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Assessment of Lower Limb Asymmetry in Elite U16 Football Players Using Jump Tests and Kineo Technology

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Abstract

Inter-limb asymmetry is recognized as a key factor influencing performance and injury risk in elite youth football. This study aimed to assess lower limb asymmetry in U16 players using vertical jump tests—Squat Jump (SJ) and Countermovement Jump (CMJ)—and isokinetic assessments via the Kineo Intelligent Load system. Eighteen elite U16 male players (age 15.9±0.3 years) performed SJ and CMJ tests on a contact platform, with the Elasticity Index (EI) calculated. Isokinetic tests (leg extension and curl) at 60°/s and 300°/s were conducted using Kineo. Asymmetry was determined for each variable using standard formulas, with >10% considered clinically significant. Paired t-tests and correlation analyses compared limbs and explored links between strength and jump performance. No significant group-level differences between limbs were found (p>0.05), but several players exceeded the clinical threshold, especially in hamstring strength. EI values fell within normal reference ranges (≈15–25%) and correlated moderately with isokinetic strength at certain velocities (e.g., r=0.51 for leg extension at 60°/s). Correlations between jump height and absolute strength were weak (r=-0.15 to 0.13), indicating the multifactorial nature of jump performance. Combining jump and isokinetic testing provides valuable insights into asymmetry and neuromuscular function. While no significant group-level asymmetries were observed, several players exceeded the clinical threshold, particularly in hamstring strength, highlighting the need for individualized monitoring to prevent injuries and guide performance training.

Keywords: *inter-limb asymmetry, youth football, isokinetic testing, Kineo, jump tests, elasticity index, injury prevention*

Introduction

Football is one of the world's most popular and physically demanding sports, characterized by its high intensity, multidirectional movements, and repeated high-impact actions (Caldbeck & Dos'Santos, 2022). Players must perform a wide range of motor tasks—sprinting, jumping, tackling, turning, and kicking—often under time pressure and in asymmetrical movement patterns (Gadev et al., 2020; Granero-Gil et al., 2020). This dynamic nature of the game places significant demands on both the musculoskeletal and neuromuscular systems.

As football performance heavily depends on lower-limb strength, power, and coordination, understanding the biomechanical characteristics of the athlete becomes essential (Burhaein et al., 2020; Di Paolo et al., 2021). Modern sports science increasingly emphasizes the importance of individualized assessment to optimize performance and reduce injury risk (Afonso et al., 2022). Among these assessments, the evaluation of bilateral asymmetry has gained attention as a potential predictor of performance deficits and injury vulnerability in football players.

Bilateral symmetry of the lower limbs is fundamental for

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achieving optimal athletic performance and reducing the risk of musculoskeletal injuries in football players (Skalski et al., 2024). Football is a sport characterized by a high frequency of unilateral actions—accelerations, decelerations, rapid changes in direction, jumps, and kicking—which can lead to functional imbalances between the dominant and non-dominant limbs (Bishop et al., 2018; Impellizzeri et al., 2008).

There is evidence that inter-limb asymmetries greater than 10% in various performance indicators, including strength and power, are associated with an increased risk of injuries such as anterior cruciate ligament (ACL) tears, hamstring strains, and Achilles tendon injuries (Croisier et al., 2008; Hewett et al., 2005). Furthermore, such imbalances may negatively impact athletic performance by limiting the ability to generate explosive power, land safely, and maintain dynamic stability (Lockie et al., 2014).

Objective evaluation of limb symmetry using validated assessments such as the Squat Jump (SJ), Countermovement Jump (CMJ), and isokinetic strength testing provides a reliable method for the early detection of functional imbalances and guidance for individualized intervention programs (Hart et al., 2014; Markovic et al., 2004). In recent years, the Kineo Training System has gained popularity for its ability to assess muscle strength and asymmetry under dynamic loading conditions, offering high sensitivity and reproducibility (Armstrong et al., 2022).

Monitoring muscular symmetry, particularly in elite youth athletes, may support long-term development, optimize training load, and reduce the risk of overuse and acute injuries.

Vertical jump tests - Squat Jump (SJ) and Countermovement Jump (CMJ) are established methods for objectively assessing lower-limb explosive strength and are widely used in sports science and coaching practice (Markovic et al., 2004). These tests provide reliable data on an athlete's neuromuscular condition and enable performance monitoring throughout training cycles.

