Original Article

doi: 10.16926/par.2026.14.17

Explosive Strength Parameters of the Lower Limbs in Young Female Track and Field Athletes

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Authors' Contribution: A – Study Design, B – Data Collection, C – Statistical Analysis, D – Manuscript Preparation, E – Funds Collection

Abstract: *Introduction.* Monitoring and development of lower-limb explosive strength play a crucial role in youth athletic preparation and talent development. Vertical jump performance is widely used as a reliable indicator of explosive strength; however, data concerning differences between training modalities and training frequency in pre-adolescent female athletes remain limited. The aim of the study was to compare the level of lower-limb explosive strength among two groups of young female track-and-field athletes differing in strength training frequency and a non-athletic control group, using selected vertical jump tests. *Methods***.** The research sample consisted of 92 girls (mean age: 12.1 ± 0.7 years), all classified as pre–peak height velocity individuals. Participants were divided into three groups: athletes performing strength training once per week (G1, n = 20), athletes performing strength training twice per week supplemented with basic weightlifting exercises (G2, n = 38), and a non-athletic control group (G3, n = 34). Lower-limb explosive strength was assessed using the countermovement jump (CMJ), countermovement jump with arm swing (CMJ FA), and squat jump (SJ) measured by a Chronojump system. One-way ANOVA, Tukey's post hoc test, and ANCOVA with body height as a covariate were applied. *Results.* Statistically significant differences between groups were observed in all vertical jump tests ($p < 0.05$). The athletic groups achieved higher jump heights than the control group, with G2 demonstrating the highest performance across all tests. The largest practical differences were identified in the CMJ FA test. Group membership explained a substantially greater proportion of performance variance than body height, which showed only a limited predictive contribution. ANCOVA confirmed significant between-group effects after controlling for body height. *Conclusions.* The findings indicate that systematic power-oriented strength training positively influences lower-limb explosive strength in young female athletes. Increasing strength training frequency to two sessions per week, particularly when supplemented with basic weightlifting exercises, appears to provide additional performance benefits. These results support the inclusion of structured and progressive strength training programmes in youth athletics and physical education.

Keywords: lower-limb explosive strength; vertical jump; plyometric training; youth athletes; strength training frequency; female adolescents; athletic performance

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Recevied: 14.11.2025; Accepted: 16.01.2025; Published online: 12.03.2026

Citation: Falat Leütterová D, Sučka J. Explosive Strength Parameters of the Lower Limbs in Young Female Track and Field Athletes. Phys Act Rev 2026; 14(2): 10-23. doi: 10.16926/par.2026.14.17

INTRODUCTION

The assessment of physical fitness in young athletes is justified across all age categories and is commonly applied both in the identification of movement-talented individuals and in the evaluation of the effectiveness of intervention training programmes [1]. In the diagnosis and development of explosive strength, particular attention should be given to the strength component, whose most sensitive developmental period begins at approximately 13 years of age. Muscular strength represents a key determinant of athletic performance, influencing not only overall performance capacity but also injury risk. During the execution of vertical jump tasks, the strength component plays a decisive role in performance outcomes [1,2].

Based on currently available evidence, test protocols focused on vertical jump performance can be effectively used for the objective assessment and diagnosis of lower-limb explosive strength [3,4]. Consequently, the evaluation of lower-limb explosive strength is regarded as an important diagnostic method for assessing athletes' strength capabilities. Nevertheless, this area has not yet been sufficiently investigated in youth populations, and a lack of studies examining differences in lower-limb explosive strength across age groups among young athletes has been highlighted [1,5-7].

Vertical jump tests, particularly the countermovement jump (CMJ) and squat jump (SJ), are widely considered reliable and valid field-based methods for assessing lower-limb explosive strength [8]. A notable limitation of previous research is the inconsistency in study design, especially regarding the timing of measurements within the training cycle and the comparison of athletes with differing performance levels. Furthermore, although many studies have focused on the effects of plyometric or resistance training on athletic performance, the systematic incorporation of basic weightlifting exercises into the training process of young athletes remains insufficiently explored. Available evidence suggests that the acquisition of fundamental weightlifting skills may begin as early as 10 years of age [2].

