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Research article

Effects of Unilateral, Bilateral and Combined Plyometric Jump Training on Asymmetry of Muscular Strength and Power, and Change-of-Direction in Youth Male Basketball Players

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Abstract
This study aimed to compare the effects of unilateral (UT), bilateral (BT), and combined (UBT) plyometric training on muscular strength, power, and change-of-direction performance in youth male basketball players. Sixty-six male youth basketball players (age: 16.1 ± 0.8 years) participated in this randomized experimental study, which lasted 8 weeks with a training frequency of 2 sessions per week. The UT group performed only single-leg plyometric exercises, while the BT group conducted similar plyometric drills using both feet. The UBT group combined both approaches, performing one session of UT and one session of BT each week. The players were evaluated at baseline and after the 8-week period using a force platform for the unilateral countermovement jump test (UCMJ), isometric squat test (IST), isometric knee flexor strength test (KFS), leg land and hold test (LHT), and 5 - 0 - 5 tests. The asymmetry between legs per outcome was measured using the symmetry angle. The UT, BT, and UBT all significantly improved outcomes in the IST, UCMJ, KFS, LHT, and 5 - 0 - 5 tests ($p < 0.05$) following the intervention, with no significant differences among the three methods. However, while UT and UBT significantly reduced asymmetries in the tests ($p < 0.05$), BT increased asymmetries. Only, the UT group showed significant improvements over the control group in asymmetry measures: IST asymmetry (mean difference: 1.2%, $p = 0.049$), KFS asymmetry (mean difference: 2.5%, $p < 0.001$), and LHT asymmetry (mean difference: 1.1%, $p = 0.013$). While there are no substantial differences among UT, BT, and UBT in terms of improvements in unilateral tests and symmetry levels, UT stands out for its effectiveness in enhancing neuromuscular performance and reducing asymmetries among basketball players compared to the control condition. UT was the only method that showed significant benefits in this context. Strength and conditioning coaches might consider incorporating UT, either alone or alongside BT, to optimize individual limb strength and coordination.

Key words: Team sports, reactive strength, resistance training, single leg, athletic performance.

Introduction

Mitigating large and/or unfunctional leg asymmetries in neuromuscular strength and power and change of direction (COD) can be relevant for enhancing basketball performance (Maloney, 2019) and possibly reducing injury risk in athletes (Helme et al., 2021). Significant and/or unfunctional asymmetries can indicate imbalances in strength, power, and neuromuscular control (Roso-Moliner et al., 2023), which may compromise athletic performance. Research has demonstrated that athletes with reduced leg asymmetries exhibit better balance, coordination, and overall functional performance (Fort-Vanmeerhaeghe et al., 2020), which are essential for optimal execution of basketball-specific skills. Furthermore, unfunctional imbalances can lead to compensatory movement patterns, placing excessive stress on counterbalanced muscles, thereby increasing the likelihood of injury (Heil et al., 2020). By addressing and minimizing large and/or unfunctional leg asymmetries through strength and conditioning programs, athletes can achieve more symmetrical muscle development and improved neuromuscular control (Bettariga et al., 2022).

Plyometric jump training focused on unilateral-leg exercises (UT) can be particularly relevant for mitigating muscular strength and power asymmetries and improving COD performance in basketball (Gonzalo-Skok et al., 2019). Unilateral-leg drills may emphasize unilateral strength and power development, promoting balanced muscle growth and neuromuscular coordination between limbs (Drouzas et al., 2020). Research indicates that UT can be more effective than bilateral exercises in addressing imbalances because they force each leg to generate force independently, reducing the reliance on the dominant leg and encouraging the weaker leg to develop similarly (Ujaković and Šarabon, 2023). This balanced development can be crucial for optimizing performance in basketball which often requires rapid changes of direction (Asadi et al., 2016). Studies have shown that athletes who incorporate UT exhibit improved symmetry in power output, which translates to more functional directional changes (Zhang et al., 2023).

Despite the research comparing UT and BT, most studies focus on results related to muscular strength and power based on unilateral or bilateral tests (Bogdanis et al., 2019; Drouzas et al., 2020; Moran et al., 2021). However, there is little examination of how UT and BT actually affect symmetry in unilateral tests (Ramirez-Campillo et al., 2018). Although a certain level of asymmetry is expected and can even be functional (Afonso et al., 2022), extreme asymmetry or asymmetry beyond an individual threshold can be potentially dangerous for players (Mandorino et al., 2023). Unfortunately, the impact on symmetry is often overlooked in research comparing the effects of UT and BT (Ramirez-Campillo et al., 2018). Moreover, although some research has compared UT and BT in basketball (Gonzalo-Skok et al., 2019), none have used a study design that identifies whether a combined approach can produce similar or

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even better results than using each method in isolation. Additionally, while research has explored the impacts of UT and BT in basketball (Gonzalo-Skok et al., 2019), none have focused on asymmetries between limbs in key neuromuscular tests such as the isometric squat test (IST), unilateral countermovement jump test (UCMJ), isometric knee flexor strength test (KFS), leg land and hold test (LHT), and key COD tests like the 5 - 0 - 5 COD test (5 - 0 - 5).

The current research aims to compare UT, BT, and combined plyometric jump (UBT) training approaches, with a particular focus on asymmetries in key neuromuscular and COD outcomes. By doing so, it aims to provide new evidence to help sports scientists regulate plyometric training and support coaches in making informed decisions for basketball athletes. Unlike previous studies that separately compare UT and BT (Bogdanis et al., 2019; Drouzas et al., 2020; Moran et al., 2021), this innovative approach explores how combining them offers a practical solution, bridging the gap between research and real-world training. Considering the reasons mentioned above, this study aimed to compare the effects of UT, BT, and UBT training on muscular strength, power, and COD performance in youth male basketball players. We hypothesize that UT may significantly improve asymmetry indices in the IST, UCMJ, KFS, LHT, and 5 - 0 - 5 tests more than BT and the control groups.

Methods

Study design

The study employed a randomized controlled design, integrating three experimental intervention groups (UT, BT and UBT) into the standard training program, while a control group continued with regular basketball training only. Participants were recruited through convenience sampling from nearby basketball teams. To prevent the influence of club-specific training on the outcomes, players within each team were randomly allocated to the four groups. Among the six teams, Team A had 11 participants, Team B had 13 participants, Team C had 13 participants, Team D had 11 participants, Team E had 10 participants, and Team F had 9 participants. This approach aimed to minimize the potential impact of pre-existing training routines on the final results. Group assignments were determined through simple randomization using opaque envelopes, which were randomly handed out to the players prior to the initial assessment, ensuring each player had an equal chance of being placed in any group. This procedure ensured the allocation concealment necessary for randomized studies. The randomization process was supervised by a researcher uninvolved in the subsequent evaluation, thus ensuring the blinding process. Assessments were conducted one week before the intervention began and again during the week following the eighth week of the training program. These assessments were performed by independent researchers who were blinded to both the group assignments and the training intervention. The players and the researchers who administered the training protocols were not blinded.

Ethical procedures

Before involvement, basketball players and their parents or legal guardians received detailed information about the study's protocol and objectives. Participation was voluntary, and legal guardians provided consent by signing an informed consent form. The research adheres to ethical standards outlined in the Declaration of Helsinki and received approval for its protocol from the Ethics Committee of Chendu Institute of Physical Education (code number 10/2024).

