



Plyometric Training Effects on Relative Lower-Limb Strength and Estimated VO₂max in Student Soccer Players

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Abstract

Study purpose. The primary objective of this study is to investigate the effects of a structured plyometric training intervention on relative lower-limb muscular strength and estimated maximal oxygen uptake ($\text{VO}_{2\text{max}}$) in student soccer players. Specifically, this research seeks to determine whether systematic plyometric exercises can induce neuromuscular adaptations that enhance relative force production per unit of body mass, while concurrently evaluating their transfer effects on aerobic capacity

Materials and methods. This study examined the effects of plyometric training on relative lower-limb strength and estimated VO₂max in student soccer players. Thirty athletes were screened, and 27 with complete pretest and posttest data were analyzed, comprising a plyometric group (n = 14) and a control group (n = 13). The plyometric group completed two progressive plyometric sessions per week for eight weeks in addition to routine soccer training. Relative lower-limb strength was calculated as the ratio of one-repetition maximum (1RM) back squat to body mass, whereas estimated VO₂max was obtained from the 20-m multistage shuttle run.

Results. Baseline-adjusted ANCOVA was the primary inferential analysis, supported by Wilcoxon and Mann-Whitney tests. Relative lower-limb strength showed a significant adjusted between-group difference of 0.312 (95% CI 0.054 to 0.570), $F(1,24) = 6.21$, $p = 0.020$, $\eta^2 = 0.206$, and remained significant in the HC3 sensitivity analysis ($p = 0.023$). Estimated VO₂max also differed significantly by 3.97 mL·kg⁻¹·min⁻¹ (95% CI 2.88 to 5.07), $F(1,24) = 55.90$, $p < 0.001$, $\eta^2 = 0.700$. Absolute 1RM was not significant after adjustment ($p = 0.095$).

Conclusions. A structured plyometric training program effectively enhances relative lower-limb strength in student soccer players, driven by neuromuscular adaptations and improved stretch-shortening cycle efficiency. Additionally, plyometric drills induce positive concurrent adaptations in estimated $\text{VO}_{2\text{max}}$, demonstrating that high-intensity explosive training supports aerobic conditioning without blunting cardiovascular performance.

Consequently, incorporating systematic plyometric exercises into youth soccer regimens serves as a time-efficient strategy to concurrently optimize relative muscular power and sport-specific endurance.

Keywords: Plyometric Training, Relative Lower-Limb Strength, Estimated VO₂Max, Student Soccer Players.

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Introduction

Soccer is a team sport that requires players to repeatedly perform high-intensity actions, including sprinting, jumping, acceleration, deceleration, changes of direction, and physical duels. The ability to perform these actions is influenced in part by lower-limb strength and power, which contribute to force production during running, kicking, jumping, landing, tackling, and rapid changes of direction. Aerobic endurance is also important for meeting energy demands during matches, accelerating recovery between high-intensity efforts, and helping players maintain work intensity during training and competition (Compton et al., 2026). The MOVE–THINK–RISE model was developed to address these limitations by integrating three components: plyometric-based movement activities (MOVE), cognitive engagement in understanding and controlling movement (THINK), and reflection on performance progress (RISE). The model's novelty lies in the systematic integration of physiological adaptations, cognitive processes, and learning reflection within a single intervention framework, rather than merely combining physical training methods (Markovic & Mikulic, 2010; Slimani et al., 2016; Wulf & Lewthwaite, 2016).

Plyometric training uses the stretch-shortening cycle (SSC), a rapid eccentric contraction immediately followed by an explosive concentric contraction. This mechanism allows muscles and tendons to store and release elastic energy efficiently, supporting greater force production, maximal strength, and muscular power (Sun et al., 2025). Exercises such as squat jumps, countermovement jumps, hopping, bounding, hurdle jumps, and drop jumps may increase motor-unit recruitment, muscle-tendon complex stiffness, elastic-energy utilization, and rate of force development. Evidence in youth soccer generally shows improvements in jumping, sprinting, and change-of-direction ability, although responses may vary according to age, maturation, exercise selection, volume, and technical proficiency (Chen et al., 2024; Ramirez-Campillo et al., 2023; Zghal et al., 2025). Therefore, supervision, landing quality, and gradual progression of training load are important when plyometric training is applied to school-age athletes.

Recent studies have reported benefits of plyometric training across different groups of youth soccer players. Improvements in jumping, sprinting, and change-of-direction performance have been observed after high-intensity programs, programs performed once or twice weekly, and programs that account for maturation status (Bianchi et al., 2019; Sammoud et al., 2024; Söyler et al., 2024; Zheng et al., 2025). Randomized studies have also shown improvements in strength and functional performance (Hasan, 2023), while longer interventions have improved short-distance sprint performance and reactive-strength indicators (Matuszczyk et al., 2025). The within-session order of balance and plyometric exercises appears less important than the consistency and overall quality of the program (Chaouachi et al., 2017). Beyond explosive performance, plyometric training performed alone or combined with short sprints has also been associated with improved repeated-sprint ability and endurance (Aloui et al., 2022; Ramirez-Campillo et al., 2016).

