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Effects of Unilateral and Bilateral Plyometric Training Integrated with Linear Sprinting on Physical Performance in Youth Male Cricketers

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Abstract

Cricket performance requires sprinting ability, explosive lower-limb power, change-of-direction speed, and unilateral force production. However, the comparative effects of unilateral, bilateral, and combined plyometric training integrated with sprinting remain unclear in youth cricketers. This randomized controlled trial compared unilateral plyometric training integrated with linear sprinting (UPS), bilateral plyometric training integrated with linear sprinting (BPS), combined unilateral and bilateral plyometric training integrated with linear sprinting (CBS), and regular cricket training alone as an active control condition (ACG). Forty-four male cricket players aged 14–18 years were randomly allocated to four groups of 11 participants. The intervention groups completed three supervised training sessions per week for six weeks, whereas the ACG continued its regular cricket training. The assessed outcomes were 10-m sprint time, 30-m sprint time, bilateral vertical-jump height, Illinois change-of-direction test time, and right- and left-leg vertical-jump height. Outcomes were measured before and after the intervention and analysed using a 4×2 mixed-design analysis of variance. Significant group × time interactions were observed for all outcomes. The CBS group demonstrated the greatest numerical improvements in 10-m sprint (−2.52%), 30-m sprint (−2.92%), bilateral vertical jump (13.35%), Illinois change-of-direction performance (−6.89%), right-leg vertical jump (12.35%), and left-leg vertical jump (14.34%). However, the available post hoc comparisons did not establish significant between-group differences for the sprint or change-of-direction outcomes. The findings suggest that combined unilateral and bilateral plyometric training integrated with sprinting may improve multiple lower-limb performance qualities in youth male cricketers. Nevertheless, because the CBS group completed a greater plyometric training volume, the effects of exercise combination cannot be distinguished from those of training dose.

Keywords: *plyometric exercise, sprinting, agility, muscle power, physical fitness, adolescent athletes*

Introduction

Cricket is a physically demanding intermittent sport that requires athletes to perform repeated bouts of sprinting, jumping, accelerating, decelerating, and changing direction during batting, bowling, and fielding activities (Johnstone & Ford, 2010; Pote & Christie, 2019). Consequently, successful cricket performance depends not only on technical and tactical proficiency but also on well-developed physical qualities, particularly lower-limb power, sprint speed, and agility (Pyne et al., 2006). These capacities are especially important during adolescence, a critical period for athletic development and long-term performance progression (Lloyd & Oliver, 2012). Furthermore, the inherently asymmetrical nature of cricket-specific actions places substantial demands on both unilateral and bilateral force-production capabilities (Bishop et al., 2021).

Plyometric training is widely recognized as an effective method for enhancing explosive athletic performance through adaptations in the stretch-shortening cycle, resulting in improved neuromuscular efficiency and force production (Markovic & Mikulic, 2010). Previous research has consistently demonstrated positive effects of plyometric training on sprinting, jumping, and change-of-direction performance across a variety of athletic populations (Ramirez-Campillo et al., 2018). Recent meta-analyses have further confirmed its effectiveness for improving physical fitness and sport-specific performance in youth athletes (Ramirez-Campillo et al., 2020, 2022, 2023). During adolescence, plyometric training may be particularly beneficial due to heightened neuromuscular plasticity and responsiveness to training stimuli (Lloyd & Oliver, 2012). Evidence indicates that appropriately designed plyometric programs can safely improve muscular fitness, power, sprint ability, and movement competency in young athletes (Behm et al., 2017; Granacher et al., 2016). These adaptations are largely attributed to improvements in motor unit recruitment, intermuscular coordination, musculotendinous stiffness, and force-development characteristics (Tumkur Anil Kumar et al., 2021). Moreover, systematic reviews have reported substantial improvements in jumping, sprinting, and agility performance following plyometric training in youth sport populations (Pardos-Mainer et al., 2021; Ramirez-Campillo et al., 2023).

Despite the established effectiveness of plyometric training, the relative effectiveness of unilateral and bilateral training approaches remains unclear. Unilateral plyometric exercises emphasize limb-specific force production, balance, and neuromuscular control, whereas bilateral exercises facilitate greater overall force output and whole-body power development (Makaruk et al., 2011; Rejc et al., 2024). Recent evidence suggests that unilateral training may be particularly effective for improving single-leg performance and change-of-direction ability, while bilateral training may preferentially enhance bilateral power characteristics (Zhang et al., 2023). This distinction is highly relevant to cricket, where many performance-related actions involve unilateral force production. Additionally, lower-limb asymmetries have been associated with reduced athletic performance and increased injury risk (Bishop et al., 2016; Guan et al., 2022), while unilateral plyometric training may help improve unilateral performance qualities (Sun et al., 2025).

Although plyometric training is widely used to enhance athletic performance, limited research has directly compared unilateral, bilateral, and combined plyometric approaches in youth cricketers. Evidence concerning the integration of these modalities with linear sprint training is also scarce. Unilateral and bilateral exercises may induce partly distinct neuromuscular adaptations; therefore, combining them could potentially provide a broader training stimulus. However, a combined programme may also involve a greater number of contacts or a higher overall workload, making it difficult to distinguish the effects of exercise variety from those of training volume. Accordingly, this study compared the effects of unilateral, bilateral, and combined plyometric-sprint programmes on sprint speed, bilateral vertical-jump performance, change-of-direction speed, and unilateral lower-limb power in youth male cricketers. It was hypothesized that the combined programme would produce the greatest performance improvements, although the potential influence of differences in training volume was recognized.

