.000) sides. Significant group effects were also found in the vertical jump tests for the left ($F_{1,13}$ = 4.87, P = 0.046) and right ($F_{1,13}$ = 4.66, P = 0.049) sides. Additionally, the short-distance acceleration test revealed a significant group effect ($F_{1,13}$ = 19.69, P = 0.001). These findings indicate that plyometric training effectively enhances an athlete's agility, explosive power, and acceleration. It's important to note that the control group, probably as a result of their general tennis instruction, also shown significant effects. These results have practical implications for coaches, trainers, and athletes aiming to improve performance in sports that require agility. Further research should focus on exploring the long-term effects and optimal training protocols of plyometric interventions in athletic training.

***Key Word**: Change of direction, Jumping, Training, Sports performance*

Date of Submission: 21-07-2023 Date of Acceptance: 01-08-2023

I. Introduction

Plyometrics, a widely used training method among athletes in various sports, focuses on improving strength and explosiveness [5]. This technique involves rapidly stretching the muscles (eccentric action), followed immediately by a shortening action (concentric action) of the same muscles and connective tissues [3]. By utilizing the elastic energy stored in the muscles, plyometrics enables athletes to generate greater force than is possible with concentric action alone [19,26,29,32].

The advantages of introducing plyometric exercises into a periodized strength-training program have been repeatedly shown by numerous research. These advantages include enhanced proprioception, acceleration, leg strength, muscular power, and vertical jump performance [1,2,14,15,16,17,18,26,34,45]. These findings highlight the beneficial effects of plyometric exercises when paired with a planned strength-training program.

Plyometric exercises typically involve explosive movements that require sudden stops, starts, and changes in direction. These dynamic movements play a crucial role in the development of agility [6,8,25,30,46,47]. Agility refers to the ability to effectively control body position while rapidly changing direction through a series of movements [12]. Through neuromuscular conditioning, adaptation of muscle spindles, Golgi tendon organs, and joint proprioceptors, agility training seeks to reinforce neuromuscular programming [4,8,34]. By enhancing balance and control of body positions during movement, agility training has the potential to improve overall agility.

Plyometric training has been suggested as a method to enhance power, efficiency, and agility in sports like football, tennis, soccer, and other activities that require agility [30,37,38,39,46]. However, despite indications of plyometric training's positive influence on performance variables, there is a lack of comprehensive scientific research establishing its effect on agility improvement. Hence, the objective of this study was to evaluate the impact of a six-week plyometric training program on levels of agility [6].

Table 1. Demographic data Control group. Data are means (± SD)

	Control group	
	Pre – Test n = 8 (Male)	**Post – Test n = 8 (Male)**
Age (yrs)	16.38 (± 0.52)	16.38 (± 0.52)
Weight (kg)	60.88 (± 7.19)	59.88 (± 6.06)
Height (m)	1.68 (± 0.06)	1.71 (± 0.04)

Table 2. Demographic data Plyometric training group. Data are means (± SD)

	Plyometric training group	
	Pre – Test n = 8 (Male)	**Post – Test n = 8 (Male)**
Age (yrs)	16.38 (± 0.52)	16.38 (± 0.52)
Weight (kg)	63.00 (± 3.46)	62.75 (± 2.05)
Height (m)	1.68 (± 0.07)	1.71 (± 0.06)

II. Material And Methods

Subjects

Sixteen subjects in all volunteered to take part. The participants were split into two groups at random: a control group and a group that underwent plyometric training (Tables 1 and 2). The participants in the study were 16 to 17 years old, free of lower extremity injuries, and not involved in any plyometric exercise at the time.

Procedure methodology

All participants in the study agreed not to change or intensify their current exercise routines. Over a six-week period, the plyometric training group completed a variety of plyometric activities made specifically for the lower extremities, while the control group did not (Table 3). Subjects were told not to start any lower extremity strengthening programs throughout the six-week period, and to simply participate in session activities. The techniques and rules were explained to the participants both verbally and in writing before to the research's start. Participants in the study voluntarily signed a permission form that had been authorized by the institution in question.

