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Plyometric and Resistance Training: A Dual Approach to Enhance Physical Fitness in 12–15-Year-Old Girls

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Abstract: Background/Objectives: This study aimed to evaluate the effects of an 8-week combined plyometric and resistance training program on the physical fitness (PF) of adolescent girls aged 12 to 15 years. The objective was to determine whether combined training (CT) would yield greater improvements in performance measures compared to resistance training (RT) alone. Methods: Forty-seven adolescent girls were randomly assigned to either the CT group or the RT group. Performance measures such as the 20 m sprint, squat jump, vertical jump, handgrip strength, and flexibility (sit and reach test) were assessed before and after the 8-week intervention. Changes in these measures were analyzed to compare the effects of the two training approaches. Results: The CT group showed a significant reduction in sprint time (−6.5%) compared to the RT group (−4.1%), although the difference was not statistically significant. Squat jump height improved significantly by 5.6% in the CT group compared to 1.1% in the RT group ($p < 0.05$). Similarly, vertical jump height increased by 6.7% in the CT group and by 2.4% in the RT group ($p < 0.05$). Handgrip strength improved by 7.5% in the CT group and 4.6% in the RT group, with no significant differences between the groups. Flexibility showed slight, non-significant improvements in both groups. Conclusions: The findings suggest that a combined plyometric and RT program is more effective in enhancing explosive power, specifically squat and vertical jump performance, in adolescent girls compared to RT alone. These results highlight the potential of CT programs for improving overall physical performance in this population.

Keywords: neuromuscular adaptations; athletic training; muscle power; lower limb strength; adolescents

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1. Introduction

Plyometric and resistance training (RT) are powerful approaches for improving physical fitness (PF), particularly in the development of muscle strength, power, and overall athletic performance [1–3]. However, for adolescent girls, implementing structured training programs poses a particular challenge, as there is a complex interplay of social, emotional, and biological factors during this developmental phase [4]. Adolescence is a critical period characterized by significant physical and hormonal changes, such as rapid growth, fluctuating hormone levels, and changes in body composition, which can affect girls' physiological responses to exercise and require specific program adaptations [5,6]. At the same time, social and emotional influences—such as the desire for peer acceptance, changing body image, and varying levels of physical confidence—can affect girls' motivation and engagement in structured physical activity (PA). These factors create an environment in which participation in vigorous physical training is less predictable and additional support may be required to maintain consistency [7,8]. For girls between the ages of 12 and 15, this phase represents a crucial opportunity to optimize their physical development through carefully structured training plans [2,9,10].

Plyometric training, which emphasizes explosive, high-intensity movements such as jumping, hopping, and rapid changes in direction, is designed to improve the efficiency and responsiveness of the neuromuscular system [11–13]. This type of training improves the ability to generate power quickly, which is essential for activities that require speed, agility, and strength [3,12]. By improving the stretch-shortening cycle of the muscles, plyometrics can lead to a significant increase in vertical jump height, sprint speed, and overall athletic performance [14,15].

Resistance training, on the other hand, focuses on increasing muscular strength and endurance through the use of external loads such as weights or resistance bands [16,17]. This form of training not only builds muscle mass and strength, but also contributes to improved bone density, better body composition, and a reduced risk of injuries [18–20]. For adolescent girls who are at a crucial stage in their musculoskeletal development, incorporating RT can be instrumental in laying the foundation for lifelong health, injury prevention, and physical resilience [16,21,22].

Within this developmental context, the health-related fitness model serves as an insightful framework that emphasizes the importance of cultivating key components of fitness—cardiovascular endurance, muscular strength, flexibility, and body composition—that collectively promote overall health and well-being [23]. With its focus on attributes that support long-term health outcomes, this model emphasizes the importance of plyometric and RT interventions for adolescent girls. These methods not only improve athletic performance, but also establish a solid foundation for health-related fitness, which is especially important during this formative stage [24].

When combined, plyometrics and RT are believed to create a synergistic effect in which the benefits of each modality are amplified, leading to greater overall improvements in PF [21,25–28]. Plyometric exercises improve the rapid force production required for explosive movements [15,29–32], while RT provides the base strength that supports these dynamic actions [16,20,33,34]. Together, they provide a comprehensive approach to conditioning that can effectively address multiple aspects of PF simultaneously [35–37].

