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# Associations Between Inter-Limb Asymmetry in Lower Limb Strength and Jump Performance in 14–15-Year-Old Basketball Players

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**Abstract:** This study aims to (1) assess the inter-limb asymmetry in hip, knee, and ankle strength and countermovement jump (CMJ) performance among adolescent basketball players and (2) examine the relationship between inter-limb asymmetry and CMJ performance. Moreover, 30 adolescent basketball players (15 boys and 15 girls) aged 14 to 15 years participated in this study. The strength of the lower limb joints was measured using an isokinetic dynamometer at a speed of 60 degrees per second. Three maximal CMJs were performed, and the highest jump was used for the final analysis. The subjects were median-split into high-asymmetry ($n$ = 15) and low-asymmetry ($n$ = 15) groups based on the calculated strength asymmetry scores. The asymmetry scores were calculated using the formula: (dominant–non-dominant)/dominant* 100%. The inter-limb asymmetry data ranged from 12.2% to 21.6%. A Spearman correlation analysis showed that only the inter-limb asymmetry of the ankle plantar flexor was significantly correlated with the CMJ heights ($\rho = -0.56$, $p = 0.001$). An independent t-test revealed no significant differences in strength asymmetry between boys and girls (all $p > 0.05$). The low-asymmetry group demonstrated significantly greater CMJ performance compared to the high-asymmetry group (ES = 1.11, 95% CI = 0.34–1.87, $p = 0.007$), indicating that inter-limb asymmetry of the ankle plantar flexor has a significant negative impact on CMJ performance. Coaches should focus on enhancing both the strength and symmetry of the ankle joints to improve athletic performance and prevent injuries in sports, where jumping is a common movement.

**Keywords:** basketball; inter-limb asymmetry; jump; strength



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## 1. Introduction

Asymmetry in sports science typically refers to disparities in performance or function between the two sides of the body [1], encompassing aspects such as morphology, strength, flexibility, coordination, and functionality. These disparities, known as inter-limb asymmetries, can significantly impact athletic performance and injury risk [2]. Inter-limb asymmetry arises from factors such as genetics, training history, injuries, and habitual movement patterns [2,3]. Different asymmetry tests yield varying scores; therefore, it is recommended that practitioners employ a variety of assessment methods to quantify asymmetry, which are tailored to the specific demands of the athlete's sport. Typically, most sporting movements rely on the coordinated exertion of the hip, knee, and ankle joints. If the strength of the same joint differs excessively between limbs, it could be detrimental to sports that demand high bilateral limb coordination (e.g., when jumping for a shot, rebound, or block in basketball). In turn, such strength asymmetry might also alter movement stability, potentially leading to injuries [4]. Thus, it is crucial to examine inter-limb asymmetry in the strength of the three primary lower limb joints.

In basketball, bilateral jumping ability is crucial, as many actions rely on powerful bilateral jumps (e.g., blocking and dunking) [5]. During the jump, the hip joint primarily generates power, ensuring explosive takeoff and stability upon landing. The knee joint aids in propelling the body off the ground while also attenuating the force during landing to protect joints and soft tissues. Finally, the ankle joint provides the push to jump and helps maintain balance and stability during both takeoff and landing [6]. The three lower limb joints work together to facilitate effective jumping, and imbalances in any of these joints may affect the overall jump height and stability [7]. Furthermore, flexion strength facilitates rapid preparatory actions, reducing reaction times and increasing jump efficiency, while extension strength propels the body upwards, enhancing jump height and power [8,9]. Šarabon et al. examined inter-limb asymmetry in 101 young male basketball players and found that the peak torque asymmetry of knee extensors and knee flexors reached 11.5 $\pm$ 8.4 and 10.4 $\pm$ 7.9, respectively, while the asymmetry in CMJ was only 5.4 $\pm$ 4.2. This indicates that single-joint muscle strength tests may reveal greater asymmetry, as the jump test involves coordinated movement across multiple joints [10]. Therefore, to understand and improve the performance of basketball players, it is necessary to assess the strength and asymmetry of individual lower limb joints. This approach can provide more detailed insights into specific joint weaknesses or imbalances, which aids in the design of more targeted training programs. Although previous studies have examined muscle torque asymmetry of the knee flexors and extensors, minimal research has investigated strength asymmetry across all lower limb joints in a single athletic group [11].

This study aims to (1) assess the lower limb joint strength of adolescent basketball players and calculate the inter-limb asymmetry for each joint, and (2) examine the correlation between these asymmetries and countermovement jump (CMJ) performance. We hypothesize that inter-limb asymmetry in all joint strengths correlates with CMJ performance and impacts overall jump ability.

## 2. Materials and Methods

### *2.1. Study Design*

This study employed a cross-sectional design to assess the relationship between lower limb strength asymmetry and CMJ performance. The tests included the CMJ test and the isokinetic dynamometer strength assessments. Before the test, the participants performed a standardized warm-up including jogging and dynamic stretching and then performed three sub-maximal CMJ trials. After a 2-min rest period, the formal maximal CMJ tests were conducted, followed by the isokinetic strength tests. All subjects were asked to indicate their lateral preference for kicking a ball, with the dominant limb (DL) identified as the preferred kicking leg and the supporting leg identified as the non-dominant limb (NDL) [12].

### *2.2. Participants*

Thirty adolescent basketball athletes (15 boys and 15 girls; age 14.5 $\pm$ 0.5 yrs; body mass 70.0 $\pm$ 15.4 kg; height 178.6 $\pm$ 11.1 cm; mean $\pm$ SD) were recruited in this study. Both male and female athletes were elite adolescent basketball players at the national level in China. All the athletes had been training for more than three years, with at least six basketball training sessions and three strength and conditioning sessions per week. All participants were being tested with isokinetic equipment for the first time. This study was approved by the committee of the local university (approval number: 102772024RT021). Considering that the subjects were adolescents, all informed consent forms were obtained from their parents.