Three training sessions per week were planned for a six-week plyometric training program. The recommendations of Piper and Erdmann (1998), who provided recommendations for intensity and volume, served as the foundation for the creation of the program. The sets and repetitions were slightly altered, even though the drills employed were same. It is widely accepted that a period of four to six weeks of high-intensity power training is ideal for successfully stimulating the central nervous system (CNS) without creating undue strain or exhaustion. This belief takes into account both physiological and psychological factors. Sports physiologists indicate that neuromuscular adaptations necessary for explosive power typically take place early in the power cycle of the training periodization phase. According to the advice of experts like Adams, O'Shea, O'Shea, and Climstein (1992), the plyometric exercises were only conducted three times a week to ensure enough recovery between workouts.

Table 3. Plyometric six-weeks training protocol [24]

Training Weeks	Training Volume (Foot Contacts)	Plyometric Drill	Set x Reps	Training Intensity
Week 1	92	Side to Side Hops 15 cm Hurdles Jump (Both legs) 20 cm Box Jump	2 x 16 3 x 12 2 x 12	Low Low Low
Week 2	104	Side to Side Hops over 15 cm Barrier 20 cm Hurdles Jump (Both legs) 20 cm Box Jump Standing long Jump	2 x 10 3 x 10 2 x 12 5 x 6	Low Low Medium Medium

Week 3	120	Side to Side Hops over 15 cm Barrier 20 cm Hurdles Jump (Both legs) 15 cm One Leg Box Jump Standing long Jump 30 cm box Jumps	2 x 10 3 x 10 2 x 8 5 x 6 4 x 6	Low Low Medium Medium High
Week 4	134	Side to Side Hops over 15 cm Barrier 20 cm Hurdles Jump (Both legs) 15 cm One Leg Box Jump Standing long Jump with lateral sprints 30 cm box Jumps	2 x 10 3 x 10 4 x 8 5 x 4 4 x 8	Low Medium Medium High High
Week 5	130	Side to Side Hops over 15 cm Barrier 20 cm Hurdles Jump (Both legs) 15 cm One Leg Box Jump Standing long Jump with lateral sprints 30 cm box Jumps Lateral Jump single Leg	2 x 10 3 x 10 2 x 8 5 x 4 4 x 8 2 x 6	Low Medium Medium Medium High High
Week 6	118	Side to Side Hops 15 cm Hurdles Jump (Both legs) 20 cm Box Jump Hexagon drill Double leg hop	2 x 12 3 x 10 2 x 12 2 x 12 2 x 8	Low Low Medium Medium High

The training plan incorporated different training volumes, ranging from 92 to 134 feet contacts per session. The intensity of the exercises increased progressively over a five-week period, following the recommended approach outlined by Piper and Erdmann (1998). Similar approaches had been utilized in previous studies conducted by Miller, Berry, Bullard, and Gilders (2002) and Miller, Herniman, Ricard, Cheatham, and Michael (2006). In the sixth week, the intensity was gradually reduced to prevent excessive fatigue that could potentially impact the post-testing results. Throughout the study, the participants in the plyometric training group adhered to a consistent training schedule, conducting sessions twice a week at the same designated time. Notably, all participants received direct supervision and detailed instructions on the proper execution of each exercise.

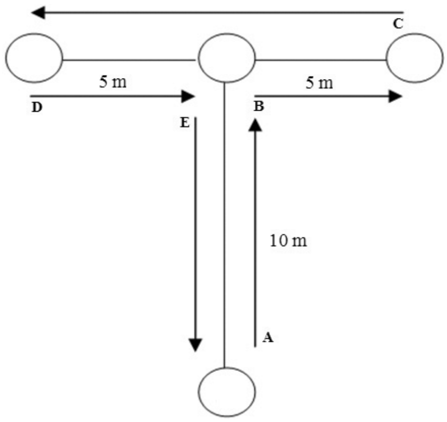

Figure 1. Diagram of T-Test (Direction - A, B, C, D, E and A)

Testing procedures

Four tests were conducted before and after the training to assess agility, leg power, and short distance acceleration. The T-test (Figure 1) evaluated speed during directional changes like forward sprinting, side shuffling, and backpedaling. The 505-agility test (Figure 2) measured the ability to accelerate, decelerate, display agility, and execute 180-degree turns. These tests were chosen based on established criteria data for males and their proven validity and reproducibility [31,41]. The Vertical Jump Test (Figure 3) assessed lower body power, while the final assessment was the 10 m distance acceleration test (Figure 4), which evaluated athletes' acceleration abilities.