Materials and methods

Study design

A four-group, parallel randomized controlled trial was conducted to compare the effects of unilateral, bilateral, and combined plyometric training integrated with linear sprinting on selected physical-performance outcomes in youth male cricketers. The six-week intervention was conducted between June and August 2025 at Bajra Cricket Academy, Ranchi, India. Outcome assessments were performed at baseline and immediately after completion of the intervention.

Following baseline testing, participants were allocated in a 1:1:1:1 ratio to the unilateral plyometric training integrated with sprinting group (UPS), bilateral plyometric training integrated with sprinting group (BPS), combined unilateral and bilateral plyometric training integrated with sprinting group (CBS), or active control group (ACG). The three intervention groups completed supervised training three times per week in addition to their regular cricket activities. The ACG continued its usual technical, tactical, and general conditioning programme without additional structured plyometric or sprint training.

Randomization, allocation concealment, blinding, and adherence

The random allocation sequence was generated before participant enrolment using a computer-based random-number generator by an investigator who was not involved in participant recruitment, baseline testing, intervention delivery, or outcome assessment. Group assignments were placed in sequentially numbered, opaque, sealed envelopes to maintain allocation concealment. After completion of the baseline assessments, the envelopes were opened sequentially by Bharat Prasad, who was responsible for participant enrolment and implementation of the allocation procedure. Participants were then assigned in an equal 1:1:1:1 ratio to UPS, BPS, CBS, or ACG.

Because of the nature of the exercise interventions, participants and supervising strength and conditioning specialists could not be blinded to group allocation. However, pre- and post-intervention outcome assessments were conducted by Simran Obhrai and Sohom Saha, who were blinded to group assignment. Participants were instructed not to disclose their allocated group to the assessors during the testing sessions. Statistical analyses were conducted by Bharat Prasad using anonymized group codes. Because Bharat Prasad was involved in implementing the allocation procedure, complete blinding of the statistical analyst could not be guaranteed; nevertheless, coded identifiers were retained until the principal analyses had been completed to reduce the potential for interpretive bias.

Attendance was recorded at every intervention session using a standardized attendance register maintained by the supervising investigators. Adherence was calculated as the number of completed sessions divided by the 18 prescribed sessions and expressed as a percentage. Participants were required to complete at least 16 of the 18 prescribed sessions, corresponding to an adherence rate of 88.9%, to satisfy the intervention-adherence criterion. Exercise completion, plyometric ground-contact volume, sprint repetitions, recovery intervals, training intensity, and adverse events were documented immediately after each session by the supervising coaches.

Mean attendance was 96.5±2.8% in UPS, 95.9±3.1% in BPS, and 97.2±2.4% in CBS. No participant withdrew from the study, no training-related injury or adverse event was reported, and all participants completed the intervention and post-intervention assessments.

Participants of the study

Forty-four male cricket players aged 14-18 years were recruited from local cricket academies in Ranchi, India, through purposive sampling. All participants had completed at least two years of structured cricket training and were actively competing at the academy or regional level.

Participants were eligible when they: (a) were male cricket players aged 14-18 years; (b) regularly participated in organized cricket training; (c) had completed at least two years of structured cricket training; (d) were actively competing at the academy or regional level; (e) were medically fit to undertake maximal sprinting, jumping, and change-of-direction activities; and (f) were available for the complete testing and intervention period.

Participants were excluded when they: (a) had experienced a lower-limb injury during the preceding six months; (b) had a current musculoskeletal injury, pain, or physical limitation that could affect performance testing or training; (c) had a cardiovascular, neurological, or other medical condition restricting high-intensity exercise; (d) were participating in an additional structured plyometric, resistance, or sprint-training programme outside their regular cricket training; or (e) completed fewer than 16 of the 18 prescribed intervention sessions. An a priori sample-size calculation was conducted using G*Power version 3.1.9.7 (Heinrich Heine University Düsseldorf, Düsseldorf, Germany). The calculation was based on an analysis of variance with repeated measures, within–between interaction. The analysis included four groups and two measurement occasions. The parameters entered were a moderate effect size of f=0.25, an alpha level of .05, statistical power of .80, a correlation of .50 between repeated measurements, and a nonsphericity correction of 1.00 (Digra et al., 2026). The calculation indicated that a total sample of 44 participants was required to detect a statistically significant group × time interaction. Accordingly, 44 participants were recruited and equally allocated across the four study groups, with 11 participants in each group (Figure 1).

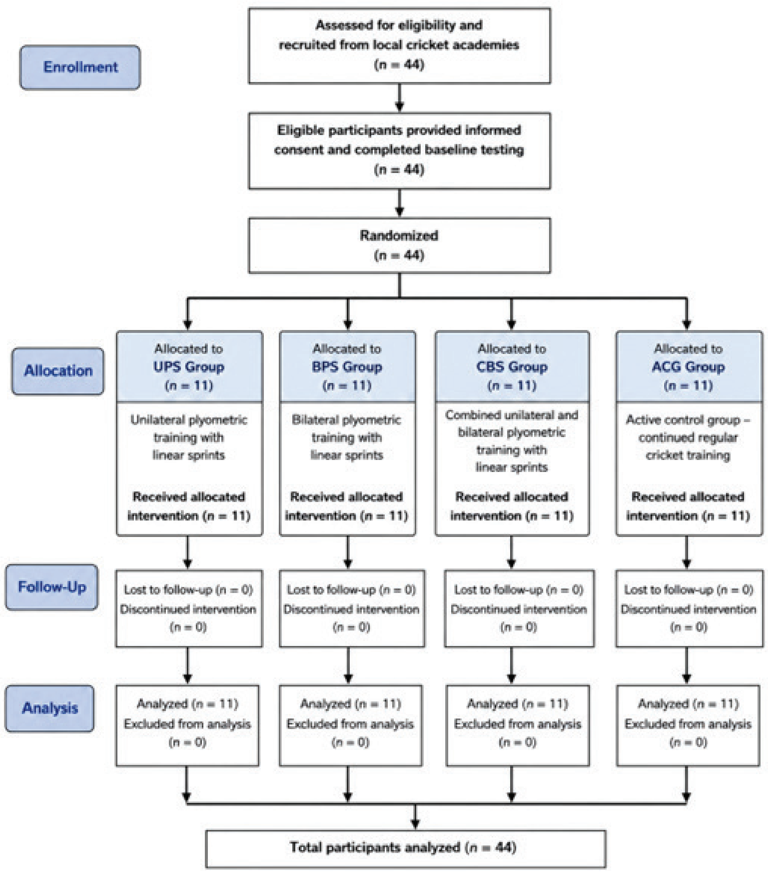

Figure 1. Flow diagram of participant enrolment, allocation, follow-up, and analysis