Despite the broad evidence supporting plyometric training, several questions remain insufficiently resolved. Youth soccer research more often prioritizes jump height, sprint time,

and change-of-direction ability, while maximal strength is frequently represented indirectly through explosive tests or examined together with other conditioning methods (Sammoud et al., 2024; Zheng et al., 2025). Endurance findings are also more difficult to isolate because plyometric programs are often combined with sprinting or other sport-specific conditioning, which makes the independent contribution of plyometric training less clear (Aloui et al., 2022; Ramírez-Campillo et al., 2016). In adolescent athletes, interpretation is further complicated because age, body size, training experience, and biological maturation can influence both strength and aerobic performance (Chen et al., 2024; Ramirez-Campillo et al., 2023). Based on this gap, the present study examined two more specific outcomes, relative lower-limb strength and estimated VO₂max, in student soccer players. Relative strength was selected because it normalizes 1RM performance to body mass, whereas estimated VO₂max was obtained using the 20-m multistage shuttle run as a field test of aerobic fitness. Absolute 1RM was retained as a supporting outcome to describe raw strength change. We hypothesized that, after controlling for baseline values, the plyometric group would show higher posttest relative lower-limb strength and estimated VO₂max than the control group.

Materials and Methods

Study participants

This study employed a pretest–posttest design with parallel groups, conducted from March to July 2026 at Garuda Muda Academy in North Bolaang Mongondow Regency, North Sulawesi, Indonesia. A total of 30 athletes underwent an initial screening process; three did not proceed to the allocation stage as they failed to meet the study criteria. The 27 athletes who met the inclusion criteria and completed the entire series of final measurements were included in the analysis, comprising 14 athletes in the plyometric training group and 13 in the control group.

Participants were selected using purposive sampling based on the alignment of their characteristics with the target users of the MOVE–THINK–RISE model. The selection of the research site took into account the presence of an active soccer development program, the participants' training experience, and the adequacy of facilities and the training environment for implementing the intervention. These characteristics made the participants relevant representatives of the school-aged young athletes targeted by the model—specifically those requiring physical skill development alongside enhanced movement awareness and learning processes during training. Purposive sampling was utilized because sample selection in intervention research relies on aligning participant characteristics with the objectives and implementation context of the model (Palinkas et al., 2021).

Group Allocation

After screening and pretest measurements, 27 athletes were allocated to the plyometric group (n = 14) and control group (n = 13). Study records state that group allocation was random. Specific procedures, such as the use of a random-number generator or sealed envelopes, are not documented as facts in this manuscript. This documentation limitation is important because baseline imbalance existed between groups and was subsequently considered in the analysis and discussion. Reporting follows CONSORT transparency principles (Schulz et al., 2010).

The limited documentation of allocation was treated as a reporting limitation. The absence of sequence-generation and allocation-concealment logs means that the independence of the allocation process cannot be reverified from the available study documentation. Therefore, the findings were interpreted with consideration of possible residual confounding, particularly that related to age, body size, and biological maturation.

Table 1. Comparison of Intervention Models

Component	Conventional Plyometric Model	MOVE-THINK-RISE
Theoretical basis	Neuromuscular adaptation and the stretch-shortening cycle	Neuromuscular, motor learning, and reflexes
Focus	Improvements in power, strength, and sprinting	Physical, cognitive, and personal development
Target results	Athlete's physical performance	Relative lower-limb strength, estimated VO ₂ max, movement awareness, and self-regulation.
Mechanism	Repetition of exercises and progressive overload	MOVE → THINK → RISE through practice, understanding, and reflection.
The role of the coach	Training instructor	Training and learning facilitator

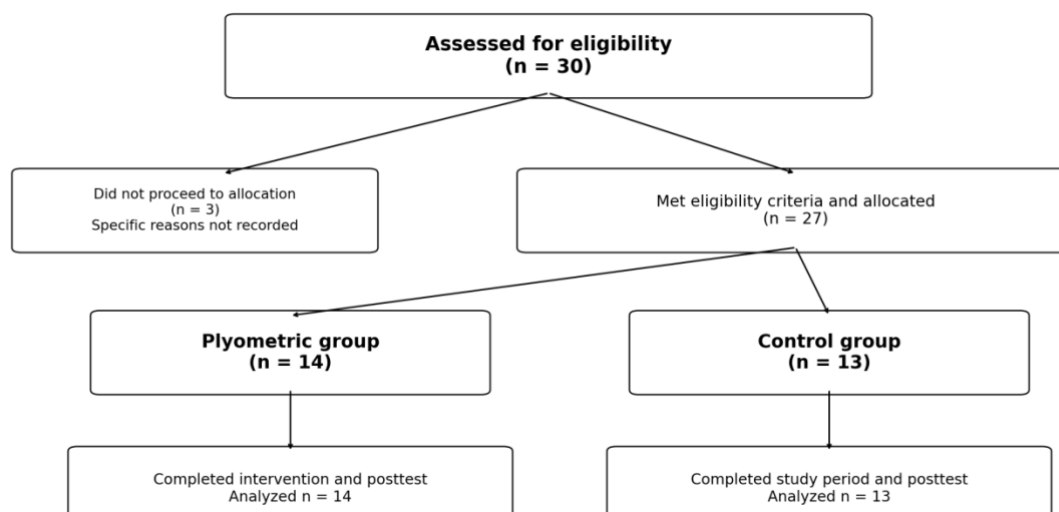


Figure 1. Participant flow from screening to final analysis. Thirty athletes were screened, 27 proceeded to allocation, and all had complete posttest data.

