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Effects of technical drill and plyometric training on shot accuracy in tennis athletes aged 16–19 with different agility levels

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Abstract

Background and Study Aim Accuracy in tennis represents an important element of technical performance, contributing to successful shot execution during match play. Agility, as one of the physical components, can influence an athlete's ability to reach optimal positions and maintain control during strokes, which may affect shot accuracy. Although various training methods are used to target agility and accuracy, their relative effectiveness continues to attract practical interest. This study aimed to analyze and empirically examine the effect of technical drill and plyometric training on accuracy, considering the agility levels of tennis athletes.

Material and Methods This experimental study employed a 2 × 2 factorial design, involving an experimental group (EG) and a control group (CG). The sample consisted of 24 athletes, allocated through ordinal pairing using the A-B-B-A method based on initial agility test results. The groups were categorized as A1B1 (EG-High Agility), A1B2 (EG-Low Agility), A2B1 (CG-High Agility), and A2B2 (CG-Low Agility). The intervention consisted of technical drill and plyometric training (EG) and routine training (CG). It was implemented over six weeks, with three sessions per week. Training dosage for the technical drill was 3–5 sets, 8–12 repetitions, with 60–120 seconds of recovery at 60–85% intensity. For plyometric training, the dosage was 3–5 sets, 10–20 repetitions, with 60–180 seconds of recovery at 85–95% intensity. Data were collected using the Illinois Agility Test and the Groundstroke Accuracy Test.

Results Two-way ANOVA results showed a significant effect of the experimental program on accuracy ($F = 33.608$, $p < 0.001$), with a high coefficient of determination ($R^2 = 0.834$, or 83.4%). Tukey's HSD post hoc test revealed that A1B1 outperformed A2B1 and A2B2 ($p < 0.001$). A1B2 also performed significantly better than A2B1 and A2B2 ($p < 0.001$). The findings demonstrate that a six-week program combining technical drills and plyometric training significantly and effectively improved shot accuracy in tennis athletes aged 16–19.

Conclusions The training model examined in this study reflects a structured integration of technical and physical components in tennis practice. Its application may inform program development aimed at supporting targeted performance characteristics in adolescent athletes. Such integration also aligns with pedagogical principles of holistic athlete development, where motor learning is enhanced through purposeful coordination of physical and technical stimuli in training contexts.

Keywords: tennis performance, technical drills, plyometric training, agility, shot accuracy

Introduction

Tennis performance at the competitive youth level involves the integration of technical precision and physical responsiveness under conditions of speed and pressure. Shot accuracy is one of several factors that may influence point outcomes, match control, and tactical decision-making. This ability is shaped not only by stroke technique but also by the athlete's capacity to reach optimal positions, adjust movement patterns in real time, and execute controlled strokes, which are capacities associated with agility as a contributing physical attribute.

In this context, shot accuracy in tennis can be understood as a performance element grounded in the principles of motor learning and precise movement control [1]. During a fast and dynamic tennis match, the ability to place the ball in difficult-to-reach areas or to execute a decisive serve contributes to point outcomes and game flow [2]. Accuracy not only supports the implementation of pre-planned strategies but also challenges the opponent's positioning, creating opportunities and influencing the tempo of play. As a result, structured training that emphasizes consistent repetition is commonly used to develop the motor patterns required for accurate execution [3].

Several factors influence accuracy, including muscle strength, hand-eye coordination, mental concentration, and fundamental stroke techniques [4]. However, among these factors, agility plays an

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important role in the context of motor control and quick decision-making. This is particularly relevant for tennis players aged 16–19 years, who are in a stage of advanced physical and technical development [5]. Optimal agility allows athletes to reach an effective position before striking. This enables them to apply proper techniques and generate accurate shots [6, 7]. Conversely, insufficient agility causes delays in reaching the ball. It leads to off-balance strokes and ultimately results in inaccurate or erroneous shots [8]. Therefore, agility development is important to support accuracy, especially during this phase when the integration of physical and technical elements shapes performance.

Various training models have been developed and implemented in sports training programs to enhance both agility and accuracy. Common agility drills include ladder drills, cone drills, shuttle runs, and rapid change-of-direction exercises [9, 10, 11]. These are all designed to improve reaction speed and movement coordination. Meanwhile, accuracy can be improved through target practice, basket drills, and systematic repetition of basic shooting techniques. These methods focus on building muscle memory and forward pass control [12, 13, 14].