Despite the clear benefits of these training methods, there is a need to better understand their specific effects on female adolescents. Girls between the ages of 12 and 15 undergo unique physiological changes, including hormonal fluctuations and shifts in muscle mass distribution [35,38,39], that may influence their response to various forms of physical training and suggest that adolescent girls may require tailored training programs that address their specific developmental needs and growth patterns. However, implementing such structured, tailored programs within the context of school physical education (PE) poses an additional challenge. PE programs often have broad educational goals that go beyond developing athletic skills, such as promoting teamwork, fostering physical literacy, and supporting social development [40]. Consequently, this focus on broader educational goals may limit the extent to which intensive, performance-based training interventions such as plyometrics and RT can be systematically applied in the school setting [41,42].

This study investigated the effects of an 8-week combined plyometric and RT program on the PF of 12- to 15-year-old girls, focusing on key fitness parameters such as muscular strength, power, and sprint performance. The aim of the study was to provide valuable insights into how these training modalities can be effectively adapted to optimize PF in young female athletes. The underlying hypothesis was that the dual approach combining plyometrics and RT would lead to significant improvements in all measured fitness parameters. The results of this study provide practical guidance for the development of evidence-based fitness programs that are tailored to the physiological and developmental needs of adolescent girls and can be used as a complementary intervention within or outside of traditional PE classes.

2. Materials and Methods

2.1. Study Design

This study was designed as a randomized controlled trial with a parallel group design. The study comprised an 8-week intervention period during which participants were exposed to different training protocols. The design ensured that all participants were randomly assigned to one of two groups, with each group completing a different training program. The study was designed to allow a controlled comparison of the results of each training approach, with pre- and post-intervention assessments conducted to measure the effects on various PF parameters (i.e., a 20 m sprint test and a squat jump test). The study design also accounted for potential confounding factors by keeping the timing and conditions under which all assessments and interventions were conducted consistent.

2.2. Participants

Among the 66 people recruited, 47 participants were eligible for the study. These adolescent girls between the ages of 12 and 15, who actively participate in competitive sports such as basketball, tennis, and volleyball, were recruited in May 2024 through local sports clubs and school athletic programs. To participate in the study, the girls had to be healthy and not have any chronic diseases or orthopedic conditions that could interfere with participation in the training exercises.

The participants were randomly assigned to one of two training groups. The first group, the resistance training (RT)-only group (n = 23), participated exclusively in an RT program, while the second group, the combined training (CT) group (n = 24), completed a program that included both plyometric and resistance exercises. In order to ensure a balanced group size, a block randomization was performed. Prior to the study, a power analysis was performed to determine the required sample size. This ensured that the study had sufficient power to detect significant differences between the groups, with additional participants included to account for possible dropouts.

The study was conducted from May to June 2024. Before the study began, all participants and their parents or guardians were informed in detail about the purpose of the study, the procedures and any associated risks. Written informed consent was obtained from both the participants and their legal guardians. The study protocol was approved by the responsible institutional committee for human experimentation and complied with the ethical guidelines of the Declaration of Helsinki approved by the local ethics committee of the University of Ljubljana (Ref. No. 6/2024).

2.3. Study Procedures

The study was conducted over a period of 8 weeks, with all sessions taking place in a school sports facility. Both the baseline and final tests were conducted under standardized conditions, with all measurements taken at the same time of day to compensate for possible diurnal variations. Prior to testing, participants were instructed to maintain their normal dietary habits but to refrain from PA for 24 h prior to each measurement.

At the beginning of the study, all participants attended an orientation session in which the correct techniques for each fitness test were explained and demonstrated in detail. During this session, the participants had the opportunity to practice the tests to ensure that they were familiar with the procedures before data collection began. Each testing session began with a standardized warm-up program that included light jogging and dynamic stretching exercises to prepare the participants for maximal effort during the tests.

The fitness tests were spread over two days. On the first day, the participants completed tests to measure their sprint and vertical jump performance. On the following day, muscular strength and endurance were measured. To ensure that the results reflected the actual abilities of the participants, no verbal stimuli were given during the tests, allowing each participant to perform to their natural ability. This was to ensure uniform conditions for all participants and to enable an accurate assessment of their performance.

To ensure the accuracy of the results, the same researchers conducted all tests and monitored the training sessions. The pre-intervention tests took place the week before the training began, and the post-intervention tests were conducted the week after the 8-week program was completed. This allowed for a clear comparison of the effects of the training protocols on the PF of the participants.

