

# Effects of plyometric and agility-based training on physical performance in adolescent male volleyball players: a controlled experimental study

Müjde Atıcı<sup>1ABCDE</sup>, Akan Bayrakdar<sup>2ABCDE</sup>

<sup>1</sup> Faculty of Sport Sciences, Kahramanmaraş Sütçü İmam University, Turkey

<sup>2</sup> Faculty of Sport Sciences, Alanya Alaaddin Keykubat University, Turkey

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## Abstract

### Background and Study Aim

Plyometric and agility training are widely used among adolescent male volleyball players to support neuromuscular development. These types of training can have different effects on the fundamental components of physical performance in young volleyball players. This study aims to investigate the effects of plyometric and agility training on sprint performance, vertical jump, anaerobic power, and agility in adolescent male volleyball players over an 8-week program.

### Material and Methods

Thirty adolescent male volleyball players participated in the study. They were randomly assigned to one of three groups: plyometric training (PT), agility training (AT), or control (CON), with 10 participants in each group. The PT and AT groups performed their respective training programs twice per week for 8 weeks. The control group continued with regular volleyball training only. Performance tests were conducted before and after the intervention. These included a 10-meter sprint, vertical jump, agility (Arrowhead test), and anaerobic power (peak power calculated using the Sayers formula). The data were analyzed using the SPSS software.

### Results

The PT group showed significant improvements in vertical jump (+14.1%), peak power (+13.25%), and sprint performance (+3.07%). The AT group recorded significant improvements in agility (+2.05%) and sprint (+1.77%). Significant changes in the control group were limited. Both types of training led to improvements in different performance components. The PT group was more effective in enhancing explosive power and speed, while the AT group improved agility.

### Conclusions

Plyometric and agility training play complementary roles in improving physical performance in adolescent volleyball players. PT programs develop explosive strength and sprint capacity. AT programs are more effective for improving agility and change-of-direction skills. Coaches can combine these two approaches based on the athletes' needs to achieve comprehensive performance enhancement.

**Keywords:** plyometric, agility, physical performance, adolescent, volleyball.

## Introduction

Adolescent volleyball players undergo intensive physical and technical development as they transition toward higher levels of performance. During this stage, targeted training programs are often implemented to improve specific motor abilities such as speed, explosive power, and agility. Plyometric and agility-based exercises are among the most commonly used methods to enhance these physical qualities in youth athletes.

Volleyball is a high-intensity, dynamic team sport characterized by frequent jumping, sudden changes in direction, explosive force production, and short-distance sprints [1, 2]. Therefore, volleyball players must be able to effectively perform specific movement patterns that involve high levels of force, quick directional changes, and speed [3, 4, 5]. For developing athletes, this demand requires the improvement of fundamental physical performance

components. These include agility, speed, strength, balance, and muscle power, which can be enhanced through training [6, 7, 8, 9]. In this context, the effects of the training types used in this study were examined through the lens of the neuromuscular adaptation model. This model suggests that physical performance can be improved by enhancing motor unit activation, muscle-tendon coordination, and movement pattern efficiency [9, 10, 11, 12].

In recent years, there has been growing interest in training methods designed to support neuromuscular development in adolescent athletes. Two important methods stand out in this regard: plyometric training and agility-based exercises. Plyometric training is based on the stretch-shortening cycle of muscles. It aims to increase strength and jumping capacity, particularly in the lower extremity muscles [9, 13, 14]. The literature frequently highlights the positive effects of this training on parameters such as muscle strength, explosive strength, jump height, and sprint performance [15, 16, 17, 18, 19]. For example,

Pramono et al. [15] reported that plyometric exercises supported by agility ladders significantly increased muscle strength and agility in athletes aged 13 to 15 years. Similarly, Alp and Mansuroğlu [20] emphasized that regional plyometric training combined with volleyball training supports agility development. However, some studies have shown no significant changes in parameters such as sprint performance [21], suggesting that the effects may vary depending on the type and duration of the program.

However, agility-based exercises are also commonly used in volleyball. These training methods aim to develop on-court skills such as changing direction, reaction time, and short-distance sprints [22, 23, 24]. Such exercises target the adaptation of the neuromuscular system. They are reported to have the potential to improve movement efficiency in sports like volleyball, which require sudden acceleration and deceleration. Chuang et al. [25] reported that agility ladder and trapezoid running protocols applied to young volleyball players led to significant improvements in sprint and agility performance. In addition, agility training supports not only physical agility but also cognitive and athletic processes, such as decision-making [26]. Systematic reviews of studies combining plyometric and agility training reported an average improvement of 7.7% in agility.