Recent meta-analyses confirm that plyometric training exerts a significant positive effect on most parameters of physical fitness and athletic performance [9,10]. In particular, plyometric interventions consistently improve vertical jump performance, and their systematic inclusion in training programmes is recommended to maximize jumping ability. This conclusion is further supported by numerous studies demonstrating the growing emphasis placed on plyometric training in the design of contemporary training programmes [1,11-14].

Plyometric exercises exploit the elastic energy of the muscle–tendon complex to generate powerful explosive movements. Activities such as jumps, hops, and drop jumps substantially enhance the function of the stretch–shortening cycle (SSC), which directly influences the ability to produce high force output and, consequently, athletic performance [11]. Additional evidence indicates that plyometric training improves neuromuscular efficiency, optimizes SSC function, and enhances motor unit recruitment [12,15].

Based on the existing literature, it is hypothesised that athletes undergoing strength-oriented training will demonstrate statistically significant improvements across all assessed vertical jump tests ($p < 0.05$). Therefore, the primary aim of the present study is to examine the effects of two different training modalities on selected performance parameters in female athletes. The specific objectives of the study are as follows:

– to evaluate the effect of plyometric training on lower-limb explosive strength in female athletes;

- to determine which of the selected training modalities produces greater improvements in explosive strength, as assessed by vertical jump performance;
- to compare performance outcomes between female athletes who completed plyometric training and a non-athletic control group
- to provide practical recommendations for coaches and physical education teachers regarding the effective integration of plyometric and weightlifting exercises into athletic training programs.

MATERIAL AND METHODS

Participants

The research sample comprised 92 girls with a mean age of 12.1 ± 0.7 years. Participants were divided into three distinct groups:

- Group 1 (G1) consisted of girls training in a track and field club who performed strength training once per week (n = 20; mean age: 12.3 ± 0.5 years),
- Group 2 (G2) included girls training in a track and field club who performed strength training twice per week (n = 38; mean age: 12.0 ± 0.6 years),
- Group 3 (G3), the control group, consisted of girls who did not participate in any organized extracurricular sports activities (n = 34; mean age: 12.2 ± 1.0 years).

Participants from the athletic groups (G1 and G2) were considered physically gifted and talented individuals. Based on an assessment of biological maturation, all girls included in the study were classified as being in the pre–peak height velocity (pre-PHV) period. Participants identified as being in a phase of accelerated growth were excluded from the study.

Within the applied training regimen, Group 1 performed strength training once per week, with a primary focus on plyometric exercises and bodyweight resistance training. Group 2 completed strength training twice per week as part of their regular training process, combining plyometric exercises with basic weightlifting movements. Athletes in both G1 and G2 participated in track and field and running events at regional and national competition levels and competed in an average of two competitions per month during the main competitive season.

Both athletic groups trained a total of three to four times per week, with an average of 13 training sessions per month. During the training microcycle, G1 and G2 completed athletic training sessions focused on the development of speed and coordination abilities. Training content included short- and middle-distance running intervals, as well as technical and preparatory exercises related to athletic disciplines, such as the standing long jump and hurdle sprint drills. Strength training sessions lasted approximately 70 minutes.

Plyometric training in both athletic groups emphasized dynamic repetitive jumping exercises performed either without external resistance or with additional load. In Group 2, basic weightlifting exercises were incorporated as a supplement to plyometric training. Participants were instructed in the fundamentals of weightlifting, including the clean, jerk, and snatch. These exercises are considered multi-joint, whole-body strength movements with a broad impact on the development of athletic performance (Table 1).

Group 3 consisted of girls from the general population with no sports specialization and no additional training load beyond school requirements. All three groups participated in compulsory school physical education classes twice per week.

Table 1 Plyometric and Basic Weightlifting Training Schedule

Training Type	exercises	Repetition (No.)	Sets (No.)	Intensity (%)	Recovery (min)
Plyometric	Box jumps	25	2-3	40-60%	2
	Hurdles jumps	30	2-3	50%	2
	Bounding	16	2-4	60-70%	2-3
	Lateral jumps	12	2-4	50%	2-3
Weightlifting	Clean	5-7	3-4	60%	2-3
	Clean &Jerk	4	3-4	60%	2-3
	Snatch	4	3-4	60%	2-3