Study organization

Training Intervention

Both groups continued the same routine soccer training program, including warm-up, technical and tactical training, small-sided games or team play, and cool-down. The plyometric group received additional training twice per week for eight weeks, with at least 48 hours between sessions. Plyometric sessions were scheduled after the warm-up and before technical or tactical training involving high loads. The exercise sequence progressed from bilateral movements and simple landings to unilateral and multidirectional exercises, hurdle jumps, bounding, split-squat jumps, and drop jumps. The target dose was maintained at 2 to 3 sets of 6 to 8 repetitions for most exercises, with approximately 48 to 96 jump contacts per session. Rest intervals were approximately 60 to 90 seconds between sets and 2 to 3 minutes between exercise types. Drop jumps were introduced from 20 cm and progressed to 30 to 40 cm only when athletes could maintain knee alignment, balance, controlled landing, and report no pain. The program targets were the same for all athletes in the plyometric group, while progression of drop-jump height and movement complexity was adjusted according to technical quality. Dose and progression were based on the study intervention parameters and previously reported

training principles for youth soccer (Bianchi et al., 2019; Chaouachi et al., 2017; Ramirez-Campillo et al., 2019; de Salles et al., 2009). Weekly program targets are presented in Table 2.

Table 2. Eight-Week Progressive Plyometric Training Program

Week	Exercise sequence per session	Target dose and volume	Progression focus
1	Session 1: squat jump, countermovement jump, standing long jump, lateral line jump. Session 2: squat jump, countermovement jump, ankle jump, lateral jump.	2 × 6 per exercise. Approximately 48 contacts per session and 96 contacts per week.	Technical adaptation. Low intensity. Focus on knee position, two-leg landing, and body control. Drop jumps not yet used.
2	Session 1: squat jump, tuck jump, standing long jump, bounding. Session 2: countermovement jump, tuck jump, lateral jump, low hurdle jump.	2 × 8 per exercise. Approximately 64 contacts per session and 128 contacts per week.	Low to moderate intensity. Volume increased without increasing drop height. Technique remains the primary criterion.
3	Session 1: countermovement jump, bounding, split-squat jump, 20-cm drop jump. Session 2: tuck jump, lateral jump, hurdle jump, 20-cm drop jump.	3 × 6 per exercise. Approximately 72 contacts per session and 144 contacts per week.	Drop jumps introduced at 20 cm. Athletes progress only with stable landings and no pain.
4	Session 1: countermovement jump, bounding, split-squat jump, 20-cm drop jump. Session 2: tuck jump, standing long jump, hurdle jump, 20-cm drop jump.	3 × 8 per exercise. Approximately 96 contacts per session and 192 contacts per week.	Moderate intensity. Emphasis on eccentric-concentric transition speed and landing quality.
5	Session 1: split-squat jump, bounding, lateral multidirectional jump, 30-cm drop jump. Session 2: countermovement jump, hurdle jump, standing long jump, 30-cm drop jump.	3 × 8 per exercise. Approximately 96 contacts per session and 192 contacts per week.	Unilateral and multidirectional complexity increased. Drop-jump height may progress to 30 cm when technique meets the criteria.
6	Session 1: split-squat jump, bounding, lateral multidirectional jump, 30-cm drop jump. Session 2: tuck jump, hurdle jump, standing long jump, 30-cm drop jump.	3 × 8 per exercise. Approximately 96 contacts per session and 192 contacts per week.	Moderate to high intensity. Movement quality prioritized. Repetitions reduced if landing control declines.

Week	Exercise sequence per session	Target dose and volume	Progression focus
7	Session 1: split-squat jump, bounding, hurdle jump, 40-cm drop jump. Session 2: countermovement jump, tuck jump, lateral multidirectional jump, 40-cm drop jump.	3 × 8 per exercise. Approximately 96 contacts per session and 192 contacts per week.	Highest-load phase. A 40-cm drop jump is used only for athletes who are consistent at 30 cm and show no pain or loss of control.
8	Session 1: countermovement jump, standing long jump, hurdle jump, 40-cm drop jump. Session 2: squat jump, bounding, lateral jump, 40-cm drop jump.	2 × 8 per exercise. Approximately 64 contacts per session and 128 contacts per week.	Consolidation and volume reduction before posttest. Technical intensity maintained while volume is reduced to limit residual fatigue.

Note: [Table 2.](#) presents weekly program targets organized from the intervention parameters and methodological references used.

Attendance and Training Exposure

The intervention comprised 16 scheduled sessions over eight weeks. Study documentation included detailed attendance sheets for each training session, allowing participation by athletes in the plyometric group to be monitored throughout the intervention. All 14 athletes in the plyometric group included in the analysis completed the study through posttest and had complete final measurement data. All 13 athletes in the control group included in the analysis also had complete pretest and posttest data. Attendance sheets were used as the basis for monitoring participation at each session, whereas each athlete's actual jump volume, session rating of perceived exertion (session-RPE), and external training-load measures were not completely documented for analysis. Routine soccer-training exposure was kept as similar as possible between groups. This reporting clarifies that attendance was documented at the session level, while interpretation of training dose remains limited to the available program-volume information.