Although the effects of plyometric and agility-based training on physical performance have been examined separately in numerous studies, experimental research directly comparing these two types of training and controlling for variables such as age group, sport discipline, and training duration remains limited. Current findings suggest that both types of training may influence different performance parameters to varying degrees. For example, some studies indicate that agility-based training is more effective for improving sprint performance and reaction time [24, 25, 26]. In contrast, other studies have shown that plyometric training leads to greater improvements in parameters such as jump height and explosive power [15, 20, 27]. However, some studies report similar results for both methods. Others reach conflicting conclusions regarding which training method is more advantageous [21, 28]. This inconsistency complicates the scientific guidance provided to decision-makers in training planning, especially for adolescent athletes.

An analysis of previous research has shown that both plyometric and agility-based training positively influence various components of physical performance in young volleyball players. The authors emphasize that each training type affects different variables such as speed, strength, jump endurance, and agility in distinct ways. They also highlight that, despite the growing body of evidence, there is still no clear scientific consensus regarding the comparative effectiveness of these two training methods. At the same time, there remains a need for further controlled

experimental studies directly comparing the effects of plyometric and agility-based training on physical performance in adolescent male volleyball players. This gap continues to hinder scientifically grounded training planning and limits the practical guidance available to coaches and practitioners.

Based on the reviewed literature and the lack of clear consensus regarding the comparative effects of plyometric and agility-based training, the following hypotheses were proposed:

1. Both training groups are expected to show significant improvements in physical performance indicators after 8 weeks of application.
2. It is hypothesized that agility-based training will result in greater improvements in the 10-meter sprint and agility tests compared to plyometric training.
3. It is also hypothesized that plyometric training will lead to greater improvements in vertical jump and anaerobic power parameters compared to agility-based training.

This study aims to investigate the effects of plyometric and agility training on sprint performance, vertical jump, anaerobic power, and agility in adolescent male volleyball players over an 8-week program.

## Materials and Methods

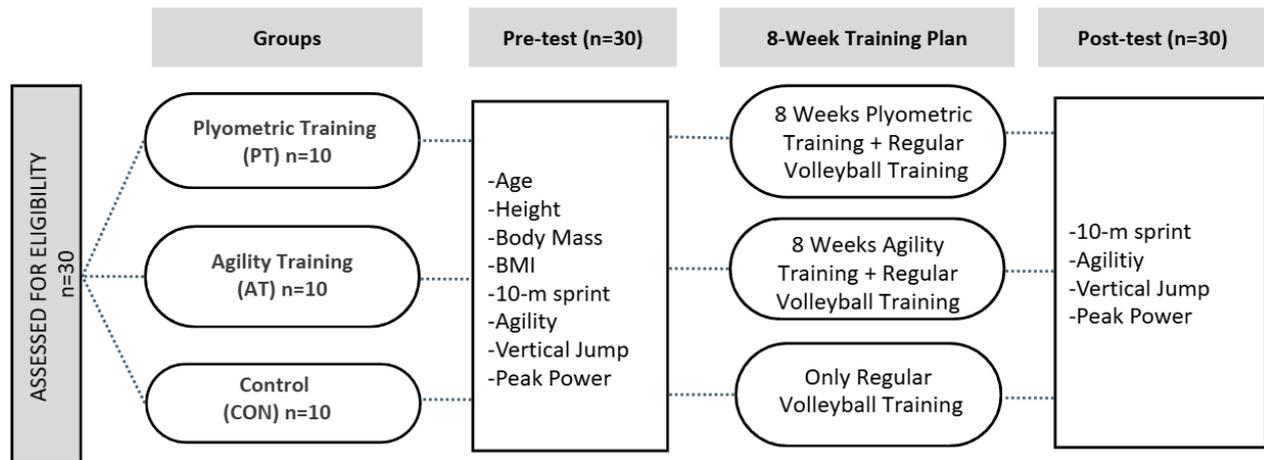
### *Participants*

This study was conducted to examine the effects of an eight-week plyometric and agility-based training program on physical performance in young male volleyball players. A total of 30 volunteer athletes aged between 13 and 14 years participated in the study. Participants were randomly assigned to one of three groups: the plyometric training group (PT,  $n = 10$ ), the agility training group (AT,  $n = 10$ ), and the control group (CON,  $n = 10$ ). There were no cases of exclusion or withdrawal during the study. The flow of participants through the study is shown in Figure 1.