### 2.3. Warm-Up

The participants performed a standardized warm-up consisting of 5 min of jogging and dynamic stretching exercises. This routine aimed to prepare the muscles and joints for maximal effort tests, ensuring consistency and reducing injury risk. These included two repetitions of the world's greatest stretch on each side, two repetitions of inchworms, and two repetitions of sumo squats. Following this, the subjects were shown a demonstration of how to perform a CMJ; then, they performed a series of sub-maximal practice attempts at <50% effort, followed by three practice attempts at 60, 80, and 100% of perceived maximal effort.

### 2.4. Countermovement Jump Test

The subjects stood with hands placed on the sides of their hips, performed a countermovement to a self-selected depth, and then jumped as high as possible when they were ready. The participants performed three maximal CMJs after a 2-min rest period, with the highest jump used for analysis. The jumps were measured using the MYJUMP2 app, validated for its reliability in assessing jump height (MYJUMP2).

### 2.5. Isokinetic Dynamometer Strength Testing

The isokinetic strength of the hip flexors, hip extensors, knee flexors, knee extensors, ankle plantar flexors, and ankle dorsiflexors for both lower limbs was assessed using an IsoMed-2000 isokinetic dynamometer. Testing was conducted at an angular velocity of 60°/s in concentric mode for all muscle groups. The testing protocol was standardized across all participants to ensure consistent measurement and minimize variability. Prior to the testing, all participants performed 3 sub-maximal practice trials at the specific movements and angular velocities to familiarize themselves with the protocol and ensure proper execution of the movements. This warm-up phase aimed to reduce the risk of injury and eliminate potential learning effects that could influence the test results. The order of the tested limbs and joints was as follows: the dominant limb (DL) was always tested first, followed by the non-dominant limb (NDL). The sequence of the muscle groups was set in the following order to avoid fatigue effects from proximal to distal muscle groups: (1) hip flexors and extensors, (2) knee flexors and extensors, and (3) ankle plantar flexors and dorsiflexors. Between each muscle group test, a 2-min rest interval was provided to prevent muscular fatigue, while a 2-min rest interval was also applied between testing of the limbs, angular velocities, and different modes. During the testing of each muscle group, participants were instructed to perform 5 maximal effort repetitions to obtain peak torque values. For consistency, the same evaluator conducted all tests, and verbal encouragement was provided to each participant to achieve maximal effort. The peak torque was normalized by body weight (Nm/kg) to ensure the comparability of strength levels across participants, and the highest value from the 5 repetitions was used for further data analysis [13].

### 2.6. Hip Isokinetic Strength Test

The participants were positioned in a supine position on a bench. The dynamometer's rotational axis was aligned with the greater trochanter of the femur, and the dynamometer pad was secured at the lower end of the thigh, approximately 4 cm above the lateral femoral condyle. The limb not being tested was rested on a stool. To stabilize the body, a strap was placed over the pelvis, and two additional straps were positioned diagonally from the shoulders to the opposite hips. Participants were asked to keep their arms crossed over their chests. Before the tests were started, the limb of each participant was weighed using the isokinetic dynamometer to adjust for gravity. The range of movement was set from 0° to 120°.

### 2.7. Knee Isokinetic Strength Test

Participants were seated with their hips flexed at 75° and secured to the dynamometer with Velcro straps around the thigh. Their upper bodies were stabilized using the dynamometer's shoulder apparatus, and additional stabilization straps were used for the waist and distal femur. The knee joint axis was aligned with the dynamometer's rotational axis at the lateral femoral condyle, leaving the leg unrestrained. A static gravitational correction was applied at a 30° knee flexion position to counteract the influence of gravity on the torque measurements. The range of movement was set from 10° (0° = full knee extension) to 90°.

### 2.8. Ankle Isokinetic Strength Test

Participants lay in a supine position on the dynamometer seat, with their hips and knees fully extended. Their bare foot was positioned on the foot adapter, which was attached to the dynamometer and secured with two Velcro straps. The axis of rotation of the lever arm was aligned with the lateral malleolus. Straps were used to secure the waist and thigh of the tested leg, while shoulder straps and pads held the shoulders in place in both the ventral–dorsal and cranial–caudal directions. Participants were instructed to cross their arms over their chest. Once secured, the dynamometer measured the weight of each participant's limb to correct for gravity. The ankle neutral position was set to 0°, and the range of ankle movement started from 15° dorsiflexion to 40° plantar flexion.

### 2.9. Statistical Analysis

The descriptive data are presented as the mean ± standard deviation (SD). The normality of the data distribution and the homogeneity of variance were assessed using the Shapiro–Wilk test and Levene's test, respectively. The reliability was evaluated using a two-way random intraclass correlation coefficient (ICC) with absolute agreement and 95% confidence intervals, along with the typical error of measurement (TEM) and the coefficient of variation (CV). The magnitude of the CV was based on the following parameters: poor (>10%), moderate (5–10%), or good (<5%) [14]. The ICC values were interpreted, according to Koo and Li, as follows: excellent (>0.9), good (0.75–0.9), moderate (0.5–0.75), and poor (<0.5) [15]. Asymmetries for all tasks were calculated by identifying the dominant (D) limb (the limb with the better score) and the non-dominant (ND) limb, using the formula: asymmetry index = (D–ND)/D* 100% [2]. Kappa coefficients were calculated to determine the levels of agreement for how consistently an asymmetry favored the same side (direction of asymmetry). Kappa values were interpreted as: ≤0 = poor, 0.01–0.20 = slight, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = substantial, and 0.81–0.99 = almost perfect. The participants were median-split into a high-asymmetry group (HAG, $n$ = 15) and a low-asymmetry group (LAG, $n$ = 15) based on their inter-limb asymmetry scores of the hip flexor, hip extensor, knee flexor, knee extensor, ankle plantar flexor, and ankle dorsiflexor tests [16]. Independent sample $t$-tests were used to compare the differences in the hip flexor, hip extensor, knee flexor, knee extensor, ankle plantar flexor, and ankle dorsiflexor strength between the DL and NDL. Independent samples and the Mann–Whitney U test were used to assess the difference in the asymmetry scores between the HAG and LAG and the differences between boys and girls. Hedges' $g$ effect sizes (ES) were computed for pairwise comparisons, defined as small (<0.2), moderate (0.2–0.5), and large (>0.8), based on the mean difference divided by the pooled standard deviation. Spearman's $\rho$ correlation analyses were conducted to examine the relationships between the asymmetry scores of the hip flexor, hip extensor, knee flexor, knee extensor, ankle plantar flexor, ankle dorsiflexor, and CMJ. The magnitude of correlations was categorized as follows: trivial (≤0.1), small (0.1–0.3), moderate (0.3–0.5), large (0.5–0.7), very large (0.7–0.9), and almost perfect (0.9–1.0) [17]. Statistical significance was set at $p < 0.05$. All statistical analyses were performed using IBM SPSS software version 26.0 (IBM, Armonk, NY, USA).