Instruments and Outcome Definitions

The two main outcomes were relative lower-limb strength and estimated $\text{VO}_{2\text{max}}$. Relative lower-limb strength was calculated as the ratio of 1RM back squat to body mass, while absolute 1RM was reported as a supporting outcome. The 1RM assessment was performed after a general warm-up and several familiarization sets with progressively increasing loads. The load was then increased by 2.5 to 5 kg until the athlete could no longer complete one repetition using the specified technique. The barbell was positioned across the upper trapezius, squat depth was standardized until the top of the thighs was approximately parallel to the floor, and 3 to 5 minutes of recovery was provided between maximal attempts. The heaviest successfully lifted load was recorded in kilograms. The same equipment, depth criteria, instructions, and assessors were used at pretest and posttest. Familiarization and technique standardization support the reliability of 1RM testing, while movement depth must be controlled because inconsistency can alter the recorded load (Niewiadomski et al., 2008; Ryman Augustsson & Svantesson, 2013; Keiner et al., 2025).

$\text{VO}_{2\text{max}}$ estimation in this study utilized the 20-m multistage shuttle run test (20-m MSFT), a field-based instrument with established criterion validity and test-retest reliability for

assessing cardiorespiratory fitness in adolescents and young athletes (Lang et al., 2018; Tomkinson et al., 2019). Measurement reliability was ensured through the standardization of pre-test and post-test procedures, including the use of consistent tracks, audio recordings, warm-up routines, instructions, timing, and evaluators. As the obtained values represent estimated VO_2max rather than direct measurements derived from respiratory gas analysis, the interpretation of results takes into account performance factors such as motivation, change-of-direction ability, and participant familiarity with the test (Tomkinson et al., 2019). Furthermore, the suitability of the measurement procedures was evaluated by three experts in sports science and exercise physiology through content validation using the Content Validity Index (CVI) approach; a value of ≥ 0.80 indicates acceptable content validity, while ≥ 0.90 indicates excellent validity (Polit & Beck, 2021).

Statistical analysis

Data were summarized as mean $\pm$ standard deviation and categorical frequencies. The initial protocol did not prospectively designate a single primary outcome. To maintain consistency with the study objective, relative lower-limb strength and estimated VO_2max were treated as the two main outcomes for interpretation, while absolute 1RM was retained as a supporting outcome. Baseline-adjusted ANCOVA was used as the primary inferential analysis to compare posttest values between groups. Each model included group as a fixed factor and the corresponding pretest value as a covariate. Baseline adjustment was prioritized because the groups showed material differences in initial conditions (Egbewale et al., 2014; Wang et al., 2019; Tackney et al., 2023). Wilcoxon signed-rank tests for within-group change and Mann-Whitney tests for between-group differences in gain scores were used as supporting analyses because some change-score distributions were non-normal. Use of ANCOVA does not depend on normality of change scores. Model diagnostics included the group $\times$ pretest interaction for homogeneity of regression slopes, the Shapiro-Wilk test on ANCOVA residuals, and the Breusch-Pagan test for heteroscedasticity. When residual normality was questionable, HC3 robust standard errors were used as a sensitivity analysis. ANCOVA results were reported as adjusted means, adjusted between-group differences with 95% confidence intervals, F statistics, p values, and partial eta squared (η^2). Values of η^2 of 0.01, 0.06, and 0.14 were interpreted as small, medium, and large effects, respectively. As a conservative approach to multiple testing, Holm correction was applied to the three reported ANCOVA models, comprising the two main outcomes and one supporting outcome. Statistical significance was set at $p < 0.05$. Broad multivariable adjustment for age, height, and body mass was not used as the primary model because the sample was small and these covariates were interrelated. The implications are discussed as a limitation.

Results

Participant Characteristics

Of the 30 athletes screened, 27 were included in the final analysis, comprising 14 in the plyometric group and 13 in the control group. Baseline characteristics showed marked imbalance between groups. The plyometric group was older, taller, heavier, and stronger at pretest, whereas the control group had a higher mean pretest estimated VO_2max . Standardized mean differences were large for age (1.51), height (1.57), body mass (0.90), pretest absolute 1RM (1.19), pretest relative lower-limb strength (0.93), and estimated VO_2max (-1.01). These imbalances are relevant because age, body size, and maturation can affect strength performance and aerobic fitness in adolescents. Participant characteristics are presented in Table 3.

Table 3. Participant Characteristics

Group	n	Age (years)	Training experience (years)	Height (cm)	Body mass (kg)
Plyometric	14	15.36 ± 0.93	2.29 ± 1.07	158.29 ± 9.72	48.78 ± 15.25
Control	13	13.15 ± 1.86	1.69 ± 2.21	142.08 ± 10.87	37.05 ± 10.10

Note: Data are presented as mean ± standard deviation.

Lower-Limb Strength Results

The principal strength outcome in this study was relative lower-limb strength, defined as the 1RM-to-body-mass ratio. Absolute 1RM is also presented to provide context for the ratio. Descriptively, mean squat 1RM increased from 63.04 to 89.32 kg in the plyometric group and from 43.92 to 55.15 kg in the control group, with mean raw increases of 26.29 and 11.23 kg, respectively. Because baseline absolute 1RM was higher in the plyometric group, raw gain was not used as the primary evidence of the intervention effect. Descriptive 1RM statistics are presented in Table 4.