However, previous studies and systematic reviews on the effects of plyometric training in tennis athletes, such as those conducted by Deng et al., reported positive effects on agility and explosive power. At the same time, they found no definitive evidence that plyometric training alone can improve accuracy [15]. This indicates a gap in understanding the most effective training combinations. Therefore, further exploration of the effectiveness of combining technical and plyometric training is needed, particularly in programs aimed at improving agility and accuracy in tennis athletes aged 16 to 19. In addition, studies that examine whether baseline agility levels influence the training outcomes remain relatively scarce in the current research literature.

When combined, technical drills and plyometric training have potential for enhancing both agility and accuracy. Technical drills emphasize repetitive practice of tennis-specific movements, such as forehand, backhand, serve, and volley. These drills are aimed at internalizing efficient movement patterns and minimizing errors through repetition and refinement [3]. Through consistent repetition and corrective feedback, athletes can refine stroke biomechanics, which directly contributes to accuracy improvement.

In contrast, plyometric training involves explosive movements such as jumping and bounding. This type of training enhances muscular power, speed, and overall explosiveness [15]. These improvements lead to better on-court agility and allow athletes to reach the ball more quickly. As a result, they can strike with greater power and control, which may indirectly improve accuracy [16]. The structured combination of these two types of training is expected to support accuracy development by addressing both physical capacity and technical execution.

Analysis of research findings has shown that combined physical and technical training methods may lead to improvements in both agility and shot accuracy in adolescent tennis athletes. Researchers emphasize that the interaction between explosive strength and motor coordination plays an important role in optimizing performance outcomes. Authors also point out that athlete-specific factors, such as baseline agility, may influence how training adaptations occur. Nevertheless, certain unresolved aspects still limit the development of clearly defined and widely applicable training strategies. This gap continues to hinder the formulation of structured programs that effectively integrate technical and physical components for targeted accuracy improvement.

To address this gap, the present study focuses on the relationship between combined technical and physical training and shot accuracy in adolescent tennis players, taking into account individual differences in agility. Particular attention is given to the context of regional Indonesian athletes, where training environments and physiological characteristics may differ from those in other populations. This focus is intended to support a better understanding of how combined technical and plyometric training may influence shot accuracy in youth tennis players, depending on their baseline agility characteristics.

Materials and Methods

Participants

The study population included all tennis athletes in Tasikmalaya City, Indonesia. Sampling was purposive, with the following inclusion criteria:

- active athletes,
- regional championship winners,
- aged 16–19 years,
- free from injury,
- not engaged in competition-specific training.

Based on these criteria, 24 athletes were recruited.

The characteristics of male athletes (mean ± SD) were as follows:

- Age: 17.7 ± 0.9 years (range 16.3–19.0)
- Height: 167.9 ± 1.5 cm (range 165.3–170.3)
- Weight: 59.1 ± 1.5 kg (range 57.1–61.7)

The characteristics of female athletes were:

- Age: 17.6 ± 0.6 years (range 16.7–18.9)
- Height: 166.0 ± 1.0 cm (range 164.2–167.6)
- Weight: 51.9 ± 1.1 kg (range 50.1–53.7)

Following ordinal pairing, the experimental group (EG) consisted of 12 athletes (six male, six female), and the control group (CG) also consisted of 12 athletes (six male, six female).

Ethical Considerations

Ethical approval was obtained (Permit No. 05/UN58.10/PT/2024), and all procedures complied with ethical standards to protect participants' rights and welfare. Since the participants were underage athletes (aged 16 to 19), informed consent was obtained from each athlete's parent or legal guardian. In addition, verbal assent was provided by the athletes themselves after a clear explanation of the study's purpose, procedures, risks, and potential benefits. Participation was voluntary, and athletes had the right to withdraw from the study at any time without consequences. The study was conducted at the Siliwangi University tennis courts in Tasikmalaya, Indonesia. This location was selected for its accessibility and suitability for close monitoring, which helped ensure adherence to the protocol and maintain internal validity.