## 3. Results

Table 1 shows strength, jump performance, asymmetry, and reliability data. The ICC values were good to excellent for all tests (≥0.90). The coefficient of variation (CV) values were below 10% for all tests, indicating acceptable measurement precision. The strength data for each joint followed a normal distribution, while the asymmetry data for each joint did not follow a normal distribution. There were significant differences observed in all lower limb strength measures between the DL and NDL (all $p < 0.01$). The asymmetry scores of all tests were observed and ranged from 12.2% to 21.6%. For all tests, the Kappa coefficients ranged from –0.267 to 0.211, indicating poor to fair levels of agreement (Table 2). This suggests significant variability and task-specific differences in limb dominance across the three primary joints of the lower body (Figure 1).

**Table 1.** Lower limb strength, asymmetry score, correlation, and test reliability data.

| Test | Mean ± SD | ES (95% CI) | Asymmetry (%) | TEM (95% CI) | CV (%) | ICC (95% CI) |
|---|---|---|---|---|---|---|
| HF-DL (nm) | 1.71 ± 0.30 * | 0.77 (0.23, 1.31) | 13.5 ± 9.7 | 5.6 (1.7, 9.5) | 8.0 (1.3, 13.0) | 0.90 (0.87, 0.95) |
| HF-NDL (nm) | 1.48 ± 0.29 | | | 5.8 (1.3, 9.8) | 8.1 (1.3, 12.0) | 0.92 (0.89, 0.96) |
| HE-DL (nm) | 3.28 ± 1.09 * | 0.75 (0.22, 1.29) | 21.6 ± 12.9 | 6.6 (2.7, 9.7) | 7.2 (1.2, 9.0) | 0.93 (0.89, 0.98) |
| HE-NDL (nm) | 2.54 ± 0.84 | | | 4.8 (1.3, 7.8) | 7.1 (1.4, 12.0) | 0.95 (0.92, 0.97) |
| KF-DL (nm) | 1.46 ± 0.31 * | 0.71 (0.17, 1.24) | 17.2 ± 15.3 | 3.6 (1.5, 6.2) | 4.4 (1.0, 7.7) | 0.92 (0.89, 0.96) |
| KF-NDL (nm) | 1.22 ± 0.36 | | | 4.6 (1.5, 7.2) | 6.8 (1.0, 9.9) | 0.97 (0.95, 0.98) |
| KE-DL (nm) | 2.34 ± 0.54 * | 0.54 (0.01, 1.06) | 12.2 ± 9.7 | 4.4 (1.3, 8.4) | 5.8 (1.0, 9.8) | 0.96 (0.93, 0.98) |
| KE-NDL (nm) | 2.05 ± 0.53 | | | 6.1 (3.5, 7.6) | 6.0 (2.0, 9.2) | 0.93 (0.88, 0.96) |
| APF-DL (nm) | 1.23 ± 0.37 * | 0.73 (0.20, 1.27) | 19.6 ± 11.0 † | 3.3 (1.3, 5.7) | 6.7 (1.0, 9.6) | 0.98 (0.97, 0.99) |
| APF-NDL (nm) | 0.98 ± 0.30 | | | 3.1 (1.9, 4.6) | 6.2 (2.2, 9.5) | 0.98 (0.97, 0.99) |
| ADF-DL (nm) | 0.41 ± 0.13 * | 0.57 (0.05, 1.10) | 16.3 ± 11.2 | 2.4 (1.7, 4.5) | 8.1 (3.7, 10.9) | 0.96 (0.95, 0.97) |
| ADF-NDL (nm) | 0.34 ± 0.11 | | | 2.6 (1.7, 4.2) | 7.1 (3.0, 10.8) | 0.98 (0.98, 0.99) |
| CMJ (cm) | 33.14 ± 4.57 | | | 2.2 (0.3, 3.9) | 5.1 (1.7, 9.4) | 0.92 (0.88, 0.95) |

Abbreviations: HF—hip flexor; HE—hip extensor; KF—knee flexor; KE—knee extensor; APF—ankle plantar flexor; ADF—ankle dorsiflexor; DL—dominant limb; NDL—non-dominant limb; SD—standard deviation; TEM—typical error of measurement; CI—confidence intervals; CV—coefficient of variation; ICC—intraclass correlation coefficient; ES—effect size; cm: centimeters; Nm—newton meter. * = significantly different to the test on the non-dominant limb ($p < 0.01$); † = significantly correlated with CMJ performance ($p < 0.01$).

**Table 2.** Kappa coefficients and accompanying descriptors for levels of agreement describing how consistently asymmetry favored the same side in ankle, knee, and hip strength.

| | HF | HE | KF | KE | APF | ADF |
|---|---|---|---|---|---|---|
| HF | 1 | 0.21 | −0.13 | −0.08 | −0.20 | −0.27 |
| HE | | 1 | 0.06 | −0.04 | −0.27 | −0.17 |
| KF | | | 1 | 0 | −0.13 | 0.12 |
| KE | | | | 1 | −0.07 | 0.03 |
| APF | | | | | 1 | 0 |
| ADF | | | | | | 1 |

Abbreviations: HF—hip flexor; HE—hip extensor; KF—knee flexor; KE—knee extensor; APF—ankle plantar flexor; ADF—ankle dorsiflexor.