Table 2 Descriptive Statistics of Anthropometric Characteristics

V	Group	M±SD	95% CI	Min/Max	Statistic	Tukey's post hoc analysis
BM (kg)	G1 (n=20)	44.9±8.4	40.9-48.8	30.0/58.2	F = 0.292; p = 0.748; η^2 = 0.007 (S)	G1 vs G2 * G1 vs G3 * G2 vs G3 †
	G2 (n=38)	45.3±9.6	42.1-48.4	29.0/71.3		
	G3 (n=34)	43.6±10.1	40.0-47.1	28.0/64.1		
	Total (n=92)	44.6±9.5	42.6-46.5	28/71.3		
BH (cm)	G1 (n=20)	156.9±7.4	153.5-160.4	142.0/167.1	F = 3.730; p = 0.028; η^2 = 0.077 (M)	G1 vs G2 * G1 vs G3 ‡ G2 vs G3 †
	G2 (n=38)	154.3±6.7	152.1-156.5	141.0/167.6		
	G3 (n=34)	150.9±9.9	147.3-154.3	122.0/163.0		
	Total (n=92)	153.6±8.4	151.8-155.3	122.0/167.6		
SM %	G1 (n=20)	43.0±3.5	41.3-44.6	36.4/50.1	F = 0.342; p = 0.711; η^2 = 0.008 (S)	G1 vs G2 † G1 vs G3 * G2 vs G3 *
	G2 (n=38)	42.1±6.7	39.9-44.3	19.7/50.3		
	G3 (n=34)	41.4±9.2	38.1-44.5	21.9/58.8		
	Total (n=92)	42.0±7.1	40.5-43.5	9.7/58.8		

V – variable; G – group; N – sample size; M – mean; SD – standard deviation; BM – body mass; BH – body height; Min – minimum; Max – maximum; F – test statistic value; statistical significance at $p < 0.05$; kg – kilogram; cm – centimeter; SM – skeletal muscle mass; Cohen's effect size: * small effect, † medium effect, ‡ large effect; η^2 – eta squared coefficient (S – small effect, M – medium effect, L – large effect); CI – confidence interval.

Figure 1. Types of vertical jumps CMJ-CMJFA-SJ (Source: Author's own elaboration).

This study employed a cross-sectional design, as all variables were assessed at a single time point without longitudinal follow-up. Consequently, the results reflect the current strength and training-related characteristics of the examined groups at the time of measurement.

Table 2 presents the basic anthropometric characteristics of the participants across the examined groups. Mean body mass was comparable among all groups, and one-way analysis of variance (ANOVA) revealed no statistically significant between-group differences, indicating that body mass did not differ substantially among participants.

The highest mean body height was observed in Group 1 (G1), exceeding that of Group 2 (G2) by approximately 2 cm and that of the general population group by approximately 6 cm. For this age category, such differences may be considered meaningful. One-way ANOVA confirmed statistically significant differences in body height between groups, suggesting that participants from the athletic groups were, on average, taller than those from the non-athletic population. Post hoc analysis using Tukey's test indicated that the statistically significant difference occurred between G1 and the control group (G3). These findings demonstrate that body height varied across groups and that the observed differences were clearly distinguishable.

The mean percentage of skeletal muscle mass was slightly higher in G1 compared with G2; however, ANOVA did not reveal statistically significant differences, indicating a similar muscle mass composition across all examined groups.

Procedure

Vertical jump height was assessed using the Chronojump diagnostic system (Bosco system; Chronojump, Barcelona, Spain). The objectivity of diagnostic outcomes depends on both the composition of the test battery and the psychometric properties of the test procedures, including validity and reliability [16]. The reliability and validity of the Chronojump system have been extensively evaluated, with previous studies reporting a high level of test–retest reliability for vertical jump measurements [16–19].

Each participant performed individual jumps from a stationary position, with trials conducted one at a time. One familiarization trial and two measured trials were completed for each vertical jump condition, and the better of the two recorded trials was used for subsequent analysis. After standardized instructions were provided, participants stood in the center of the measurement area and completed three vertical jump tests in the following order: countermovement jump (CMJ), countermovement jump with free arm swing (CMJ FA), and squat jump (SJ) (figure 1).

During squat jump trials, particular attention was paid to correct execution of the technique. If any countermovement was observed prior to take-off, the trial was deemed invalid and repeated. A minimum rest interval of 1 min was provided between consecutive jump conditions to minimize the effects of fatigue. All jump heights were recorded in centimeters.