Participants

Sixty-six male basketball players (16.1 ± 0.8 years old; 179.5 ± 7.3 cm; 68.1 ± 8.4 kg; 21.1 ± 1.8 kg/m²; maturity offset (Mirwald et al., 2002): +2.1 ± 0.4 years), classified at the trained/developmental level in the Participants Classification Framework (McKay et al., 2022), typically engaged in an average of three training sessions per week (~80 minutes per session), in addition to competitive matches. Training sessions were oriented towards both competition preparation and skill specialization. Further details regarding the characteristics of each group can be found in Table 1.

The initial sample size was determined based on an effect size of 0.70, considering the partial eta squared value of 0.33 from a study comparing unilateral versus bilateral plyometric training in basketball (Gonzalo-Skok et al., 2019). With a desired power of 0.95 and a significance level of 0.05 for F tests, particularly ANOVA repeated measures within-between interaction, the G*power software (version 3.1.9., Universität Düsseldorf, Germany) recommended a total sample size of 16.

Table 1. Descriptive statistics, including the mean values along with their respective standard deviations, for participant characteristics within each group.

	UT (n = 16)	BT (n = 16)	UBT (n = 17)	Control (n = 17)
Age (years)	15.9 ± 0.9	16.3 ± 0.8	16.2 ± 0.7	16.1 ± 0.8
Height (cm)	175.5 ± 6.9	180.5 ± 5.0	181.5 ± 9.4	179.8 ± 6.4
Body mass (kg)	62.4 ± 5.2	68.9 ± 6.7	71.5 ± 10.4	68.5 ± 8.1
BMI (kg/m^2)	20.2 ± 1.0	21.1 ± 1.8	21.6 ± 1.9	21.2 ± 2.0
Maturity offset (years)	+2.0 ± 0.3	+2.2 ± 0.4	+2.0 ± 0.5	+2.1 ± 0.4
Point guard (n)	3	3	3	4
Shooting guard (n)	3	4	3	3
Power forward (n)	3	3	4	3
Center (n)	3	3	3	3
Small forward (n)	4	3	3	3

UP: unilateral plyometric jump training; BT: bilateral plyometric jump training; UBT: combined unilateral and bilateral plyometric jump training; BMI: body mass index.

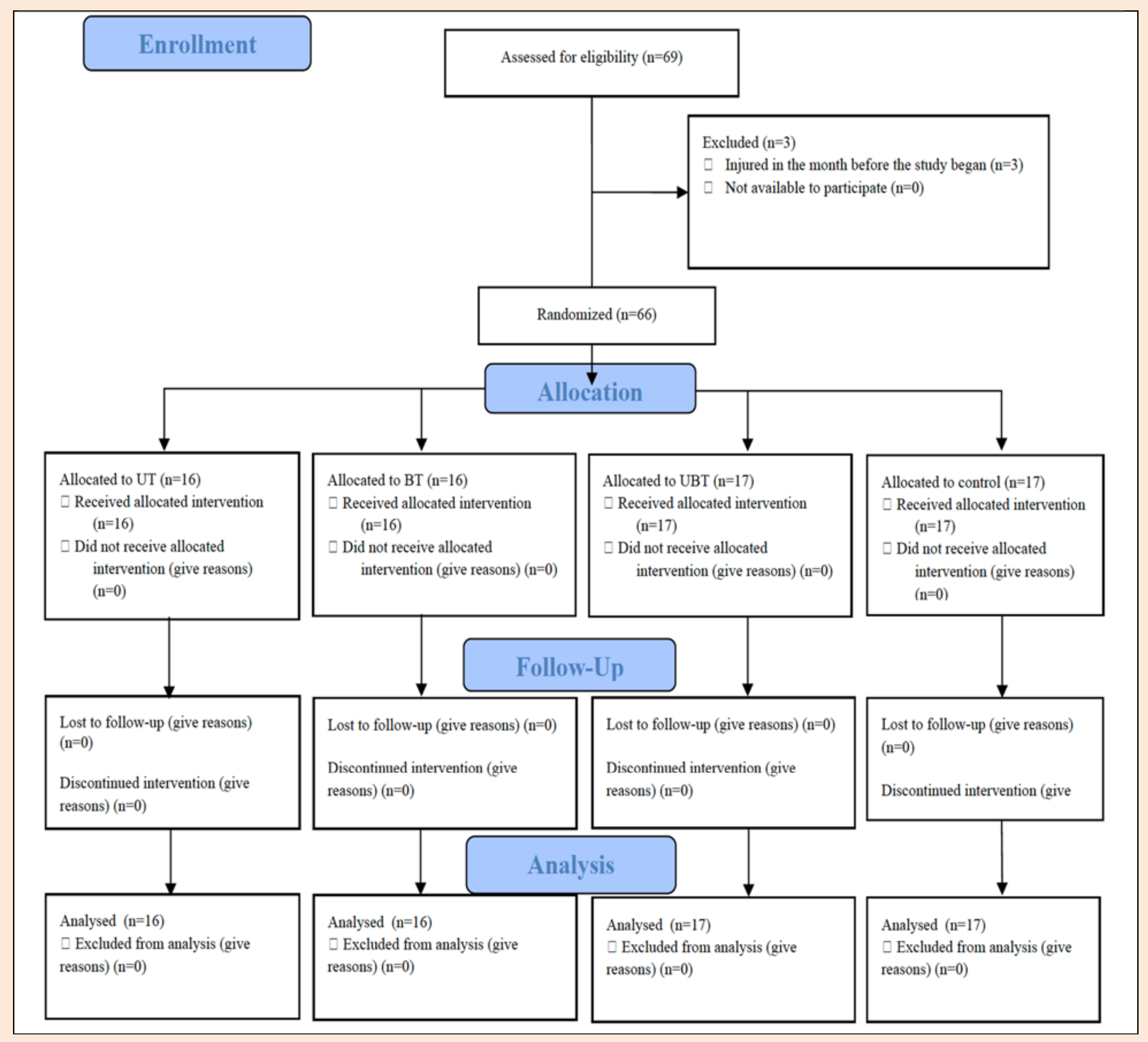

Figure 1. Participant flow across the phases of the experimental study. UT: unilateral plyometric jump training; BT: bilateral plyometric jump training; UBT: combined unilateral and bilateral plyometric jump training.

After determining the required sample size, the recruitment process started with direct outreach to regional basketball teams, engaging with directors and coaches. Upon identifying available clubs, the research team presented the study's design to players and their legal guardians, inviting them to participate voluntarily. Players who expressed interest in participating were then assessed against the inclusion criteria established for the current research.

The inclusion criteria were defined as follows: (i) being present at both evaluation points, (ii) possessing a minimum of two years of experience in the sport, (iii) attending at least 90% of regular training sessions, (iv) not experiencing any injury or illness during the experiment or in the month preceding its beginning, (v) not participating in any additional strength and conditioning training programs, and (vi) being male. The exclusion criteria were defined as follows: (i) failing to attend any of the evaluation moments or tests; and (ii) using any drugs or illegal substances that could influence the adaptations being studied.

Out of the six teams that expressed interest in participating in the study, 69 players volunteered. However, upon identifying those 3 players had suffered lower-limb injuries in the month prior the study's beginning, they were deemed ineligible for inclusion. Consequently, sixty-six players were randomly assigned to one of the four groups (Figure 1).