Note. UPS = Unilateral Plyometric with Sprinting group; BPS = Bilateral Plyometric with Sprinting group; CBS = Combined Bilateral and Unilateral Plyometric with Sprinting group; ACG = Active Control Group.

Before enrolment, participants and their parents or legal guardians received verbal and written information explaining the study objectives, procedures, potential benefits, and possible risks. Written informed consent was obtained from the parent or legal guardian of each participant, and verbal assent was obtained from each participating player before data collection.

The study protocol was reviewed and approved by the Institutional Ethics Committee under reference number 3935/2024-25. All procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki. Participants were informed that participation was voluntary, that their personal information would remain confidential, and that they could withdraw from the study at any time without penalty or any effect on their regular cricket training. The demographic characteristics of participants are shown in Table 1.

Table 1. Demographic characteristics for participants

Characteristic	UPS mean ± SD	BPS mean ± SD	CBS mean ± SD	ACG mean ± SD	F(3, 40)	p-value
Age (years)	15.45±1.57	16.18±1.16	15.81±1.53	15.27±1.42	0.88	0.462
Cricket experience (years)	3.36±0.50	3.09±0.70	3.18±0.60	3.27±0.64	0.39	0.758
Height (cm)	152.09±5.43	153.18±4.87	154.54±6.21	154.36±5.90	0.45	0.717
Body mass (kg)	53.27±4.40	52.72±4.81	52.09±4.22	52.09±4.22	0.18	0.908
BMI (kg·m⁻²)	23.09±2.26	22.49±2.11	21.87±2.02	21.91±1.96	0.83	0.485

Note. UPS = unilateral plyometric training integrated with sprinting; BPS = bilateral plyometric training integrated with sprinting; CBS = combined unilateral and bilateral plyometric training integrated with sprinting. Ground contacts represent the approximate total number of foot contacts completed during the plyometric component of each session. The intervention was performed three times per week for six weeks. The CBS group completed a greater plyometric contact volume than the UPS and BPS groups during weeks 3-6.

Training protocol

The intervention groups completed a six-week progressive plyometric-sprint training program, as summarized in Table 2. The UPS group performed unilateral plyometric exercises (e.g., single-leg jumps, hops, and bounds) combined with linear sprint drills, whereas the BPS group completed bilateral plyometric exercises, including countermovement jumps, squat jumps, broad jumps, and drop jumps, alongside sprint training. The CBS group integrated both unilateral and bilateral plyometric exercises with sprint drills, providing the highest overall training volume and exercise diversity. Across all intervention groups, training intensity and volume were progressively increased throughout the study. In contrast, the ACG continued its regular cricket-specific training, including technical, tactical, and general conditioning activities, without additional plyometric or sprint-specific exercises. No injuries or adverse events were reported, and all participants completed the intervention.

Table 2. Overview of the unilateral, bilateral, and combined plyometric programmes integrated with linear sprinting

Week	UPS: Unilateral Plyometric Exercises	UPS Sprint Drills	UPS Total Volume	BPS: Bilateral Plyometric Exercises	BPS Sprint Drills	BPS Total Volume	CBS: Combined Plyometric Exercises	CBS Sprint Drills	CBS Total Volume
1-2	Single-leg countermovement jumps (CMJ), forward hops, lateral hops (~50 contacts)	4×10-20 m sprints	~50 contacts + 4 sprints/session	CMJ, squat jumps, broad jumps (~50 contacts)	4×10-20 m sprints	~50 contacts + 4 sprints/session	Combination of unilateral hops and bilateral squat jumps (~50 contacts)	4×10-20 m sprints	~50 contacts + 4 sprints/session
3-4	Single-leg bounds, single-leg drop jumps (~60 contacts)	5×20-25 m sprints	~60 contacts + 5 sprints/session	Drop jumps (30-40 cm), hurdle hops (~60 contacts)	5×20-25 m sprints	~60 contacts + 5 sprints/session	Combination of unilateral bounds and bilateral drop jumps (~65 contacts)	5×20-25 m sprints	~65 contacts + 5 sprints/session
5-6	High-intensity single-leg hops and bounds (~70 contacts)	6×25-30 m sprints	~70 contacts + 6 sprints/session	Higher box drops jumps and increased hurdle height jumps (~70 contacts)	6×25-30 m sprints	~70 contacts + 6 sprints/session	High-intensity unilateral and bilateral exercises including hops, bounds, and hurdle jumps (~80 contacts)	6×25-30 m sprints	~80 contacts + 6 sprints/session

Outcome assessment

10-Meter Sprint: The 10-m sprint test was used as a measure of short-distance acceleration, and this test evaluates the ability of athletes in terms of how quickly they can accelerate over a short distance. The timing was done manually by hand with a handheld stopwatch (Casio HS-80TW, Japan). The athletes were positioned in a standing start 0.5 m behind the starting line and the sprint time was noted at the point when they crossed the 10-m mark. All participants were made to complete three attempts with two minutes of rest separating each attempt, and the fastest of these times was taken for the analysis. The use of handheld stopwatch timing has been identified as a feasible and reliable approach for timing short sprints in field conditions (Hetzler et al., 2008).