Statistical analysis

Normality of data distribution was verified using the Shapiro–Wilk test. As the data met the assumption of normality, descriptive statistics are presented as means (M) and standard deviations (SD), with minimum and maximum values used to describe data variability. Differences between groups were analyzed using one-way analysis of variance (one-way ANOVA). When statistically significant main effects were identified, multiple comparisons of means were conducted using Tukey's post hoc test. The level of statistical significance was set at $p = 0.05$.

To quantify the magnitude of between-group differences, effect sizes were calculated using eta squared (η^2). The magnitude of η^2 was interpreted according to established criteria: η^2 = 0.01 (small effect), η^2 = 0.06 (medium effect), and η^2 = 0.14 (large effect). In addition, effect sizes for pairwise comparisons were calculated using Cohen's d and interpreted as follows: d < 0.20 (negligible effect), d = 0.20–0.49 (small effect), d = 0.50–0.79 (medium effect), and d ≥ 0.80 (large effect) [20,21].

To control for potential differences in body height between groups, analysis of covariance (ANCOVA) was performed with body height included as a covariate. When significant effects were detected, Bonferroni-adjusted post hoc comparisons were applied.

All statistical analyses were conducted using IBM SPSS Statistics version 27 (IBM SPSS Inc., Chicago, IL, USA). The study was carried out in accordance with the principles of the Declaration of Helsinki and was approved by the Ethics Committee of the University of Prešov (ECUP 092024PO, 2024).

RESULTS

Based on the obtained data, the mean vertical jump values recorded in the general population group were approximately 3–5 cm lower than those observed in the athletic groups, which was consistent with the initial expectations (table 3). Among the athletes, Group 2 (G2) achieved higher performance values than Group 1 (G1), demonstrating the most pronounced level of lower-limb explosive strength. Effect size analysis indicated a medium effect for the countermovement jump (CMJ), whereas large effects were observed for the countermovement jump with free arm swing (CMJ FA) and the squat jump (SJ).

Table 3 Results of Analysis of Vertical Jump tests

V	Group	M±SD (cm)	95% CI	Max	Statistic	Tukey's post hoc analysis
CMJ	G1 (n=20)	20.6±3.2	19.9-22.0	14.8/30.0	F = 5.606; p = 0.005; η^2 = 0.112 (M)	G^1 vs G^2 * G^1 vs G^3 † G^2 vs G^3 ‡
	G2 (n=38)	21.5±3.7	20.2-22.6	12.8/29.9		
	G3 (n=34)	18.7±3.7	17.3-19.9	12.9/28.0		
	Total (n=92)	20.3±3.8	19.4-21.0	12.8/30.0		
CMJ FA	G1 (n=20)	26.1±3.7	24.3-27.8	21.4/37.1	F = 12.202; p = 0.001; η^2 = 0.215 (L)	G^1 vs G^2 † G^1 vs G^3 ‡ G^2 vs G^3 ‡
	G2 (n=38)	27.4±4.3	25.9-28.7	18.5/34.4		
	G3 (n=34)	22.6±4.3	21.0-24.0	12.1/30.2		
	Total (n=92)	25.3±4.7	24.3-26.2	12.1/37.1		
SJ	G1 (n=20)	20.7±3.6	19.0-22.4	16.1/31.4	F = 6.960; p = 0.002; η^2 = 0.135 (L)	G^1 vs G^2 † G^1 vs G^3 ‡ G^2 vs G^3 ‡
	G2 (n=38)	22.0±3.8	20.6-23.2	10.7/30.2		
	G3 (n=34)	18.7±3.7	17.3-19.9	13.0/28.0		
	Total (n=92)	20.5±4.1	19.6-21.2	10.7/31.4		

V – variable; G – group; N – sample size; M – mean; SD – standard deviation; Min – minimum; Max – maximum; F – test statistic value; statistical significance at p < 0.05; CMJ – countermovement jump; CMJ FA – countermovement jump with free arm swing; SJ – squat jump; Cohen's effect size: * small effect, † medium effect, ‡ large effect; η^2 – eta squared coefficient (S – small effect, M – medium effect, L – large effect); CI – confidence interval.

Statistically significant performance differences were identified in the CMJ and SJ tests between female athletes in Group 2 and girls from the general population. In contrast, no statistically significant differences were observed between Group 1 and the other examined groups in these two jump conditions. In the CMJ FA test, statistically significant differences were found between both athletic groups and the general population group, specifically between G1 and G3 as well as between G2 and G3.