Table 4. Descriptive Statistics for Back Squat 1RM as a Supporting Outcome

Group	n	Pretest (kg)	Posttest (kg)	Increase (kg)	Increase (%)	Range of increase (kg)
Plyometric	14	63.04 ± 17.77	89.32 ± 25.38	26.29 ± 14.60	42.69	2.00–51.00
Control	13	43.92 ± 14.05	55.15 ± 22.01	11.23 ± 13.17	24.93	1.50–39.00

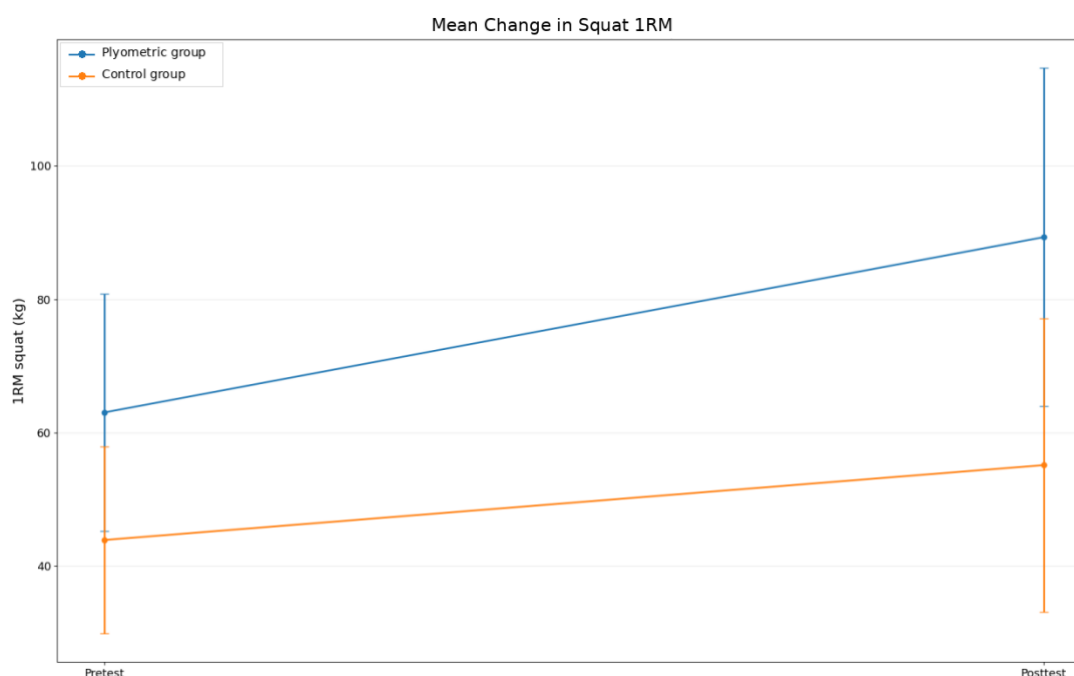


Figure 2. Mean change in squat 1RM in the plyometric and control groups.

Based on the 1RM-to-body-mass ratio, mean relative lower-limb strength in the plyometric group increased from 1.309 to 1.855, while the control group increased from 1.177 to 1.463. Category distributions are presented in Table 5 and mean changes in Figure 3.

Table 5. Distribution of Relative Lower-Limb Strength Categories Based on the 1RM-to-Body-Mass Ratio

Group	Time	Moderate, n (%)	Good, n (%)	Very good, n (%)	Total
Plyometric	Pretest	9 (64.3%)	5 (35.7%)	0 (0.0%)	14
Plyometric	Posttest	1 (7.1%)	4 (28.6%)	9 (64.3%)	14
Control	Pretest	12 (92.3%)	1 (7.7%)	0 (0.0%)	13
Control	Posttest	7 (53.8%)	5 (38.5%)	1 (7.7%)	13

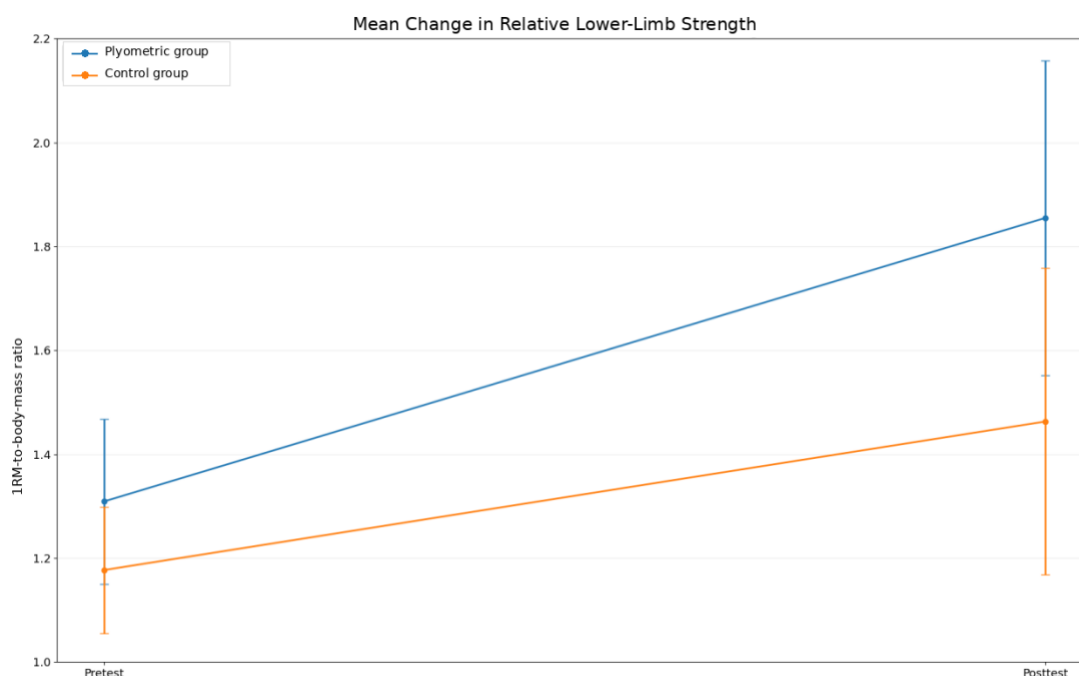


Figure 3. Mean change in relative lower-limb strength based on the 1RM-to-body-mass ratio.