All groups continued their routine volleyball training throughout the eight-week period. The PT group additionally followed a training program consisting of plyometric exercises twice per week. Similarly, the AT group participated in agility-based training twice per week. In contrast, the CON group continued with volleyball training only and did not take part in any additional training. No adverse events, injuries, or side effects were observed during the study. This supports the safety and applicability of the implemented training programs.

### *Sample size (g\*power)*

The sample size was calculated using G\*Power software (version 3.1.9.7; Franz Faul, Kiel University, Germany). The calculation was based on a significance level ( $\alpha$ ) of 0.05, statistical power ( $1 - \beta$ ) of 80%, an effect size ( $f$ ) of 0.4, and a repeated measures ANOVA



**Figure 1.** Flow Diagram

with a group × time interaction [29].

Informed consent was obtained from all participants prior to the study. The research was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Non-Interventional Clinical Research Ethics Committee of Alanya Alaaddin Keykubat University (approval number: 2025/01). Descriptive anthropometric data for the groups are presented in Table 1.

**Table 1.** Descriptive characteristics of the participants ( $\bar{x} \pm SD$ )

Variables	Groups	N	$\bar{x} \pm SD$	Min	Max
Age (years)	PT	10	13.30 ± 0.48	13.00	14.00
	AT	10	13.40 ± 0.51	13.00	14.00
	CON	10	13.40 ± 0.51	13.00	14.00
Height (m)	PT	10	1.51 ± 0.03	1.44	1.56
	AT	10	1.52 ± 0.08	1.43	1.72
	CON	10	1.51 ± 0.07	1.42	1.62
Body Mass (kg)	PT	10	44.60 ± 8.57	35.00	67.00
	AT	10	43.00 ± 7.42	33.00	53.00
	CON	10	44.80 ± 5.24	36.00	55.00
BMI (kg/m <sup>2</sup> )	PT	10	19.35 ± 3.65	16.88	29.38
	AT	10	18.90 ± 2.39	15.35	21.93
	CON	10	19.56 ± 1.81	17.15	22.89

Note: PT = plyometric training group, AT = agility training group, CON = control group, BMI = Body Mass Index,  $\bar{x}$  = mean, SD = standard deviation.

Table 1 presents the descriptive characteristics of the participants, including age, height, body mass, and BMI for each group. The mean age of participants in all three groups was similar, ranging from 13.30 to 13.40 years, indicating homogeneity in age distribution. Height and body mass values also showed comparable averages, with only minor variations among groups. The agility training group (AT) exhibited slightly greater variation in height (sd = 0.08) compared to the PT and CON groups. In terms of BMI, all groups were within a similar range,

with slightly higher variability in the PT group (sd = 3.65). Overall, the groups were well-matched at baseline, showing no notable differences in descriptive characteristics.

#### Research Design

The plyometric training program applied to the PT group was implemented regularly over a period of eight weeks, with two sessions per week. Each session lasted approximately 30 minutes and included 10 minutes of warm-up and dynamic stretching exercises, followed by 20 minutes of plyometric drills. This part of the training consisted of basic lower-extremity-focused plyometric exercises, such as squat jumps, box jumps (approximately 30–40 cm), lateral bounds, and depth jumps. The exercises were structured progressively by week. The first two weeks focused on basic movements. In the subsequent weeks, training intensity was gradually increased by adjusting jump height, number of repetitions, and tempo. The program was developed based on previous studies, including those by Hernandez-Martinez et al. [16] and Iranpour et al. [30], which demonstrated positive effects on jump height and explosive power in young athletes (Table 2).

The AT group also participated in two 30-minute agility-based training sessions per week for eight weeks. Each session consisted of a general warm-up followed by agility ladder drills, change-of-direction runs, and short-distance sprints. During the first two weeks, basic ladder drills such as “two-in-the-hole” and “lateral shuffle” were included. In the third and fourth weeks, more advanced variations such as crossovers and high-tempo drills were introduced. From the fifth week onward, the focus shifted to reactive tasks involving backward movements and decision-making elements. The program was based on agility training protocols developed by Chuang et al. [25], which have been shown to significantly improve lateral agility and sprint performance in young athletes (Table 3).