T – test: Three cones are set five meters apart on a straight line. A fourth cone is placed 10 meters from the middle cone so that the cones form a T. The player initiates the exercise from the right base of the "T" formation. Upon receiving the signal from the examiner, the player starts moving, and the timer begins as soon as the player crosses the photocell. The player then performs side steps covering a distance of 5 meters towards the right cone, touching it. Subsequently, the player side steps an additional 10 meters to reach the far cone and touches it as well. Afterward, the player side steps back for 5 meters towards the middle cone and touches it. Finally, the player moves 10 meters backward, reaching and touching the cone positioned at the base of the "T" formation. The timer stops when the athlete crosses the finish line [24].

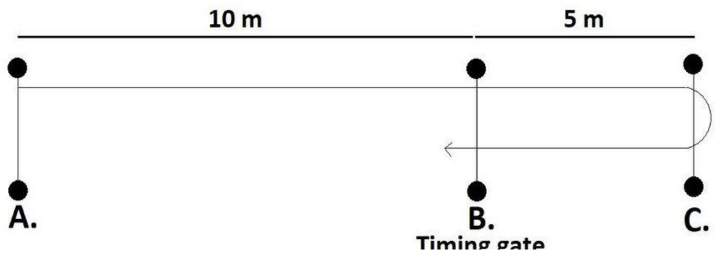

Figure 2. Diagram of 505 Agility test (Direction - A, C, B)

505 Agility test: In this test, players are tasked with completing the distance between two markers placed 15 meters apart in the quickest time possible. A computerized timing gauge system will be positioned at the tenth meter to accurately measure time. Participants aim to achieve maximum acceleration from the starting line to the timing gate located at the 10-meter mark. They then stop behind the line of the second marker, execute a 180-degree change in direction, and accelerate once more towards the finish line, which is positioned 5 meters away. The total distance covered in this drill is 20 meters, consisting of a 10-meter run-up and two 5-meter distances.

505 Agility test (Left & Right), the widely used 505 Agility test serves as a common assessment tool for evaluating an athlete's agility and their ability to swiftly change direction. It involves sprinting 5 meters, executing a sharp turn, and returning to the starting point as quickly as possible. While this test provides valuable insights into overall agility performance, it overlooks an essential aspect leg dominance, which can significantly influence an athlete's movement patterns and outcomes.

Leg dominance refers to an athlete's preference for using one leg over the other during sports activities, and it is frequently observed among athletes. In the context of tennis, players often exhibit a dominant leg, whether it is their right or left, which plays a critical role in specific movements such as explosive lateral motions and maintaining stability during rapid changes in direction. Recognizing the impact of leg dominance on tennis agility performance is crucial for designing targeted training programs and optimizing athletic capabilities.

To address these dynamics, we propose a modification to the 505 Agility test that incorporates leg dominance into the test design. Our objective is to explore performance variations when the right leg serves as the final leg in the right-side agility test and when the left leg serves as the final leg in the left-side agility test. This innovative approach will provide valuable insights into how leg dominance influences movement mechanics, speed, and overall agility during tennis-specific tasks [27].

By integrating leg dominance considerations into agility testing, we can acquire a deeper understanding of the nuanced factors affecting an athlete's performance. This knowledge will facilitate the development of targeted training protocols, tailored interventions, and refined strategies to enhance agility and optimize overall tennis performance [40].