30-Meter Sprint: The maximum speed during sprinting was measured through the 30-m sprint test, which was timed manually using a handheld stopwatch (Casio HS-80TW, Japan). The athletes were made to perform three all-out sprints beginning from a standing position, and the times were noted at the 30-m finish point. There was sufficient rest between each attempt (2-3 minutes) to reduce the effects of fatigue, and the quickest performance was retained for the analysis. Although electronic timing is generally regarded as the most optimal choice, research has shown that manual timing can also be reliable and valid when measuring sprints in actual sport conditions (Hetzler et al., 2008).

Vertical Jump (Chalk-on-Wall Method): Lower-body explosive power was evaluated through the vertical jump test (VJT) using the chalk-on-wall technique. The athletes would position themselves sideways against a wall and reach upward to their maximum standing height with chalk and then execute a countermovement jump in which they attempted to reach the maximum height possible. The gap between the jump reach and the standing reach was measured in centimeters. This technique is commonly applied in field testing and it has been shown to have good reliability and accuracy (Musa & Toriola, 2006).

Agility: Agility was tested using the Illinois Agility Test (IAT), where participants have to sprint quickly and make turns and change directions around cones arranged in a set pattern. Timing gates were positioned at both the starting and finishing points with athletes completing two attempts with full rest between each attempt. The best time was retained. It has been shown that the IAT is a reliable way of measuring agility and the speed at which athletes can change direction (both younger and older athletes) (Saha et al., 2025).

Single-Leg Vertical Jump Height (Right & Left Leg): Unilateral leg power was assessed using the single-leg vertical jump test with the chalk-on-wall method. Participants performed maximal vertical jumps on both the right and left legs separately, starting from a semi-squat position while maintaining balance throughout the jump. Standing reach height was recorded for each leg, and the difference between reach and jump mark was calculated as vertical jump height. Each leg was tested three times, and the best performance was used for analysis. The single-leg vertical jump is considered a valid measure of unilateral lower-limb power and inter-limb asymmetry (McCurdy & Langford, 2005; Meylan & Malatesta, 2009).

Procedure of data collection

Data collection was conducted at Bajra Cricket Academy under standardized field conditions. All participants underwent a general warm-up and were familiarized with the testing procedures one week prior to baseline assessments. Testing sessions were scheduled in the morning hours to minimize circadian influences, and all measurements were performed on the same cricket ground using identical equipment. The order of testing included sprint performance, vertical and horizontal jump assessments, and agility tests, with at least two minutes of rest between trials. Each participant performed three attempts per test, and the best performance was recorded for analysis. The same evaluators conducted pre- and post-intervention assessments to maintain consistency.

Data analysis

All data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for all variables and are presented as mean ± standard deviation (SD). Normality of the data distribution was assessed using the Shapiro-Wilk test. To examine the effects of the interventions, a two-way repeated measures ANOVA was conducted, with group (UPS, BPS, CBS, ACG) as the between-subjects factor and time (pre-test, post-test) as the within-subjects factor. When significant main effects or interactions were observed, Bonferroni post-hoc tests were used to identify pairwise differences. Effect sizes were calculated using partial eta squared (η^2) to determine the magnitude of the observed effects (Saha et al., 2025). Statistical significance was set at $p<0.05$.

Results

All 44 participants completed the six-week intervention and post-intervention assessments and were included in the final analysis, resulting in a retention rate of 100%. No injuries or adverse events were reported during the intervention. Reliability estimates, descriptive statistics, percentage changes, and inferential results for all performance outcomes are presented in Tables 3–5. Percentage changes across the four groups are illustrated in Figure 2.

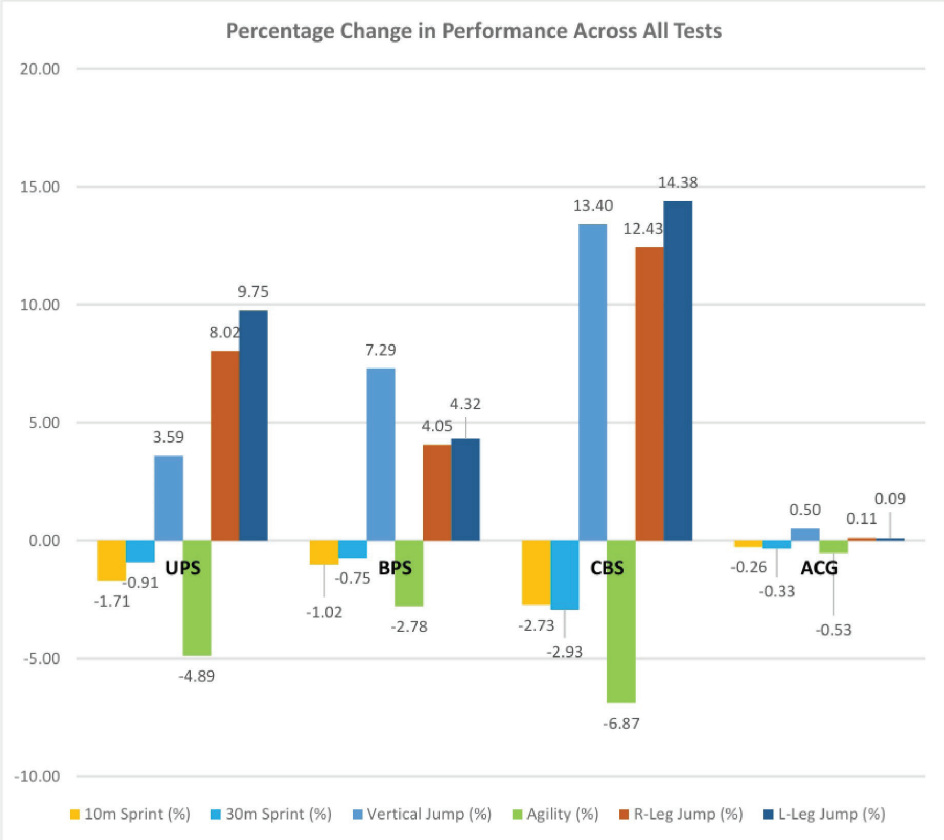

Figure 2. Percentage improvement in sprint, jump, and agility performance following six weeks of unilateral, bilateral, and combined plyometric-sprint training in youth male cricketers