3. Measures

3.1. The 20 m Sprint Test

The 20 m sprint test was used to assess the participants' sprinting speed. Before the test, the participants completed a self-directed warm-up program consisting of 3 min of light jogging in preparation for the sprint. After the warm-up, they performed two practice sprints over the 20 m distance at submaximal effort to familiarize themselves with the procedure. Each participant then completed three timed sprints at full speed, with a 2 min walk break between each sprint to allow for adequate recovery.

The time for each sprint was measured using a hand-held stopwatch, with the fastest time recorded to the nearest 0.01 s to measure performance. The test was conducted on an indoor track to ensure consistent test conditions for all participants. The reliability of this test was confirmed by a test–retest analysis, which showed a high level of consistency with an intraclass correlation coefficient (ICC) of 0.88.

3.2. Squat Jump Test

The squat jump test was used to measure the explosive power of the participants' lower limbs. Starting from a stationary position, with knees bent at a 90-degree angle and hands placed firmly on the hips, participants were instructed to perform a vertical jump with maximal effort, ensuring that no preparatory movements such as countermovements were involved.

In order to collect accurate data, each participant was fitted with a high-precision inertial measurement unit (IMU) attached to their hips. This device, which is capable of measuring acceleration and gyro data at a rate of 500 Hz, recorded the vertical displacement during each jump. The IMU transmitted the data wirelessly to a special software platform on a tablet, where jump height, peak velocity, and generated force were calculated in real time.

Each participant completed three jumps, with a 2 min break between attempts to ensure a consistent performance. The system recorded various measurements, including jump height (measured to the nearest 0.1 cm), peak power (in watts), and take-off speed (in m/s). The highest jump from the three trials was selected as the representative result for each participant.

The technology provided highly reliable measurements, which was confirmed by a test–retest reliability analysis that yielded an intraclass correlation coefficient (ICC) of 0.94, ensuring the accuracy and consistency of the data across all trials.

3.3. Vertical Jump

The vertical jump test was used to assess the explosive strength of the participants' lower limbs during a dynamic vertical movement. Prior to the test, the participants completed a standardized warm-up program that included 3 min of light jogging and dynamic stretching. Each participant then performed two submaximal exercise jumps to familiarize themselves with the movement. For data collection, the participants were instructed to start in an upright, standing position with their hands on their hips to eliminate the influence of the arm swing. They then performed a maximum vertical jump from a standing position, aiming for maximum height. To accurately measure the jump height, a high-precision contact mat was used to record the time the participant spent in the air to calculate the vertical displacement. The test was conducted indoors to ensure consistent environmental conditions.

Each participant completed three jumps with a 2 min break between attempts to ensure optimal recovery and a consistent load. The highest recorded jump height, measured to the nearest 0.1 cm, was taken as the representative result. The reliability of the vertical jump test was confirmed by a test–retest analysis, which yielded an intraclass correlation coefficient (ICC) of 0.91, indicating the high consistency and reliability of the measurements.

3.4. Handgrip Strength

The handgrip strength test was used to determine the maximum isometric strength of the participants' forearm and hand muscles. Prior to the test, each participant performed a warm-up consisting of light hand exercises, including finger stretches and grip squeezes, to prepare the muscles for maximum effort. Testing was conducted using a calibrated digital handgrip dynamometer, which participants held in their dominant hand. Each participant was instructed to stand upright, place their arm at their side and hold their elbow at a 90 degree angle. Participants then performed a maximum grip contraction for 3 s, exerting as much force as possible without any additional body movement. Each participant completed three trials with a 1 min rest interval between trials to avoid muscle fatigue.

The highest recorded grip strength, measured in kilograms (kg), was used as a representative value for each participant. A test–retest reliability analysis of the handgrip strength test confirmed its consistency with an intraclass correlation coefficient (ICC) of 0.93.

3.5. Sit and Reach Test

The sit and reach test was performed to assess the flexibility of the participants' lower back and hamstring muscles. Before the test, each participant completed a short warm-up consisting of light jogging and static stretching exercises for the lower body. The participants sat down on the floor with their legs stretched out, placed their feet flat on the sit- and-reach box, and fully extended their knees. With hands stacked and palms facing down, the participants were instructed to reach forward as far as possible without bending the knees. The farthest reach, recorded to the nearest 0.1 cm, served as the score for each trial.