Training intervention

All groups received regular on-court basketball training, which was planned exclusively by the coaches without any influence from the researchers. These sessions typically included warm-up exercises, conditioning focused on aerobic capacity and anaerobic power, and individual technical skills, followed by tactical and strategic drills.

However, in addition to these regular training sessions, the experimental groups (i.e., UT, BT, and UBT) also participated in plyometric jump training. This additional training was conducted during the first training session of the week (48 hours after the last match) and the third training session (72 hours after the first training session of the week). Between the first and the third training session, a second on-court training occurred, usually with 24-h rest in regards the third training session. Although the researchers did not use a strict protocol for monitoring the players' recovery process, they ensured that players were informed to refrain from physical exercise outside of the training sessions and to maintain optimal dietary habits and lifestyle choices.

The plyometric training sessions were incorporated immediately before the regular on-court basketball training and began with a standardized warm-up protocol consisting of 5 minutes of jogging, 5 minutes of lower limb dynamic stretching, and 5 minutes of balance drills.

Table 2 provides an overview of the training regimen followed by the three experimental groups. The experimental groups adhered to the same sequence of training sessions. Each week, the first training day was dedicated to horizontal plyometric exercises, while the second training day focused on vertical plyometric exercises. A progression in training volume was introduced after the fourth week, with this increase applied uniformly across all three experimental groups.

To ensure proper technique and effort from the players, each group was assigned a dedicated researcher or assistant with at least two years of experience in strength and conditioning coaching to implement the program. Given the six targeted teams, a team of four researchers and one assistant per researcher was assembled to facilitate the program's implementation across all teams. Each coaching group delivered the program to the athletes, provided appropriate feedback, and ensured that all exercises were performed with maximum intent to optimize the training stimulus. Players were explicitly instructed to give their maximum effort in each repetition, and verbal encouragement was provided during exercises to promote commitment and engagement.

During each session, participants rested for 3 minutes between sets and exercises. All exercises were performed with maximum effort to ensure proper exertion. Each group completed 40 jumps during the first weekly session (increasing to 60 jumps after the fourth week) and 60 jumps during the second weekly session (increasing to 90 jumps after the fourth week). This resulted in a total of 100 jumps per week for the first four weeks and 150 jumps per week from the fourth to the eighth week. The plyometric training sessions were conducted on synthetic indoor basketball courts.

Evaluation of the outcomes

Evaluations were conducted twice: before and after the intervention, consistently on the same days of the week to ensure uniform conditions. These assessments took place indoors in the afternoon. Before the evaluations, participants had a 48-hour rest period following their last match. The evaluations followed a structured sequence that began with gathering demographic information and anthropometric measurements. This was followed by a warm-up, which included 5 minutes of running, 5 minutes of dynamic stretching focused on lower limbs, and 5 minutes of balance and jumping drills. After warming up, participants performed, always in the same sequence: (i) IST; (ii) KFS; (iii) LHT; (iv) UCMJ; and (v) 5 - 0 - 5. Half of the players were randomly selected to start all tests with the left leg, while the other half always started with the right leg. This sequence remained consistent throughout all evaluation sessions. A 5-minute rest was provided between each assessment test. Within each test, there was a 3-minute rest between repetitions. Each player started with one leg, rested, performed with the other leg, rested again, and repeated this sequence for the second trial. Each test had two trials per leg during each evaluation, and the average per leg was considered for further data treatment. All participants underwent the assessments in the same order and sequence during both evaluation periods. The symmetry between the legs for all the tests was determined using the symmetry angle, calculated by the equation (45º - arctan [left / right])/ 90º × 100), since this method has showed robust for identifying asymmetries (Zifchock et al., 2008; Bishop et al., 2016). The symmetry angle was selected as narrative review about the topic (Bishop et al., 2016) have suggested that it is significantly smaller than all other equations (as limb symmetry, bilateral asymmetry, asymmetry index), keeping in mind that the outcome remains unaffected by reference values and inflated scores, thus providing a more appropriate reference to identify the asymmetry level between limbs.

Anthropometric measurements

Basic anthropometric measurements, including height and body mass, were recorded. Height was measured using a stadiometer (Seca 217, Seca, Hamburg), and body mass was recorded with an electronic scale (SECA 813; Seca GmbH & Co., Hamburg, Germany) to the nearest 0.1 kg. Participants wore a t-shirt and basketball shorts during these measurements for consistency.

Isometric Squat Test (IST)

The unilateral IST protocol involved positioning the player at the center of a weightlifting rack, stepping onto a force platform (ForceDecks, Vald Performance, Brisbane, Australia), precisely aligned between the rack posts. Following established guidelines (Bishop et al., 2019), a goniometer was used to set individualized hip and knee flexion angles (140º), ensuring the knee joint reached full extension (180º) during knee extension. Participants maintained a static position for 2 seconds before receiving instructions. They were then instructed to rapidly extend their knees and hips with one leg over a five-second period, aiming for maximum force output. Peak force (N) was recorded as the highest force achieved during the movement. Data processing utilized the VALD ForceDecks software, with the average peak force per leg used for further analysis. The intra-class correlation (ICC) test for within-subjects was conducted, revealing a value of 0.93, indicating excellent reliability (Koo and Li, 2016). Additionally, the data was utilized to calculate the symmetry angle.

Table 2. Detailed training protocols for the experimental groups.