Estimated VO₂max Results from the 20-m Shuttle Run

The mean estimated VO₂max in the plyometric group increased from 51.31 to 55.89 mL·kg⁻¹·min⁻¹ (an increase of 4.58 mL·kg⁻¹·min⁻¹ or 8.96%), whereas the control group increased from 54.60 to 55.03 mL·kg⁻¹·min⁻¹ (a change of 0.43 mL·kg⁻¹·min⁻¹ or 0.82%). These increases indicate an improvement in aerobic fitness performance based on the 20-meter shuttle-run test results. However, these values are interpreted as field-based estimates of VO₂max rather than direct measurements of maximal oxygen consumption via respiratory gas analysis. Consequently, the observed changes may reflect an enhanced ability to perform high-intensity aerobic activity, yet they remain influenced by factors such as movement efficiency, change-of-direction ability, motivation, and familiarity with the test protocol.

Table 6. Descriptive Statistics for Estimated VO₂max from the 20-m Shuttle Run

Group	n	Pretest	Posttest	Increase	Increase (%)	Range of increase
Plyometric	14	51.31 ± 2.68	55.89 ± 2.93	4.58 ± 1.34	8.96	2.77–5.70
Control	13	54.60 ± 3.78	55.03 ± 3.66	0.43 ± 1.05	0.82	0.00–3.00

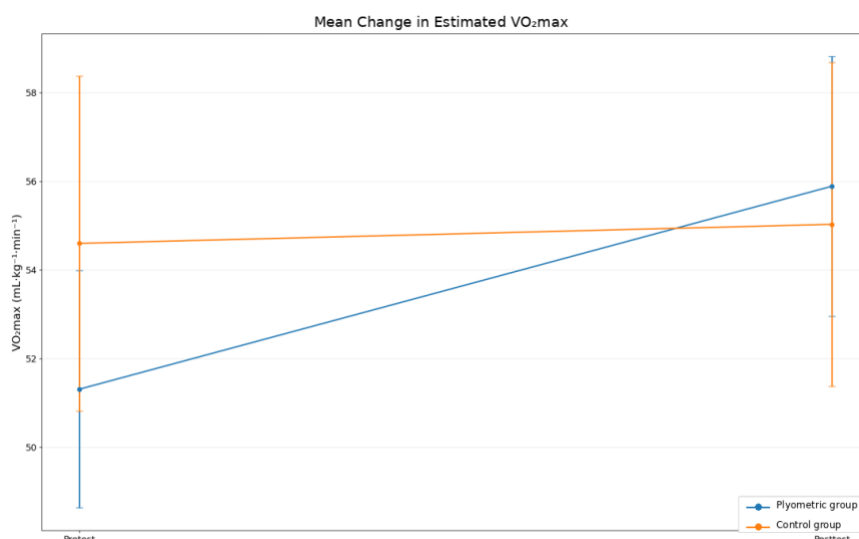


Figure 4. Mean change in estimated VO₂max from the 20-m shuttle run in the plyometric and control groups.

Table 7. Distribution of Estimated VO₂max Categories

Group	Time	Moderate, n (%)	Good, n (%)	Very good, n (%)	Total
Plyometric	Pretest	5 (35.7%)	8 (57.1%)	1 (7.1%)	14
Plyometric	Posttest	0 (0.0%)	7 (50.0%)	7 (50.0%)	14
Control	Pretest	1 (7.7%)	6 (46.2%)	6 (46.2%)	13
Control	Posttest	0 (0.0%)	7 (53.8%)	6 (46.2%)	13

Statistical Analysis Results

Statistical testing was conducted at a significance level of 0.05. Shapiro-Wilk results for change scores are presented in Table 8 and support the use of nonparametric tests for the supporting change analyses. In the ANCOVA models, the group × pretest interaction was not significant for absolute 1RM ($p = 0.776$), relative lower-limb strength ($p = 0.816$), or estimated VO₂max ($p = 0.783$), supporting the homogeneity-of-regression-slopes assumption. The Breusch-Pagan test indicated no heteroscedasticity, with all $p \geq 0.356$. ANCOVA residuals were approximately normally distributed for absolute 1RM (Shapiro-Wilk $p = 0.180$) and estimated VO₂max ($p = 0.133$), whereas relative lower-limb strength residuals deviated from normality ($p = 0.018$). In the sensitivity analysis using HC3 robust standard errors, the group effect on relative lower-limb strength remained significant ($p = 0.023$), the effect on estimated VO₂max remained significant ($p < 0.001$), and the effect on absolute 1RM remained non-significant ($p = 0.153$).