Overall, female athletes achieved higher jump heights across all three tests compared with non-athletic girls, with Group 2 demonstrating the highest overall performance. The greatest practical relevance, as indicated by effect size magnitude, was observed in the CMJ FA test.

Body height was identified as a statistically significant but relatively weak predictor of vertical jump performance, explaining approximately 4% of the variance in CMJ performance and about 2% of the variance in CMJ FA and SJ. These findings suggest that greater body height may slightly contribute to higher jump performance; however, its practical impact appears limited.

In contrast, between-group differences accounted for a substantially larger proportion of explained variance, with group membership explaining nearly 13% of the variance in CMJ, 23% in CMJ FA, and 15% in SJ performance. These results indicate that differences between groups—specifically, in the present study, the frequency of training interventions and the focus of strength-oriented training—represent primary determinants of vertical jump performance.

The influence of body height on vertical jump performance identified by ANCOVA (Table 4) was further examined through correlation analyses between body height and vertical jump outcomes (CMJ, CMJ FA, and SJ) within each group (Table 5). These analyses revealed weak and statistically non-significant relationships across all groups.

Table 4. ANCOVA results for vertical jump performance with body height as a covariate

Test	Group	N	Adjusted Mean (cm)	95% CI	Source	Statistic	Bonferroni post hoc
CMJ	G1	20	20.8	19.2–22.5	Group	F = 7.08; p = 0.001; η^2 = 0.13 (M)	G2 vs G3
	G2	38	21.5	20.4–22.7	Body height	F = 4.06; p = 0.047; η^2 = 0.04 (S)	
	G3	34	18.4	17.1–19.6	-	-	
CMJ FA	G1	20	26.3	24.4–28.2	Group	F = 13.45; p < 0.001; η^2 = 0.23 (L)	G2 vs G3; G1 vs G3
	G2	38	27.4	26.0–28.7	Body height	F = 2.28; p = 0.135; η^2 = 0.02 (S)	
	G3	34	22.3	20.8–23.7	-	-	
SJ	G1	20	20.9	19.2–22.6	Group	F = 7.79; p = 0.001; η^2 = 0.15 (L)	G2 vs G3
	G2	38	21.9	20.7–23.2	Body height	F = 1.83; p = 0.179; η^2 = 0.02 (S)	
	G3	34	18.4	17.1–19.7	-	-	

G – group; N – sample size; CI – confidence interval; BH – body height (covariate); CMJ – countermovement jump; CMJ FA – countermovement jump with free arm swing; SJ – squat jump; statistical significance at $p < 0.05$; η^2 – eta squared coefficient (S – small effect, M – medium effect, L – large effect).

Table 5. Relationship between lower-limb explosive performance and body height

Group	Statistic	BH vs. CMJ	BH vs. CMJ FA	BH vs. SJ
G1	r	-0.14	-0.19	-0.12
	p	0.53	0.41	0.61
G2	r	-0.22	-0.07	-0.05
	p	0.17	0.65	0.73
G3	r	-0.22	-0.21	-0.22
	p	0.19	0.22	0.20
Total	r	-0.12	-0.03	-0.05
	p	0.25	0.75	0.61

BH – body height; CMJ – countermovement jump; CMJ FA – countermovement jump with free arm swing; SJ – squat jump; r – Pearson's correlation coefficient; p – statistical significance. Statistical significance was set at $p < 0.05$.

In Group 1 (G1), the correlations between body height and the assessed vertical jump variables were not statistically significant, indicating that body height did not exert a meaningful influence on jump performance within this group. Similarly, in Group 2 (G2), weak and non-significant negative correlations were observed between body height and vertical jump performance. In the control group (G3), the correlations were also weak and statistically non-significant, further confirming the absence of a practically relevant relationship.

Overall, these results indicate that body height is not a statistically significant determinant of vertical jump height in the examined sample, regardless of training status or group membership.

DISCUSSION

Monitoring anthropometric indicators and body composition is crucial not only for assessing athletic performance in children and adolescents but also for tracking healthy growth, development, and overall health status. Somatic growth is primarily determined by genetic factors; however, hormonal changes and environmental conditions also exert a significant influence, resulting in considerable interindividual variability in growth patterns [22]. The findings of the present study are consistent with previous international research and correspond with anthropometric reference values reported for the general population of school-aged girls [23–25].

