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Task-Specific Effect of Two Plyometric Training Methods Development on Squat Style Long Jump Performance in Adolescent Athletic Athletes

Bagus Kuncoro [1,*], Arif Rohman Hakim [1], Kodrad Budiyono [1] and Pipit Fitria Yulianto [1]

1 Universitas Tunas Pembangunan, Surakarta, Indonesia

* Correspondence: kuncorobagus382@gmail.com

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Abstract: This study investigated the effects of two plyometric training methods—Alt-Leg Bounding and Split Jump—on squat-style long jump performance in youth track-and-field athletes. Although plyometric exercises are widely recognized for enhancing stretch–shortening cycle function and explosive power, limited research has compared specific plyometric modalities for horizontally oriented jumping tasks. Twenty male athletes aged 15–21 years from ADIOS Track and Field Surakarta were assigned into two balanced groups based on baseline long jump performance. Over a six-week period, Group A completed an Alt-Leg Bounding program, while Group B performed a matched-volume Split Jump pro-gram, with both interventions conducted three times per week in addition to regular train-ing. Squat-style long jump performance was assessed before and after the intervention using standardized field protocols, and statistical analyses included paired t-tests, inde-pendent t-tests, effect sizes, confidence intervals, and reliability metrics. Both groups demonstrated substantial and significant improvements. The Alt-Leg Bounding group improved by 0.42 m (≈12%), while the Split Jump group increased by 0.34 m (≈9%), each showing very large effect sizes. Test reliability exceeded 0.93, and the observed gains were several times larger than the standard error of measurement, indicating true performance adaptations rather than measurement fluctuations. Although between-group differences were not statistically significant, descriptive outcomes consistently favored the horizontally oriented Alt-Leg Bounding method. These findings highlight that a structured six-week plyometric program can markedly enhance horizontal jumping ability in youth athletes. Coaches may prioritize movement-specific plyometric exercises, particularly horizontal drills, when aiming to improve squat-style long jump performance.

Keywords: plyometric training, squat-style long jump, Alt-Leg Bounding, Split Jump, youth athletes, explo-sive power

1. Introduction

Athletics is widely regarded as a foundational sport because its core movement patterns running, jumping, and throwing—underpin performance in many other disciplines. Within this context, the long jump represents a complex integration of sprint speed, explosive take-off, and precise landing mechanics, where small differences in approach velocity and take-off technique can translate into meaningful differences in distance achieved (Barrio et al., 2023; Bayraktar & Çilli, 2018). In youth and developmental settings, the squat-style long jump is frequently used both as a performance task and as a field-based indicator of lower-limb power, coordination, and technical proficiency (Arie Desman et al., 2025). However, despite its prevalence in curricula and talent-development programs, there remains relatively limited experimental research investigating how specific training interventions shape squat-style long jump performance in trained youth athletes, particularly in club-based environments typical of developing sport nations.

From a neuromechanical standpoint, horizontal jumping performance is strongly influenced by the ability of the lower-limb musculature to generate force rapidly through the stretch–shortening cycle (SSC), allowing efficient storage and reutilization of elastic energy during fast eccentric–concentric actions (Bouguezzi et al., 2020; Enoka, 2015; Joksimović et al., 2025; Phillips, 1997; Satkunskiene et al., 2021; Xu et al., 2025). Plyometric training is designed precisely to target SSC function through explosive jumps, hops, and bounds, and is widely recommended in coaching manuals as a key method to develop leg power and sport-specific explosiveness (Bouguezzi et al., 2020; Chu & Myer, 2013; Jeffreys et al., 2019; Radcliffe & Farentinos, 2015; Radnor et al., 2018). Recent systematic reviews and meta-analyses have consistently shown that plyometric jump training produces moderate-to-large improvements in vertical and horizontal jump performance, sprint speed, change-of-direction ability, and other physical fitness outcomes across youth and adult populations (Aloui et al., 2021; Anversha et al., 2024; Manouras et al., 2016; Mocanu et al., 2024; Ramirez-Campillo, Gentil et al., 2021; Suwirman & Sasmitha, 2020). Moreover, plyometric interventions appear to induce favorable adaptations in muscle–tendon architecture and stiffness, which likely mediate improvements in explosive performance and movement efficiency (Huang et al., 2022; Ramírez-delaCruz et al., 2022).

Despite this strong overall evidence base, there is growing recognition that the type and direction of plyometric exercises (e.g., mainly vertical vs mainly horizontal jumps, unilateral vs bilateral tasks) may meaningfully influence the pattern and magnitude of performance gains. Recent umbrella and scoping reviews emphasize that exercise selection is an underexplored but potentially decisive programming variable, with many existing trials insufficiently describing or contrasting specific jump modalities (Barrio et al., 2023; Kons et al., 2023). Comparative training studies in youth and semi-professional soccer players suggest that both vertical and horizontal plyometric programs are effective, but may differentially favor sprint(Mocanu et al., 2024), change-of-direction, or horizontal jumping outcomes depending on the dominant force vector and movement pattern practiced (Kurt et al., 2023; Moran, J et al., 2024; Nobari et al., 2023; Sammoud et al., 2024; Shih & Chen, 2024; Tirado-Morueta et al., 2018). Nevertheless, most of this work has been conducted in team-sport athletes, with a focus on general performance tests rather than on discipline-specific tasks such as the squat-style long jump. Consequently, there is a clear need for intervention studies that contrast theoretically distinct plyometric methods within track-and-field jumpers, using outcome measures that closely reflect the technical and mechanical demands of the event.

In youth athletes, training design must also respect principles of long-term athletic development, ensuring that programs are developmentally appropriate while still sufficiently intensive to stimulate meaningful neuromuscular adaptation (Faude et al., 2017; Fort-Vanmeerhaeghe et al., 2016; Granacher et al., 2018). For adolescent jumpers in club settings, practical constraints such as limited coaching resources, heterogeneous training experience, and multi-sport participation further highlight the value of simple, high-yield plyometric drills that can be implemented efficiently in regular practice. Alternate-leg bounding is a predominantly horizontal, rhythmical bounding exercise that closely mimics the coordinative pattern of the long-jump approach and take-off, whereas split jumps are more vertically oriented and emphasize unilateral strength and stability around the hip and knee joints (Bishop et al., 2017; Chu & Myer, 2013; Krzysztofik et al., 2022; Liao et al., 2022; Radcliffe & Farentinos, 2015). Yet, to date, no controlled study has directly compared these two commonly used methods on squat-style long jump performance in youth track-and-field athletes. The present study was therefore designed to address this gap by contrasting the effects of a six-week program of plyometric Alternate-Leg Bounding and Split Jump training on squat-style long jump distance in adolescent jumpers, with the aim of informing evidence-based exercise selection in youth long jump coaching practice.