CMJ evaluates the stretch-shortening cycle (SSC) by measuring the muscles' and tendons' ability to store and utilize elastic energy during the transition from eccentric to concentric contraction (Komi, 2003). In contrast, the SJ eliminates the contribution of the eccentric phase and offers a more isolated assessment of concentric strength (Markovic et al., 2004; McGuigan et al., 2006).

The difference between CMJ and SJ, commonly expressed as the Elasticity Index (EI), evaluates SSC efficiency and neuromuscular coordination (Nuzzo et al., 2008). High EI values are associated with superior explosiveness and sports performance, while low or asymmetric values may indicate a need for individualized corrective programs (Bishop et al., 2018).

In addition to measuring performance, bilateral analysis of CMJ and SJ has proven to be an effective tool for identifying inter-limb asymmetries, which are linked to an elevated risk of musculoskeletal injuries (Hart et al., 2014; Lockie et al., 2014).

Isokinetic Testing and the Role of Kineo in Strength and Symmetry Assessment

Isokinetic testing is regarded as the gold standard for measuring muscular strength, power, and imbalance at various angular velocities (Drouin et al., 2004). These tests allow for the precise assessment of peak force in both concentric and eccentric contractions, facilitating detailed analysis of symmetry between limbs—especially through exercises like leg extension and leg curl, which are essential for knee joint stability.

The Kineo Training System integrates isokinetic, isotonic, and eccentric loading in sport-specific movement conditions. This makes it particularly suitable for field-based assessments and strength monitoring in football players, while also delivering high accuracy, reproducibility, and digital feedback (Riva et al., 2016). Kineo technology enables the identification of: functional asymmetries between limbs, deficits during post-injury recovery, weaknesses in specific movement patterns (e.g., hamstring curl vs. quadriceps extension), and individual risk profiles requiring corrective training interventions.

The combination of jump tests (SJ/CMJ) with isokinetic analysis using the Kineo system offers a comprehensive profile of football players' lower-limb strength, allowing for a more individualized and preventive approach to performance and injury management.

Recent research in football science has increasingly focused on identifying neuromuscular imbalances and their impact on athletic performance and injury risk. Vertical jump tests, particularly the Squat Jump (SJ) and Countermovement Jump (CMJ), have emerged as practical and non-invasive tools for evaluating inter-limb asymmetry in athletes (Bishop et al., 2018; Lockie et al., 2014). Studies have demonstrated that asymmetries in jump height between limbs may reflect underlying functional deficits and contribute to injury susceptibility, particularly in sports characterized by unilateral loading, such as football. However, most existing investigations have either focused on adult or collegiate athletes or have relied solely on jump-based assessments without integrating objective strength measurements. Moreover, there is a lack of studies that combine jump test data with isokinetic evaluations using adaptive resistance technologies such as the Kineo system, especially in youth populations undergoing rapid growth and neuromuscular development. This gap underscores the need for a comprehensive approach to quantify asymmetry in adolescent footballers and to better understand how different metrics relate to one another.

The primary aim of this study was to evaluate the degree of inter-limb asymmetry in elite under-16 (U16) football players using a combined assessment of vertical jump tests (CMJ and SJ) and isokinetic measurements performed on the Kineo platform.

Null Hypothesis (H_0): There are no statistically significant asymmetries between the dominant and non-dominant lower limbs in the tested football players.

Alternative Hypothesis (H_1): Statistically significant inter-limb asymmetries exist in the tested variables (e.g., jump height, peak forces), particularly under eccentric loading conditions and at higher velocities.

Additional Hypothesis: Players who demonstrate a lower Elasticity Index (EI<10%) or exhibit interlimb asymmetries greater than 10% in isokinetic tests are expected to display reduced performance in vertical jump tests (CMJ and SJ). This suggests that insufficient utilization of the stretch-shortening cycle (SSC) or pronounced strength imbalances between limbs may negatively affect explosive lower-limb power.

In this context, the present study aims to explore lower-limb asymmetries in elite youth footballers, integrating vertical jump performance metrics and isokinetic strength testing via advanced technology platforms such as Kineo. This approach allows for a comprehensive analysis of functional imbalances, supporting evidence-based strategies in athletic development and injury prevention.