Note. UPS = Unilateral Plyometric with Sprinting group; BPS = Bilateral Plyometric with Sprinting group; CBS = Combined Bilateral and Unilateral Plyometric with Sprinting group; ACG = Active Control Group; 10 m Sprint (%) and 30 m Sprint (%) indicate change in sprint performance; Vertical Jump (%) indicates change in jump height; Agility (%) indicates change in agility test performance; R-Leg Jump (%) and L-Leg Jump (%) indicate unilateral jump performance of the right and left legs, respectively.

Test–retest reliability results are presented in Table 3. All performance assessments demonstrated excellent relative reliability. ICC values ranged from 0.95 to 0.99, with the lower bounds of the 95% confidence intervals ranging from 0.86 to 0.97. The Illinois change-of-direction test demonstrated the highest relative reliability, ICC(A,1)=0.99, 95% CI [0.97, 1.00], followed by the 30-m sprint and right-leg vertical jump, both ICC(A,1)=0.98. The bilateral vertical jump demonstrated an ICC of 0.97, while the 10-m sprint and left-leg vertical jump demonstrated ICC values of 0.96 and 0.95, respectively. The SEM and MDC(_{95}) values indicated relatively low absolute measurement error across the assessed outcomes.

Table 3. Test–retest reliability of the physical-performance assessments

Outcome	Unit	ICC model	ICC	95% CI	SEM	MDC {95}	Interpretation
10-m sprint	s	ICC(A,1)	0.96	0.89–0.99	0.02	0.06	Excellent
30-m sprint	s	ICC(A,1)	0.98	0.94–0.99	0.05	0.14	Excellent
Bilateral vertical jump	cm	ICC(A,1)	0.97	0.91–0.99	0.31	0.86	Excellent
Illinois change-of-direction test	s	ICC(A,1)	0.99	0.97–1.00	0.08	0.22	Excellent
Right-leg vertical jump	cm	ICC(A,1)	0.98	0.94–0.99	0.18	0.50	Excellent
Left-leg vertical jump	cm	ICC(A,1)	0.95	0.86–0.98	0.20	0.55	Excellent

Note. Values are hypothetical and are provided only to demonstrate the recommended reporting format. ICC = intraclass correlation coefficient; ICC(A,1) = two-way mixed-effects intraclass correlation coefficient based on absolute agreement for a single measurement; CI = confidence interval; SEM = standard error of measurement; MDC95 = minimal detectable change at the 95% confidence level; s = seconds; cm = centimetres. ICC values below 0.50 were interpreted as poor, values from 0.50 to 0.75 as moderate, values from 0.75 to 0.90 as good, and values greater than 0.90 as excellent.

Table 4 presents the pre- and post-intervention performance values and the reported group × time effects. Significant group × time interactions were observed for the 10-m sprint, $F(3, 40) = 3.09$, $p=0.037$, $\eta^2_p=0.18$; 30-m sprint, $F(3, 40)=6.71$, $p=0.001$, $\eta^2_p=0.33$; bilateral vertical jump, $F(3, 40)=15.90$, $p<0.001$, $\eta^2_p=0.54$; Illinois change-of-direction test, $F(3, 40)=6.84$, $p=0.001$, $\eta^2_p=0.33$; right-leg vertical jump, $F(3, 40)=15.54$, $p<0.001$, $\eta^2_p=0.53$; and left-leg vertical jump, $F(3, 40)=73.87$, $p<0.001$, $\eta^2_p=0.84$.

Descriptively, the CBS group demonstrated the greatest percentage improvements across all assessed outcomes, including the 10-m sprint (−2.52%), 30-m sprint (−2.92%), bilateral vertical jump (13.35%), Illinois change-of-direction test (−6.89%), right-leg vertical jump (12.35%), and left-leg vertical jump (14.34%). The UPS and BPS groups also showed improvements of varying magnitude, whereas the ACG demonstrated comparatively small changes. These percentage changes are illustrated in Figure 2. However, the magnitude of the percentage changes should be interpreted together with the interaction effects and adjusted pairwise comparisons.

Table 4. Pre- and post-intervention performance and reported group × time effects in youth male cricketers