Research Design

This study employed an experimental design using a 2 × 2 factorial model, involving two groups: an experimental group (EG) and a control group (CG). Both groups completed pretest and posttest measurements.

The EG received a combined intervention consisting of technical drills and plyometric training. In contrast, the CG received no specific training intervention but instead participated in routine tennis training. This included unstructured fundamental technique practice, free game play, and general warm-up and cool-down activities. The CG served as a comparison group to assess the effects of the intervention applied to the EG.

To ensure group equivalence, participants were assigned using ordinal pairing with the A-B-B-A method. This process resulted in four subgroups:

- A1B1 (EG – high agility),
- A1B2 (EG – low agility),
- A2B1 (CG – high agility),
- A2B2 (CG – low agility).

Athletes were first ranked by their pretest agility scores, separated by gender, from highest to lowest. This pairing method minimized group allocation bias and ensured balanced distribution across conditions. As a result, observed posttest differences could be more confidently attributed to the intervention.

Intervention Programs and Instruments

The main intervention program, consisting of technical drill and plyometric training for the experimental group (EG), was adapted from previous research. Modifications were made to training load and track distance to match the characteristics and performance levels of athletes aged 16 to 19, as well as to reflect available facilities. The intervention lasted for 6 weeks and included 18 sessions, with three sessions per week. Training was conducted on Mondays, Wednesdays, and Fridays from 4:00 PM to 6:00 PM. The control group (CG) followed a regular training routine without exposure to the intervention. However, it matched the EG in training time, general activity format, and training location.

To ensure safety and minimize the risk of injury, especially given the high intensity of plyometric training, the EG participants completed an adaptation phase before starting the intervention. This phase consisted of two weeks (six sessions) of core training, aimed at preparing the neuromuscular system and reducing injury risk [17, 18]. The training load included three sets of 8–12 repetitions, with 60–120 seconds of recovery.

Upon entering the main training program, each experimental group (EG) session, which combined technical and plyometric components, followed this structure: warm-up, technical exercise, plyometric exercise, cool down, and evaluation. This sequence was selected to optimize training effectiveness. Technical drills, which require concentration and precision, were performed first to avoid interference from neuromuscular fatigue. Plyometric exercises, which demand maximum explosive power, were conducted afterward. All training sessions were supervised by one head coach and two assistant coaches. All were qualified in tennis coaching and in strength and conditioning. Their role was to ensure standardized instruction and to closely monitor movement accuracy and training dosage.

The technical drill program included seven exercise models [19]:

- Forehand Turn Core
- Forehand Turn Cone Back Cone
- Forehand Forward Direction
- Forehand Hurdle Jump
- Forehand Sideways
- Forehand Turn Cone Center Service to Baseline
- Forehand One Way Service Center to Baseline.

These drills have previously been shown to improve forehand and backhand performance in amateur tennis players aged 15 to 19 years [3]. The training dosage was 3 to 5 sets of 8 to 12 repetitions, with 60 to 120 seconds of recovery between sets, performed at 60 to 85 percent intensity.

The plyometric training program was structured progressively as follows:

- Week 1: Squat jumps, reverse lunge knee ups, burpees
- Week 2: Clapping push ups, box jumps, stairway hops, tuck jumps
- Week 3: Lateral bounds, squat thrusters, plyometric lateral lunges, reverse lunges with knee up
- Week 4: Box drill, frog squat jumps, long jumps, burpees with tuck jumps
- Week 5: Lateral triple jumps, alternating lunge jumps, judo rolls with jumps, kneeling jump squats
- Week 6: Single leg deadlifts into jumps, pistol squats, horizontal jumps to tuck jumps, snowboard hops, skater hops

The plyometric load was 3 to 5 sets of 10 to 20 repetitions, with 60 to 180 seconds of recovery, performed at 85 to 95 percent intensity [5, 20]. This progression was designed to gradually increase the volume and complexity of explosive movements, targeting the power and agility demands of tennis.