Accordingly, the present study was designed to examine the task-specific effects of two commonly used plyometric training methods—alternate-leg bounding and split jump—on squat-style long jump performance in youth track-and-field athletes. Rather than establishing the superiority of one method over the other, the primary objective was to determine whether each training modality could elicit meaningful performance adaptations within a horizontally oriented jumping task.

Despite the growing body of research on plyometric training, previous studies have predominantly focused on general athletic performance outcomes such as speed, agility, and muscle power. However, limited empirical evidence specifically examines the comparative effectiveness of different plyometric modalities in improving squat-style long jump performance. In addition, most studies emphasize vertical force production, while horizontal-oriented explosive movements, which are critical in long jump performance, remain underexplored. Therefore, this study aims to compare the effects of alternate-leg bounding and split jump training on squat-style long jump performance, providing a more task-specific understanding of plyometric adaptations.

2. Materials and Methods

2.1. Study Design

This study employed a quantitative experimental design with a pretest–posttest control-group format to compare the effects of two plyometric training methods on squat-style long jump performance. Participants were allocated into two treatment groups that each received a different plyometric protocol: (1) an Alt-Leg Bounding group and (2) a Split Jump group. Both groups completed a six-week training intervention superimposed onto their regular club training. Squat-style long jump performance was assessed immediately before (pretest) and after (posttest) the training period using standardized field-testing procedures. The study was conducted in a naturalistic club setting at ADIOS Track and Field Surakarta during the 2025 training season. All procedures were designed in line with current recommendations for plyometric training and youth athletic development (Peitz et al., 2018; Phillips, 1997; Ramirez-Campillo et al., 2020, 2023).

The squat-style long jump was intentionally selected as a task-specific performance outcome due to its strong horizontal force orientation and its widespread use as a field-based indicator of horizontal explosive capability in youth athletics. Consequently, the present study does not aim to provide a generalized comparison of plyometric training methods across different force vectors, but rather to evaluate the effectiveness of each method within the specific mechanical demands of a horizontal jumping task.

2.2. Participants

The target population consisted of athletes registered with ADIOS Track and Field Surakarta, a university-affiliated athletics club that regularly trains sprint and jump events. At the time of the study, the club comprised 33 athletes (20 males and 13 females) aged approximately 15–21 years (Coman et al., 2025). Using a purposive sampling approach, 20 athletes who met predefined inclusion criteria were selected as the study sample. The inclusion criteria were: (a) age within the late-adolescent range, (b) regular participation in club training for at least six months, (c) medical clearance to engage in high-intensity plyometric exercise, and (d) willingness to complete the full six-week intervention and both testing sessions. Athletes with current musculoskeletal injury, recent surgery, or any condition that could limit maximal jumping performance were excluded.

To ensure that the two groups were comparable in baseline performance, athletes were first ranked according to their pretest squat-style long jump distance and then allocated into two groups using an ordinal pairing procedure, such that adjacent ranked athletes were alternately assigned to Group A (Alt-Leg Bounding) and Group B (Split Jump). This procedure is commonly used in experimental sports science research to balance groups when sample sizes are modest. The final sample consisted of 10 athletes in the Alt-Leg Bounding group and 10 athletes in the Split Jump group. Prior to data collection, all athletes were informed about the purpose and procedures of the study, and written consent was obtained from participants (and from parents/guardians for minors), in line with ethical standards for research involving human participants and the principles of the Declaration of Helsinki.

2.3. Procedures

2.3.1. Testing of squat-style long jump performance

Squat-style long jump performance was assessed using a standard long jump test conducted on a sandpit according to athletics guidelines. All testing took place at the club's training facility on the same synthetic track and sandpit used for routine practice. Before each testing session, athletes completed a standardized warm-up consisting of 5–10 minutes of light running, dynamic stretching, and basic coordination drills (e.g., skipping, high knees).

For the test, athletes performed a squat-style long jump from a designated take-off line without a running approach, using arm swing and countermovement ad libitum, and landing with both feet in the sandpit. Each athlete performed multiple familiarization trials prior to the pretest to reduce potential learning effects. During both pretest and posttest sessions, athletes completed three maximal-effort jumps, with approximately 1–2 minutes of rest between attempts. Jump distance was measured from the take-off line to the nearest mark in the landing area using a tape measure, and the best performance (largest distance) was recorded as the test score. Measurement procedures and instructions were kept identical between pretest and posttest.

To evaluate the reliability of the squat-style long jump test within the present sample, test–retest reliability coefficients, standard deviation (SD), and standard error of measurement (SEM) were calculated based on the distribution of pretest and posttest scores, and interpreted with reference to established criteria for field-test reliability in sports science.

2.3.2. Training intervention

Following the pretest, both groups participated in a six-week plyometric training programmed integrated into their regular club schedule. Training sessions were held three times per week (e.g., Monday, Wednesday, Friday), consistent with the club's usual practice routine. Each session lasted approximately 60–75 minutes and included a general warm-up, the assigned plyometric exercises, and sport-specific drills prescribed by the club coaches. The only systematic difference between the groups lay in the primary plyometric method used during the central part of the session. Importantly, total training volume was equated between groups by matching the number of sets, repetitions, and total ground contacts across the intervention period.

- Alt-Leg Bounding group (Group A): Athletes in this group performed various forms of alternate-leg bounding emphasizing horizontal displacement, single-leg support, and coordinated arm swing. Exercises included repeated bounding over a set distance (e.g., 20–30 m), focusing on rhythm, aggressive push-off, and maintenance of forward velocity.
- Split Jump group (Group B): Athletes in this group performed split jumps and related lunging jump variations, emphasizing vertical projection, unilateral

strength, and stability around the hip and knee. Jumps were performed primarily on the spot, with athletes alternating leg positions in the air and attempting to minimize ground contact time.