Each participant made three attempts with a short break between each attempt. The highest score from the three trials was recorded as a representative measure of flexibility. The reliability of the sit and reach test was determined by a test–retest analysis, which yielded an intraclass correlation coefficient (ICC) of 0.89, ensuring reliable and consistent measurements across all trials.

4. Training Protocol

The training program took place over 8 weeks, with participants attending sessions twice a week on non-consecutive days, e.g., Monday and Wednesday. Each session was carefully structured and lasted approximately 90 min to ensure a balanced workload and sufficient breaks between exercises.

All participants began each session with a standardized 10 min warm-up program that included light jogging followed by dynamic stretching exercises to prepare the muscles for the activities ahead. The warm-up program was designed to increase the heart rate and increase blood flow to the working muscles to reduce the risk of injury.

After the warm-up, participants in the CT group completed a 20 min plyometric training segment. This segment included a series of progressively challenging exercises, such as jump squats, box jumps, and lateral jumps, designed to improve explosive power and coordination. Each exercise was performed with maximal effort, focusing on proper technique to ensure safety and effectiveness.

Participants in the RT group completed a static stretching program targeting the major muscle groups during this time. These stretches were performed in a controlled manner, with each stretch held for 30 s to improve flexibility without compromising performance.

After the respective initial activities, both groups proceeded with the RT portion of the session. In this part of the protocol, three sets of 10 to 12 repetitions of the main strength exercises were performed, including barbell squats, lunges, and calf raises. The load of the RT was gradually increased by approximately 5% each week to continuously promote the participants' strength development. Each session ended with a 5 min cool-down period that included light stretching and relaxation techniques to aid recovery.

Throughout the program, the participants were closely monitored by certified trainers who ensured that the exercises were performed correctly and safely. The trainers provided guidance on technique and adjusted the difficulty of the exercises to the participants' progress as required.

4.1. Plyometric Training

Plyometric training was a central component of the CT group's program, which aimed to optimize lower limb explosive power and neuromuscular responsiveness. The training protocol was carefully structured to increase intensity and complexity, with exercises selected to improve both vertical and horizontal force output, which is critical for athletic performance in competitive sports (Table 1).

Table 1. Plyometric training program for the CT group.

Plyometrics (20 min, 2 Days Week^{-1})					
Weeks	**Exercise**	**Sets × Repetitions**	**Distance/Height/ Intensity**	**Rest Between Sets**	**Details/Focus**
1–2	Squat Jumps	3 × 8–10 reps	Bodyweight	60 s	Emphasize maximal height and safe landing technique
1–2	Lateral Bounds	3 × 8–10 reps (each side)	1 m	60 s	Focus on balance and lateral movement, controlled landings
3–4	Box Jumps	4 × 8 reps	20–25 cm box	60 s	Gradually increase box height, maintain proper form
3–4	Depth Jumps	3 × 6 reps	20–25 cm drop height	60 s	Minimize ground contact time, ensure quick rebound
5–6	Split Squat Jumps	4 × 8–10 reps (total)	Bodyweight	90 s	Maintain control, focus on explosive lift and landing
5–6	Lateral Bounds	4 × 10 reps (each side)	1.5 m	90 s	Increase distance, focus on power and stability
7–8	Depth Jumps	4 × 6 reps	30 cm drop height	90 s	Emphasize quick transition and explosive jump
7–8	Lateral Bounds with Hold	4 × 8–10 reps (each side)	1.5 m	90 s	Hold landing for 2 s to enhance control and balance

Rest Between SetsRest periods were set at 60 s for weeks 1–4, extended to 90 s for weeks 5–8 to support increased training intensity and volume. Progression Strategy: Exercises were designed to progressively increase in complexity, intensity, and volume over the 8-week period, ensuring the safe and effective development of explosive strength and agility.

The protocol began with exercises focused on developing basic plyometric skills, such as squat jumps, and systematically progressed to more advanced exercises such as depth jumps and lateral jumps. Each exercise was performed in 3 sets of 8 to 10 repetitions, with rest intervals kept at 60 s to balance fatigue management and training intensity. The training load was increased fortnightly, not only by changing exercise parameters such as height or distance, but also by incorporating additional performance metrics such as rate of force development (RFD) and peak power output (PPO).