All training sessions for both groups were supervised by a certified strength and conditioning

**Table 2.** Plyometric training program

Week	Frequency (days/week)	Duration (min)	Intensity	Content	Progression
1–2	2	30	Low–Moderate	Warm-up + squat jumps, box jumps (30 cm), lateral jumps (3 × 8 reps)	Focus on basic technique, low platform height
3–4	2	30	Moderate	Add: depth jumps (30 cm), split squat jumps, skipping drills	Increase repetitions (3 × 10), maintain control and form
5–6	2	30	Moderate–High	Add: single-leg jumps, bounding drills, tuck jumps	Reduce ground contact time, develop reactive strength
7–8	2	30	High	Combined sequences: box-to-lateral jumps, depth-to-vertical jump combos	Gradual overload of reactivity and plyometric complexity

**Table 3.** Agility training program

Week	Frequency (days/week)	Duration (min)	Intensity	Content	Progression
1–2	2	30	Low–Moderate	Warm-up + basic agility ladder drills (e.g., two-in, side step), 10-m sprints (3 × 2 reps)	Focus on coordination and directional control
3–4	2	30	Moderate	Add: Ickey shuffle, zig-zag ladder drills, T-test (2 × 2 reps)	Increase movement speed and sharper angles
5–6	2	30	Moderate–High	Ladder tempo drills, arrowhead drill, lateral sprints (4 × 2 reps)	Add reaction-based movements and decision-making tasks
7–8	2	30	High	Random cone drills, game-based agility tasks, Illinois Agility Test (1 × 2 reps)	Emphasis on multi-directional change of direction and complex movement

specialist to ensure the technical accuracy of participants’ movements. In addition, the training programs were designed not only for physical development but also to enhance athletes’ motor skills. They included coaching cues and specific learning objectives. These practices are consistent with physical education curricula and youth athlete development standards, supporting both physical and pedagogical outcomes.

*Testing Procedure*

Prior to testing, all participants completed a five-minute warm-up consisting of light jogging, followed by five minutes of dynamic and static stretching exercises. The purpose of the warm-up was to elevate heart rate, increase blood circulation and body temperature, improve range of motion, and prepare the body for physical effort. In all tests, participants were instructed to exert maximum effort and received verbal encouragement throughout the procedures.

The Arrowhead Agility Test was administered according to the protocol proposed by Jalilvand et al. [31]. Time measurements were recorded using the Brower Speed Trap I Timing System (Brower Timing Systems, Salt Lake City, UT, USA). Participants began the test approximately 1 meter behind the starting photocell. They sprinted toward the middle cone, turned outward in their preferred direction,

and continued forward. The course was completed by running around the side cone and then the upper cone before reaching the finish photocell.

The 10-meter sprint test was conducted on a 30-meter running track with a flat, hard surface. Time measurements were recorded using the Brower Speed Trap I Timing System, which operates with dual light sensors and has an accuracy of 0.001 seconds. After a general warm-up, athletes took their positions at the starting line and began running at their own discretion following the “ready” command. This procedure ensured that reaction time was excluded from the measurement. Timing started when the athlete crossed the first photoelectric cell and stopped upon crossing the second cell at the 10-meter mark [32].

The Vertical Jump Test was administered using a force platform or an electronic jump mat. Participants began in a standing position with feet shoulder-width apart and hands placed on the hips. They performed a vertical jump by bending their knees to approximately 90 degrees and jumping upward. To eliminate the effect of arm movement, participants were instructed to keep their hands stationary throughout the movement. Each participant performed three trials, and the average of the best two attempts was used for analysis [33].

Peak power was calculated using the Sayers formula, which estimates lower-limb anaerobic power based on vertical jump height and body mass [34]. The formula is expressed as:

$$\text{Peak Power (W)} = (60.7 \times H) + (45.3 \times M) - 2055$$

Where:  $H$  = vertical jump height in centimeters;  $M$  = body mass in kilograms;  $W$  = peak power in watts.