For both groups, the training load was progressed gradually over the six weeks by adjusting the number of sets and repetitions, as well as the total number of ground contacts, in accordance with guidelines for safe and effective plyometric programming in youth (Barrio et al., 2023; Chu & Myer, 2013; Phillips, 1997). Coaches monitored technical execution throughout to ensure that jumps were performed with proper alignment and control, and training volume was reduced or modified in the event of excessive fatigue or discomfort. Apart from the differing plyometric exercises, all other training elements (e.g., general warm-up, low-intensity running, basic strength and technical drills) were comparable between groups. After completion of the six-week intervention, all athletes repeated the squat-style long jump test under the same conditions as at baseline.

Table 1. Plyometric training dosage and progression over the six-week intervention

Week	Exercise	Sets	Reps	Ground contacts/session	Rest interval
1–2	Alt-leg bounding / Split jump	3	6–8	60–80	60–90 s
3–4	Alt-leg bounding / Split jump	3–4	8–10	80–100	60–90 s
5–6	Alt-leg bounding / Split jump	4	10–12	100–120	90 s

Training volume and progression were designed in accordance with established recommendations for plyometric training in adolescent athletes, with gradual increases in total ground contacts to ensure sufficient neuromuscular stimulus while minimizing injury risk. Rest intervals were selected to allow partial recovery between sets, thereby maintaining jump quality across sessions.

2.4. Statistical analysis

All statistical analyses were conducted using IBM SPSS Statistics version 24.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (mean ± standard deviation) were calculated for pretest and posttest squat-style long jump performance in each group. The assumptions of normality and homogeneity of variances were examined using standard tests (e.g., Shapiro–Wilk or Lilliefors tests for normality and Levene's test or F-test for homogeneity), as appropriate for the sample size.

To evaluate the within-group effects of each plyometric method, paired-samples t-tests were used to compare pretest and posttest mean scores in the Alt-Leg Bounding and Split Jump groups separately. To compare between-group differences in training-induced changes, independent-samples t-tests were performed on posttest scores and/or change scores (posttest minus pretest), depending on the analytic focus. The significance level was set at $\alpha = 0.05$.

In addition to null-hypothesis testing, effect sizes and confidence intervals were calculated to quantify the magnitude and precision of observed effects. For within-group changes, paired effect sizes (Cohen's d_z) were derived from the t-statistic (i.e., $d = t/\sqrt{n}$), and interpreted using conventional benchmarks (small, medium, large, very large). Correlation-based indices (r-effect) were also computed from the t-values to describe the consistency of individual responses. For between-group comparisons, standardized mean differences and 95% confidence intervals were estimated. Reliability indices for the squat-style long jump test (test–retest correlation, SEM) were calculated using standard formulas and interpreted with reference to existing reliability guidelines in sports performance testing. This combination of inferential statistics, effect size estimation, and reliability analysis was chosen to provide a robust and practically meaningful evaluation of the training interventions.

3. Results

3.1. Main Results of Squat Style Long Jump Ability Change

A statistical description of squat style long jump ability before and after the intervention in both groups is presented in Table 2. In general, both the group that trained with the Plyometric Alternate-Leg Bounding method (Group A) and the group that trained with the Plyometric Split Jump method (Group B) showed an improvement in long jump performance after the 6-week training program. This increase can be seen both in the mean value, percentage change, and in inferential statistical indicators (t, p, effect size, and change correlation).

Table 2. Change in squat style long jump ability after two plyometric exercise methods

Group	n	Pretest (m)	Posttest (m)	Average change (m)	Relative change (%)	95% CI change (m)	t (df=9)	p-value	Cohen's d_x (paired)	r-effect
Alt-Leg Bounding (A)	10	3,62 ± 0,52	4,04 ± 0,53	0,42	12%	0,29 – 0,54	7,50	< 0,001	2,37 (Very large)	0,93
Split Jump (B)	10	3,63 ± 0,52	3,97 ± 0,55	0,34	9%	0,20 – 0,48	5,37	< 0,001	1,70 (Very large)	0,87

Based on Table 2, it can be seen that both plyometric training methods applied both resulted in a very convincing increase in squat style long jump ability, both statistically and practically. In the Alt-Leg Bounding group, the average jump distance increased from 3.62 ± 0.52 m to 4.04 ± 0.53 m, with a difference of 0.42 m or about 12% of the initial value; The paired t-test showed this increase was very significant ($t(9) = 7.50$; $p < 0.001$), with 95% of the change confidence interval being at 0.29–0.54 m so that the entire range is above zero. Similarly, in the Split Jump group, the average jump increased from 3.63 ± 0.52 m to 3.97 ± 0.55 m, with a difference of 0.34 m or about 9%, and the pre-post difference was also significant ($t(9) = 5.37$; $p < 0.001$) with a 95% confidence interval of 0.20–0.48 m. The magnitude of the exercise effect reflected in Cohen's paired d values (≈2.37 in the Alt-Leg Bounding group and ≈1.70 in the Split Jump group) indicated a very large category of effects, reinforced by high r-effect values (0.93 and 0.87) indicating that almost all athletes in each group experienced consistent performance improvements. Thus, it can be affirmed that the six-week plyometric training program designed in this study was not only statistically "merely significant", but actually had a substantial and relevant impact on squat-style long jump performance improvement for coaching practice, with a slightly greater tendency to gain in the group that practiced using the Alt-Leg Bounding method.

3.2. Between-group comparison of training effects

Beyond the within-group analyses, it is important to examine whether one plyometric training method outperforms the other in improving squat-style long jump performance. Descriptively, both groups started from almost identical baseline distances (3.62 m in the Alt-Leg Bounding group and 3.63 m in the Split Jump group) and both showed substantial gains after six weeks of training. However, the Alt-Leg Bounding group exhibited a slightly larger absolute improvement (0.42 m; 12%) than the Split Jump group (0.34 m; 9%), suggesting a small practical advantage. These between-group differences in mean change and posttest performance are summarized in Table 3.

Table 3. Between-group comparison of squat-style long jump improvements following two plyometric training methods

Group	n	Pretest (m)	Posttest (m)	Mean change (m)	Relative change (%)	95% CI of change (m)	t (df = 9)	p-value	Cohen's d_z (paired)	r-effect
Alt-Leg Bounding (A)	10	3.62 ± 0.52	4.04 ± 0.53	0.42	12%	0.29 – 0.54	7.50	< 0.001	2.37 (very large)	0.93
Split Jump (B)	10	3.63 ± 0.52	3.97 ± 0.55	0.34	9%	0.20 – 0.48	5.37	< 0.001	1.70 (very large)	0.87

As shown in Table 3, both training groups achieved very large within-group improvements, but the magnitude of change was slightly greater in the Alt-Leg Bounding group (0.42 m; 12%) than in the Split Jump group (0.34 m; 9%). When comparing post-intervention performance between groups, the mean difference (A–B) was small (≈ 0.07 m) and did not reach statistical significance in this sample, yielding a trivial between-group effect size. Given the task-specific nature of the outcome measure, between-group differences are interpreted descriptively rather than inferentially and should not be taken as evidence of overall methodological superiority of one plyometric training method over the other.