Week | Session	UT	BT	UBT
Week 1, Session 1	Unilateral horizontal jump (2×5 per leg); unilateral 3-bounce jumps per leg (2×5 per leg)	Bilateral horizontal jumps (2×10); bilateral three consecutive horizontal jumps (2×10)	Unilateral horizontal jump (2×5 per leg); three consecutive horizontal jumps (2×10)
Week 1, Session 2	Unilateral reactive pogo jumps (2×5 per leg); unilateral countermovement jumps (2×5 per leg); unilateral drop jumps at 10 cm (2×5 per leg)	Bilateral reactive pogo jumps (2×10); bilateral countermovement jumps (2×10); bilateral drop jumps at 10 cm (2×10)	Bilateral reactive pogo jumps (2×10); unilateral countermovement jumps (2×5 per leg); bilateral drop jumps at 10 cm (2×10)
Week 2, Session 3	Unilateral horizontal jump (2×5 per leg); unilateral 3-bounce jumps per leg (2×5 per leg)	Bilateral horizontal jumps (2×10); bilateral three consecutive horizontal jumps (2×10)	Bilateral horizontal jumps (2×10); unilateral 3-bounce jumps per leg (2×5 per leg)
Week 2, Session 4	Unilateral reactive pogo jumps (2×5 per leg); unilateral countermovement jumps (2×5 per leg); unilateral drop jumps at 10 cm (2×5 per leg)	Bilateral reactive pogo jumps (2×10); bilateral countermovement jumps (2×10); bilateral drop jumps at 10 cm (2×10)	Unilateral reactive pogo jumps (2×5 per leg); bilateral countermovement jumps (2×10); unilateral drop jumps at 10 cm (2×5 per leg)
Week 3, Session 5	Unilateral horizontal jump (2×5 per leg); unilateral 3-bounce jumps per leg (2×5 per leg)	Bilateral horizontal jumps (2×10); bilateral three consecutive horizontal jumps (2×10)	Unilateral horizontal jump (2×5 per leg); bilateral three consecutive horizontal jumps (2×10)
Week 3, Session 6	Unilateral reactive pogo jumps (2×5 per leg); unilateral countermovement jumps (2×5 per leg); unilateral drop jumps at 10 cm (2×5 per leg)	Bilateral reactive pogo jumps (2×10); bilateral countermovement jumps (2×10); bilateral drop jumps at 10 cm (2×10)	Bilateral reactive pogo jumps (2×10); unilateral countermovement jumps (2×5 per leg); bilateral drop jumps at 10 cm (2×10)
Week 4, Session 7	Unilateral horizontal jump (2×5 per leg); unilateral 3-bounce jumps per leg (2×5 per leg)	Bilateral horizontal jumps (2×10); bilateral three consecutive horizontal jumps (2×10)	Bilateral horizontal jumps (2×10); unilateral 3-bounce jumps per leg (2×5 per leg)
Week 4, Session 8	Unilateral reactive pogo jumps (2×5 per leg); unilateral countermovement jumps (2×5 per leg); unilateral drop jumps at 10 cm (2×5 per leg)	Bilateral reactive pogo jumps (2×10); bilateral countermovement jumps (2×10); bilateral drop jumps at 10 cm (2×10)	Unilateral reactive pogo jumps (2×5 per leg); bilateral countermovement jumps (2×10); unilateral drop jumps at 10 cm (2×5 per leg)
Week 5, Session 9	Unilateral horizontal jump (3×5 per leg); unilateral 3-bounce jumps per leg (3×5 per leg)	Bilateral horizontal jumps (3×10); bilateral three consecutive horizontal jumps (3×10)	Unilateral horizontal jump (3×5 per leg); bilateral three consecutive horizontal jumps (3×10)
Week 5, Session 10	Unilateral reactive pogo jumps (3×5 per leg); unilateral countermovement jumps (3×5 per leg); unilateral drop jumps at 10 cm (3×5 per leg)	Bilateral reactive pogo jumps (3×10); bilateral countermovement jumps (3×10); bilateral drop jumps at 10 cm (3×10)	Bilateral reactive pogo jumps (3×10); unilateral countermovement jumps (3×5 per leg); bilateral drop jumps at 10 cm (3×10)
Week 6, Session 11	Unilateral horizontal jump (3×5 per leg); unilateral 3-bounce jumps per leg (3×5 per leg)	Bilateral horizontal jumps (3×10); bilateral three consecutive horizontal jumps (3×10)	Bilateral horizontal jumps (3×10); unilateral 3-bounce jumps per leg (3×5 per leg)
Week 6, Session 12	Unilateral reactive pogo jumps (3×5 per leg); unilateral countermovement jumps (3×5 per leg); unilateral drop jumps at 10 cm (3×5 per leg)	Bilateral reactive pogo jumps (3×10); bilateral countermovement jumps (3×10); bilateral drop jumps at 10 cm (3×10)	Unilateral reactive pogo jumps (3×5 per leg); bilateral countermovement jumps (3×10); unilateral drop jumps at 10 cm (3×5 per leg)
Week 7, Session 13	Unilateral horizontal jump (3×5 per leg); unilateral 3-bounce jumps per leg (3×5 per leg)	Bilateral horizontal jumps (3×10); bilateral three consecutive horizontal jumps (3×10)	Unilateral horizontal jump (3×5 per leg); bilateral three consecutive horizontal jumps (3×10)
Week 7, Session 14	Unilateral reactive pogo jumps (3×5 per leg); unilateral countermovement jumps (3×5 per leg); unilateral drop jumps at 10 cm (3×5 per leg)	Bilateral reactive pogo jumps (3×10); bilateral countermovement jumps (3×10); bilateral drop jumps at 10 cm (3×10)	Bilateral reactive pogo jumps (3×10); unilateral countermovement jumps (3×5 per leg); bilateral drop jumps at 10 cm (3×10)
Week 8, Session 15	Unilateral horizontal jump (3×5 per leg); unilateral 3-bounce jumps per leg (3×5 per leg)	Bilateral horizontal jumps (3×10); bilateral three consecutive horizontal jumps (3×10)	Bilateral horizontal jumps (3×10); unilateral 3-bounce jumps per leg (3×5 per leg)
Week 8, Session 16	Unilateral reactive pogo jumps (3×5 per leg); unilateral countermovement jumps (3×5 per leg); unilateral drop jumps at 10 cm (3×5 per leg)	Bilateral reactive pogo jumps (3×10); bilateral countermovement jumps (3×10); bilateral drop jumps at 10 cm (3×10)	Unilateral reactive pogo jumps (3×5 per leg); bilateral countermovement jumps (3×10); unilateral drop jumps at 10 cm (3×5 per leg)
Total jumps (n)	1000 jumps	1000 jumps	1000 jumps

UT: unilateral plyometric jump training; BT: bilateral plyometric jump training; UBT: combined unilateral and bilateral plyometric jump training

Isometric Knee flexor strength (KFS)

Participants' muscle strength in knee flexors (KFS) was assessed using the ForceFrame Strength Testing System (Vald Performance, Brisbane, Australia). The participants stood upright with one knee flexed at 30°, placing the lower leg's front section at the dynamometer's center to measure force using 50 Hz sensors. The opposite leg remained straight to provide stability during testing. The assessments involved performing two five-second maximum voluntary contractions per leg. Maximum force (N) was recorded for both limbs. The ICC test for within-subjects was conducted, revealing a value of 0.88, indicating good reliability (Koo and Li, 2016). The average of the two trials per leg was used as the participant's result and subsequently used to calculate the symmetry angle.

Single Leg Land and Hold (LHT)

The participants began on an elevated platform 30 cm high, positioned immediately behind force plates (ForceDecks, Vald Performance, Brisbane, Australia). They stood with their feet together, hands on their hips, and eyes fixed straight ahead. Upon receiving the signal, they landed on one leg, keeping their foot on the force plate for 3 seconds after landing. The depth of knee flexion during landing was self-selected by the players. However, during the familiarization period, they were instructed to achieve a minimum depth of 15 cm, with a target of approximately 30 cm for those who felt more comfortable. This variation was intended to respect individual preferences and comfort to ensure optimal performance in the test. This sequence was repeated two times per leg. Data collected included the peak drop landing force (N), processed using the VALD ForceDecks software (Wrona et al., 2023). The ICC test for within-subjects was conducted, revealing a value of 0.86, indicating good reliability (Koo and Li, 2016). The average result from the two trials per leg was utilized for subsequent data analysis and incorporated into the previously described symmetry angle.

Unilateral Countermovement Jump Test (UCMJ)

Athletes were directed to step onto the force platform (ForceDecks, Vald Performance, Brisbane, Australia) with their designated leg and hands on hips, maintaining this stance throughout the test. They initiated the jump with a countermovement to a self-selected depth, followed by a rapid vertical ascent with maximum explosiveness. Although the participants were allowed to select their own depth, they were instructed to achieve a depth of at least 30 cm, as previous studies have identified this as the minimum depth for optimal jump performance (Kirby et al., 2010). However, to respect individual preferences, the self-selected depth could be slightly higher or lower than this margin. Throughout the flight phase of the jump, the test leg remained fully extended, landing back on the force plate in its original position. Meanwhile, the non-jumping leg was kept slightly flexed with the foot hovering at mid-shin level, ensuring no swinging motion during the trials. Peak force (N) was obtained for each trial and leg, and the average peak force per leg was calculated and used to determine the symmetry angle. The ICC test for within-subjects was conducted, revealing a value of 0.91, indicating excellent reliability (Koo and Li, 2016).