In the present study, body height was the only anthropometric parameter that differed significantly between groups, with athletes being taller on average than their non-athletic peers. In contrast, body mass and the percentage of skeletal muscle mass did not differ significantly between athletic and non-athletic participants. Effect size analysis revealed a medium effect (Cohen's d) for between-group differences in body height, indicating both statistical significance and practical relevance. Conversely, comparisons of body mass and skeletal muscle percentage yielded small to negligible effect sizes. Overall, these results suggest that while stature varied between groups, other body composition characteristics remained comparable.

When predicting performance in the countermovement jump (CMJ), body height played only a supportive role, whereas group membership emerged as a substantially stronger determinant of performance. This finding is particularly important for the interpretation of experimental interventions and the planning of training programmes. Notably, approximately 85% of the variance in CMJ performance remained unexplained by either body height or group affiliation, indicating the influence of additional factors such as maximal muscle strength, jumping technique, reaction speed, and neuromuscular coordination that were not included in the present analytical model.

Recent studies published after 2020 have further emphasized the importance of systematic monitoring of physical development in children and adolescents. Comparative analyses of anthropometric and body composition characteristics across different stages of somatic maturity have demonstrated their relevance for sports performance [26]. Similarly, longitudinal research examining growth and development in children aged 3–12 years has identified regional and environmental factors influencing these parameters [27]. Collectively, these findings underscore the need for continuous monitoring of physical development in diverse contexts. Anthropometric indicators and body composition parameters are closely related to physical performance, particularly lower-limb explosive strength, which represents a key determinant in many sports disciplines.

Previous research has demonstrated that targeted exercise and training programmes can significantly enhance lower-limb explosive strength, thereby positively affecting overall athletic performance [28,29]. In line with these findings, the primary aim of the present study was to compare lower-limb explosive strength among three groups of girls—two athletic groups and one non-athletic control group—using the CMJ, countermovement jump with arm swing (CMJ FA), and squat jump (SJ) tests. The results showed that athletic girls achieved higher vertical jump values across all tests compared with non-athletic girls, which is consistent with the study hypothesis and existing literature. One-way analysis of variance revealed statistically significant differences between groups across all measured jump tests, and Tukey's post hoc analysis confirmed significant between-group differences.

The most pronounced differences were observed in the CMJ FA test, highlighting the importance of coordinated involvement of the upper and lower limbs. Higher performance values in the athletic groups indicate a more effective utilization of the stretch–shortening cycle (SSC), which is characteristic of systematically trained individuals. These findings emphasize the role of movement technique and intermuscular coordination in the development of lower-limb explosive strength.

A secondary aim of the study was to examine the effects of strength-oriented training modalities targeting explosive strength development in athletic girls. Diagnostic results indicated that training programmes supplemented with basic weightlifting exercises from an early age represent an effective stimulus for increasing lower-limb explosive strength, a conclusion supported by previous evidence [2]. The medium to large effect sizes observed across the jump tests confirm the practical relevance of these findings.

Comparison of the two athletic groups revealed that Group 2 achieved higher mean jump values across all tests than Group 1, with statistically significant differences observed primarily in comparison with the non-athletic control group. These results suggest a potential influence of training frequency, training specialization, or the overall quality of strength training. The superior performance of Group 2 supports the positive effect of systematic strength training performed twice per week, with training frequency showing a statistically significant impact on performance outcomes ($p < 0.05$).

Analysis of covariance further demonstrated a significant between-group effect in CMJ performance, indicating a medium-sized group effect. Post hoc Bonferroni analysis confirmed that the significant difference occurred between Groups G2 and G3 ($p = 0.001$), with the control group exhibiting substantially lower performance. This suggests a limited ability of the non-athletic group to utilize the SSC during the CMJ, potentially reflecting differences in muscular strength development or jumping technique. For the CMJ FA test, ANCOVA revealed a highly significant between-group effect with a very large effect size, and post hoc analysis confirmed significant differences between both athletic groups and the control group. Performance in the SJ test followed a similar pattern, with the control group achieving markedly lower jump heights, indicating a reduced capacity to generate concentric muscular force without SSC contribution.