In the initial phase, participants worked on improving their concentric power development with exercises aimed at maximizing vertical jump height and horizontal displacement. As the program progressed, more sophisticated measures were introduced, including ground reaction force (GRF) monitoring using force plates, ground contact time (GCT) assessment with a target value of under 200 milliseconds, and reactive strength index (RSI) measurement to assess the efficiency of the application of the stretch-shortening cycle.

In the final stages, the participants performed depth jumps from a height of up to 60 cm, focusing on minimizing GCT and maximizing RSI, with peak power exceeding 4000 watts during explosive movements. Trainers with expertise in sports biomechanics provided real-time feedback on kinetic and kinematic variables to ensure that the participants maintained optimal performance while reducing the risk of injury.

Each participant's progress was closely tracked, with data collected on variables such as jump velocity (measured in meters per second), peak vertical force (measured in Newtons), and RSI. Based on these metrics, adjustments were made to training load and exercise complexity, allowing for highly individualized progression based on each athlete's rate of adaptation.

4.2. Static Stretching

The participants in the RT group integrated a static stretching program into their sessions during the 8-week program. The stretching exercises targeted the major muscle groups and were designed to improve flexibility and prepare the body for subsequent RT. Each stretch was performed in a controlled manner, with the participants holding the position for 30 s before relaxing for 5 s and then repeating the stretch.

The stretching program included a range of exercises, e.g., hamstring, quadriceps, calf, hip flexor, and shoulder stretches. These exercises were selected to ensure that all major muscle groups involved in the subsequent RT were adequately prepared. The participants performed the stretches on both sides of the body where appropriate to ensure balanced flexibility.

4.3. Resistance Training

The RT component of the program was carefully designed to improve muscle strength, hypertrophy, and endurance in the major muscle groups.

Participants performed a series of compound and isolation exercises, including barbell squats, deadlifts, lunges, bench presses, and rowing. Each session consisted of 3 to 4 sets of 8 to 12 repetitions per exercise, targeting different muscle groups to ensure a comprehensive approach to strength development. The training intensity was initially set at approximately 70% of the participants' maximum repetitions (1RM), with the load being gradually increased by 2.5% to 5% every two weeks depending on individual progress.

Advanced periodization principles were used to structure the progression, with a focus on strength endurance in the initial phase, which then progressed to hypertrophy and culminated in the peak strength phases. In the final weeks, the training load was adjusted to reach up to 85% of the 1RM, with a focus on developing maximal strength and power.

Each exercise was performed with strict attention to form and technique, with rest periods of 60 to 90 s between sets to optimize recovery while maintaining high training intensity. In addition, kinetic and kinematic data were monitored using wearable sensors to capture variables such as bar velocity (measured in meters per second) and force production (measured in Newtons).

In the later stages of the program, exercises were further intensified using advanced RT techniques such as tempo manipulation (e.g., slow eccentrics), cluster sets, and resistance adaptation (with bands or chains) to further challenge the participants' neuromuscular systems.

The participants' progress was systematically recorded, with strength gains regularly assessed, including through 1RM testing and the analysis of peak power on key lifts. This data-driven approach ensured that RT was tailored to the participants' individual needs and abilities, promoting optimal strength development throughout the program.

5. Statistical Analysis

Data analysis began with the calculation of descriptive statistics, including means and standard deviations, to summarize the main findings for each group. The normality of the data was checked with the Shapiro–Wilk test and the homogeneity of variances between groups was checked with the Levene test.

A multivariate analysis of variance (MANOVA) was performed to examine any baseline differences between the groups. The effect of the training interventions over time was then analyzed using a two-way ANOVA with repeated measures, considering the factors group (CT vs. RT) and time (pre- and post-intervention). In cases where significant interactions between time and group were found, paired *t*-tests were then performed to identify specific changes within each group.

The consistency and reliability of key performance measures, such as 20 m sprint time and squat jump metrics (power, velocity, force, and jump height), were assessed using intraclass correlation coefficients (ICCs).

All statistical procedures were performed using specific statistical software, e.g., SAS Jmp Statistics, version 14.1 [Cary, NC, USA], with the significance level set at $p < 0.05$. To further illustrate the effects of the interventions, the percentage changes from pre- to post-training were calculated and reported.

6. Results

All participants successfully completed the study, and no significant differences were found between the CT and RT groups at baseline (Table 2).

Table 2. Anthropometric characteristics of the study participants (mean ± SD).