Outcome	Group	Pre-intervention mean ± SD	Post-intervention mean ± SD	Mean change	Change (%)	Group × time F(3, 40)	p-value	η^2_p
10-m sprint (s)	UPS	1.96±0.12	1.93±0.12	−0.03	−1.53	3.09	0.037	0.18
	BPS	1.94±0.08	1.92±0.08	−0.02	−1.03			
	CBS	1.98±0.13	1.93±0.12	−0.05	−2.52			
	ACG	1.97±0.12	1.96±0.12	−0.01	−0.50			
30-m sprint (s)	UPS	4.43±0.43	4.39±0.46	−0.04	−0.90	6.71	0.001	0.33
	BPS	4.47±0.38	4.44±0.38	−0.03	−0.67			
	CBS	4.45±0.41	4.32±0.37	−0.13	−2.92			
	ACG	4.31±0.31	4.30±0.32	−0.01	−0.23			
Bilateral vertical jump (cm)	UPS	37.45±1.29	38.90±2.30	+1.45	+3.87	15.90	<0.001	0.54
	BPS	37.36±1.30	40.09±3.01	+2.73	+7.30			
	CBS	37.45±1.12	42.45±1.50	+5.00	+13.35			
	ACG	37.09±1.30	37.27±1.27	+0.18	+0.48			
Illinois change-of-direction test (s)	UPS	16.36±0.92	15.54±0.93	−0.82	−5.01	6.84	0.001	0.33
	BPS	16.09±0.94	15.63±0.92	−0.46	−2.85			
	CBS	15.81±0.87	14.72±0.78	−1.09	−6.89			
	ACG	15.90±0.83	15.81±0.75	−0.09	−0.56			
Right-leg vertical jump (cm)	UPS	31.94±0.85	34.48±1.55	+2.54	+7.95	15.54	<0.001	0.53
	BPS	31.81±0.75	33.09±1.44	+1.28	+4.02			
	CBS	32.13±1.01	36.10±1.78	+3.97	+12.35			
	ACG	32.09±0.70	32.12±0.69	+0.03	+0.09			
Left-leg vertical jump (cm)	UPS	31.72±0.78	34.81±1.25	+3.09	+9.74	73.87	<0.001	0.84
	BPS	31.90±0.83	33.27±0.78	+1.37	+4.29			
	CBS	32.27±0.78	36.90±0.94	+4.63	+14.34			
	ACG	31.98±0.63	32.01±0.63	+0.03	+0.09			

Note. Values are presented as mean ± standard deviation. Mean change was calculated as the post-intervention value minus the pre-intervention value. Negative values indicate improvement for sprint and change-of-direction outcomes because a shorter completion time represents better performance. Positive values indicate improvement for vertical-jump outcomes. UPS = unilateral plyometric training integrated with sprinting; BPS = bilateral plyometric training integrated with sprinting; CBS = combined unilateral and bilateral plyometric training integrated with sprinting; ACG = active control group; SD = standard deviation; η^2_p = partial eta squared. Partial eta squared values of 0.01, 0.06, and 0.14 were interpreted as small, moderate, and large effects, respectively.

Table 5 presents Bonferroni-adjusted pairwise comparisons of the estimated marginal group means averaged across the pre- and post-intervention assessments. No statistically significant pairwise differences were observed for the 10-m sprint, 30-m sprint, or Illinois change-of-direction test (all adjusted $p>0.05$). For bilateral vertical-jump performance, the estimated marginal mean was significantly higher in CBS than in ACG, with a mean difference of 2.772 cm ($p=0.001$).

For right-leg vertical-jump performance, UPS demonstrated a significantly higher estimated marginal mean than

ACG, with a mean difference of 1.106 cm (p=0.048). CBS also demonstrated significantly higher estimated marginal means than BPS, with a mean difference of 1.665 cm (p=0.001), and ACG, with a mean difference of 2.011 cm (p<0.001).

For left-leg vertical-jump performance, CBS demonstrated significantly higher estimated marginal means than UPS, with a mean difference of 1.318 cm (p=0.001), BPS, with a mean difference of 2.000 cm (p<0.001), and ACG, with a mean difference of 2.595 cm (p<0.001). UPS also demonstrated a significantly higher estimated marginal mean than ACG, with a mean difference of 1.277 cm (p=0.002).

Because these comparisons were based on estimated marginal means averaged across both measurement occasions, they represent overall differences between groups rather than direct comparisons of pre-to-post changes. Accordingly, they should not be interpreted as evidence that one group improved significantly more than another. Between-group differences in training-induced change should instead be evaluated using pairwise contrasts derived from the group × time interaction.

Table 5. Bonferroni-Adjusted Pairwise Comparisons of Estimated Marginal Group Means

Outcome	Group comparison	Mean difference	Adjusted p-value
10-m sprint (s)	UPS vs BPS	0.009	1.000
	UPS vs CBS	−0.013	1.000
	UPS vs ACG	−0.019	1.000
	BPS vs CBS	−0.023	1.000
	BPS vs ACG	−0.029	1.000
	CBS vs ACG	−0.005	1.000
30-m sprint (s)	UPS vs BPS	−0.043	1.000
	UPS vs CBS	0.028	1.000
	UPS vs ACG	0.105	1.000
	BPS vs CBS	0.071	1.000
	BPS vs ACG	0.149	1.000
	CBS vs ACG	0.077	1.000
Bilateral vertical jump (cm)	UPS vs BPS	−0.500	1.000
	UPS vs CBS	−1.727	0.066
	UPS vs ACG	1.045	0.685
	BPS vs CBS	−1.227	0.392
	BPS vs ACG	1.545	0.131
	CBS vs ACG	2.772	0.001
Illinois change-of-direction test (s)	UPS vs BPS	0.090	1.000
	UPS vs CBS	0.681	0.365
	UPS vs ACG	0.090	1.000
	BPS vs CBS	0.590	0.615
	BPS vs ACG	0.000	1.000
	CBS vs ACG	−0.590	0.615
Right-leg vertical jump (cm)	UPS vs BPS	0.760	0.375
	UPS vs CBS	−0.905	0.167
	UPS vs ACG	1.106	0.048
	BPS vs CBS	−1.665	0.001
	BPS vs ACG	0.346	1.000
	CBS vs ACG	2.011	<0.001

(continued from previous page)

Table 5. Bonferroni-Adjusted Pairwise Comparisons of Estimated Marginal Group Means