Vertical Jump test: In this study, the player adopts a side-on position facing a wall and raises their arm closest to the wall to its maximum height. With feet planted firmly on the ground, the player's fingertips are marked at this standing reach height. Before initiating the jump, the player bends their knee to approximately a 90-degree angle. They then execute a vertical leap, employing both arms and legs to propel their body upwards. The objective is to touch or leave a mark on the wall at the highest point achieved during the jump. The discrepancy between the standing reach height and the jump height is recorded, with the best out of three attempts being documented. It is worth noting that in this particular study, single-leg vertical jump measurements were utilized [20].

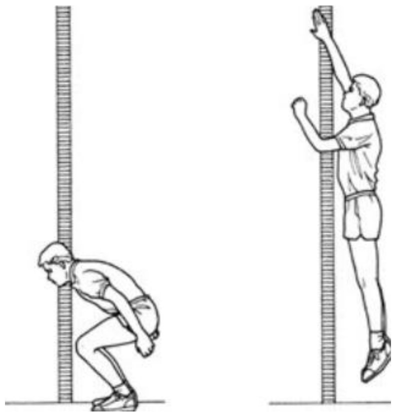

Figure 3. Diagram of Vertical jump test

Short distance Acceleration test: This test was to accurately measure sprint times; electronic timing gates were employed in the sprint test. The test took place on a grass surface, with the timing gates precisely positioned 10 meters away from a predetermined starting point. Participants were instructed to sprint with maximum speed along the 10-meter distance from the starting line. Speed measurements were recorded with a precision of 0.01 seconds, and the fastest time out of three trials was considered as the final result.

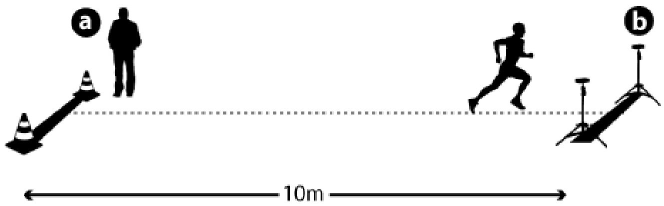

Figure 4. Diagram of 10 m acceleration test (Direction – a to b)

All individuals performed baseline agility testing prior to commencing the training program, which included the three aforementioned tests. The entire testing process, which included a warm-up phase, ten-minute rest breaks between tests, and roughly three minutes of respite in between repetitions, lasted about an hour per participant. To ensure that participants understood the testing processes, thorough explanations and demonstrations of each test were given. Furthermore, practice tests were conducted to acquaint participants with the testing protocols [7,21].

The tests were counterbalanced in both the pre- and post-testing sessions to mitigate any potential biases in the testing procedure. For a more accurate evaluation of performance, each test was administered three times, with the results averaged [11].

Statistical analysis

Both the Kolmogorov-Smirnov goodness-of-fit test and the Shapiro-Wilk normality test were applied to the before and post values to evaluate the normality of the distributions for the dependent variables. For each dependent variable, in-cluding the T-Test Agility, 505-Agility, Vertical Jump, and 10 m Acceleration tests, change scores calculated as the difference between the post and pre values were found. The change scores of the dependent variables were compared between the groups (Control, Plyometric Training) using single factor ANCOVAs, with the pre-test values acting as a covariate. The alpha level was specified to be $p < 0.05$, a level of significance. The statistical calculations were carried out utilizing the Statistical Package for IBM SPSS Statistics (version 26).