Only the ankle plantar flexor asymmetry score was correlated with the CMJ performance, and the correlation was significantly negative ($\rho = -0.56$, $p < 0.01$). This indicates that higher asymmetry in ankle plantar flexor strength is associated with lower CMJ performance. Figure 1 shows the difference in the CMJ between HAG and LAG in all the tests. The median asymmetry values for each joint strength are as follows: HF: 13.5%, HE: 21.6%, KF: 17.2%, KE: 12.2%, APF: 19.6%, ADF: 16.3%. Only the ankle plantar flexor showed a significant difference between the HAG and LAG (ES = 1.11, $p < 0.01$) (Table 3). There was a significant difference in CMJ performance between boys and girls (ES = 1.31, $p < 0.01$), but there were no differences in the inter-limb asymmetry scores (all $p > 0.05$) (Table 4). There were no correlations between inter-limb asymmetry and CMJ performance for boys or girls (all $p > 0.05$), except for ankle plantar flexor asymmetry (boys' $\rho = -0.47$, $p < 0.05$; girls' $\rho = -0.78$, $p < 0.01$).

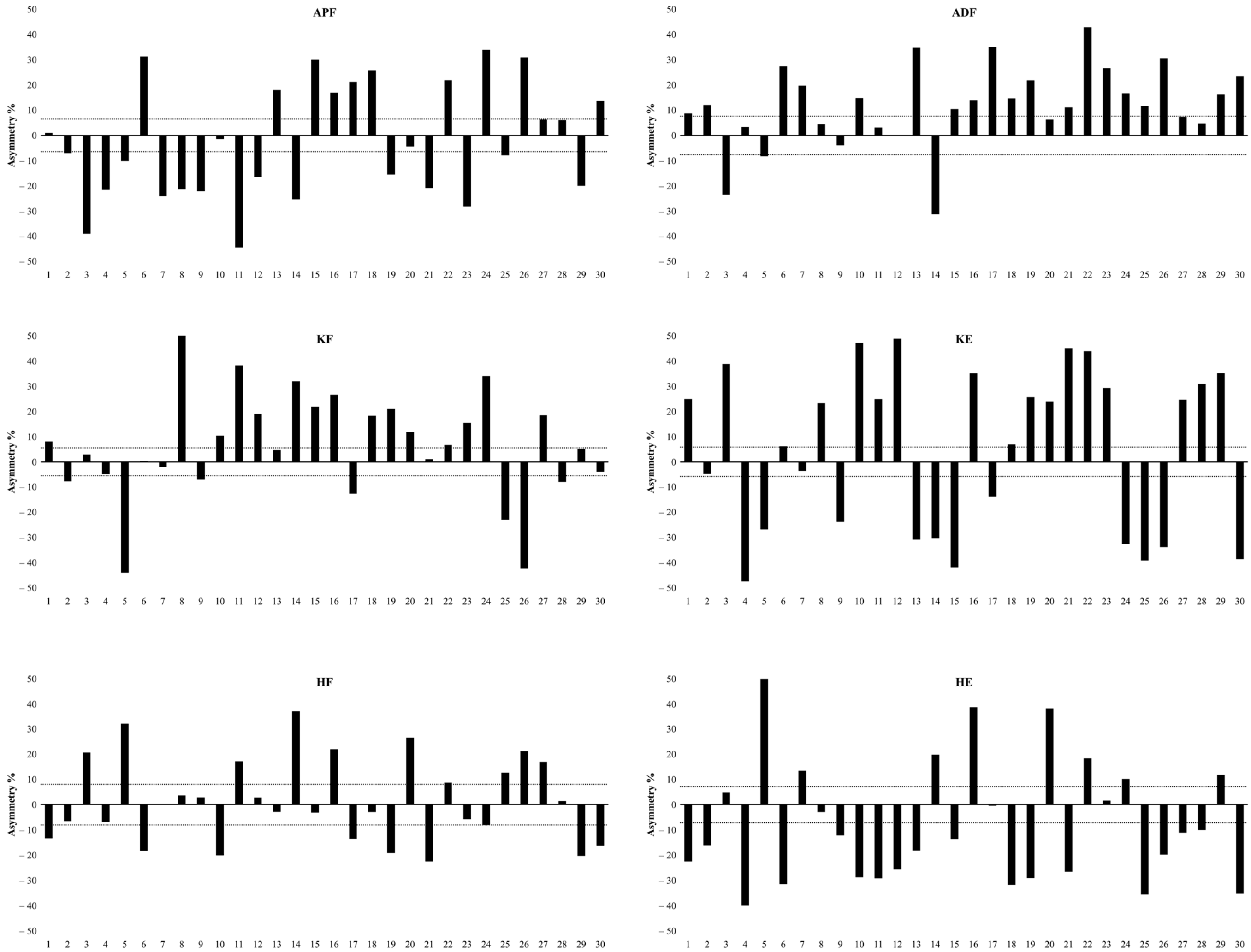


**Figure 1.** Individual inter-limb asymmetry data for ankle, knee, and hip strength. Note: Above 0 means the asymmetry favors the right limb, and below 0 means the asymmetry favors the left limb. The dotted lines represent the group threshold calculated from the pooled CV of the right and left limb or direction test scores (APF = 6.45%, ADF = 7.6%, KF = 5.6%, KE = 5.9%, HF = 8.05%, HE = 7.15%). Abbreviations: APF—ankle plantar flexor; ADF—ankle dorsiflexor; KF—knee flexor; KE—knee extensor; HF—hip flexor; HE—hip extensor.

**Table 3.** The difference in inter-limb asymmetry in each joint strength in countermovement jump.

| | | CMJ (cm) | ES (95% CI) | *p* |
|---|---|---|---|---|
| HF (%) | SG | 33.64 ± 4.45 | 0.22 (−0.50, 0.94) | 0.528 |
| | AG | 32.61 ± 4.80 | | |
| HE (%) | SG | 32.58 ± 4.89 | −0.24 (−0.65, 0.78) | 0.556 |
| | AG | 32.28 ± 3.93 | | |
| KF (%) | SG | 32.45 ± 3.13 | −0.29 (−1.01, 0.43) | 0.478 |
| | AG | 33.80 ± 5.71 | | |
| KE (%) | SG | 32.12 ± 4.95 | −0.44 (−1.16, 0.28) | 0.314 |
| | AG | 34.12 ± 4.10 | | |
| APF (%) | SG | 35.36 ± 4.35 * | 1.11 (0.34, 1.87) | 0.007 |
| | AG | 30.89 ± 3.71 | | |

**Table 3.** *Cont.*

| | | CMJ (cm) | ES (95% CI) | *p* |
|---|---|---|---|---|
| ADF (%) | SG<br>AG | 33.96 ± 5.15<br>32.28 ± 3.93 | 0.37 (−0.35, 1.09) | 0.343 |

Abbreviations: HF—hip flexor; HE—hip extensor; KF—knee flexor; KE—knee extensor; APF—ankle plantar flexor; ADF—ankle dorsiflexor; SG—symmetry group; AG—asymmetry group; ES—effect size; cm—centimeters. * = significantly different to the performance of the asymmetry group ($p < 0.01$).