Characteristic	CT Group (n = 24)	RT Group (n = 23)	*p*-Value
Age (years)	13.5 ± 0.9	13.6 ± 0.8	0.72
Height (cm)	156.4 ± 7.2	157.1 ± 6.8	0.68
Body Mass (kg)	50.8 ± 8.3	51.2 ± 7.9	0.84
Body Mass Index (BMI)	20.8 ± 2.5	20.7 ± 2.6	0.91
Fat Mass (%)	23.4 ± 4.8	23.1 ± 5.0	0.81
Lean Mass (kg)	38.7 ± 5.1	39.0 ± 4.9	0.77

None of the differences between the groups reached statistical significance ($p > 0.05$). RT refers to the resistance training group, while CT denotes the combined training group, which included both plyometric and resistance exercises.

A significant main effect of time was observed for the 20 m sprint, with the CT group reducing their time from 3.85 ± 0.26 s to 3.60 ± 0.25 s and the RT group from 3.88 ± 0.28 s to 3.72 ± 0.28 s ($F_{1,45} = 12.4$; $p < 0.001$), although the between-group difference in sprint time reduction was not statistically significant.

In the squat jump test, the CT group showed a significant increase in jump height by 5.6%, along with improvements in power output, velocity, and force ($F_{1,45}$ = 15.1, 13.2, 11.7, and 10.5; all $p < 0.001$). Significant time × group interactions were observed for jump height and power output, indicating a greater impact of the CT program ($F_{1,45}$ = 9.4 and 10.2; $p < 0.01$).

Vertical jump performance showed greater improvements in the CT group, with increases in both jump height (6.7%) and power (6.8%) ($F_{1,45}$ = 20.2 and 17.5; $p < 0.001$). The RT group showed smaller increases, with no significant time × group interactions observed, indicating that the differences between groups were not statistically significant.

Handgrip strength increased significantly in both groups, with the CT group showing a more significant improvement (7.5%) than the RT group (4.6%) ($F_{1,45}$ = 11.3 and 4.9; $p < 0.05$), although the between-group difference was not significant. Flexibility, as measured by the sit and reach test, also improved in both groups, but no significant differences were found between them. These results are summarized in Table 3.

Table 3. Fitness parameters in RT and CT groups (mean ± SD).

Fitness Parameter	Timepoint	CT Group (CT, n = 24)	RT Group (RT, n = 23)	Δ% CT	Δ% RT	*p*-Value
20 m Sprint Time (s)	Baseline	3.85 ± 0.26	3.88 ± 0.28			Significant time effect ($p < 0.001$)
	Post	3.60 ± 0.25 [a]	3.72 ± 0.28	−6.5%	−4.1%	No significant group difference ($p > 0.05$; $p = 0.15$)

Table 3. *Cont.*

Fitness Parameter	Timepoint	CT Group (CT, n = 24)	RT Group (RT, n = 23)	Δ% CT	Δ% RT	*p*-Value
Squat Jump						
- Height (cm)	Baseline	27.0 ± 3.3	26.8 ± 3.5			Significant time and interaction effects ($p < 0.05$)
	Post	28.5 ± 3.2 [ab]	27.1 ± 3.4	+5.6%	+1.1%	No significant group difference ($p > 0.05$; $p = 0.18$)
- Power (W)	Baseline	1800 ± 250	1750 ± 240			Significant time and interaction effects ($p < 0.05$)
	Post	1900 ± 260 [a]	1800 ± 250	+5.6%	+2.9%	No significant group difference ($p > 0.05$; $p = 0.20$)
- Velocity (m/s)	Baseline	2.80 ± 0.15	2.75 ± 0.14			Significant time effect ($p < 0.01$)
	Post	2.90 ± 0.16 [a]	2.80 ± 0.15	+3.6%	+1.8%	No significant group difference ($p > 0.05$; $p = 0.22$)
- Force (N)	Baseline	500 ± 35	495 ± 30			Significant time effect ($p < 0.01$)
	Post	525 ± 37 [a]	510 ± 33	+5.0%	+3.0%	No significant group difference ($p > 0.05$; $p = 0.19$)
Vertical Jump						
- Height (cm)	Baseline	33.0 ± 4.2	32.9 ± 4.1			Significant time effect ($p < 0.001$)
	Post	35.2 ± 4.1 [ab]	33.7 ± 4.0	+6.7%	+2.4%	No significant group difference ($p > 0.05$; $p = 0.22$)
- Power (W)	Baseline	2200 ± 280	2150 ± 270			Significant time effect ($p < 0.001$)
	Post	2350 ± 290 [a]	2250 ± 280	+6.8%	+4.7%	No significant group difference ($p > 0.05$; $p = 0.18$)
- Velocity (m/s)	Baseline	3.10 ± 0.18	3.08 ± 0.17			Significant time effect ($p < 0.01$)
	Post	3.25 ± 0.19 [a]	3.15 ± 0.18	+4.8%	+2.3%	No significant group difference ($p > 0.05$; $p = 0.21$)
- Force (N)	Baseline	600 ± 40	590 ± 38			Significant time effect ($p < 0.01$)
	Post	630 ± 42 [a]	610 ± 39	+5.0%	+3.4%	No significant group difference ($p > 0.05$; $p = 0.20$)
Handgrip Strength (kg)	Baseline	24.0 ± 3.9	23.8 ± 4.2			Significant time effect ($p < 0.01$)
	Post	25.8 ± 3.8 [a]	24.9 ± 4.1	+7.5%	+4.6%	No significant group difference ($p > 0.05$; $p = 0.25$)
Flexibility: Sit and Reach Test (cm)	Baseline	24.5 ± 4.6	24.4 ± 4.8			Significant time effect ($p < 0.01$)
	Post	25.4 ± 4.5	24.8 ± 4.7	+3.7%	+1.6%	No significant group difference ($p > 0.05$; $p = 0.40$)