The 5 - 0 - 5 change-of-direction test (5 - 0 - 5)

The study utilized the original 5 - 0 - 5 test, which involves accelerating maximally over a ten-meter distance, followed by a maximal intensity 5-meter sprint. This is immediately followed by a 180° COD, and another 5-meter sprint back to the starting point. All participants began with the designated leg and executed the braking phase at the COD line with the same leg for consistency across all attempts. For the starting position, players began 0.25 meters away from the first pair of photocells (Fusion Sport, Coopers Plains, Australia), positioned in alignment with the hip line of the participants. They adopted a staggered stance, placing the same foot forward for each attempt. The best time recorded from the two trials for each foot was used as the reference measurement, measured in seconds. The average value per leg was used to determine the symmetry angle. The ICC test for within-subjects was conducted, revealing a value of 0.94, indicating excellent reliability (Koo and Li, 2016).

Statistical analysis

The normal distribution of the sample was assessed using the Kolmogorov-Smirnov test ($p > 0.05$) before conducting inferential analyses, as the sample size was ≥50 (Mishra et al., 2019). Additionally, Levene's test was employed to verify the assumption of homogeneity ($p > 0.05$). A mixed ANOVA (time * group) was applied. This analytical approach included the calculation of partial eta squared (η_p^2) to estimate effect sizes and also the calculation of Cohen's d for comparisons between pre and post. Effect sizes were interpreted based on established thresholds (Hopkins et al., 2009): <0.2, trivial; 0.2 - 0.6, small; 0.6 - 1.2, moderate; 1.2 - 2.0, large; 2.0 - 4.0, very large; and >4.0, nearly perfect. Post-hoc comparisons were conducted using the Bonferroni test. Statistical analyses were performed using JASP software (version 0.18.3, University of Amsterdam, The Netherlands), with a predetermined significance level set at $p < 0.05$.

Results

Table 3 shows the descriptive statistics for the IST, UCMJ, and KFS tests before and after the intervention period across the four groups. Significant interactions between time and groups were observed in IST left ($F = 4769.876$; $p < 0.001$; $\eta_p^2 = 0.996$), IST right ($F = 3499.238$; $p < 0.001$; $\eta_p^2 = 0.994$) and IST asymmetry ($F = 1932.478$; $p < 0.001$; $\eta_p^2 = 0.989$). Similarly, significant interactions between time and groups were observed in UCMJ left peak force ($F = 1981.314$; $p < 0.001$; $\eta_p^2 = 0.990$), UCMJ right peak force ($F = 1645.302$; $p < 0.001$; $\eta_p^2 = 0.988$) and UCMJ peak force asymmetry ($F = 900.140$; $p < 0.001$; $\eta_p^2 = 0.978$). Also, significant interactions were found in UCMJ left height ($F = 1945.210$; $p < 0.001$; $\eta_p^2 = 0.989$), UCMJ right height ($F = 1585.230$; $p < 0.001$; $\eta_p^2 = 0.987$), and UCMJ height asymmetry ($F = 0.513$; $p = 0.675$; $\eta_p^2 = 0.024$). Finally, significant interactions between time and groups were observed in KFS left ($F = 104.230$; $p < 0.001$; $\eta_p^2 = 0.835$), KFS ($F = 95.004$; $p < 0.001$; $\eta_p^2 = 0.821$) and KFS asymmetry ($F = 10.282$; $p < 0.001$; $\eta_p^2 = 0.332$).

Post-hoc comparisons of the IST left post-intervention revealed significantly higher values in the UT group compared to the BT (mean difference: 100.9 N; $p < 0.001$), UBT (mean difference: 68.8 N; $p < 0.001$), and control groups (mean difference: 147.1 N; p < 0.001). Additionally, the UT group showed significantly better results in the IST right compared to the BT (mean difference: 93.0 N; p = 0.002) and control groups (mean difference: 116.1 N; p < 0.001). Finally, the UT group was significantly better than the control group in IST asymmetry (mean difference: 1.236 %; p = 0.049).

Table 3. Descriptive statistics (mean and standard deviation) for the IST, UCMJ, and KFS tests before and after the intervention period across the four groups.

		UT (n = 16)	BT (n = 16)	UBT (n = 17)	Control (n = 17)	*Comparisons between groups in pre and post evaluations* ***F*** **|** ***p*-value | Effect size**
IST left (N)	Pre	1011.1 ± 50.6	991.8 ± 38.3	993.9 ± 50.6	995.2 ± 41.9	F=0.602; p=0.616; η_p^2=0.028
	Post	1122.3 ± 56.2 b,c,d,*	1021.5 ± 39.5 d,*	1053.6 ± 53.6 d,*	975.3 ± 41.1 *	F=26.992; p<0.001; η_p^2=0.566
	ES	2.09 (1.58;2.60)	0.76 (0.56;0.96)	1.13 (0.93;1.33)	0.48 (0.28;0.68)	
	%dif	+11.0	+3.0	+6.0	–2.0	
IST right (N)	Pre	1120.3 ± 59.5	1095.2 ± 69.9	1106.5 ± 76.1	1104.9 ± 60.6	F=0.384; p=0.765; η_p^2=0.018
	Post	1210.0 ± 64.2 b,d,*	1117.1 ± 71.3 *	1150.7 ± 79.1 *	1093.9 ± 60.0 *	F=8.701; p<0.001; η_p^2=0.296
	ES	1.45 (1.09;1.81)	0.31 (–0.05;0.66)	0.57 (0.21;0.93)	0.18 (–0.18;0.54)	
	%dif	+8.0	+2.0	+4.0	–1.0	
IST asymmetry (%)	Pre	3.24 ± 1.26	2.11 ± 1.24	3.37 ± 1.22	3.30 ± 1.37	F=0.127; p=0.944; η_p^2=0.006
	Post	2.39 ± 1.29 d,*	2.78 ± 1.27 *	2.75 ± 1.25 *	3.63 ± 1.37 *	F=2.735; p=0.051; η_p^2=0.117
	ES	0.66 (0.30;1.02)	0.53 (0.17;0.89)	0.50 (0.14;0.86)	0.24 (–0.12;0.60)	
	%dif	–26.2	+31.8	–18.4	+10.0	
UCMJ left (N)	Pre	691.6 ± 58.8	692.1 ± 50.4	687.2 ± 50.7	698.1 ± 56.3	F=0.116; p=0.950; η_p^2=0.006
	Post	767.7 ± 65.2 b,d,*	706.0 ± 51.4 *	714.7 ± 52.8 *	684.2 ± 55.2 *	F=6.448; p<0.001; η_p^2=0.238
	ES	1.23 (0.87;1.59)	0.27 (–0.09;0.66)	0.53 (0.17;0.89)	0.25 (–0.11;0.62)	
	%dif	+11.0	+2.0	+4.0	–2.0	
UCMJ right (N)	Pre	756.8 ± 71.4	762.8 ± 63.9	754.8 ± 61.5	775.8 ± 78.8	F=0.316; p=0.814; η_p^2=0.015
	Post	828.7 ± 78.2 d,*	785.7 ± 65.8 *	777.4 ± 63.4 *	756.4 ± 76.8 *	F=2.968; p=0.039; η_p^2=0.126
	ES	0.96 (0.60;1.32)	0.35 (–0.01;0.71)	0.36 (0.00;0.72)	0.25 (–0.11;0.62)	
	%dif	+9.5	+3.0	+3.0	–2.5	
UCMJ asymmetry (%)	Pre	2.83 ± 0.82	3.06 ± 1.11	2.95 ± 1.04	3.27 ± 1.16	F=0.535; p=0.660; η_p^2=0.025
	Post	2.39 ± 0.83 *	3.38 ± 1.12 *	2.62 ± 1.06 *	3.15 ± 1.16 *	F=3.049; p=0.035; η_p^2=0.129
	ES	0.53 (0.17;0.89)	0.29 (–0.07;0.65)	0.31 (–0.05;0.67)	0.10 (–0.26;0.46)	
	%dif	–15.6	+10.5	–11.2	–3.7	
UCMJ left (cm)	Pre	12.9 ± 0.6	12.9 ± 0.5	12.9 ± 0.5	13.0 ± 0.6	F=0.116; p=0.951; η_p^2=0.006
	Post	16.7 ± 0.6 c,d,*	16.1 ± 0.5 *	16.1 ± 0.5 *	15.8 ± 0.6 *	F=6.429; p<0.001; η_p^2=0.237
	ES	6.33 (3.93;8.73)	6.4 (3.97;8.83)	6.4 (3.97;8.83)	4.67 (2.78;6.56)	
	%dif	+29.5	+24.8	+24.8	+21.5	