**Table 4.** The differences in countermovement jump heights, joint strength, and asymmetry index between boys and girls.

| | Boys | Girls | *ES* (95% CI) | *p* |
|---|---|---|---|---|
| CMJ (cm) | 35.64 ± 4.70 * | 30.6 ± 2.78 | 1.31 (−1.46, 4.07) | 0.001 |
| HF-L | 128.51 ± 43.00 * | 91.64 ± 13.15 | 1.16 (0.39, 1.93) | 0.004 |
| HE-L | 267.48 ± 71.23 * | 154.40 ± 46.72 | 1.88 (1.02, 2.74) | 0.001 |
| HF-R | 133.19 ± 41.96 * | 91.87 ± 13.34 | 1.33 (0.54, 2.12) | 0.001 |
| HE-R | 243.11 ± 83.36 * | 148.12 ± 55.12 | 1.34 (0.55, 2.14) | 0.001 |
| KF-L | 108.69 ± 33.11 * | 70.95 ± 18.32 | 1.41 (0.61, 2.21) | 0.001 |
| KE-L | 190.26 ± 36.67 * | 114.22 ± 26.62 | 2.37 (1.44, 3.31) | 0.001 |
| KF-R | 119.28 ± 26.50 * | 75.78 ± 23.29 | 1.74 (0.90, 2.58) | 0.001 |
| KE-R | 181.42 ± 32.22 * | 124.92 ± 36.88 | 1.63 (0.81, 2.46) | 0.001 |
| APF-L | 92.67 ± 25.87 * | 62.24 ± 21.63 | 1.28 (0.49, 2.06) | 0.002 |
| ADF-L | 32.66 ± 7.43 * | 16.68 ± 5.44 | 2.45 (1.51, 3.40) | 0.001 |
| APF-R | 84.09 ± 32.09 | 65.11 ± 16.59 | 0.74 (0.00, 1.48) | 0.051 |
| ADF-R | 34.39 ± 7.68 * | 20.64 ± 6.52 | 1.93 (1.06, 2.80) | 0.001 |
| HF (%) | 12.50 ± 11.46 | 14.52 ± 7.72 | −0.21 (−0.28, −0.14) | 0.576 |
| HE (%) | 21.98 ± 12.90 | 21.26 ± 13.29 | 0.06 (−0.04, 0.15) | 0.881 |
| KF (%) | 17.83 ± 18.73 | 16.63 ± 11.58 | 0.07 (−0.04, 0.18) | 0.834 |
| KE (%) | 28.26 ± 15.06 | 30.62 ± 10.45 | −0.19 (−0.28, −0.10) | 0.622 |
| APF (%) | 20.89 ± 12.60 | 18.23 ± 9.30 | 0.23 (0.15, 0.31) | 0.515 |
| ADF (%) | 13.69 ± 11.10 | 18.89 ± 11.09 | −0.48 (−0.56, −0.40) | 0.210 |

Abbreviations: HF—hip flexor; HE—hip extensor; KF—knee flexor; KE—knee extensor; APF—ankle plantar flexor; ADF—ankle dorsiflexor; L—left limb; R—right limb; ES—effect size; cm—centimeters. * = significantly different to the girl's group ($p < 0.01$).

## 4. Discussion

The objectives of this study were to (1) assess the strength of the hips, knees, and ankles and calculate the inter-limb asymmetry and (2) examine the correlation between inter-limb asymmetry and CMJ performance and the effects of inter-limb asymmetry on CMJ performance. Our results indicate that the inter-limb asymmetry of hip strength showed the highest scores; however, only the inter-limb asymmetry of the ankle plantar flexor was significantly correlated with the CMJ and was associated with reduced CMJ performance.

Our results show that within the same age group, the CMJ height of our athletes is very similar to the findings of previous studies [18], and a similar result was also observed in the strength performance of various lower limb joints [10,19]. Previous studies have examined inter-limb asymmetry in adolescents participating in various sports using the single-leg countermovement jump test, such as tennis ($n$ = 22) [20], handball ($n$ = 26) [21], and soccer ($n$ = 19) [22]. Collectively, the results showed that the inter-limb asymmetry values ranged from 8.76% to 15.03% in adolescent athletes from these sports [20–22]. Our results for the asymmetry of single-joint strength in 30 adolescent basketball players indicated that the asymmetry of the hip extensor and ankle plantar flexor strength was considerably higher than the upper threshold of this range. This may be because the jump test is a multi-joint action [23], which can mask specific information about single-joint inter-limb asymmetry. Therefore, our results suggest that testing single-joint strength in adolescent athletes may be equally as important. The higher inter-limb asymmetry observed in this study may be related to the inappropriate design of training programs for adolescent athletes. Training for adolescent athletes often focuses on the overall development of skills, while lacking training strategies aimed at achieving balanced development of both limbs. For example, athletes may rely more on their dominant limb to perform key movements (such as jumping, sudden stops, changes in direction, and shooting) during technical training, while the non-dominant limb participates less in training, resulting in an imbalance in the development of strength, stability, and coordination between the two limbs [24]. Therefore, future training programs should strengthen the muscle strength of the non-dominant limb and the stability of smaller muscle groups to reduce the negative impact of inter-limb asymmetry on athletic performance. On the other hand, adolescent athletes are in a critical stage of growth and development, during which the growth rates of bones, muscles, and the nervous system may not be synchronized, which is also an important factor contributing to the high asymmetry. The rapid growth period typically occurs between the ages 14 and 15 [25], during which the growth rate of bones is significantly faster than the development of muscle strength and neuromuscular control [18]. This growth imbalance may lead to differences in strength and motor coordination development between different limbs in adolescent athletes. For instance, the dominant limb of some athletes may be more technically mature, while the non-dominant limb exhibits greater strength deficiencies due to lagging muscle development. Therefore, during this critical stage, coaches should regularly assess the growth and development status of adolescent athletes and design targeted intervention strategies in training to maintain strength and functional symmetry throughout the developmental process.