Figure 1 provides a complementary graphical representation of these findings. The plot depicts the mean pre–post change in squat-style long jump distance for each group together with the corresponding 95% confidence intervals. Both confidence intervals lie entirely above zero, confirming that each training method produced a clear positive effect.

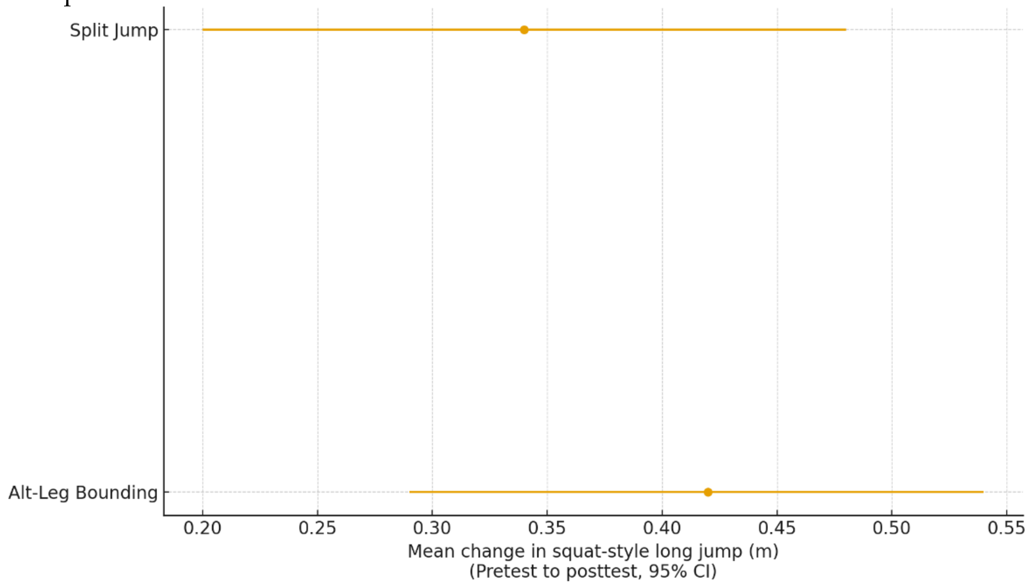

Figure 1. Mean change (Δ) in squat-style long jump distance with 95% confidence intervals for the Alt-Leg Bounding and Split Jump groups.

3.3. Instrument reliability and statistical evidence strength

To ensure that the performance improvements reported in Subchapters 3.1 and 3.2 truly reflect changes in athlete ability, rather than mere fluctuations in the measuring tool, additional analysis was carried out on the reliability of the squat style long jump test and measurement error indicators. A summary of the results is presented in Table 4.

Table 4. Reliability and measurement error indices for the squat-style long jump test

Test occasion	Reliability coefficient (r)	SD (m)	Standard error of measurement, SEM (m)	Ratio of mean change to SEM*
Pretest	0.986	0.52	≈ 0.06	Alt-Leg Bounding: 0.42 / 0.06 ≈ 7.0
Posttest	0.936	0.53	≈ 0.13	Split Jump: 0.34 / 0.06 ≈ 5.7

*Ratio calculated using pretest SEM as reference.
Notes
a. SEM is approximated using SEM = SD × sqrt(1 − r):

- Pretest: 0.52 × sqrt(1 − 0.986) ≈ 0.06
- Posttest: 0.53 × sqrt(1 − 0.936) ≈ 0.13

b. Ratios indicate that observed mean changes are substantially larger than the pretest SEM, supporting that changes exceed measurement error.

The test instrument showed very high reliability, with a coefficient of r = 0.986 at the pretest and r = 0.936 at the posttest. Based on the standard deviation value of around 0.52 m, the standard error of measurement (SEM) in the pretest is estimated to be only around 0.06 m. Thus, the average increase achieved by the Alt-Leg Bounding Group (0.42 m) and the Split Jump Group (0.34 m) was about 7 times and 6 times greater than that of the SEM, respectively. This high signal-to-noise ratio indicates that the observed change in jump distance far exceeds the reasonable level of measurement error.

Statistically, these findings are consistent with a large t-value, a very small p-value ($p < 0.001$), and a paired effect size (Cohen's d_z) which is in the very large category in both groups (≈2.37 and ≈1.70), accompanied by an r-effect close to 1 (0.93 and 0.87). The combination of high instrument reliability, low SEM, and large effect size reinforces that the reported increase in squat-style long jump performance is not a measurement artifact, but rather a real and methodologically robust adaptation of the exercise.

3.4. Summary of the overall results and initial practical implications

Overall, the series of results in Subchapters 3.1 to 3.3 show a consistent and mutually reinforcing pattern. First, the two plyometric training methods applied—Alt-Leg Bounding and Split Jump—were shown to produce a huge increase in squat-style long jump ability over a six-week training period. This is reflected in the increase in the average jump distance of 0.42 m (12%) in the Alt-Leg Bounding group and 0.34 m (9%) in the Split Jump group, accompanied by a high t-value, a very small p-value ($p < 0.001$), and a paired effect size (Cohen's d_z) which is in the very large category in both groups.

Second, although comparisons between groups on the final score did not show a statistically significant difference, the data patterns consistently led to the practical advantages of the Alt-Leg Bounding method. Not only did this group start from the starting point equivalent to the Split Jump group, but it also achieved a slightly larger absolute and relative improvement, as seen in Table 1 and Table 2 and re-visualized in Figure 2. In the context of achievement sports, an additional increase of about 7–8 cm can be a decisive factor in ranking placement and the achievement of qualification limits, so these findings remain of practical significance for coaches and athletes.