UT: unilateral plyometric jump training; BT: bilateral plyometric jump training; UBT: combined unilateral and bilateral plyometric jump training; IST: unilateral isometric squat test; UCMJ: unilateral countermovement jump test; KFS: unilateral isometric knee flexor strength test; ES: Effect size comparing pre- and post-measurements using Cohen's d presented in form of mean (95% confidence interval); %dif: Percentage difference between pre- and post-measurements; * significant differences within-group (p<0.05); b: significantly different from BT (p < 0.05); c: significantly different from UBT (p < 0.05); d: significantly different from control group (p < 0.05).

Table 3. Continue...

		UT (n = 16)	BT (n = 16)	UBT (n = 17)	Control (n = 17)	Comparisons between groups in pre and post evaluations F | p-value | Effect size
UCMJ right (cm)	Pre	14.6 ± 0.7	14.6 ± 0.6	14.5 ± 0.6	14.8 ± 0.8	$F = 0.322$; $p = 0.810$; $\eta_p^2 = 0.015$
	Post	15.3 ± 0.8 [d,*]	14.9 ± 0.7 *	14.8 ± 0.6 *	14.6 ± 0.8 *	$F = 2.969$; $p = 0.039$; $\eta_p^2 = 0.126$
	ES	0.93 (0.21;1.65)	0.46 (−0.25;1.17)	0.50 (−0.21;1.21)	−0.25 (−0.95;0.45)	
	%dif	+4.8	+2.1	+2.1	−1.4	
UCMJ asymmetry (%)	Pre	3.8 ± 0.4	3.9 ± 0.6	3.9 ± 0.6	4.0 ± 0.6	$F = 0.549$; $p = 0.650$; $\eta_p^2 = 0.026$
	Post	2.8 ± 0.6 *	2.5 ± 0.6 *	2.8 ± 0.6 *	2.7 ± 0.7 *	$F = 0.891$; $p = 0.451$; $\eta_p^2 = 0.041$
	ES	−1.96 (−2.80;−1.12)	−2.33 (−3.23;−1.43)	−1.83 (−2.65;−1.01)	−2.00 (−2.84;−1.16)	
	%dif	−26.3	−35.9	−28.2	−32.5	
KFS left (N)	Pre	191.8 ± 61.8	210.3 ± 50.5	209.7 ± 30.8	191.9 ± 36.5	$F = 0.852$; $p = 0.471$; $\eta_p^2 = 0.040$
	Post	322.1 ± 103.2 [b,d,*]	246.0 ± 59.1 *	262.1 ± 38.6 [d,*]	192.1 ± 35.8	$F = 11.394$; $p<0.001$; $\eta_p^2 = 0.355$
	ES	1.50 (1.14;1.86)	0.65 (0.29;1.01)	1.37 (1.01;1.73)	0.01 (−0.35;0.37)	
	%dif	+67.9	+16.9	+25.0	+0.1	
KFS right (N)	Pre	207.4 ± 65.0	226.6 ± 47.8	233.0 ± 43.9	210.8 ± 42.4	$F = 0.997$; $p = 0.400$; $\eta_p^2 = 0.046$
	Post	338.0 ± 105.9 [b,d,*]	269.7 ± 56.9 *	286.6 ± 53.9 [d,*]	217.5 ± 45.8	$F = 8.507$; $p<0.001$; $\eta_p^2 = 0.292$
	ES	1.46 (1.10;1.82)	0.82 (0.46;1.18)	1.09 (0.73;1.45)	0.15 (−0.21;0.51)	
	%dif	+63.0	+19.0	+23.0	+3.2	
KFS asymmetry (%)	Pre	2.82 ± 1.37	3.20 ± 1.32	3.72 ± 1.60	3.25 ± 1.31	$F = 1.133$; $p = 0.343$; $\eta_p^2 = 0.052$
	Post	2.17 ± 0.94 [d,*]	3.48 ± 1.78	3.45 ± 1.25	4.64 ± 2.15 *	$F = 6.540$; $p<0.001$; $\eta_p^2 = 0.240$
	ES	0.56 (0.20;0.92)	0.18 (−0.18;0.54)	0.19 (−0.17;0.55)	0.78 (0.42;1.14)	
	%dif	−23.1	+8.8	−7.3	+42.8	

UT: unilateral plyometric jump training; BT: bilateral plyometric jump training; UBT: combined unilateral and bilateral plyometric jump training; IST: unilateral isometric squat test; UCMJ: unilateral countermovement jump test; KFS: unilateral isometric knee flexor strength test; ES: Effect size comparing pre- and post-measurements using Cohen's d presented in form of mean (95% confidence interval); %dif: Percentage difference between pre- and post-measurements; *significant differences within-group (p<0.05); b: significantly different from BT (p < 0.05); c: significantly different from UBT (p < 0.05); d: significantly different from control group (p < 0.05).

Post-hoc comparisons of the UCMJ left post-intervention revealed significantly higher values in the UT group compared to the BT (mean difference: 61.7 N; p = 0.018), and control groups (mean difference: 83.5 N; p < 0.001). Additionally, the UT group showed significantly better results in the UCMJ right compared to the control (mean difference: 72.3 N; p = 0.030).

Post-hoc comparisons of the KFS left post-intervention revealed significantly higher values in the UT group compared to the BT (mean difference: 76.1 N; p = 0.008), and control groups (mean difference: 130.0 N; p < 0.001). Additionally, the UT group showed significantly better results in the KFS right compared to the BT (mean difference: 24.5 N; p = 0.042), and control (mean difference: 24.1 N; p < 0.001). Finally, the UT group was significantly better than the control group in KFS asymmetry (mean difference: 2.472 %; p < 0.001).