There are several possible reasons why the hip asymmetry was the highest among the three lower limb joints. Firstly, the hip joint is structurally complex, involving multiple muscles and allowing a wide range of motion. This complexity increases the possibility of developing asymmetric strength and coordination due to uneven usage and muscle imbalances [26]. Secondly, all thirty athletes had their right leg as the dominant leg, which they tend to use more frequently for powerful movements and skills [27,28]. This preferential use results in the dominant leg being stronger, more flexible, and better coordinated than the non-dominant leg, thereby exacerbating hip asymmetry [12]. Lastly, the specific demands of basketball require frequent and dynamic movements, including sudden changes in direction, rapid acceleration and deceleration, and single-leg jumps for layups and rebounds [29]. These sport-specific actions are likely to have placed significant stress on the hip joint and, subsequently, may have caused increases in inter-limb asymmetry as athletes repeatedly use their dominant leg to gain a performance advantage [30].

In the results of the correlation analysis, only the inter-limb asymmetry of the ankle plantar flexor was correlated with CMJ performance. This observation diverges from our hypothesis. We postulated that strength asymmetry in all major joints could negatively impact jump performance due to the involvement of larger and more numerous muscle groups surrounding these joints, where strength asymmetry might be particularly pronounced. However, our findings indicate that asymmetries in the knee and hip joints do not significantly influence jump performance. There are several potential explanations for the impact of ankle joint strength asymmetry on vertical jump performance. Firstly, the ankle joint plays a crucial role in power transmission during jumping as the final point of contact with the ground. Effective transmission through the ankle ensures the optimal utilization of power generated from the hip and knee joints, thereby maximizing jumping performance. Imbalances in ankle joint strength generation may lead to inefficient force transfer, potentially resulting in reduced jump heights [9]. Secondly, ankle joint stability is essential for maintaining control of body movements, which is critical for effective and safe CMJ execution. Asymmetry in ankle joint function could impair this stability, affecting the transfer of force during takeoff [31]. Lastly, the muscles associated with the ankle joint play a significant role in propulsion and control during jumping. For instance, the tibialis anterior provides the necessary force to lift the body off the ground, and the gastrocnemius and soleus stabilize the foot during landing and prepare for subsequent actions. Asymmetry in the strength or coordination of these muscle groups may lead to notable differences in jumping performance [9]. Based on the results regarding the effects of inter-limb asymmetry on the CMJ, it was found that only the inter-limb asymmetry of the ankle plantar flexor significantly affected the CMJ. The ankle plantar flexor serves as the final point of force generation in CMJ actions. The ankle plantar flexor is crucial for propelling the body upwards during the jump, exerting substantial force to achieve the maximum height. This pivotal role in the jumping process means that any asymmetry in the ankle plantar flexor strength or function could directly impact CMJ performance [32].

In terms of gender differences, our results showed that the lower limb joint strength of boys was significantly higher than that of girls. However, there were no significant differences in joint strength between the left and right limbs in both boys and girls. All strength asymmetry indices also showed no differences between boys and girls, which may indicate that asymmetry does not differ between genders. This has been explained in numerous prior empirical investigations on the topic of asymmetry, owing to the large within-group variation of relative percentage difference data [7]. Put simply, the large standard deviation relative to the mean makes it challenging to find any meaningful differences between test sessions, groups, or conditions. Moreover, the strength difference between males and females is mainly attributed to the higher testosterone levels in males [33], which result in greater muscle mass (including muscle volume and strength) compared to their female peers. Consequently, males tend to exhibit higher absolute strength in most joints. However, strength asymmetry reflects the relative balance between the strength of the left and right limbs rather than the total muscle strength. The lack of asymmetry differences may indicate that both males and females have relatively balanced growth patterns in the development of strength in both limbs.

Previous studies have demonstrated the importance of functional asymmetry in the ankle joint for athletic performance and injury prevention. For example, Exell et al. found a positive correlation between asymmetry in ankle work during sprinting and peak vertical force ($r$ = 0.895) and power ($r$ = 0.761) during jump trials, suggesting that the larger imbalances in ankle work during sprinting are associated with greater force and power during jumping [34]. Similarly, Fousekis et al., after analyzing knee and ankle strength asymmetry in soccer players, found significant differences in ankle plantar flexor strength between the left and right sides [35]. They concluded that long-term participation in soccer leads to the development of various degrees and modes of functional asymmetry [35]. Additionally, Jeon et al. suggested that muscle strength asymmetry in the ankle joint can lead to increased load on the knee joint, as it acts as the center for maintaining body balance [36]. Combined with our results, our findings suggest that coaches should focus more on strength training to reduce asymmetry. To achieve this, coaches can incorporate specific exercises targeting the ankle plantar flexor, such as calf raises and plyometric drills, which can help strengthen the muscles involved in plantar flexion, ensuring more balanced force generation during jumps [37]. Additionally, incorporating unilateral exercises can address muscle imbalances between the dominant and non-dominant limbs, promoting symmetry in strength and coordination [38]. Furthermore, incorporating balance and stability exercises can enhance ankle joint stability, which is crucial for effective force transmission and injury prevention. Exercises such as single-leg stands, balance board training, and proprioceptive drills can improve neuromuscular control and reduce the risk of ankle injuries [31].