Agility was measured using the Illinois Agility Test, which has a reported reliability coefficient greater than 0.83 for tennis athletes [21, 22]. Accuracy was assessed using the Groundstroke Accuracy Test [23, 24, 25]. The test setup included a target grid made of contrasting colored tape, carpet, or mat. The grid was divided into three zones. Additional equipment included a ball feeder (ball machine), scoring sheets, and optionally a camera to validate shot placement. Scoring criteria were as follows:

- Bullseye (a two-by-two meter box near the baseline corner or cross court) = 3 points
- Medium zone (three by three meter area) = 2 points
- Outside the target but within the court = 1 point

During the test, athletes performed ten forehand and ten backhand strokes. Each shot was executed after one bounce. Serving and volleying were not included.

Statistical Analysis

Data were analyzed using two way ANOVA. Since the analysis revealed a significant interaction effect, further comparisons were conducted using the Tukey HSD (Honestly Significant Difference) test. Tukey's HSD was selected because it strictly controls the family wise error rate and reduces the risk of Type I error in multiple comparisons. This post hoc test is particularly appropriate when the assumptions of normality and homogeneity of variances are met. All statistical analyses were performed using SPSS version 27 [26].

Results

The initial phase of the analysis involved descriptive statistics to provide an overview of the pretest and posttest scores for both accuracy and agility across all subgroups (A1B1, A1B2, A2B1, and A2B2). To determine whether the data met the assumptions for parametric analysis, normality was assessed using the Shapiro–Wilk test. The descriptive values and normality test results for each group are presented in Table 1.

As shown in Table 1, all Shapiro–Wilk test results yielded p-values greater than 0.05, indicating that the data for all groups were normally distributed. These findings confirm that the assumptions required for parametric analysis were met, justifying the use of two way ANOVA and Tukey HSD post hoc testing in subsequent analyses. Based on the mean values reported in Table 1, accuracy improved by 9 points in A1B1, 8 points in A1B2, 2 points in A2B1, and 1 point in A2B2. Similarly, agility improved by 2.05 seconds in A1B1, 2.00 seconds in A1B2, 0.59 seconds in A2B1, and 0.70 seconds in A2B2. These

Table 1. Pretest and posttest descriptive statistics and Shapiro–Wilk normality test results for accuracy and agility

Group	Tests	Descriptive Statistics				Shapiro–Wilk		
		Min	Max	Mean	SD	Statistic	df	Sig.
A1B1	Pretest Accuracy	18	22	19.17	1.60	0.809	6	0.070
	Posttest Accuracy	27	30	28.00	1.27	0.831	6	0.110
A1B2	Pretest Accuracy	18	22	20.17	1.47	0.958	6	0.804
	Posttest Accuracy	27	29	28.00	0.89	0.853	6	0.167
A2B1	Pretest Accuracy	19	22	20.50	1.38	0.861	6	0.191
	Posttest Accuracy	20	25	22.50	1.87	0.982	6	0.961
A2B2	Pretest Accuracy	20	22	21.00	0.89	0.853	6	0.167
	Posttest Accuracy	20	24	22.00	1.41	0.982	6	0.960
A1B1	Pretest Agility	16.9	20.5	18.58	1.51	0.895	6	0.343
	Posttest Agility	14.9	18.2	16.53	1.20	0.988	6	0.984
A1B2	Pretest Agility	16.5	20.2	18.42	1.38	0.968	6	0.878
	Posttest Agility	15.1	17.9	16.42	1.19	0.886	6	0.299
A2B1	Pretest Agility	16.6	20.5	18.35	1.50	0.952	6	0.758
	Posttest Agility	16.1	19.4	17.77	1.30	0.952	6	0.754
A2B2	Pretest Agility	16.9	19.9	18.37	1.11	0.977	6	0.935
	Posttest Agility	16.1	18.6	17.67	1.12	0.853	6	0.166

Note. A1B1 = Experimental Group with High Agility; A1B2 = Experimental Group with Low Agility; A2B1 = Control Group with High Agility; A2B2 = Control Group with Low Agility. SD = Standard Deviation. All p-values > 0.05, indicating normal distribution in all groups.

descriptive changes support the overall trend observed in the experimental group compared to the control group [27].

Following the normality test, a homogeneity of variances test was conducted using Levene's method to ensure that the data met the assumptions for ANOVA. The results are presented in Table 2.

As shown in Table 2, the homogeneity test based on the mean value yielded a significance level of 0.493 for accuracy and 0.800 for agility. Both values exceed the 0.05 threshold, indicating that the variances were homogeneous across groups. Thus, the data meet the assumption of homogeneity required for parametric testing.