III. Result

The means and standard deviations of the group times for each of the three tests are shown in Table 4. The dependent variables appeared to have a normal distribution, according to the results of the normality tests. When adjusting for pre-test differences, the single-factor ANCOVA showed a significant group effect for the T-test agility measure change score ($F_{1,13} = 23.75$, $p = 0.000$, power = 0.994). Table 4 shows that the plyometric training group's T-Test agility times improved by 0.91 ± 0.39 seconds, while the control group's times only changed by 0.32 ± 0.28 seconds. Similar results were found for the 505 Agility test (Left) change score while adjusting for pre-test variables ($F_{1,13}$ = 37.67, p = 0.000, power = 1.00). In their 505 Agility test (Left) times, the plyometric training group demonstrated a reduction of 0.69 ± 0.22 seconds, whereas the control group only saw a difference of 0.17 ± 0.07 seconds. When adjusting for pre-test differences, a significant group effect was discovered for the 505 Agility test (Right) change score ($F_{1,13}$ = 28.22, p = 0.000, power = 0.998). The 505 Agility test (Right) times of the plyometric training group improved by 0.50 ± 0.14 seconds, whereas those of the control group changed by 0.20 ± 0.78 seconds. When the pre-test values were used as a covariate, the Vertical Jump test (Left) change score revealed a significant group effect ($F_{1,13}$ = 4.87, p = 0.046, power = 0.533). The Vertical Jump test (Left) displacement was reduced by -4.38 ± 1.30 cm in the plyometric training group while it was changed by -2.88 ± 1.13 cm in the control group. When utilizing the pre-test values as a covariate, it was also possible to detect a significant group effect for the Vertical Jump test (Right) change score ($F_{1,13}$ = 4.66, p = 0.049, power = 0.516). When compared to the control group, the plyometric training group showed an improvement in the Vertical Jump test (Right) displacement of -4.38 ± 0.74 cm. After adjusting for pre-test differences, a significant group effect was found for the change score on the 10m Acceleration test ($F_{1,13}$ = 19.67, p = 0.001, power = 0.983). The 10m Acceleration times of the plyometric training group decreased by 0.48 ± 0.13 seconds, whereas those of the control group changed by 0.21 ± 0.10 seconds. Refer to Table 4 for further information in detail.

IV. Discussion

In the T-test, participants demonstrated an 8.03 % improvement in times. The 505-agility test (left) showed a significant improvement of 21.03 %, while the 505-agility test (right) exhibited a notable improvement of 15.01 %. For the vertical jump (left), subjects improved by over 16.07 %, and for the vertical jump (right), the improvement was 14.53 %, both surpassing 16.07 %. The short distance acceleration test showed an improvement of 19.59 %. These results indicate significant improvements across all four tests. Notably, the findings from the 505-agility test (left and right) showed an improvement difference of 6.02 %, while no difference was observed in the vertical jump test (left and right).

The results of this study show that plyometric training improves agility test performance, which may be explained by increased motor recruitment or neural changes. Plyometric training is thought to improve motor unit recruitment patterns, according to previous studies [34]. When athletes demonstrate greater synchronization between central nervous system (CNS) impulses and proprioceptive feedback, they are often exhibiting neural changes [8]. As suggested by Potteiger et al. (1999), our investigation was unable to distinguish whether neural changes happened as a result of synchronous motor neuron firing or better facilitation of neural impulses to the spinal cord. In order to fully understand the brain modifications brought on by plyometric training and how they affect agility performance, more research is required.

In this study used a jumping test to measure ground contact time during directional changes, which is an important component of agility and a benefit of plyometric training. The high link shown between plyometric exercise and better performance in agility tests may be due to the close alignment between plyometric activities and the movement patterns necessary for agility. This alignment allows it easier to move more quickly and efficiently, especially when changing directions right away after landing. In this study used a jumping test to measure ground contact time during directional changes, which is an important component of agility and a benefit of plyometric training. The high link shown between plyometric exercise and better performance in agility tests may be due to the close alignment between plyometric activities and the movement patterns necessary for agility. This alignment allows it easier to move more quickly and efficiently, especially when changing directions right away after landing.

Previous research consistently reports significant improvements in vertical jump performance among male and female athletes following plyometric training [10,13,22,35,36,43]. In this study's findings support these findings, as the plyometric training program resulted in a significant difference in jump ability between the pre-training and post-training values in the plyometric group compared to the control group.

Table 4. Mean (± SD) For the 2 Agility measures, lower body power and Acceleration.