Despite the usefulness of our findings, there are some limitations to this study that we must acknowledge. Firstly, the sample size may lead to insufficient significance in some results. Therefore, future research should consider increasing the sample size to improve the accuracy of the statistical tests and the reliability of the study's conclusions. Secondly, we only examined the inter-limb asymmetry effects on the CMJ; however, basketball is a multi-directional sport, and future research should compare sports performance in different directions [39]. Thirdly, we only tested the concentric strength of athletes' lower limbs; future research can test more muscle contraction patterns and examine the inter-limb asymmetry to provide more asymmetry information. Lastly, considering the combined effects of the hip, knee, and ankle on the CMJ, the muscle strength measured on isokinetic devices may lack some ecological validity. Future research could explore methods that possess greater ecological validity for measuring muscle strength.

## 5. Conclusions

In conclusion, our research indicated that inter-limb asymmetry of the ankle plantar flexor was negatively correlated with the CMJ, and it significantly impacted the jump performance of adolescent basketball players. Practitioners should pay attention to inter-limb asymmetry of the ankle to prevent injuries and enhance performance for adolescent basketball players.

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## References

1. Maloney, S.J. The Relationship Between Asymmetry and Athletic Performance: A Critical Review. *J. Strength Cond. Res.* **2019**, *33*, 2579–2593. [CrossRef] [PubMed]
2. Bishop, C.; De Keijzer, K.L.; Turner, A.N.; Beato, M. Measuring Interlimb Asymmetry for Strength and Power: A Brief Review of Assessment Methods, Data Analysis, Current Evidence, and Practical Recommendations. *J. Strength Cond. Res.* **2023**, *37*, 745–750. [CrossRef] [PubMed]
3. Bishop, C. Interlimb Asymmetries: Are Thresholds a Usable Concept? *Strength Cond. J.* **2021**, *43*, 32–36. [CrossRef]
4. Dai, B.; Layer, J.; Vertz, C.; Hinshaw, T.; Cook, R.; Li, Y.; Sha, Z. Baseline Assessments of Strength and Balance Performance and Bilateral Asymmetries in Collegiate Athletes. *J. Strength Cond. Res.* **2019**, *33*, 3015–3029. [CrossRef]
5. Balsalobre-Fernandez, C.; Nevado-Garrosa, F.; Del Campo-Vecino, J.; Ganancias-Gomez, P. Repeated Sprints and Vertical Jumps in Young Elite Soccer and Basketball Players. *Apunts. Educ. Fis. Deportes* **2015**, *120*, 52–57. [CrossRef]
6. Kipp, K.; Kiely, M.; Giordanelli, M.; Malloy, P.; Geiser, C. Joint- and Subject-Specific Strategies in Male Basketball Players across a Range of Countermovement Jump Heights. *J. Sports Sci.* **2020**, *38*, 652–657. [CrossRef]
7. Bishop, C.; Read, P.; Stern, D.; Turner, A. Effects of Soccer Match-Play on Unilateral Jumping and Interlimb Asymmetry: A Repeated-Measures Design. *J. Strength Cond. Res.* **2022**, *36*, 193–200. [CrossRef]
8. Deane, R.S.; Chow, J.W.; Tillman, M.D.; Fournier, K.A. Effects of Hip Flexor Training on Sprint, Shuttle Run, and Vertical Jump Performance. *J. Strength Cond. Res.* **2005**, *19*, 615. [CrossRef]
9. Lees, A.; Vanrenterghem, J.; De Clercq, D. The Maximal and Submaximal Vertical Jump: Implications for Strength and Conditioning. *J. Strength Cond. Res.* **2004**, *18*, 787. [CrossRef]
10. Šarabon, N.; Smajla, D.; Maffiuletti, N.A.; Bishop, C. Strength, Jumping and Change of Direction Speed Asymmetries in Soccer, Basketball and Tennis Players. *Symmetry* **2020**, *12*, 1664. [CrossRef]
11. Rutkowska-Kucharska, A. Asymmetry of Lower Limb Strength and Jumping Ability of Young Soccer Players. *Acta Bioeng. Biomech.* **2020**, *22*, 79–85. [CrossRef] [PubMed]
12. Haddad, M.; Abbes, Z.; Zarrouk, N.; Aganovic, Z.; Hulweh, A.; Moussa-Chamari, I.; Behm, D. Difference Asymmetry between Preferred Dominant and Non-Dominant Legs in Muscular Power and Balance among Sub-Elite Soccer Players in Qatar. *Symmetry* **2023**, *15*, 625. [CrossRef]
13. Arokoski, M.H.; Arokoski, J.P.A.; Haara, M.; Kankaanpää, M.; Vesterinen, M.; Niemitukia, L.H.; Helminen, H.J. Hip Muscle Strength and Muscle Cross Sectional Area in Men with and without Hip Osteoarthritis. *J. Rheumatol.* **2002**, *29*, 2185–2195. [PubMed]
14. Banyard, H.G.; Nosaka, K.; Haff, G.G. Reliability and Validity of the Load–Velocity Relationship to Predict the 1RM Back Squat. *J. Strength Cond. Res.* **2017**, *31*, 1897–1904. [CrossRef] [PubMed]
15. Koo, T.K.; Li, M.Y. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J. Chiropr. Med.* **2016**, *15*, 155–163. [CrossRef]