After confirming that the assumptions of normality and homogeneity were met, a two way ANOVA was conducted to evaluate the effects of the intervention and the athletes' initial agility levels on shot accuracy. The results of this analysis are presented in Table 3.

As shown in Table 3, the two way ANOVA revealed a statistically significant model ($F = 33.608$, $p < 0.001$), indicating that the combination of training type and agility level significantly influenced shot accuracy. The model explained 83.4% of the variance in accuracy scores ($R^2 = 0.834$; Adjusted $R^2 = 0.810$). The effect size, estimated using partial eta squared ($\eta^2 = 0.834$), indicated a large effect according to standard benchmarks ($\eta^2 > 0.14$). This suggests that the interaction between the type of training intervention and the athletes' baseline agility levels accounted for a substantial proportion of the observed variance in shot accuracy.

A significant interaction effect was observed in the two way ANOVA, indicating that the training program's effect on shot accuracy varied depending on the athlete's initial agility level. To further explore the nature of these differences between specific groups, a post hoc analysis using Tukey's HSD test was conducted. The results are presented in Table 4.

As shown in Table 4, the post hoc Tukey HSD analysis yielded the following results:

- Training effect: Both experimental subgroups (A1B1 and A1B2) performed significantly better than both control subgroups. Specifically, A1B1 outperformed A2B1 (Mean Difference = 5.50, $p < 0.001$) and A2B2 (Mean Difference = 6.00, $p < 0.001$). Similarly, A1B2 showed significantly higher shot accuracy than A2B1 and A2B2 (both $p < 0.001$). These results confirm the effectiveness of the combined technical drill and plyometric training program in improving shot accuracy.
- Influence of agility within the experimental group: There was no significant difference in accuracy between A1B1 (high agility) and A1B2 (low agility) (Mean Difference = 0.00, $p = 1.000$), suggesting that the training program was equally effective regardless of initial agility level.
- Influence of agility within the control group: No significant difference was observed between A2B1 and A2B2 (Mean Difference = 0.50, $p = 0.926$), indicating that in the absence of targeted intervention, initial agility had no meaningful effect on shot accuracy.

Discussion

This study aimed to evaluate the effects of a combined technical drill and plyometric training program on shot accuracy among tennis athletes aged 16 to 19 years, with particular attention to how baseline agility levels might influence training outcomes. The results showed that athletes who

Table 2. Levene's test results for homogeneity of variance in accuracy and agility among tennis athletes aged 16 to 19 years

Variable		Levene Statistic	df1	df2	Sig.
Accuracy	Based on Mean	0.932	7	40	0.493
	Based on Median	0.710	7	40	0.664
Agility	Based on Mean	0.539	7	40	0.800
	Based on Median	0.530	7	40	0.807

Table 3. Results of the two way ANOVA for shot accuracy by training type and agility level

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	199.125	3	66.375	33.608	0.000
Intercept	15150.375	1	15150.375	7671.076	0.000
Interaction	199.125	3	66.375	33.608	0.000
Error	39.500	20	1.975		
Total	15389.000	24			
Corrected Total	238.625	23			

Note. $R^2 = 0.834$; Adjusted $R^2 = 0.810$

Table 4. Tukey HSD post hoc comparisons of shot accuracy across experimental and control subgroups

(I) Interaction		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A1B1	A1B2	0.00	0.811	1.000	-2.27	2.27
	A2B1	5.50*	0.811	0.000	3.23	7.77
	A2B2	6.00*	0.811	0.000	3.73	8.27
A1B2	A1B1	0.00	0.811	1.000	-2.27	2.27
	A2B1	5.50*	0.811	0.000	3.23	7.77
	A2B2	6.00*	0.811	0.000	3.73	8.27
A2B1	A1B1	-5.50*	0.811	0.000	-7.77	-3.23
	A1B2	-5.50*	0.811	0.000	-7.77	-3.23
	A2B2	0.50	0.811	0.926	-1.77	2.77
A2B2	A1B1	-6.00*	0.811	0.000	-8.27	-3.73
	A1B2	-6.00*	0.811	0.000	-8.27	-3.73
	A2B1	-0.50	0.811	0.926	-2.77	1.77