Tests	**Pre-test**	**Post-test**
T- test (sec)		
Training	11.33 (± 0.22)	10.43 (± 0.29) *
Control	11.49 (± 0.42)	11.18 (± 0.29)
505 Agility test (sec)		
Left: Training	3.28 (± 0.19)	2.60 (± 0.24) *
Control	3.33 (± 0.15)	3.16 (± 0.18)
Right: Training	3.33 (± 0.13)	2.83 (± 0.15) *
Control	3.35 (± 0.09)	3.15 (± 0.12)
Vertical Jump Test (cm)		

Left: Training	27.25 (± 3.33)	31.63 (± 4.34) *
Control	25.63 (± 4.72)	28.50 (± 5.04)
Right: Training	30.13 (± 3.36)	34.50 (± 3.82) *
Control	24.38 (± 4.72)	27.50 (± 4.69)
10m Acceleration Test (sec)		
Training	2.45 (± 0.16)	1.98 (± 0.09) *
Control	2.50 (± 0.25)	2.29 (± 0.32)

* Indicates significant change (post – pre) when using Pre-test score as a covariate, $p < 0.05$.

The implications of the study go beyond contributing to the existing knowledge of tennis agility. These findings have practical implications for coaches, trainers, and athletes seeking to enhance their performance. By understanding the influence of leg dominance on tennis agility, targeted training protocols can be developed to address potential weaknesses and improve overall on-court performance.

Both the T-test and the 505-agility test saw a substantial improvement in this study's participants who completed plyometric exercise. As a result, there is now evidence linking plyometric exercise to enhanced agility assessments. These agility gains are especially helpful for athletes whose sports require fast movements, which is in line with the findings of earlier studies. For instance, a study on tennis players evaluated speed and agility using the T-test and dot drill test, and the researchers found that as the players' speed and agility increased, they were better able to reach more balls and perform more successfully on the tennis court [30]. Similar to Renfro (1999), Robinson and Owens (2004) used vertical, lateral, and horizontal plyometric jumps to demonstrate gains in agility. Renfro (1999) assessed agility using the T-test with plyometric training.

Additionally, plyometric exercise was found to improve agility performance and raise vertical jump height. Proprioception is improved after plyometric training, according to prior study [28]. Additionally, there is a slight link between agility and leg muscular strength. The neuromuscular adaptations and the concept of specificity, which were previously described in relation to leaping ability, may have contributed to the performance gains seen in our study. It's possible that these hypothesized modifications enhanced the capacity to switch quickly and strongly between decelerating and accelerating actions.

The primary objective of this research was to examine the results of substituting a six-week plyometric training program for some parts of tennis training during young tennis players' usual 90-minute practice sessions. Tennis players seem to benefit most from plyometric training as a stimulus for improving their physical attributes. It is difficult to draw comparisons with earlier research since participant ages vary and earlier training regimens did not exclusively emphasize plyometric training.

V. Conclusion

The findings of this study strongly support the benefits of plyometric training for improving agility in athletes. These results demonstrate that plyometric exercises not only offer a refreshing change to training routines but also contribute to enhanced strength, explosiveness, and overall agility. It is noteworthy that significant improvements in agility were observed within a relatively short duration of six weeks, making plyometric training a valuable addition to the final preparatory phase before in-season competitions for athletes. It is important to mention that the control group also exhibited significant effects, likely attributed to the general tennis training they received. This underscores the significance of considering the impact of other training modalities when evaluating the effectiveness of specific interventions.

Furthermore, this research successfully addresses the gap in understanding of the relationship between leg dominance and tennis agility performance. By incorporating leg dominance into the modified 505 agility test, this study has gained valuable insights into the biomechanical and performance differences associated with agility on the right and left sides. This knowledge will facilitate the development of targeted training strategies and customized interventions to enhance agility and optimize performance in tennis. Further research is warranted to investigate the long-term effects of plyometric training and to establish optimal training protocols tailored to specific sports and athlete populations. Such investigations would provide deeper insights into the sustainability and individualized implementation of plyometric interventions in athletic training.

In conclusion, this study demonstrates that a six-week plyometric training program enhances explosive strength in young elite players, particularly in relation to their jumping ability and acceleration during directional changes. These findings highlight the effectiveness of plyometric training techniques in improving the power-related aspects of tennis, which are crucial for achieving success. Based on these results, we strongly recommend that tennis coaches incorporate in-season plyometric training to optimize the performance of their players.

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