Table 8. Normality Test Results for Change Scores

Variable	Group	Shapiro-Wilk W	p	Result
1RM squat	Experimental	0.960	0.726	Normal
1RM squat	Control	0.748	0.002	Non-normal
VO ₂ max	Experimental	0.683	< 0.001	Non-normal
VO ₂ max	Control	0.459	< 0.001	Non-normal

Tabel 9. Main Adjusted Analysis and Supporting Change Analyses

Variable	Analysis	Statistic / adjusted estimate (95% CI)	p (Holm- corrected)	Effect / interpretation
1RM squat	Wilcoxon: Plyometric pre- post	W = 0.00	<0.001	Supporting, significant
1RM squat	Wilcoxon: Control pre-post	W = 0.00	<0.001	Supporting, significant
1RM increase	Mann-Whitney: between groups	U = 138.00	0.024	Supporting, significant
Absolute 1RM	ANCOVA (supporting)	Adjusted difference = 10.83 kg (-2.01 to 23.66)	0.095 (0.095)	$\eta^2 = 0.112$, not significant
Relative lower- limb strength	ANCOVA (main)	Adjusted difference = 0.312 (0.054 to 0.570)	0.020 (0.040)	$\eta^2 = 0.206$, significant
Estimated VO ₂ max	Wilcoxon: Plyometric pre- post	W = 0.00	<0.001	Supporting, significant
Estimated VO ₂ max	Wilcoxon: Control pre-post	W = 0.00	0.500	Supporting, not significant
VO ₂ max increase	Mann-Whitney: between groups	U = 177.00	<0.001	Supporting, significant
Estimated VO ₂ max	ANCOVA (main)	Adjusted difference = 3.97 mL·kg ⁻¹ ·min ⁻¹ (2.88 to 5.07)	<0.001 (<0.001)	$\eta^2 = 0.700$, significant

Note: ANCOVA rows show between-group differences after baseline adjustment. Relative lower-limb strength and estimated VO₂max are the two main outcomes for interpretation, while absolute 1RM is a supporting outcome. Wilcoxon and Mann-Whitney rows are supporting change analyses. Values in parentheses in the p column are Holm-corrected p values for the three ANCOVA models. CI = confidence interval, η^2 = partial eta squared.

The supporting Wilcoxon tests showed significant pretest-to-posttest increases in squat 1RM in both the plyometric group (W = 0.00, p < 0.001) and the control group (W = 0.00, p < 0.001). Comparison of raw gain scores also favored the plyometric group (U = 138.00, p =

0.024). These analyses describe the observed changes but were not used as the primary basis for causal interpretation because the groups differed markedly at baseline.

For the two main outcomes, ANCOVA showed significant between-group differences after baseline adjustment. The adjusted posttest mean for relative lower-limb strength was 1.817 (95% CI 1.647 to 1.987) in the plyometric group and 1.505 (95% CI 1.328 to 1.682) in the control group. The adjusted difference was 0.312 (95% CI 0.054 to 0.570), $F(1,24) = 6.21$, $p = 0.020$, $\eta^2 = 0.206$, and remained significant after Holm correction ($p = 0.040$). For estimated $\text{VO}_{2\text{max}}$, the adjusted posttest mean was $57.39 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (95% CI 56.67 to 58.11) in the plyometric group and $53.42 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (95% CI 52.67 to 54.16) in the control group. The adjusted difference was $3.97 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (95% CI 2.88 to 5.07), $F(1,24) = 55.90$, $p < 0.001$, $\eta^2 = 0.700$, with Holm-corrected $p < 0.001$. As a supporting outcome, the adjusted posttest mean for absolute 1RM was 78.08 kg (95% CI 69.84 to 86.33) in the plyometric group and 67.26 kg (95% CI 58.65 to 75.87) in the control group. The adjusted difference was 10.83 kg (95% CI -2.01 to 23.66), $F(1,24) = 3.03$, $p = 0.095$, $\eta^2 = 0.112$, and was not statistically significant.

The main results indicate that eight weeks of plyometric training significantly affected relative lower-limb strength and estimated $\text{VO}_{2\text{max}}$ in this sample of student soccer players after baseline values were controlled. The raw increase in absolute 1RM was greater in the plyometric group, but the adjusted effect on absolute 1RM was not significant. Therefore, interpretation focuses on the two outcomes specified in the title rather than a claim of improved absolute maximal strength.

Summary of Findings

Based on baseline-adjusted ANCOVA, the plyometric group had significantly higher posttest relative lower-limb strength and estimated $\text{VO}_{2\text{max}}$ than the control group. For relative lower-limb strength, the adjusted difference was 0.312 with $p = 0.020$ and $\eta^2 = 0.206$. For estimated $\text{VO}_{2\text{max}}$, the adjusted difference was $3.97 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ with $p < 0.001$ and $\eta^2 = 0.700$. In contrast, absolute 1RM as a supporting outcome did not show a significant adjusted difference. This pattern supports a conclusion specifically related to relative lower-limb strength and estimated $\text{VO}_{2\text{max}}$ derived from the 20-m shuttle run.