#### Statistical Analysis

The collected data were analyzed using IBM SPSS Statistics 25.0 (Chicago, IL, USA). The normality of the data distribution was assessed using the Shapiro-Wilk test, which confirmed that the data were normally distributed. A two-way repeated measures ANOVA was conducted with two factors: group (PT, AT, CON) and time (pre-test, post-test). Bonferroni-corrected post hoc tests were applied to determine between which groups significant interactions occurred. Effect sizes were calculated using partial eta-squared ( $\eta^2$ ) and interpreted according to Cohen's criteria [35] as follows:  $\eta^2 < 0.06$  = small effect,  $0.06-0.14$  = moderate effect, and  $\geq 0.14$  = large effect. Additionally, percentage (%) changes within each group were calculated using Microsoft Excel. A significance level of  $p < 0.05$  was accepted for all analyses.

## Results

Figure 2 illustrates the pre- and post-test results of the vertical jump test for each group. The PT group demonstrated the greatest improvement, followed by the AT group, while the control group showed a more modest but still statistically significant increase.

The data in Figure 2 show a significant increase in vertical jump height between the pre-test and post-test in all three groups. The PT group showed the largest improvement ( $t = 9.675$ ;  $p < 0.001$ ), followed

by the AT group ( $t = 7.584$ ;  $p < 0.001$ ). A smaller but still significant increase was also observed in the control group ( $t = 2.748$ ;  $p = 0.015$ ). The effect size was highest in the PT group ( $d = 0.691$ ). The analysis of variance confirmed a significant difference between the groups ( $F = 7.010$ ;  $p = 0.004$ ).

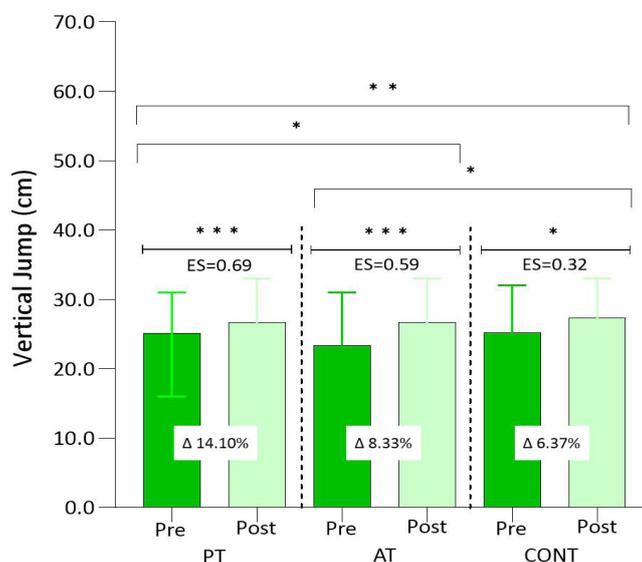
Figure 3 displays the pre- and post-test results of the 10-meter sprint test for all groups. Both the PT and AT groups showed significant reductions in sprint time after the intervention, with the PT group demonstrating the greatest improvement. The control group also showed a smaller but statistically significant decrease.

The data in Figure 3 show a significant decrease in 10-meter sprint time from pre- to post-test in all three groups. The PT group demonstrated the largest improvement ( $t = 8.573$ ;  $p < 0.001$ ), followed by the AT group ( $t = 3.910$ ;  $p = 0.004$ ). The CON group also showed a statistically significant, but more limited, reduction ( $t = 2.539$ ;  $p = 0.017$ ). The greatest effect size was observed in the PT group ( $d = -0.482$ ). Analysis of variance indicated a statistically significant difference between the groups ( $F = 14.444$ ;  $p < 0.001$ ).

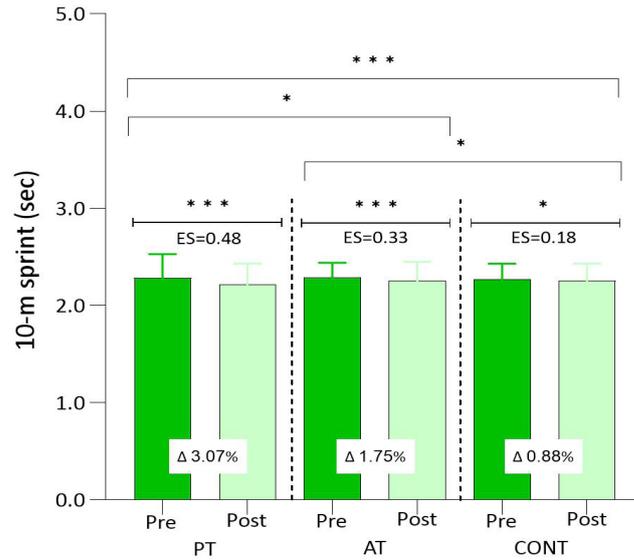
Figure 4 presents the pre- and post-test results of the Arrowhead Agility Test across all groups. Both the PT and AT groups showed significant improvements in agility performance, with slightly greater progress in the PT group. No significant change was observed in the control group.