Table 4 introduce the descriptive statistics for the LHT and 5 - 0 - 5 tests before and after the intervention period across the four groups. Significant interactions between time and groups were observed in LHT left ($F = 114.792$; $p < 0.001$; $\eta_p^2 = 0.847$), LHT right ($F = 80.792$; $p < 0.001$; $\eta_p^2 = 0.796$) and LHT asymmetry ($F = 4.053$; $p = 0.011$; $\eta_p^2 = 0.164$). Similarly, significant interactions between time and groups were observed in 5 - 0 - 5 left ($F = 168.196$; $p < 0.001$; $\eta_p^2 = 0.891$), and 5 - 0 - 5 right ($F = 135.334$; $p < 0.001$; $\eta_p^2 = 0.868$), although no significant interactions were observed in 5 - 0 - 5 asymmetry ($F = 2.623$; $p = 0.058$; $\eta_p^2 = 0.113$).

Post-hoc comparisons of the LHT left post-intervention revealed significantly better values in the UT group compared to the BT (mean difference: 124.4 N; p = 0.042), UBT (mean difference: 124.4 N; p = 0.037) and control groups (mean difference: 329.9 N; p < 0.001). Additionally, the UT group showed significantly better results in the LHT right compared to the BT (mean difference: 159.5 N; p = 0.018), and control (mean difference: 50.8 N; p < 0.001). Finally, the UT group was significantly better than the control group in LHT asymmetry (mean difference: 1.089 %; p = 0.013).

Post-hoc comparisons of the 5 - 0 - 5 left post-intervention revealed significantly better values in the UT group compared to the BT (mean difference: 0.269 s; p = 0.014), and control group (mean difference: 0.469 s; p < 0.001). Additionally, the UT group showed significantly better results in the 5 - 0 - 5 right compared to the control (mean difference: 0.412 s; p < 0.001).

Table 4. Descriptive statistics (mean and standard deviation) for the LHT and 5-0-5 tests before and after the intervention period across the four groups.

		UT (n = 16)	BT (n = 16)	UBT (n = 17)	Control (n = 17)	*Comparisons between groups in pre and post evaluations* ***F* | *p*-value | Effect size**
LHT left (N)	Pre	844.3 ± 181.3	828.4 ± 144.7	861.2 ± 169.4	895.9 ± 152.1	$F = 0.526$; $p = 0.666$; $\eta_p^2 = 0.025$
	Post	530.2 ± 110.1^{b,c,d,*}	654.6 ± 114.3^{d,*}	654.6 ± 128.7^{d,*}	860.1 ± 146.1*	$F = 19.551$; $p<0.001$; $\eta_p^2 = 0.486$
	ES	1.99 (1.63;2.35)	1.34 (0.98;1.70)	1.37 (1.01;1.73)	0.24 (–0.12;0.60)	
	%dif	–37.2	–20.9	–24.0	–4.0	
LHT right (N)	Pre	803.4 ± 141.6	831.1 ± 172.4	853.2 ± 207.8	897.7 ± 180.0	$F = 0.834$; $p = 0.481$; $\eta_p^2 = 0.039$
	Post	511.7 ± 94.4^{b,d,*}	671.2 ± 139.0^{d,*}	646.4 ± 148.8^{d,*}	884.6 ± 184.0	$F = 18.556$; $p<0.001$; $\eta_p^2 = 0.473$
	ES	2.43 (2.07;2.79)	1.02 (0.66;1.38)	1.15 (0.79;1.51)	0.07 (–0.29;0.44)	
	%dif	–36.3	–19.2	–24.2	–1.5	
LHT asymmetry (%)	Pre	2.58 ± 1.19	2.40 ± 1.11	2.26 ± 1.05	2.42 ± 0.52	$F = 0.267$; $p = 0.849$; $\eta_p^2 = 0.013$
	Post	1.79 ± 1.06^{d,*}	2.63 ± 1.33	2.08 ± 0.82	2.88 ± 0.56	$F = 4.312$; $p = 0.008$; $\eta_p^2 = 0.173$
	ES	0.70 (0.34;1.06)	–0.19 (–0.55;0.16)	0.19 (–0.17;0.55)	–0.85 (–1.21;–0.49)	
	%dif	–30.6	+9.6	–7.9	+19.0	
5-0-5 left (s)	Pre	3.99 ± 0.27	4.01 ± 0.22	3.95 ± 0.27	4.01 ± 0.23	$F = 0.173$; $p = 0.914$; $\eta_p^2 = 0.008$
	Post	3.58 ± 0.26^{b,d,*}	3.84 ± 0.22*	3.76 ± 2.25^{d,*}	4.07 ± 0.23*	$F = 12.110$; $p<0.001$; $\eta_p^2 = 0.369$
	ES	1.55 (1.19;1.91)	0.77 (0.41;1.13)	0.12 (–0.24;0.48)	–0.26 (–0.62;0.10)	
	%dif	–10.3	–4.2	–4.8	+1.5	
5-0-5 right (s)	Pre	3.80 ± 0.33	3.82 ± 0.20	3.74 ± 0.30	3.76 ± 0.28	$F = 0.267$; $p = 0.849$; $\eta_p^2 = 0.013$
	Post	3.50 ± 0.29^{d,*}	3.71 ± 0.19*	3.58 ± 0.30^{d,*}	3.91 ± 0.32*	$F = 6.793$; $p<0.001$; $\eta_p^2 = 0.247$
	ES	0.97 (0.61;1.33)	0.56 (0.20;0.92)	0.53 (0.17;0.89)	–0.50 (–0.86;–0.14)	
	%dif	–7.9	–2.9	–4.3	+4.0	
5-0-5 asymmetry (%)	Pre	1.58 ± 1.43	1.50 ± 0.97	1.84 ± 1.51	2.00 ± 1.45	$F = 0.482$; $p = 0.696$; $\eta_p^2 = 0.023$
	Post	1.00 ± 1.36*	1.28 ± 0.86	1.59 ± 1.45*	1.91 ± 1.11	$F = 1.695$; $p = 0.177$; $\eta_p^2 = 0.076$
	ES	0.42 (0.06;0.78)	0.24 (–0.12;0.60)	0.17 (–0.19;0.54)	0.07 (–0.29;0.43)	
	%dif	–36.7	–14.7	–13.6	–4.5	

UT: unilateral plyometric jump training; BT: bilateral plyometric jump training; UBT: combined unilateral and bilateral plyometric jump training; LHT: single leg land and hold; ES: Effect size comparing pre- and post-measurements using Cohen's d presented in form of mean (95% confidence interval); %dif: Percentage difference between pre- and post-measurements; *significant differences within-group (p < 0.05); b: significantly different from BT (p < 0.05); c: significantly different from UBT (p < 0.05); d: significantly different from control group (p < 0.05).

Discussion

In examining the effects of UT, BT, and UBT plyometric training on muscular strength, power, and change-of-direction performance in youth male basketball players, our study found that all three training methods significantly improved athletic performance, with no substantial differences among them. However, only UT and UBT were effective at reducing test asymmetries, while BT actually increased them. UT was the only method that showed significant improvements in reducing asymmetries compared to the control group, particularly in key performance outcomes.

In our study, UT was found to be significantly more effective than BT in enhancing unilateral IST, UCMJ, KFS, LHT and 5 - 0 - 5 performance among basketball players. These results contradict those presented in soccer players (Ramírez-Campillo et al., 2015), where combined plyometric training and unilateral training showed similar improvements in vertical jump, UCMJ, and agility tests. UT group focused on unilateral exercises drive in both vertical and horizontal vector seeking to improve force production and stability during unilateral tasks (Bogdanis et al., 2019), such as the unilateral isometric squat test and the unilateral countermovement jump test. Possibly the motor unit synchronization and increased muscle activation observed in response to unilateral training (Rejc et al., 2024), which are essential for maximizing force output and maintaining balance during single-leg movements in basketball can explain the results.