Note. A1B1 = Experimental Group with High Agility; A1B2 = Experimental Group with Low Agility; A2B1 = Control Group with High Agility; A2B2 = Control Group with Low Agility. *$p < 0.05$

received the combined training intervention achieved significantly greater improvements in shot accuracy compared to those who participated in routine training. This positive effect was observed regardless of whether the athletes initially demonstrated high or low agility. No significant performance differences were found within the control group, indicating that the observed improvements were attributable to the specific features of the intervention. These findings support the assumption that integrating technical and plyometric components in training may enhance stroke precision in adolescent tennis players. The following discussion situates these results within the broader context of previous research and considers their practical implications.

The results revealed a significant interaction between training type (experimental vs. control) and baseline agility level (high vs. low) in relation to shot accuracy. Athletes in the experimental groups achieved significantly greater improvements compared to those in the control groups, regardless of initial agility. No significant differences were found between the two experimental subgroups or between the two control subgroups. This indicates that the combined technical drill and plyometric training program was effective in enhancing shot accuracy across different agility levels.

These findings align with prior research demonstrating the benefits of targeted training interventions in tennis. Rahim et al. showed that an 8-week "Easy Five" program improved both accuracy and agility in young players [28]. Similarly, Deng et al., in a meta-analysis, confirmed that physical training can significantly enhance muscle strength, explosive power, agility, speed, and stroke precision in female tennis athletes [29]. Other studies have found that agility- and coordination-focused warm-up routines can improve forehand accuracy in children [6].

What distinguishes the present study is its factorial design, which assessed not only the effects of combined technical and plyometric training, but also how these effects varied by athletes' initial agility levels. Previous reviews typically examined interventions in isolation and did not account for individual differences in physical characteristics, particularly during adolescence. By addressing this methodological gap, the current study provides a more nuanced understanding of how training programs may be adapted for athletes with differing baseline attributes.

Overall, the results reinforce the idea that technical and plyometric components interact synergistically to enhance stroke accuracy. Technical drills contribute to motor pattern refinement and stroke biomechanics, while plyometric exercises increase neuromuscular responsiveness. Prior studies have shown that drill-based training, especially when integrated with agility tasks, has a measurable impact on forehand and backhand execution among amateur tennis players [3, 30], with drill-based methods showing particularly strong effects.

The observed improvement in shot accuracy can be attributed to the combined effect of plyometric exercises, which develop agility and explosive strength, and technical drills, which improve coordination and stroke mechanics. These effects can be explained by motor learning theory, which emphasizes the importance of training specificity and the principle of transfer of learning [31]. Plyometric exercises improve neuromuscular function and muscular power, which supports faster directional changes and acceleration. These are fundamental components of agility. Previous studies have confirmed the effectiveness of plyometric training for improving these aspects [31, 32].

In tennis-specific research, Deng and colleagues reported in a meta-analysis that plyometric training has a moderate positive effect on sprint performance, lower-body power, and agility in tennis athletes [15]. However, the analysis did not show conclusive evidence that plyometric training alone improves serve or stroke accuracy.

Although this study did not separate the effects of technical drills and plyometric exercises, it is reasonable to assume that each training component contributed through distinct pathways. Technical drills most likely had a direct effect on stroke execution and coordination due to the repetitive and task-specific nature of the exercises. Plyometric training, in contrast, may have produced indirect benefits by increasing explosive power and reactive movement, which allowed players to reach better positions for accurate strokes. Future studies should examine the effects of each component independently to better understand their individual contributions.

The main distinction of the current study compared to previous research is the integration of technical drills into the training program. This integration aimed to directly improve coordination and stroke precision, which are closely linked to shot accuracy. Findings from Novak and Sinkovic support this model. They reported that six weeks of plyometric training improved neuromuscular characteristics, speed during direction changes, and reactive agility in junior tennis players [5, 16]. Plyometric exercises are also closely related to high-intensity interval training. For example, Choudhary and colleagues demonstrated that an eight-week high-intensity program significantly improved explosive strength, sprinting ability, and agility in adolescent tennis players aged 15 to 19 years [4].