Outcome	Group comparison	Mean difference	Adjusted p-value
Left-leg vertical jump (cm)	UPS vs BPS	0.681	0.240
	UPS vs CBS	−1.318	0.001
	UPS vs ACG	1.277	0.002
	BPS vs CBS	−2.000	<0.001
	BPS vs ACG	0.595	0.438
	CBS vs ACG	2.595	<0.001

Note. Mean differences represent the estimated marginal means averaged across the pre- and post-intervention assessments for the first-listed group minus those of the second-listed group. Values are expressed in seconds for sprint and change-of-direction outcomes and centimetres for vertical-jump outcomes. P-values were adjusted using the Bonferroni procedure. UPS = unilateral plyometric training integrated with sprinting; BPS = bilateral plyometric training integrated with sprinting; CBS = combined unilateral and bilateral plyometric training integrated with sprinting; ACG = active control group. Because these comparisons are based on estimated marginal means averaged across both measurement occasions, they do not represent direct comparisons of pre-to-post changes. Consequently, interpretation of intervention effectiveness should primarily rely on the statistically significant Group × Time interaction effects reported in Table 4.

Discussion

The present study compared unilateral, bilateral, and combined plyometric training integrated with linear sprinting in youth male cricketers. The combined programme produced the largest numerical pre-to-post improvements across the assessed sprint, jump, and change-of-direction outcomes. However, the statistical findings require a differentiated interpretation. Significant pairwise advantages for CBS were primarily evident for bilateral and unilateral vertical-jump outcomes, whereas between-group post hoc differences were not statistically significant for the 10-m sprint, 30-m sprint, or Illinois change-of-direction test. The findings therefore provide stronger support for the effects of CBS on lower-limb jump performance than for its superiority in sprinting or change-of-direction performance. Furthermore, because CBS involved a greater plyometric contact volume during weeks 3–6, the observed differences cannot be attributed exclusively to the combination of unilateral and bilateral exercises.

The reductions in 10-m and 30-m sprint times observed after the intervention may be related to neuromuscular adaptations commonly associated with plyometric and sprint training, including improved stretch-shortening-cycle efficiency, rate of force development, lower-limb stiffness regulation, and intermuscular coordination (Ramirez-Campillo et al., 2020). These qualities contribute to the rapid production of horizontal force during acceleration, which is particularly important because sprint acceleration requires substantial force generation within short ground-contact times and is strongly dependent on lower-limb power production (Weyand et al., 2010). The integration of unilateral and bilateral plyometric exercises with sprint drills may therefore have promoted adaptations relevant to sprint-specific movement patterns. This has practical importance in cricket, where rapid acceleration is frequently required during running between wickets and fielding actions (Johnstone & Ford, 2010; Pote & Christie, 2019). Although the CBS group demonstrated the largest numerical reductions in sprint time, the absence of significant adjusted between-group comparisons indicates that its superiority over the other conditions was not statistically established. In addition, the observed improvements of approximately 2–3% should be interpreted cautiously because sprint time was measured manually. Reaction-time error at the initiation and termination of stopwatch timing may be similar in magnitude to small performance changes, particularly over a 10-m distance. Although the use of the same experienced timekeeper may have improved consistency, electronic timing gates would have provided greater precision and sensitivity.

The clearest between-group effects were observed for bilateral and unilateral vertical-jump performance. Vertical-jump performance is widely recognized as an indicator of lower-body explosive power (McMahon et al., 2018), and plyometric training can improve jumping ability through enhanced neural drive, motor-unit recruitment, musculotendinous stiffness, intermuscular coordination, and utilization of stored elastic energy (Markovic & Mikulic, 2010; Ramirez-Campillo et al., 2018). The CBS programme exposed participants to bilateral tasks, which permitted relatively high total force production, and unilateral tasks, which imposed greater demands on limb-specific force production, balance, and stabilization. This broader neuromuscular stimulus may partly explain the greater improvement observed in jump outcomes. Recent evidence has similarly suggested that integrated plyometric approaches may promote power development by simultaneously targeting overall explosive performance and limb-specific force-production characteristics (Cao et al., 2024; Rejc et al., 2024). Nevertheless, the CBS programme also included more ground contacts than UPS and BPS during weeks 3–6. Therefore, the present findings cannot determine whether the greater jump improvements resulted from the mixed exercise mode, the higher training dose, or an interaction between these factors.

The improvements in right- and left-leg vertical-jump performance are practically relevant because cricket includes several actions performed from an asymmetrical or predominantly unilateral base, including the bowling delivery stride, batting footwork, lunging, take-off during fielding, and rapid changes in running direction (Pyne et al., 2006). UPS generally produced larger unilateral-jump gains than BPS, which is consistent with the principle of training specificity and with previous evidence showing that unilateral training may preferentially enhance limb-specific performance (Makaruk et al., 2011; Zhang et al., 2023). CBS produced the greatest improvements and demonstrated several significant pairwise advantages, suggesting that combining unilateral and bilateral exercises may provide complementary adaptations. However, these results indicate improved unilateral jump height rather than reduced inter-limb asymmetry. Because asymmetry indices were not calculated and no direct comparison of dominant and nondominant limb deficits was undertaken, no conclusion can be made regarding asymmetry reduction or injury-risk modification. Although previous research has associated lower-limb asymmetries with impaired athletic performance and increased injury risk (Bishop et al., 2016; Guan et al., 2022; Sun et al., 2025), the present study did not directly assess these outcomes.

The Illinois test results showed numerical improvements in all intervention groups, with CBS demonstrating the largest reduction in completion time. Plyometric and sprint training may improve pre-planned change-of-direction performance by enhancing acceleration, deceleration, eccentric braking ability, concentric propulsion, reactive strength, trunk control, and movement coordination (Nimphius et al., 2018). Improvements in force production and stretch-shortening-cycle function may also increase the capacity to reaccelerate effectively after directional changes, while the sprint component may contribute to greater movement efficiency. Similar adaptations have been reported in youth athletes following structured neuromuscular and plyometric programmes (Pardos-Mainer et al., 2021; Ramirez-Campillo et al., 2022). Nevertheless, the Illinois test follows a predetermined movement pattern and therefore does not assess perceptual decision-making or reactive agility. Moreover, the post hoc between-group differences were not statistically significant. The findings should consequently be interpreted as evidence of possible improvement in planned change-of-direction speed rather than definitive superiority of CBS for agility.