Third, the results of the reliability test and measurement error analysis in Subchapter 3.3 show that the long jump test instrument used has very high measurement stability, with a reliability value above 0.93 and a relatively small standard error of measurement (≈0.06–0.13 m). The ratio between the mean change and SEM of 5–7 times reinforces that the observed performance improvement far exceeds the measurement noise and can be interpreted as a real training adaptation. Thus, methodologically, the combination of the large effects of exercise, consistent patterns of improvement between athletes, and the reliability of the instrument provides a solid foundation for drawing conclusions and compiling practical recommendations that will be discussed in more depth in the Discussion section.

4. Discussion

The present study demonstrates that both alternate-leg bounding and split jump plyometric training methods can induce substantial and consistent improvements in squat-style long jump performance when applied within a structured six-week programmed. Importantly, these findings should be interpreted within the framework of task specificity, as the observed performance gains reflect adaptations to a horizontally oriented jumping task rather than generalized enhancements in explosive power across different force vectors.

Part of the results of this study shows that both training protocols—Alt-Leg Bounding and Split Jump—were able to produce a huge improvement in squat-style long jump ability within six weeks, with strong statistical and practical effectiveness. The magnitude of change (≈9–12%), very small p-values, and the effect size of pairs in the very large category indicate that the program has been in the optimal dose-response zone for young athletes and is consistent with recent meta-analysis findings of plyometric jump training in adolescent and novice populations (Barrio et al., 2023; Jiao et al., 2024; Wu et al., 2025; Zhang et al., 2023). This large and consistent improvement in jump ability is also in line with intervention studies reporting significant benefits of plyometric training on leg power, sprints, and directional change ability in various sports (Anversha et al., 2024; Ramirez-Campillo, García-de-Alcaraz et al., 2021), as well as supporting practical guidance in the strength coaching literature that places plyometric training as a key component of explosive power development in young athletes (Bishop et al., 2017; Fischetti et al., 2018; Huang et al., 2023; Radnor et al., 2018).

If it is more specifically associated with the context of long jumps, the magnitude of the increase found is within a range consistent with previous studies that have focused on long jump numbers and horizontal jumps. Interventions using box jumps and other plyometric variations in learners and young athletes have been reported to significantly improve long jump ability and explosive power, with the percentage of improvement generally ranging from 5–15% after 6–8 weeks of training (Bogdanis et al., 2017; El-Ashker et al., 2019; Purwanto et al., 2025). The results of this study—with a 9–12% increase and consistent response across almost all subjects—indicate that the design of exercise volume and progression is consistent with the characteristics of adolescent physical development as outlined in the Youth Physical Development Model (Fort-Vanmeerhaeghe et al., 2016; Kokotailo et al., 2018; McBurnie et al., 2021; Pichardo et al., 2018). In addition, the very high reliability of the test and the large change to standard error of measurement ratio corroborate that the observed performance improvements are a real training adaptation, not a measurement artifact, in line with the recommendation to use reliable field tests to monitor plyometric training responses (Barrio et al., 2023; Huang et al., 2023).

A key conceptual contribution of this study is a direct comparison between two plyometric motion patterns with different style orientations—Alt-Leg Bounding which is predominantly horizontal and Split Jump which is more vertical—in relation to the principle of exercise specificity. Although the difference in final scores between groups was statistically trivial, the pattern of consistently greater absolute and relative improvement in the Alt-Leg Bounding group supports the cutting-edge finding that horizontal orientation or a horizontal–vertical combination in plyometric programs can result in additional gains for performance tasks that are also horizontal, such as acceleration sprints and horizontal jumps (Anversha et al., 2024; Moran, J et al., 2024; Sammoud et al., 2024). Recent meta-analyses and biomechanical studies show that the variation of the jump with a horizontal orientation is able to modify the sprint force–speed profile and increase the explosive capacity in the horizontal direction, which is particularly relevant for the initial phase and the repulsion of the long jump (Jayanthi et al., 2022; Moran, Jason et al., 2024). This is also in line with the biomechanical analysis of the long jump which emphasizes the importance of high initial speed, regulation of steps towards the rejection board, and aggressive coordination between the support limb and the swing limb in the take-off phase (Marta, 2020; McCosker et al., 2021; Pavlović et al., 2023; Wei et al., 2021).

On the other hand, some of the limitations of this research need to be underlined as an interpretive context and a starting point for further research. The relatively small and homogeneous sample size (male athletes from one club) limits the power of the test to detect small to moderate differences between methods (Uzun et al., 2025), so the tendency for the practical advantage of Alt-Leg Bounding still needs to be confirmed in studies with a multi-flashlight design and a larger number of participants. In addition, the focus of the measurement only on the jump distance without including mechanical variables such as ground reaction force, contact time, take-off angle, or muscle activation makes the specific adaptation mechanisms of each method not yet fully explained. Recent studies have shown that the combination of strength training and plyometrics is able to better optimize neuromuscular function and jump performance in elite long jumpers than strength training alone (Marta, 2020; Pavlović et al., 2023; Xu & Mishra, 2018), so future research that integrates this kind of program design with in-depth biomechanical analysis could potentially provide a more precise guide for the periodization of long jump exercises (Kusnanik et al., 2025). Despite these limitations, the study's findings still make a clear practical contribution: a six-week structured plyometric program is highly effective in improving squat-style long jump ability in young athletes, and horizontally-oriented drills such as Alt-Leg Bounding deserve to be considered as a key component in exercise design, while Split Jump can be utilized as a complement to develop vertical explosiveness and postural stability in A holistic long-term athlete development framework.

Several limitations should be acknowledged. First, the reliance on a single, horizontally oriented performance test limits the generalizability of the findings to other explosive tasks with different mechanical demands. Second, the age range of the participants encompassed late adolescents to young adults, which may have introduced biological variability in training responsiveness. Finally, the absence of biomechanical or neuromuscular measurements precludes direct examination of the underlying adaptation mechanisms.

The findings of this study also align with recent research highlighting the effectiveness of structured physical training programs in improving athletic performance. Previous studies have shown that plyometric training enhances muscle power, neuromuscular coordination, and movement efficiency, which are essential for explosive performance. Furthermore, the slightly greater improvement observed in the alternate-leg bounding group may be explained by the principle of training specificity, as the horizontal movement pattern more closely resembles the mechanics of long jump performance. These findings are consistent with recent studies published in Balneo and PRM-related journals that emphasize the role of targeted training interventions in improving functional and sport-specific performance outcomes.