Interestingly, all three groups that underwent plyometric training showed improvements in the IST at 30º. This may be attributed to the varying amplitudes of force production and muscle power involved in training program, ranging from pogo jumps to bilateral countermovement jumps. These exercises likely influenced muscle adaptation and force generation at different angles (Behrens et al., 2016), contributing to the positive outcomes even at specific angles. By repeatedly exposing muscles to angle-specific stress, these exercises possibly enhanced muscle activation and force development at the targeted angles.

Returning to the comparisons between groups, the most surprising finding was that UT significantly outperformed both UBT and BT in enhancing IST left and LHT left. Possibly the volume of unilateral exercises in UT can play a role (Drouzas et al., 2020) in creating adaptations in motor unit recruitment patterns and intra- and intermuscular coordination in the knee flexors, promoting greater strength gains specific to unilateral movements. Eventually, unilateral exercises benefit force production from unilateral training by improving muscle stability, joint stabilization, and alignment maintenance (Nijem and Galpin, 2014). This enhancement potentially justifies the observed reduction in peak landing force, attributed to improved landing mechanics in unilateral exercises, thereby facilitating better absorption and dissipation of impact forces through enhanced eccentric control and neuromuscular coordination (Pappas et al., 2007).

Based on the analysis of the symmetry angle, which measures the percentage of symmetry between limbs across various unilateral tests, we found that UT and BT had similar effects on maintaining or adapting symmetry overall. However, statistically, only UT showed a significant decline in symmetry compared to the control group, thereby reducing the asymmetries observed at baseline. Thus, while our findings do not support UT being superior to BT or the combination of both, they do demonstrate that UT has a significant advantage over the control group. This result is consistent with studies showing that unilateral training can significantly reduce asymmetries between limbs (Gonzalo-Skok et al., 2017), while also aligns with preliminary research on soccer players that found no difference between unilateral and bilateral training (Ramirez-Campillo et al., 2018).

The underlying mechanisms explaining the superior effectiveness of UT training in reducing asymmetries between legs, compared to control group may rely on the fact that unilateral training specifically targets the neuromuscular adaptations in each leg independently, fostering greater neural drive and intermuscular coordination within the trained limb (Fimland et al., 2009). This focused neural adaptation enhances the recruitment of motor units and optimizes the firing rate patterns specific to unilateral tasks (Vandervoort et al., 1984), leading to more balanced strength and power outputs between the legs. Moreover, the unilateral training imposes a higher demand on the less developed limb, increasing stabilizing muscles and proprioceptive systems of each leg individually (Zhang et al., 2023). This possibly leads to improved proprioceptive acuity and joint stability on a per leg basis (Riemann et al., 2003), contributing to better performance in tasks requiring single-leg strength and balance, such as the UCMJ, IST, LHT, or the 5 - 0 - 5. Moreover, the improvements in technique and motor control achieved through unilateral strategies can also contribute to developing the appropriate technique in the non-preferred limb, ensuring that the muscles are activated correctly to produce the desired movement (Dapi et al., 2024).

On the other hand, no significant differences were observed between UT and BT regarding their effects on symmetry angle. The minimal differences between these two approaches can be attributed to the fact that both methods, whether unilateral or bilateral, primarily enhance neural drive and muscle power output in both legs by improving overall neuromuscular efficiency and motor unit recruitment (Lynch et al., 2023). The few research shows that both training methods may effectively stimulate the central nervous system and produce similar adaptations in muscle strength and explosive power, leading to comparable improvements in jump performance and force production (Ramirez-Campillo et al., 2018). Even when there are asymmetries between limbs, the minimal changes and the inherently bilateral nature of many force and jump assessments demand symmetrical effort from both legs, which may mask subtle asymmetries that could arise from unilateral training. Thus, the lack of significant differences in symmetry levels between UT and BT can be explained by the plyometric exercises' focus on overall leg strength and power, which reduces the impact of leg-specific asymmetries in jump and force assessments.

While the present study provides interesting findings some limitations should be considered. The sample size was limited to youth men basketball, which may limit the generalizability of the findings to a broader athletic population, namely those with better fitness levels or smaller asymmetries. Future studies should aim to include larger and more diverse samples to enhance the external validity of the results. Moreover, the study's duration was relatively short, and it remains unclear whether the observed improvements in performance and symmetry would be sustained or still improved over a longer period. Moreover, although the teams are competing under similar training conditions (e.g., training frequency, duration, and core content of in-court sessions) and at a comparable competetive level, it is technically challenging to ensure identical training loads and exposure to the training process beyond the experimental intervention. This represents one of the difficulties and challenges of conducting research in real-world scenarios with players. While including more teams and increase the sample to generalize the data could be beneficial, it introduces additional challenges due to the unique dynamics of each team. Nonetheless, this challenge should be acknowledged as a limitation. Another limitation is the lack of biomechanical analysis during the training sessions, which could provide deeper information into the specific neuromuscular mechanisms underlying the observed performance improvements. Finally, our research design did not include bilateral tests due to the preliminary protocol, which focused on comparing the effects of UT and BT on asymmetry in unilateral tests. This limitation is acknowledged, as we lacked references on how training protocols might have impacted bilateral tests. Additionally, we did not examine concurrent factors that could have explained adaptations, such as improvements in balance and movement control. This is recognized as a limitation, and future studies should incorporate these variables to determine whether the observed improvements were also due to the appropriateness of the technique and enhancements in movement control and balance as part of the adaptation mechanisms.

Although the study's limitations, the findings from this study may offer practical implications for strength and conditioning coaches working with basketball players. Specifically, incorporating UT can be particularly effective in enhancing neuromuscular performance and reducing asymmetries between limbs when comparing to control conditions. The superior performance of UT in unilateral tests, such as the unilateral IST and the UCMJ, highlights its value in improving force production and stability during single-leg movements. Coaches should consider integrating UT into their training regimens to target and strengthen individual limbs, thereby fostering better balance and coordination. Additionally, the UBT approach also demonstrated significant benefits over BT alone, suggesting that a hybrid training model can effectively enhance overall performance and symmetry.

Conclusion

The study shows that UT, BT, and UBT effectively enhance athletic performance, yet only UT and UBT are successful in reducing test asymmetries. Specifically, UT emerged as superior in decreasing asymmetries compared to the control group, with significant improvements in key performance measures such as unilateral IST, UCMJ, KFS, LHT, and 5 - 0 - 5 performance. While BT showed similar effects on maintaining symmetry compared to UT, it also had the unintended consequence of increasing asymmetries, highlighting its lesser efficacy in addressing imbalances. For strength and conditioning practitioners, integrating UT into training programs is recommended to optimize individual limb performance and balance, with UBT serving as a beneficial complementary approach.

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Key points

- Unilateral-leg plyometric training (UT) showed superior efficacy in enhancing neuromuscular performance and reducing asymmetries in basketball players compared to bilateral and combined training methods.
- UT was particularly effective in promoting balanced limb strength and coordination, significantly reducing asymmetries in various tests including the unilateral isometric squat test and countermovement jump test.
- Strength and conditioning coaches are advised to incorporate UT, either alone or combined with bilateral training, into training regimens to optimize individual limb strength and neuromuscular coordination.

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