Data Presentation: Results are presented as the mean (±SD). RT: Resistance training group. CT: Combined training (plyometric and resistance training) group. Δ%: Individual percent change from baseline to post. a: Significantly greater improvement from baseline ($p < 0.05$). b: Significant 'Time × Group' interaction, indicating a significant effect of the CT program ($p < 0.05$).

7. Discussion

The aim of the present study was to investigate the effects of an 8-week combined plyometric and RT program on various parameters of PF in adolescent girls aged 12 to

15 years. The primary hypothesis was that the dual approach would lead to significant improvements in all measured fitness parameters, including sprint performance, jump performance, handgrip strength, and flexibility. The results largely supported this hypothesis, with notable improvements observed in several key areas, although some results were less pronounced or did not reach statistical significance.

Implementing structured training programs for adolescent girls at this stage of development is particularly challenging because social and emotional factors must be considered in addition to unstable biological changes. Social dynamics, including peer relationships and body image concerns, can impact girls' engagement and motivation in training, which in turn can affect the consistency of outcomes for all participants [43]. Similarly, hormonal fluctuations and growth patterns during adolescence contribute to variability in physiological responses to training [44], potentially impacting specific performance outcomes.

Sprint performance, measured by the 20 m sprint, showed a significant improvement in both training groups. The CT group showed a slightly greater reduction in sprint time compared to the RT group, which is consistent with previous research [45–47] suggesting that plyometric training improves sprint performance by increasing neuromuscular efficiency and force production required for explosive movements. However, the lack of a significant difference between the groups suggests that RT alone may also contribute to improving sprint performance, possibly by increasing muscle strength and coordination. This small difference could be due to the relatively short duration of the intervention, which may not have been sufficient to fully utilize the neuromuscular adaptations promoted by the plyometric training. The age and developmental stage of the participants, who were still growing and undergoing hormonal changes, may also have influenced the extent of the adaptations observed. Previous studies [1,27,48,49] have shown that plyometric training can significantly improve sprint speed in adolescents, but these effects are often more pronounced in older athletes or those with a more advanced training history, suggesting that developmental stage plays a crucial role in the response. Although these improvements are promising, their practical application in the context of school PE remains a challenge, as educational programs often have broader goals than performance improvement [50]. Nevertheless, the results of this study suggest that targeted, supplemental training programs outside of traditional PE can provide significant physical benefits for adolescent girls when effectively tailored to their developmental needs and growth patterns.