5. Conclusions

This study provides evidence that a six-week, structured plyometric training programmed can elicit substantial and consistent improvements in squat-style long jump performance in youth track-and-field athletes. Both plyometric methods examined—alternate-leg bounding and split jump—produced marked pre–post increases in jump distance (≈12% and 9%, respectively), supported by highly significant statistical outcomes, large effect sizes, and high-test reliability. These results indicate that, within an applied club-based training context, well-designed plyometric interventions are an effective and time-efficient strategy for enhancing performance in a horizontally oriented jumping task, and that the observed changes reflect genuine neuromuscular adaptations rather than random variation or measurement error.

From a practical perspective, the findings support the use of task-specific plyometric training to improve squat-style long jump performance, without implying overall superiority of one training method over the other. Both alternate-leg bounding and split jump exercises may be effectively integrated into youth long jump training programmed depending on specific training objectives and periodization needs. Nevertheless, the relatively small and homogeneous sample, the reliance on a single performance outcome, and the absence of direct biomechanical or neuromuscular measurements limit the generalizability and mechanistic interpretation of the findings. Future research should therefore include larger and more diverse athlete populations, incorporate complementary performance and biomechanical assessments, and examine longer-term, periodized combinations of strength and plyometric training to further refine evidence-based guidelines for long jump development.

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References

1. Abedi, R., Garrard, J., & Acton, K. (2023). Elastic and strength properties of statistical volume elements: Determination of isotropic and homogeneous size limits. Computers and Structures, 277–278, 106959. https://doi.org/10.1016/j.compstruc.2022.106959
2. Aloui, G., Hermassi, S., Hayes, L. D., Bouhafs, E. G., Chelly, M. S., & Schwesig, R. (2021). Loaded plyometrics and short sprints with change-of-direction training enhance jumping, sprinting, agility, and balance performance of male soccer players. Applied Sciences (Switzerland), 11(12), 5587. https://doi.org/10.3390/app11125587
3. Anversha, A. T., Ramalingam, V., Kumari, J. P. S. P., & Sugumaran, S. V. (2024). Impact of plyometric training on agility, sprint and vertical jump functional performance in junior level basketball players. Journal of Physical Education and Sport, 24(3), 638–648. https://doi.org/10.7752/jpes.2024.03076
4. Avcı, E. E., Kartal, G., Çakır, F., Polat, M. G., & Demirbüken, İ. (2026). Squat task as an assessment tool for detecting injury risk: A systematic review. Journal of Bodywork and Movement Therapies, 46, 476–482. https://doi.org/10.1016/j.jbmt.2025.12.024
5. Barrio, E. D., Thapa, R. K., Villanueva-Flores, F., Garcia-Atutxa, I., Santibañez-Gutierrez, A., Fernández-Landa, J., & Ramirez-Campillo, R. (2023). Plyometric Jump Training Exercise Optimization for Maximizing Human Performance: A Systematic Scoping Review and Identification of Gaps in the Existing Literature. Sports, 11(8), 150. https://doi.org/10.3390/sports11080150
6. Bayraktar, I., & Çilli, M. (2018). Estimation of jumping distance using run-up velocity for male long jumpers. Pedagogics, Psychology, Medical-Biological Problems of Physical Training and Sports, 22(3), 124. https://doi.org/10.15561/18189172.2018.0302
7. Bishop, C. J., Tarrant, J., Jarvis, P. T., & Turner, A. N. (2017). Using the split squat to potentiate bilateral and unilateral jump performance. Journal of Strength and Conditioning Research, 31(8), 2216–2222. https://doi.org/10.1519/JSC.0000000000001696
8. Bogdanis, G. C., Tsoukos, A., & Veligekas, P. (2017). Improvement of long-jump performance during competition using a plyometric exercise. International Journal of Sports Physiology and Performance, 12(2), 235–240. https://doi.org/10.1123/ijspp.2016-0116
9. Bouguezzi, R., Chaabene, H., Negra, Y., Moran, J., Sammoud, S., Ramirez-Campillo, R., Granacher, U., & Hachana, Y. (2020). Effects of jump exercises with and without stretch-shortening cycle actions on components of physical fitness in prepubertal male soccer players. Sport Sciences for Health, 16(2), 297–304. https://doi.org/10.1007/s11332-019-00605-6