The data in Figure 4 show a significant decrease in agility time from pre- to post-test in the PT group ( $t = 4.404$ ;  $p = 0.002$ ) and in the AT group ( $t = 6.137$ ;  $p < 0.001$ ). No significant change was observed in the CON group ( $t = 0.629$ ;  $p = 0.545$ ). The largest effect size was recorded in the PT group ( $d = -0.596$ ). The difference between the groups was statistically significant according to the analysis of variance ( $F = 7.012$ ;  $p = 0.004$ ).

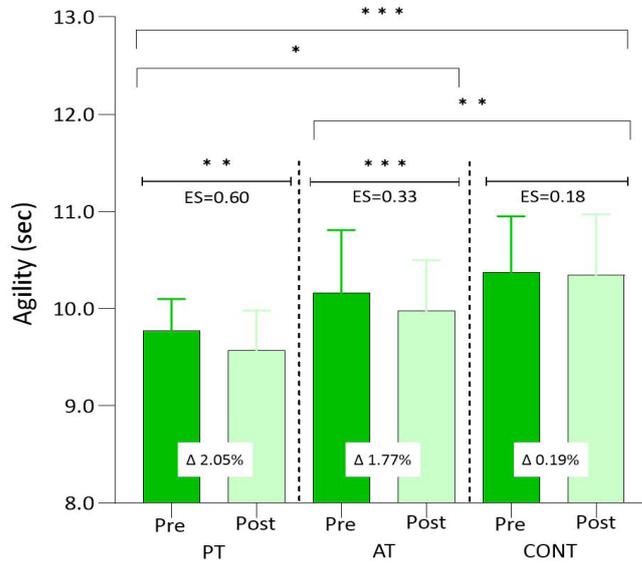
Figure 5 shows the pre- and post-test results of



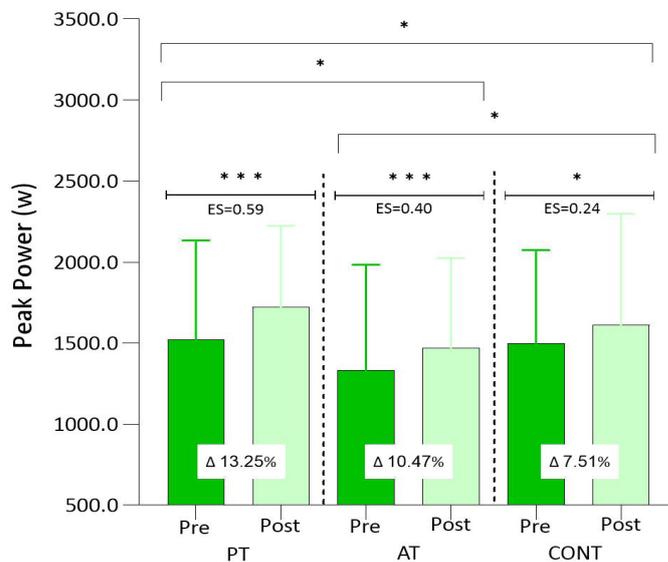
**Figure 2.** Pre- and post-test results of the vertical jump test (cm)



**Figure 3.** Pre- and post-test results of the 10-meter sprint test (sec)



**Figure 4.** Pre- and Post-test Results of the Arrowhead Agility Test (sec)



**Figure 5.** Pre- and post-test results of peak power (w)

peak anaerobic power in all groups. The PT group demonstrated the highest increase in power output, followed by the AT group. A smaller but statistically significant improvement was also recorded in the control group.