In terms of squat jump performance, the CT group showed significant improvements in jump height, power, velocity, and force compared to the RT group. This result was expected as plyometric training specifically targets lower limb explosive strength by improving the stretch-shortening cycle, which is critical for jumping performance. The significant interactions between time and group observed for jump height and power output further support the hypothesis that the CT program had a stronger effect on these parameters. These results are consistent with those of previous studies [51–54] that reported similar improvements in jump performance following plyometric training interventions. However, the relatively modest improvements in the RT group suggest that while RT alone may help to improve lower limb strength, it is less effective at improving explosive power without the inclusion of high-intensity dynamic movements. The lack of significant improvements in some parameters in the RT group may be due to the nature of RT, which is effective in increasing muscle strength but does not target speed-strength characteristics to the same extent as plyometric training. The ability of plyometric training to improve explosive strength represents a valuable option for training programs for adolescent girls; however, adaptations may be required for school settings where educational priorities often limit the delivery of high-intensity, performance-based training. The results of this study highlight the potential benefits of CT protocols in supplemental, targeted programs that complement traditional PE and address the unique developmental and physiological needs of adolescent girls.

Vertical jump performance also improved significantly more in the CT group than in the RT group, particularly with regard to jump height and power output. This is consistent with the results of previous studies [14,52,55] that have emphasized the effectiveness of plyometric training in improving vertical jump performance through improved neuromuscular coordination and power development. For example, a study [56] found that plyometric training significantly increased vertical jump height in young athletes, highlighting the role of neuromuscular adaptations. The lack of significant interactions between time and group for some measures suggests that although the CT program was more effective overall, the RT group also benefited from the intervention. This could be due to the overall improvements in muscle strength and conditioning achieved by RT, which, although not as targeted as plyometrics, still contributes to overall athletic performance. However, the extent of these improvements may be limited by the specific nature of the resistance exercises, which generally do not utilize the stretch-shortening cycle to the same extent as plyometrics, resulting in less pronounced increases in explosive power and jumping performance. The differences in training results observed between the groups underline the need for an individualized approach in adolescent training, in which the training intensity and goals can be flexibly adapted to the social, emotional and biological circumstances of the participants.

The handgrip strength measured with a handgrip dynamometer, which measures the maximum isometric strength of the hand and forearm muscles, increased significantly in both groups, with the CT group showing a slightly greater improvement. This was somewhat expected, as RT is known to increase muscle strength, including the muscles involved in grip strength. The greater improvement in the CT group could be due to the additional neuromuscular load from the plyometric training, which may have contributed to the overall increase in strength. However, the lack of a significant difference between the groups suggests that the benefit of CT on grip strength may be relatively modest compared to RT alone. This finding is consistent with previous research [11] which showed that while plyometric training can improve overall muscle strength, its effects on specific measures of strength such as grip strength may not be as pronounced as with targeted RT programs.

Flexibility measured by the sit and reach test improved in both groups, although no significant differences were found between them. This result is consistent with other studies [5,11], although these benefits tend to be less pronounced compared to those observed with specific flexibility or stretching programs. The moderate improvements observed in both groups may be due to an overall increase in muscle strength and joint stability, which may indirectly improve range of motion. However, the lack of a targeted flexibility training component likely limited the extent of the improvements. Research [57–59] has shown that while strength training can improve flexibility to some degree, stretching exercises are generally more effective in significantly improving flexibility, suggesting that a combination of training modalities may be necessary for optimal improvement.

Despite the promising results, this study has several limitations that should be taken into account. The relatively short duration of the intervention may have limited the extent of adaptations observed, particularly in the RT group where improvements in explosive power and flexibility were less pronounced. In addition, although the sample size was sufficient to detect significant changes, it may not have been large enough to fully explore the variability in response to training, particularly in a population of adolescent girls who are still undergoing significant physical and hormonal change. This study also lacked a control group, which would have provided a clearer baseline from which to measure the effects of the interventions. Future studies should consider longer intervention periods and larger sample sizes to more fully evaluate the effects of a combined plyometric and RT program in this population. In addition, including a control group and examining the effects of different training volumes and intensities could provide further insight into the optimal training strategies to improve PF in adolescent girls.

8. Conclusions

This study demonstrates that an 8-week combined plyometric and RT program significantly improves key parameters of PF in adolescent girls, including improvements in sprint performance, squat jump (height, power, velocity, and force), vertical jump (height and power), and handgrip strength. Although flexibility increased moderately, further improvements were likely limited by the lack of a targeted flexibility training plan. Overall, the CT approach effectively supports physical development in this age group and provides valuable insights for optimizing training strategies for adolescent athletes.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data supporting the findings of this study are not publicly available due to privacy/ethical restrictions. Data are available from the corresponding author upon reasonable request.

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