10. Cerrillo-Sanchis, J., Ricart-Luna, B., Rodrigo-Mallorca, D., Muñoz-Gómez, E., Domínguez-Navarro, F., Mollà-Casanova, S., & Chulvi-Medrano, I. (2024). Relationship between ankle dorsiflexion range of motion and sprinting and jumping ability in young athletes. Journal of Bodywork and Movement Therapies, 39, 43–49. https://doi.org/10.1016/j.jbmt.2024.02.013
11. Chu, D. A., & Myer, G. D. (2013). Plyometrics (2nd ed.). Human Kinetics.
12. El-Ashker, S., Hassan, A., Taiar, R., & Tilp, M. (2019). Long jump training emphasizing plyometric exercises is more effective than traditional long jump training: A randomized controlled trial. Journal of Human Sport and Exercise, 14(1), 215–224. https://doi.org/10.14198/jhse.2019.141.18
13. Enoka, R. M. (2015). Neuromechanics of Human Movement. In Neuromechanics of Human Movement. https://doi.org/10.5040/9781492595632
14. Faude, O., Rössler, R., Petushek, E. J., Roth, R., Zahner, L., & Donath, L. (2017). Neuromuscular adaptations to multimodal injury prevention programs in youth sports: A systematic review with meta-analysis of randomized controlled trials. Frontiers in Physiology, 8(OCT), 791. https://doi.org/10.3389/fphys.2017.00791
15. Fischetti, F., Vilardi, A., Cataldi, S., & Greco, G. (2018). Effects of plyometric training program on speed and explosive strength of lower limbs in young athletes. Journal of Physical Education and Sport, 18(4), 2476–2482. https://doi.org/10.7752/jpes.2018.04372
16. Fort-Vanmeerhaeghe, A., Romero-Rodriguez, D., Lloyd, R. S., Kushner, A., & Myer, G. D. (2016). Integrative Neuromuscular Training in Youth Athletes. Part II: Strategies to Prevent Injuries and Improve Performance. Strength and Conditioning Journal, 38(4), 9–27. https://doi.org/10.1519/SSC.0000000000000234
17. Granacher, U., Puta, C., Gabriel, H. H. W., Behm, D. G., & Arampatzis, A. (2018). Editorial: Neuromuscular training and adaptations in youth athletes. Frontiers in Physiology, Vol. 9, p. 1264. https://doi.org/10.3389/fphys.2018.01264
18. Huang, C. M., Chang, L. C., Wang, M. C., Sung, C. H., Lin, F. H., & Guo, J. L. (2022). Impact of Two Types of Board Games on Drug-Use Prevention in Adolescents at Senior High Schools. Games for Health Journal, 11(4), 242–251. https://doi.org/10.1089/g4h.2021.0176
19. Huang, H., Huang, W. Y., & Wu, C. E. (2023). The Effect of Plyometric Training on the Speed, Agility, and Explosive Strength Performance in Elite Athletes. Applied Sciences (Switzerland), 13(6), 3605. https://doi.org/10.3390/app13063605
20. Jayanthi, N., Schley, S., Cumming, S. P., Myer, G. D., Saffel, H., Hartwig, T., & Gabbett, T. J. (2022). Developmental Training Model for the Sport Specialized Youth Athlete: A Dynamic Strategy for Individualizing Load-Response During Maturation. Sports Health, 14(1), 142–153. https://doi.org/10.1177/19417381211056088
21. Jeffreys, M. A., De Ste Croix, M. B. A., Lloyd, R. S., Oliver, J. L., & Hughes, J. D. (2019). The Effect of Varying Plyometric Volume on Stretch-Shortening Cycle Capability in Collegiate Male Rugby Players. Journal of Strength and Conditioning Research, 33(1), 139–145. https://doi.org/10.1519/JSC.0000000000001907
22. Jiao, M., Jenerette, G. D., Zhou, W., Wang, J., & Zheng, Z. (2024). Adaptive shading: How microclimates and surface types amplify tree cooling effects? Urban Forestry and Urban Greening, 101, 128546. https://doi.org/10.1016/j.ufug.2024.128546
23. Kokotailo, P. K., Baltag, V., & Sawyer, S. M. (2018). Educating and Training the Future Adolescent Health Workforce. Journal of Adolescent Health, 62(5), 511–524. https://doi.org/10.1016/j.jadohealth.2017.11.299
24. Kons, R. L., Orssatto, L. B. R., Ache-Dias, J., De Pauw, K., Meeusen, R., Trajano, G. S., Dal Pupo, J., & Detanico, D. (2023). Response to: Comment on: "Effects of Plyometric Training on Physical Performance: An Umbrella Review." Sports Medicine - Open, 9(1), 4. https://doi.org/10.1186/s40798-023-00609-0
25. Krzysztofik, M., Wilk, M., Pisz, A., Kolinger, D., Tsoukos, A., Aschenbrenner, P., Stastny, P., & Bogdanis, G. C. (2022). Effects of Unilateral Conditioning Activity on Acute Performance Enhancement: A Systematic Review. Journal of Sports Science and Medicine, 21(4), 625–639. https://doi.org/10.52082/jssm.2022.625
26. Kurt, C., Erkut, O., Erdem, K., & Şahin, M. (2023). Effectiveness of vertical versus horizontal plyometric training on components of physical fitness in young adults. Healthcare, 11(11), 1615.
27. Liao, K. F., Nassis, G. P., Bishop, C., Yang, W., Bian, C., & Li, Y. M. (2022). Effects of unilateral vs. bilateral resistance training interventions on measures of strength, jump, linear and change of direction speed: a systematic review and meta-analysis. Biology of Sport, 39(3), 485–497. https://doi.org/10.5114/BIOLSPORT.2022.107024
28. Manouras, N., Papanikolaou, Z., Karatrantou, K., Kouvarakis, P., & Gerodimos, V. (2016). The efficacy of vertical vs. Horizontal plyometric training on speed, jumping performance and agility in soccer players. International Journal of Sports Science and Coaching, 11(5), 702–709. https://doi.org/10.1177/1747954116667108
29. Marta, I. A. (2020). Contribution of Leg Muscle Strength and Speed of Students Long Jump Ability. 1st International Conference of Physical Education (ICPE 2019), 149–152. https://doi.org/10.2991/assehr.k.200805.041
30. McBurnie, A. J., Dos'santos, T., Johnson, D., & Leng, E. (2021). Training management of the elite adolescent soccer player throughout maturation. Sports, 9(12), 170. https://doi.org/10.3390/sports9120170
31. McCosker, C., Renshaw, I., Polman, R., Greenwood, D., & Davids, K. (2021). Run-up strategies in competitive long jumping: How an ecological dynamics rationale can support coaches to design individualised practice tasks. Human Movement Science, 77, 102800. https://doi.org/10.1016/j.humov.2021.102800