The data in Figure 5 show a significant increase in anaerobic power from pre- to post-test in all three groups. The PT group showed the largest improvement ( $t = 9.399$ ;  $p < 0.001$ ), followed by the AT group ( $t = 5.732$ ;  $p < 0.001$ ). A smaller but statistically significant increase was also observed in the control group ( $t = 3.110$ ;  $p = 0.010$ ). The effect size was moderate in the PT group ( $d = 0.591$ ). Analysis of variance confirmed a significant difference between the groups ( $F = 4.079$ ;  $p = 0.028$ ).

## Discussion

This study compared the effects of an 8-week plyometric training (PT) and agility training (AT) program on physical performance components in adolescent male volleyball players. The findings indicate that both training groups achieved significant improvements in physical performance variables, but in different ways. In the control group, improvements were also observed in vertical jump, anaerobic power, and 10-meter sprint performance. This outcome can be attributed to the natural growth and development processes in adolescents, which contribute to enhanced muscle strength and motor skills [36]. In addition, previous studies have shown that volleyball training alone may positively influence muscle strength and coordination [27].

The highest improvement in vertical jump performance was observed in the PT group. This finding is consistent with the widely accepted view in the literature that plyometric training enhances lower extremity explosive strength [9, 13, 14]. Pramono et al. [15] and Alp and Mansuroğlu [20] similarly reported that plyometric exercises significantly increased muscle strength and jump height. Balasas et al. [37] observed an 8.8% increase in jump height among adolescent female volleyball players following a 15-week plyometric and resistance training program. Pacheco Naula and Torres-Palchisaca [38] reported similar results after a six-week plyometric program. Stojanovic et al. [39] also emphasized that plyometric training supports the development of explosive strength in lower limb muscles. These findings support the improvements observed in the PT group. A significant improvement in jump height was also recorded in the AT group. This suggests that agility training may indirectly enhance force production by improving neuromuscular coordination. Although the direct effect of agility-based exercises on jump performance is limited in the literature, the current study indicates that agility-focused interventions may contribute to such improvements [24].

The PT group's greater improvement in 10-meter

sprint performance compared to the AT group is consistent with studies supporting the positive effects of plyometric training on sprint ability. Ramírez-Campillo et al. [40] reported that low-volume but high-intensity plyometric training improved short-distance sprint performance. This improvement can be explained by increased explosive strength and reduced ground contact time [9]. However, a study conducted by Sitti and Köroğlu [21] in a similar age group found no significant improvement in sprint performance. This discrepancy may be related to differences in training duration, exercise content, or the biological development level of the participants [41]. The improvement observed in the PT group may also result from the fact that the exercises targeted not only strength, but also neuromuscular mechanisms affecting sprint performance, such as coordination [42].

The significant improvement observed in the AT group suggests that agility training can enhance not only change-of-direction ability, but also sprint-related components such as acceleration, balance, and reaction time [43, 44]. Chaouachi et al. [45] proposed that agility training may indirectly contribute to sprint performance. Similarly, Paul et al. [46] reported that such training could lead to neuromuscular adaptations in 10–20-meter sprint distances.

The improvement in the PT group may be primarily related to direct effects on the initial acceleration phase, whereas the improvement in the AT group may reflect gains in reaction time, directional changes, and movement preparation. The minimal but significant improvement in the control group may be attributed to biological growth-related adaptations and the influence of non-training daily physical activities on speed and strength development [47]. These findings emphasize the importance of designing training content according to specific performance goals.

Significant improvements in agility performance were observed in both the AT and PT groups. However, the higher effect size recorded in the PT group suggests that plyometric training may also be effective in enhancing agility. This finding aligns with previous studies indicating that plyometric training supports not only lower extremity strength but also multi-component motor skills [48, 49]. Asadi et al. [50] demonstrated that an 8-week plyometric program improved agility performance in young athletes. Hammami et al. [44] emphasized that agility is closely related to neuromuscular function and that adaptations in this system can be facilitated through plyometric training.

The improvement observed in the AT group suggests that agility-related parameters such as change of direction, balance, and reaction time can be effectively developed through agility training. Chuang et al. [51] reported that agility-based

programs significantly enhanced this ability in young volleyball players. Similarly, Chaouachi et al. [45] noted that agility-focused training improves motor control and reaction times to environmental stimuli.