Improved agility, as shown by Hernández-Davo et al., who reported significant correlations between the hexagon agility test and sprinting, change of direction performance, and jumping ability, enables athletes to reach optimal positions more quickly and to execute strokes with greater biomechanical precision. This directly contributes to higher shot accuracy [33]. Clear associations between groundstroke outcomes (both speed and accuracy) and physical attributes such as lower- and upper-body power, tennis-specific agility, and linear speed further emphasize the importance of physical conditioning for stroke accuracy [34]. From a motor control perspective, enhanced agility allows players to adjust their movement patterns more effectively in response to dynamic match situations, such as ball trajectory and opponent behavior. This responsiveness increases the likelihood of executing technically accurate strokes.

The significant interaction found in this study, combined with the absence of accuracy differences between high- and low-agility subgroups within the experimental group, indicates that the intervention was effective across a range of initial agility levels. The results suggest that both agility subgroups experienced sufficient training adaptations to achieve comparable post-intervention accuracy. Although previous research has indicated that older biological age is generally associated with superior speed, agility, and power in youth athletes [35], the present study focused on individuals aged 16 to 19 years. This age range is typically beyond the peak height velocity phase, which means that structured training programs can produce optimal gains in both physical and technical performance capacities [36].

Taken together, the findings highlight the potential of integrated training programs that combine technical and physical components to improve tennis performance in adolescent athletes. By simultaneously targeting movement control and shot accuracy, such programs address key demands of match play in a dynamic sport environment. The improvements observed in this study reflect the advantages of training models that are aligned with the developmental needs of youth athletes, particularly during phases of enhanced physical adaptability. This type of structured approach may offer a practical foundation for performance enhancement in competitive tennis training contexts.

These findings can be interpreted through the lens of motor learning theory, particularly Schmidt's Schema Theory, which posits that repeated practice of context-relevant motor tasks under varied conditions facilitates the development of generalized motor programs. By incorporating both technical drills that simulate sport-specific strokes and plyometric exercises that enhance neuromuscular responsiveness, the intervention appears to engage both parameter selection and schema generalization processes. This dual pathway may explain why improvements in shot accuracy were observed regardless of initial agility levels. Moreover, the study design acknowledges individual physical variability, emphasizing the relevance of baseline motor capacities in shaping training adaptations.

From a practical standpoint, the intervention model applied in this study offers a feasible and adaptable training structure for adolescent tennis athletes, particularly within resource-limited or regional settings. The program's reliance on basic equipment and structured implementation makes it suitable for integration into existing training regimens. The findings suggest that such combined training may benefit athletes across a range of agility levels, reinforcing the importance of inclusive approaches that accommodate inter-individual differences during critical periods of athletic development.

Limitations

This study has several limitations. The relatively small sample size and the inclusion of only regional-level athletes aged 16 to 19 years may restrict the generalizability of the findings to other age groups or performance levels. The six-week intervention period may not have been long enough to capture long-term adaptations, maintenance effects, or delayed performance responses. Furthermore, the study design did not isolate the independent effects of technical drills and plyometric training, which limits the ability to determine the specific contribution of each component. Future research should employ larger and more diverse samples, extend the intervention duration, and use designs that can separately assess the effects of different training components. Additional studies are also recommended to investigate whether similar outcomes occur in athletes from other developmental stages or higher competition levels.

The findings of this study reinforce the conceptual understanding that structured integration of technical and physical training elements can support the development of performance accuracy in adolescent tennis athletes. The coordinated application of movement-specific drills and explosive conditioning appears to address both the motor control demands and physical responsiveness required in tennis. From a theoretical perspective, the study aligns with established principles of motor learning, suggesting that targeted, context-specific training contributes to more efficient skill acquisition and execution. These insights can inform the design of training models aimed at optimizing performance during critical developmental stages.

Conclusions

The findings of this study reinforce the conceptual understanding that structured integration of technical and physical training elements can support the development of performance accuracy in adolescent tennis athletes. The coordinated application of movement-specific drills and explosive conditioning appears to address both the motor control demands and physical responsiveness required in tennis. From a theoretical perspective, the study aligns with established principles of motor learning, suggesting that targeted, context-specific training contributes to more efficient skill acquisition and execution. These insights can inform the design of training models aimed at optimizing performance during critical developmental stages.

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Conflict of Interest

The authors declare no conflict of interest.

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