Discussion

Research findings indicate that an eight-week progressive plyometric training program significantly influenced relative lower-body strength and estimated $\text{VO}_{2\text{max}}$ after controlling for baseline values—with a more pronounced effect observed on estimated $\text{VO}_{2\text{max}}$ than on relative strength. Conversely, absolute 1RM values showed no significant effect; consequently, the interpretation of results focuses on functional strength adaptations normalized to body mass and improvements in shuttle-run performance as an indicator of aerobic fitness. Regarding model development, this study has completed the Define, Design, and Develop stages, while the Disseminate stage remains pending for future research. Therefore, these results represent preliminary evidence of the model's effectiveness and feasibility rather than a validation of widespread implementation, necessitating further research involving dissemination and testing across more diverse learning or training contexts. The effect on relative lower-limb strength is consistent with the neuromuscular demands of the stretch-shortening cycle. Repeated rapid eccentric-concentric actions may support motor-unit recruitment, intermuscular coordination, elastic-energy utilization, and rate of force development. Previous randomized and comparative studies in soccer players have also reported improvements in strength, jumping, sprinting, and functional performance when plyometric training is provided at an appropriate dose ([Bianchi et al., 2019](#); [Hasan, 2023](#); [Matuszczyk et al., 2025](#)). Systematic evidence in youth players also supports benefits for explosive movement and change-of-direction performance ([Sammoud et](#)

al., 2024; Söyler et al., 2024; Zheng et al., 2025). The present findings are consistent with this literature, although the magnitude of the effects should be interpreted in light of the small sample and baseline imbalance.

The difference between absolute and relative strength results should be interpreted together with the baseline imbalance. Before the intervention, the plyometric group was older, taller, heavier, and stronger, while biological maturation was not directly assessed. Absolute strength is strongly influenced by body size, training experience, and maturation, whereas normalization to body mass may reduce but does not completely eliminate these influences (Chen et al., 2024; Ramirez-Campillo et al., 2023; Zghal et al., 2025). Accordingly, ANCOVA adjusting for baseline values was prioritized over raw gain scores. Broader adjustment for age, height, and body mass was not used as the primary model because there were only 27 participants and these covariates were interrelated, which could make the model unstable. Future studies should use stratified or blocked randomization based on age, maturation, or baseline performance.

The significant effect on estimated $\text{VO}_{2\text{max}}$ indicates that the plyometric group demonstrated better 20-m shuttle-run performance after the intervention. Repeated high-intensity jumps with relatively short recovery intervals may improve movement efficiency, tolerance to repeated acceleration, and the ability to sustain repeated work. This finding is consistent with studies reporting improved endurance outcomes or repeated-sprint performance after plyometric training performed alone or combined with short sprints (Aloui et al., 2022; Ramirez-Campillo et al., 2016; van de Hoef et al., 2020). However, the term estimated $\text{VO}_{2\text{max}}$ is retained because the 20-m shuttle run does not directly measure oxygen consumption using respiratory gas analysis. Some of the observed change may also be influenced by turning efficiency, test familiarity, motivation, and tolerance to repeated acceleration (Tomkinson et al., 2019).

From a practical perspective, two supervised plyometric sessions per week for eight weeks may be considered as supplemental training in similar student-soccer contexts when the objective is to develop relative lower-limb strength and shuttle-run performance. The program progressed from lower-intensity bilateral jumps to unilateral and multidirectional exercises, hurdle jumps, and drop jumps from 20 to 40 cm. Movement quality should precede increases in volume, and progression should occur only after stable landings, maintained knee alignment, adequate balance, and absence of pain. Because actual-volume logs and session attendance were not available, Table 1 should be interpreted as the target program rather than evidence that every athlete completed an identical number of contacts.

This study has several limitations, namely a small sample size, an imbalance in baseline characteristics between groups, the absence of direct biological maturation measurements, and the use of a 20-meter shuttle-run estimate for $\text{VO}_{2\text{max}}$ rather than direct measurement via gas analysis. Furthermore, the reported training program represents the intervention design rather than the exact actual training load of each participant. Nevertheless, this study contributes by developing the integrated MOVE, THINK, and RISE training model, which combines physical and cognitive stimuli with game-based responses within a single session. This approach moves beyond previous models which tended to separate physical capacity development from the situational demands of the game by offering a more holistic and efficient training framework to support soccer performance. Theoretically, the model reinforces the view that athletic performance results from the interaction between physical capabilities, cognitive processes, and game-context adaptations; practically, it holds potential for implementation as an integrated training strategy. However, further validation involving larger samples, more robust experimental designs, and implementation in real-world training settings is required to ensure the model's effectiveness and sustainability.

Conclusions and Suggestions

This study produced an initial prototype of a training model developed through the Define, Design, and Develop stages, finding that an eight-week progressive plyometric training program significantly influenced relative lower-body strength and estimated $\text{VO}_{2\text{max}}$ in student soccer players after adjusting for baseline values. Controlled differences showed an increase in relative strength of 0.312 (95% CI 0.054–0.570; $p = 0.020$; $\eta^2 = 0.206$) and estimated $\text{VO}_{2\text{max}}$ of $3.97 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (95% CI 2.88–5.07; $p < 0.001$; $\eta^2 = 0.700$), whereas absolute strength (based on 1RM) showed no significant effect. However, these results should be interpreted as preliminary evidence of the model's potential effectiveness rather than definitive confirmation of the intervention's efficacy, as the Disseminate stage has not yet been conducted. Current evaluations primarily reflect initial acceptance and feasibility based on expert assessment; validation of effectiveness requires further controlled trials involving larger samples, fully documented allocation, monitoring of adherence and training load, and testing within broader soccer contexts. Thus, while the developed model holds potential as an integrated training approach, further research is necessary before it can be recommended as a widely validated intervention.

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Conflict of Interest

The authors declare no conflict of interest.

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