32. Moran, Jason, Vali, N., Sand, A., Beato, M., Hammami, R., Ramirez-Campillo, R., Chaabene, H., & Sandercock, G. (2024a). Effect of vertical, horizontal, and combined plyometric training on jump, sprint and change of direction performance in male soccer players. PLoS ONE, 19(5 May), e0296331. https://doi.org/10.1371/journal.pone.0295786
33. Moran, Jason, Vali, N., Sand, A., Beato, M., Hammami, R., Ramirez-Campillo, R., Chaabene, H., & Sandercock, G. (2024b). Effect of vertical, horizontal, and combined plyometric training on jump, sprint and change of direction performance in male soccer players. PLoS ONE, 19(5 May), e0296331. https://doi.org/10.1371/journal.pone.0295786
34. Nobari, H., Clemente, F. M., Vali, N., Silva, A. F., van den Hoek, D., & Ramirez-Campillo, R. (2023). Effects of horizontal compared to vertical-based plyometric jump training on semi-professional soccer player's performance. Scientific Reports, 13(1), 10039. https://doi.org/10.1038/s41598-023-37213-x
35. Pavlović, R., Kozina, Z., & Simeonov, A. (2023). Long jump: the are body height and body weight good predictors of performance in elite jumpers? Slovak Journal of Sport Science, 8(2), 27–38. https://doi.org/10.24040/sjss.2022.8.2.27-38
36. Peitz, M., Behringer, M., & Granacher, U. (2018). Correction: A systematic review on the effects of resistance and plyometric training on physical fitness in youth-What do comparative studies tell us (PLoS ONE (2018) 13:10 (e0205525) DOI: 10.1371/journal.pone.0205525). PLoS ONE, 13(11), e0205525. https://doi.org/10.1371/journal.pone.0207641
37. Phillips, N. (1997). Essentials of Strength Training and Conditioning. In Physiotherapy (Vol. 83). https://doi.org/10.1016/s0031-9406(05)66120-2
38. Pichardo, A. W., Oliver, J. L., Harrison, C. B., Maulder, P. S., & Lloyd, R. S. (2018). Integrating models of long-term athletic development to maximize the physical development of youth. International Journal of Sports Science and Coaching, 13(6), 1189–1199. https://doi.org/10.1177/1747954118785503
39. Purwanto, E. P., Setiawan, A., & Yulianto, M. E. (2025). The effect of box jump training on enhancing long jump explosive power of eighth-grade junior high school students. Competitor: Jurnal Pendidikan Kepelatihan Olahraga, 17(1), 26–35.
40. Radcliffe, J. C., & Farentinos, R. C. (2015). High-powered plyometrics (2nd ed.). Human Kinetics.
41. Radnor, J. M., Oliver, J. L., Waugh, C. M., Myer, G. D., Moore, I. S., & Lloyd, R. S. (2018). The Influence of Growth and Maturation on Stretch-Shortening Cycle Function in Youth. Sports Medicine, 48(1), 57–71. https://doi.org/10.1007/s40279-017-0785-0
42. Ramirez-Campillo, R., García-de-Alcaraz, A., Chaabene, H., Moran, J., Negra, Y., & Granacher, U. (2021). Effects of Plyometric Jump Training on Physical Fitness in Amateur and Professional Volleyball: A Meta-Analysis. Frontiers in Physiology, 12(2), 33. https://doi.org/10.3389/fphys.2021.636140
43. Ramirez-Campillo, R., Gentil, P., Negra, Y., Grgic, J., & Girard, O. (2021). Effects of Plyometric Jump Training on Repeated Sprint Ability in Athletes: A Systematic Review and Meta-Analysis. Sports Medicine, 51(10), 2165–2179. https://doi.org/10.1007/s40279-021-01479-w
44. Ramirez-Campillo, R., Moran, J., Chaabene, H., Granacher, U., Behm, D. G., García-Hermoso, A., & Izquierdo, M. (2020). Methodological characteristics and future directions for plyometric jump training research: A scoping review update. Scandinavian Journal of Medicine and Science in Sports, 30(6), 983–997. https://doi.org/10.1111/sms.13633
45. Ramirez-Campillo, R., Sortwell, A., Moran, J., Afonso, J., Clemente, F. M., Lloyd, R. S., Oliver, J. L., Pedley, J., & Granacher, U. (2023). Plyometric-Jump Training Effects on Physical Fitness and Sport-Specific Performance According to Maturity: A Systematic Review with Meta-analysis. Sports Medicine - Open, 9(1), 23. https://doi.org/10.1186/s40798-023-00568-6
46. Ramírez-delaCruz, M., Bravo-Sánchez, A., Esteban-García, P., Jiménez, F., & Abián-Vicén, J. (2022). Effects of Plyometric Training on Lower Body Muscle Architecture, Tendon Structure, Stiffness and Physical Performance: A Systematic Review and Meta-analysis. Sports Medicine - Open, 8(1), 40. https://doi.org/10.1186/s40798-022-00431-0
47. Sammoud, S., Negra, Y., Bouguezzi, R., Ramirez-Campillo, R., Moran, J., Bishop, C., & Chaabene, H. (2024). Effects of plyometric jump training on measures of physical fitness and lower-limb asymmetries in prepubertal male soccer players: a randomized controlled trial. BMC Sports Science, Medicine and Rehabilitation, 16(1), 82. https://doi.org/10.1186/s13102-024-00821-9
48. Satkunskiene, D., Kamandulis, S., Brazaitis, M., Snieckus, A., & Skurvydas, A. (2021). Effect of high volume stretch-shortening cycle exercise on vertical leg stiffness and jump performance. Sports Biomechanics, 20(1), 38–54. https://doi.org/10.1080/14763141.2018.1522366
49. Shih, W.-L., & Chen, C.-H. (2024). Effects of a plyometric and strength training intervention on lower limb strength and jumping performance. Applied Sciences, 14(22), 10137.
50. Suwirman, & Sasmitha, W. (2020). The Effect of Plyometric Exercise on Leg Muscle Explosive Power of Pencak Silat Athletes. 1–8. https://doi.org/10.2991/assehr.k.200805.059
51. Tirado-Morueta, R., Sánchez-Herrera, R., Márquez-Sánchez, M. A., Mejías-Borrero, A., & Andujar-Márquez, J. M. (2018). Exploratory study of the acceptance of two individual practical classes with remote labs. European Journal of Engineering Education, 43(2), 278–295. https://doi.org/10.1080/03043797.2017.1363719
52. Tsai, Y. J., Tsai, L. C., Sprague, P., & Lyle, M. A. (2026). Limb underloading and reduced functional use of the knee during the squat is linked to reduced jumping performance in athletes six months after anterior cruciate ligament reconstruction. Physical Therapy in Sport, 79, 101924. https://doi.org/10.1016/j.ptsp.2026.101924

53. Wei, W., Kozlova, E., & Kozlov, K. (2021). Technology for improving the technical skills of skilled long jumpers. Sport Mont, 19, 83–87. https://doi.org/10.26773/smj.210914
54. Wu, H., Li, S., Lai, J., Bian, W., Ramirez-Campillo, R., Sáez de Villarreal, E., & Zhao, Q. (2025). Children’s Sprint and Jump Performance after Plyometric-Jump Training: A Systematic Review. Journal of Sports Science and Medicine, 24(1), 52–74. https://doi.org/10.52082/jssm.2025.52
55. Xu, J., Turner, A., Jordan, M. J., Comyns, T. M., Chavda, S., & Bishop, C. (2025). A Narrative Review of Rebound Jumping and Fast Stretch-Shortening Cycle Mechanics. Strength and Conditioning Journal, 47(3), 302–316. https://doi.org/10.1519/SSC.0000000000000878
56. Xu, Y. X. Z., & Mishra, S. (2018). Obesity-linked cancers: Current knowledge, challenges and limitations in mechanistic studies and rodent models. Cancers, 10(12), 523. https://doi.org/10.3390/cancers10120523
57. Zhang, Y., Duan, W., Villanueva, L. E., & Chen, S. (2023). Transforming sports training through the integration of internet technology and artificial intelligence. Soft Computing, 27(20), 15409–15423. https://doi.org/10.1007/s00500-023-08960-w