16. Lockie, R.G.; Callaghan, S.J.; Berry, S.P.; Cooke, E.R.A.; Jordan, C.A.; Luczo, T.M.; Jeffriess, M.D. Relationship Between Unilateral Jumping Ability and Asymmetry on Multidirectional Speed in Team-Sport Athletes. *J. Strength Cond. Res.* **2014**, *28*, 3557–3566. [CrossRef]
17. Hopkins, W.G.; Marshall, S.W.; Batterham, A.M.; Hanin, J. Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Med. Sci. Sports Exerc.* **2009**, *41*, 3–12. [CrossRef]
18. Parry, G.N.; Williams, S.; McKay, C.D.; Johnson, D.J.; Bergeron, M.F.; Cumming, S.P. Associations between Growth, Maturation and Injury in Youth Athletes Engaged in Elite Pathways: A Scoping Review. *Br. J. Sports Med.* **2024**, *58*, 1001–1010. [CrossRef]
19. Gerodimos, V.; Karatrantou, K.; Batatolis, C.; Ioakimidis, P. Sport-Related Effect on Knee Strength Profile during Puberty: Basketball vs. Soccer. *J. Funct. Morphol. Kinesiol.* **2023**, *8*, 57. [CrossRef]
20. Madruga-Parera, M.; Bishop, C.; Fort-Vanmeerhaeghe, A.; Beltran-Valls, M.R.; Skok, O.G.; Romero-Rodríguez, D. Interlimb Asymmetries in Youth Tennis Players: Relationships With Performance. *J. Strength Cond. Res.* **2020**, *34*, 2815–2823. [CrossRef]
21. Madruga-Parera, M.; Bishop, C.; Beato, M.; Fort-Vanmeerhaeghe, A.; Gonzalo-Skok, O.; Romero-Rodríguez, D. Relationship Between Interlimb Asymmetries and Speed and Change of Direction Speed in Youth Handball Players. *J. Strength Cond. Res.* **2021**, *35*, 3482–3490. [CrossRef] [PubMed]
22. Bishop, C.; Read, P.; McCubbine, J.; Turner, A. Vertical and Horizontal Asymmetries Are Related to Slower Sprinting and Jump Performance in Elite Youth Female Soccer Players. *J. Strength Cond. Res.* **2021**, *35*, 56–63. [CrossRef] [PubMed]
23. Place, N.; Millet, G.Y. Quantification of Neuromuscular Fatigue: What Do We Do Wrong and Why? *Sports Med.* **2020**, *50*, 439–447. [CrossRef] [PubMed]
24. Bishop, C.; Turner, A.; Read, P. Effects of Inter-Limb Asymmetries on Physical and Sports Performance: A Systematic Review. *J. Sports Sci.* **2018**, *36*, 1135–1144. [CrossRef] [PubMed]
25. Cumming, S.P.; Lloyd, R.S.; Oliver, J.L.; Eisenmann, J.C.; Malina, R.M. Bio-Banding in Sport: Applications to Competition, Talent Identification, and Strength and Conditioning of Youth Athletes. *Strength Cond. J.* **2017**, *39*, 34–47. [CrossRef]
26. Wrona, H.L.; Zerega, R.; King, V.G.; Reiter, C.R.; Odum, S.; Manifold, D.; Latorre, K.; Sell, T.C. Ability of Countermovement Jumps to Detect Bilateral Asymmetry in Hip and Knee Strength in Elite Youth Soccer Players. *Sports* **2023**, *11*, 77. [CrossRef]
27. Cameron, M.; Adams, R. Kicking Footedness and Movement Discrimination by Elite Australian Rules Footballers. *J. Sci. Med. Sport* **2003**, *6*, 266–274. [CrossRef]
28. Mitrousis, I.; Bourdas, D.I.; Kounalakis, S.; Bekris, E.; Mitrotasios, M.; Kostopoulos, N.; Ktistakis, I.E.; Zacharakis, E. The Effect of a Balance Training Program on the Balance and Technical Skills of Adolescent Soccer Players. *J. Sports Sci. Med.* **2023**, *22*, 645–657. [CrossRef]
29. Taylor, J.B.; Wright, A.A.; Dischiavi, S.L.; Townsend, M.A.; Marmon, A.R. Activity Demands During Multi-Directional Team Sports: A Systematic Review. *Sports Med.* **2017**, *47*, 2533–2551. [CrossRef]
30. Ujaković, F.; Šarabon, N. Relationship between Asymmetries Measured on Different Levels in Elite Basketball Players. *Symmetry* **2021**, *13*, 1436. [CrossRef]
31. Han, J.; Anson, J.; Waddington, G.; Adams, R.; Liu, Y. The Role of Ankle Proprioception for Balance Control in Relation to Sports Performance and Injury. *BioMed Res. Int.* **2015**, *2015*, 1–8. [CrossRef] [PubMed]
32. Tsiokanos, A.; Kellis, E.; Jamurtas, A.; Kellis, S. The Relationship between Jumping Performance and Isokinetic Strength of Hip and Knee Extensors and Ankle Plantar Flexors. *Isokinet. Exerc. Sci.* **2002**, *10*, 107–115. [CrossRef]
33. Kraemer, W.J.; Ratamess, N.A. Hormonal Responses and Adaptations to Resistance Exercise and Training. *Sports Med.* **2005**, *35*, 339–361. [CrossRef] [PubMed]
34. Exell, T.A.; Irwin, G.; Gittoes, M.J.R.; Kerwin, D.G. Implications of Intra-Limb Variability on Asymmetry Analyses. *J. Sports Sci.* **2012**, *30*, 403–409. [CrossRef] [PubMed]
35. Fousekis, K. Lower Limb Strength in Professional Soccer Players: Profile, Asymmetry, and Training Age. *J. Sports Sci. Med.* **2010**, *9*, 364–373.
36. Jeon, K.; Chun, S.; Seo, B. Effects of Muscle Strength Asymmetry between Left and Right on Isokinetic Strength of the Knee and Ankle Joints Depending on Athletic Performance Level. *J. Phys. Ther. Sci.* **2016**, *28*, 1289–1293. [CrossRef]
37. De Vasconcelos, G.S.; Cini, A.; Sbruzzi, G.; Lima, C.S. Effects of Proprioceptive Training on the Incidence of Ankle Sprain in Athletes: Systematic Review and Meta-Analysis. *Clin. Rehabil.* **2018**, *32*, 1581–1590. [CrossRef]
38. Krzysztofik, M.; Wilk, M.; Pisz, A.; Kolinger, D.; Tsoukos, A.; Aschenbrenner, P.; Stastny, P.; Bogdanis, G. Effects of Unilateral Conditioning Activity on Acute Performance Enhancement: A Systematic Review. *J. Sports Sci. Med.* **2022**, *21*, 625–639. [CrossRef]
39. Ben Abdelkrim, N.; Castagna, C.; Jabri, I.; Battikh, T.; El Fazaa, S.; Ati, J.E. Activity Profile and Physiological Requirements of Junior Elite Basketball Players in Relation to Aerobic-Anaerobic Fitness. *J. Strength Cond. Res.* **2010**, *24*, 2330–2342. [CrossRef]