The increase in agility performance observed in the control group may be attributed to overall improvements in motor coordination and maturation of the nervous system. Additionally, regular volleyball training could have contributed to the development of agility [24]. Both training methods positively influenced agility performance. However, the more comprehensive neuromuscular stimulation provided by plyometric exercises may lead to greater improvements. The inclusion of complex movement patterns such as short sprints, directional changes, and jumps in the training content may be a key factor in agility development.

The highest increase in peak power was observed in the PT group. Although increases were also recorded in the AT and control groups, these improvements were more limited. The developments observed across all groups may be attributed to factors such as biological growth, increased familiarity with the testing procedures, and the effects of ongoing volleyball training [52]. However, the greater improvements in the experimental groups reflect the specific influence of the applied training protocols.

The literature emphasizes that plyometric training enhances explosive power by improving the elastic properties of the muscle–tendon system [9, 40]. Makaruk et al. [53] reported that an 8-week plyometric training program increased anaerobic power output and was particularly effective for short-term, high-intensity performance. Furthermore, studies have shown that the combined application of plyometric and agility training enhances neuromuscular coordination, positively affecting both explosive power and agility [50, 54].

The improvements observed in the AT group suggest that agility-focused exercises may influence not only directional change abilities but also neuromuscular components related to power production. Hammami et al. [55] found that agility training had positive effects on balance, reactive strength, and lower limb strength. Both training methods were found to be effective in increasing explosive power. However, the greater improvement in the PT group suggests that plyometric training provides more specific stimuli for load patterns and musculoskeletal adaptations. Training programs that target different motor abilities may lead to different levels of performance improvement.

Compared to previous studies that examined plyometric or agility training separately [15, 20, 40, 50], the novelty of this study lies in the direct comparison of both methods within a controlled

design. It simultaneously assessed their effects on multiple performance parameters in adolescent male volleyball players. The homogeneity of the sample and the structured group comparison offer clearer insights into sport- and age-specific training responses, contributing to a better understanding of how different methods support athletic development.

In summary, both plyometric and agility-based training programs were effective in improving key physical performance components in adolescent male volleyball players. Plyometric training demonstrated greater effects on explosive power, vertical jump, and sprint performance, while agility training showed notable improvements in agility and also contributed to other performance variables. The observed differences highlight the role of training specificity and the importance of selecting exercises based on targeted outcomes. Additionally, the findings suggest that integrating both training types may offer complementary benefits and support comprehensive athletic development in youth volleyball.

#### *Limitations*

Considering the limitations of this study, the relatively small sample size, the exclusive focus on male adolescent volleyball players, and the absence of long-term follow-up restrict the generalizability of the findings. Future research should examine the effects of similar training protocols across different age groups, genders, and sports disciplines, as well as combinations of training methods. In addition, studies that provide a detailed analysis of the biomechanical and physiological foundations of neuromuscular adaptations would enhance the understanding of training effects.

#### **Conclusions**

As a result, considering that the PT and AT groups followed only their respective training programs, it was concluded that plyometric training led to greater improvements in explosive strength and speed, while agility training resulted in more pronounced gains in agility and movement ability. Although each training type was most effective for its targeted performance parameters, cross-effects were also observed in some components, likely due to overlapping neuromuscular demands. This finding suggests that both training methods contribute to different aspects of physical performance and collectively enhance athletes' overall capabilities. In this context, plyometric and agility training serve complementary and essential roles in the performance development of adolescent volleyball players. From a pedagogical standpoint, coaches and physical education teachers should strategically combine both types of training, taking into account the individual needs of their athletes. This approach

can help ensure balanced development of both explosive power and agility. The findings of this study provide a practical framework for designing scientifically grounded and effective training programs for youth athletes.

## Conflict of Interest

The authors declare no conflict of interest. The research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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#### Information about the authors:

**Müjde Atıcı**; <https://orcid.org/0000-0002-2348-1914>; [mujdeatici@ksu.edu.tr](mailto:mujdeatici@ksu.edu.tr); Faculty of Sport Sciences, Kahramanmaraş Sütçü İmam University; Kahramanmaraş, Turkey.

**Akan Bayrakdar**; (Corresponding author); <https://orcid.org/0000-0002-3217-0253>; [akan.bayrakdar@alanya.edu.tr](mailto:akan.bayrakdar@alanya.edu.tr); Faculty of Sport Sciences, Alanya Alaaddin Keykubat University; Antalya, Turkey.

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