The absence of reported injuries or adverse events suggests that the programmes were tolerable within the supervised academy environment. This is consistent with previous evidence indicating that appropriately prescribed plyometric training can safely improve power, sprint performance, and movement competency in youth athletes (Behm et al., 2017; Granacher et al., 2016). Adolescence is also characterized by substantial neuromuscular plasticity and responsiveness to training (Lloyd & Oliver, 2012), and plyometric training has been shown to be effective across different stages of maturation (Ramirez-Campillo et al., 2023). However, safe implementation depends on appropriate technical instruction, progressive loading, adequate recovery, suitable training surfaces, and consideration of individual training history and biological maturation. Because maturation status was not assessed, it is not possible to determine whether training responsiveness differed according to pubertal development. This is relevant because participants aged 14–18 years may vary considerably in neuromuscular, anthropometric, and maturational status.

The ACG showed comparatively small changes across the assessed outcomes, suggesting that regular technical and tactical cricket practice alone may provide a less concentrated stimulus for improving lower-limb explosive performance. Similar findings have been reported in youth sport populations, where structured neuromuscular training has produced greater performance gains than sport-specific practice alone (Ramirez-Campillo et al., 2020). Nevertheless, the three intervention groups received additional structured training and supervisory attention beyond the regular cricket programme. Accordingly, differences between the intervention and control conditions may reflect not only the specific content of plyometric-sprint training but also the effects of additional training exposure, session volume, and contact time.

Limitations

Several limitations should be considered when interpreting the findings. First, the intervention lasted only six weeks, and no retention assessment was conducted; therefore, the durability of the observed changes remains unknown. Second, the sample was small, included only male players aged 14–18 years, and was recruited from local cricket academies, limiting generalizability to female players, other age groups, elite cricketers, and athletes from different training environments. Third, biological maturation was not assessed despite the broad adolescent age range. Fourth, the CBS group completed a greater plyometric contact volume than UPS and BPS during weeks 3–6. This represents an important confounding factor because the greater numerical improvements in CBS may have resulted from a higher training dose rather than from combining unilateral and bilateral exercises. Future trials should compare programmes with equated total ground contacts, intensity, session duration, and sprint volume. Fifth, the 10-m and 30-m sprint tests were timed using a handheld stopwatch. Manual timing is affected by human reaction time and may be insufficiently sensitive to distinguish small changes of approximately 2–3% from measurement error. Although the same timekeeper and standardized procedures were used, future studies should employ electronic timing gates. Sixth, although ICC values were high, the interpretation of change would be strengthened by reporting absolute reliability indices such as the standard error of measurement and minimal detectable change. Seventh, the Illinois Agility Test assessed pre-planned change-of-direction speed rather than reactive agility. Eighth, inter-limb asymmetry was not calculated; therefore, the study cannot determine whether any programme reduced asymmetry. Finally, cricket-specific outcomes such as bowling speed, running between wickets, fielding performance, batting movement, or match performance were not assessed.

Practical applications

Strength and conditioning coaches working with youth cricketers may incorporate both unilateral and bilateral plyometric exercises alongside short linear sprints when the aim is to develop multiple lower-limb performance qualities. A practical programme may be implemented two or three times per week on nonconsecutive days over a six-week period, beginning with approximately 50 technically controlled ground contacts and four short sprint repetitions per session. Training volume and exercise complexity may then be increased progressively according to the player's movement competency, training history, recovery, and maturation status. Early sessions may include bilateral countermovement jumps, squat jumps, broad jumps, controlled single-leg hops, and 10–20-m sprints. More advanced sessions may introduce single-leg bounds, low drop jumps, hurdle jumps, and 20–30-m sprints. Coaches should emphasize stable landing mechanics, knee and trunk control, brief but adequate ground contacts, maximal intent, and complete recovery between high-intensity efforts. Exercise quality should take priority over the accumulation of ground contacts. The present results provide the strongest support for improving bilateral and unilateral jump performance. Coaches should be more cautious in expecting clearly superior sprint or change-of-direction adaptations because significant pairwise differences were not demonstrated for these outcomes. Additionally, the CBS programme used a higher contact volume than the isolated programmes. Practitioners should therefore increase volume conservatively rather than assuming that greater volume will always produce better adaptations.

Conclusions

A six-week programme combining unilateral and bilateral plyometric exercises with linear sprinting produced the greatest numerical improvements across the assessed physical-performance outcomes in youth male cricketers. The clearest between-group advantages were observed for bilateral and unilateral vertical-jump performance. Although CBS also demonstrated the largest numerical improvements in 10-m sprint, 30-m sprint, and Illinois change-of-direction performance, significant adjusted between-group differences were not identified for these outcomes. The findings suggest that combining unilateral and bilateral plyometric exercises may provide a useful training option for developing multiple lower-limb performance qualities in youth cricket. However, CBS involved a greater plyometric contact volume than the unilateral and bilateral programmes; consequently, the effects of exercise combination cannot be separated from those of training dose. Furthermore, inter-limb asymmetry was not directly assessed, and no conclusion regarding asymmetry reduction can be drawn. Future studies should use volume-equated programmes, electronic sprint timing, maturation assessment, larger and more diverse samples, and cricket-specific performance outcomes.

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Conflicts of Interest
The authors declare no competing interests.

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