A difference of approximately 3–5 cm in vertical jump performance is of practical relevance, as supported by meta-analytic evidence demonstrating meaningful performance improvements following plyometric interventions [8,30]. International studies further confirm the effectiveness of plyometric, strength, and combined training methods in enhancing explosive strength, with combined approaches providing additional benefits through the integration of strength and power exercises [31–35]. Moderate-volume plyometric training has also been shown to be effective, with recent studies supporting its safety and efficacy in youth populations when appropriate technique, intensity, and training volume are applied [36–41].

Despite the growing body of evidence supporting the positive effects of strength and plyometric training on motor performance, meta-analytic findings indicate that research has predominantly focused on adult populations, with adolescents remaining relatively underrepresented [5]. Extrapolating adult findings to youth athletes is problematic due to biological processes associated with maturation, including accelerated growth, transient disruptions in motor coordination, increases in muscle mass proportion, and structural adaptations of muscles and tendons, all of which directly influence performance outcomes.

In conclusion, the results of the present study indicate that the integration of plyometric training supplemented with basic strength exercises has a positive effect on lower-limb explosive strength across all types of vertical jumps, with and without arm involvement. Increasing the frequency of strength training to two sessions per week appears to be particularly beneficial. Although the applicability of these findings to highly trained athletes or other sports disciplines requires further investigation, the present evidence highlights the importance of structured, progressive, and targeted training programmes in supporting athletic development and enhancing motor performance in school-aged girls.

Limitations

Despite the statistically significant findings, the results of the present study should be interpreted in light of several limitations. First, the explanatory contribution of certain covariates—particularly body height—was relatively low. Although body height reached statistical significance, it accounted for only a small proportion of the variance in CMJ, CMJ FA, and SJ performance. This suggests that other potentially influential factors, such as body mass, detailed body composition characteristics, neuromuscular coordination, or participants' prior training history, were not included in the analytical model.

A second limitation concerns the group factor, which explained a substantial proportion of performance variability; however, the specific characteristics underlying the differences between groups were not examined in detail. Variables such as the precise structure of strength training programmes, training intensity and volume, exercise selection, and individual responsiveness to training were not quantitatively assessed. Consequently, it was not possible to determine which components of the training process had the greatest influence on vertical jump performance.

Another limitation relates to the use of the standard countermovement jump (CMJ) as the primary indicator of stretch–shortening cycle (SSC) utilization. While the CMJ provides valuable information on lower-limb explosive strength, it does not allow for a detailed assessment of SSC-related mechanisms, such as ground contact time, eccentric phase velocity, rate of force development, or muscle activation patterns. These aspects could be more accurately evaluated using advanced biomechanical analyses or electromyographic (EMG) techniques.

One of the main methodological limitations of the study is the lack of randomization of participants into the respective groups. Group allocation was based on existing training routines and sports affiliation, which may have introduced selection bias. Although all participants were classified as biologically immature and in the pre–peak height velocity (pre-PHV) period, the potential influence of individual differences in training history, genetic predispositions, or baseline motor skill levels on the observed outcomes cannot be excluded.

In addition, the sample size and its relative homogeneity should be considered. The limited number of participants and their specific performance characteristics may restrict the generalizability of the findings to broader populations, including athletes from other sports disciplines or recreationally active youth.

Finally, the cross-sectional design of the study precludes the assessment of long-term training adaptations. As a result, causal relationships between strength training interventions and improvements in vertical jump performance cannot be established, and the findings should be interpreted as associative rather than causal.

In light of these limitations, future research should incorporate a broader range of covariates, provide more detailed quantification of training interventions, and include comprehensive biomechanical and neuromuscular assessments of jumping performance. Such approaches would allow for a more precise identification of the determinants of vertical jump performance and a deeper understanding of training-related adaptations in youth athletes.

CONCLUSION

The results of the present study confirm that the inclusion of power-oriented strength training within regular athletic preparation constitutes an effective stimulus for enhancing physical abilities in young female athletes. The findings further highlight the importance of sport-specific, power-oriented strength training and its positive application in youth athletics.

Based on the present results, several key insights emerge with important implications for pedagogical practice and physical education. In particular, the assessment and development of lower-limb explosive strength in older school-age children who actively participate in organized sports appear to be especially relevant, as this topic has received increasing attention in recent years.

Funding Statement: This work was funded by the European Union – NextGenerationEU through the Recovery and Resilience Plan for Slovakia under Project No. 09I03-03-V05-00006.

Conflicts of Interest: The authors declare no conflict of interest.

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