Methods

Participants

The study included 18 elite male football players aged 15.9±0.3 years (born in 2009), competing in a professional club in Bulgaria in the U16 category. All participants were clinically healthy and had no acute or chronic lower limb injuries in the six months prior to the testing.. Voluntary informed consent was obtained from all players before the study began. Ethics approval for the tests was granted by the University Human Research Ethics Committee of the National Sports Academy "Vassil Levski", Sofia. Written permission from the club and the parents was received to record and analyze the data.

Measurement Instruments and Equipment - Kineo Multistation

The Kineo Training System (Kineo Intelligent Load, v7.0, Globus, Italy) was used for strength assessment. This advanced system utilizes artificial muscle resistance to perform isokinetic, eccentric, isometric, and adaptive loading tasks. The assessments included Leg Extension and Leg Curl tests performed at two angular velocities—60°/s and 300°/s. Peak force values (in kilograms) were recorded for both the dominant (D) and non-dominant (ND) leg. The validity and applicability of the Kineo system for measuring eccentric and concentric strength in multi-joint tasks have been supported by Spudić et al. (2020) and McNeill et al. (2021), demonstrating its ability to safely and accurately assess force–velocity characteristics in vivo.

Jump Tests – SJ and CMJ

To evaluate lower-limb explosive power and the efficiency of the stretch-shortening cycle (SSC), vertical jump tests were performed using a contact platform - OptoJump photocell system (Microgate, Bolzano, Italy): Squat Jump (SJ): executed from a static semi-squat position with hands on hips; Countermovement Jump (CMJ): performed with a rapid downward movement before takeoff, without arm swing (Petrigna et al., 2019).

The SJ, representing pure concentric lower-limb strength, was executed from a static semi-squat position without any preparatory movement. In contrast, the CMJ included an initial eccentric phase that engages the stretch-shortening cycle (SSC), thereby reflecting neuromuscular coordination and elastic energy utilization. The Elasticity Index (EI) was calculated as a percentage difference between CMJ and SJ jump heights, providing insight into the efficiency of SSC exploitation.

Jump height (in cm) was recorded across three attempts, with the highest value used for analysis. Additionally, the Elasticity Index (EI) was calculated using the following formula (Yanci et al., 2014):

$$EI = \frac{CMJ - SJ}{SJ} \times 100$$

Testing Protocol

All measurements were performed over two consecutive days under consistent environmental conditions (temperature ~21°C, humidity ~55%). The testing session followed this structure: General warm-up (10 min): light running, mobility, and dynamic drills; Specific warm-up (5 min): jumping exercises and 1–2 familiarization trials; Jump Testing: SJ and CMJ performed in random order; Kineo Strength Testing: Leg Extension followed by Leg Curl, with a 2-minute rest between exercises and 30 seconds between legs.

Data Processing and Statistical Analysis

Mean values (M) and standard deviations (SD) were calculated for all variables. Interlimb asymmetry was computed using the following formula:

$$Asymmetry(\%) = \frac{|D - ND|}{\max(D, ND)} \times 100$$

A threshold of >10% was adopted as clinically relevant asymmetry, as recommended in the literature (Bishop et al., 2018; Croisier et al., 2008).

The statistical procedures included: Shapiro–Wilk test for normality of data distribution; Paired t-tests for normally distributed variables; Wilcoxon signed-rank test for non-parametric comparisons; Statistical significance was set at $p<0.05$. All statistical analyses were performed using IBM SPSS Statistics for Mac, version 29.0 (IBM Corp., Armonk, NY, USA), on a MacBook Pro (14", 2023).

Results

Descriptive statistics for the jump and isokinetic strength variables are presented in Table 1. These values provide insight into performance variability, central tendencies, and the range of inter-limb asymmetries among the tested players.

Table 1. Interpretation: Inter-Limb Asymmetry in Isokinetic Tests

	Mean	SD	Min	Max
SJ	3.99	10.11	-0.86	39.80
CMJ	4.40	9.47	-1.25	37.60
EINDEX	14.63	7.85	-13.77	19.95
RDLEF60	3.22	6.18	-0.08	18.00
RNDLEF60	3.36	6.12	0.00	18.00
RDLCF60	5.49	8.07	-0.46	18.00
RNDLCF60	5.44	8.07	-1.13	18.00
RDLEF300	2.13	5.53	-0.67	18.00
RNDLEF300	1.99	4.95	-1.35	18.00
RDLCF300	3.31	7.40	-1.28	18.48

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Table 1. Interpretation: Inter-Limb Asymmetry in Isokinetic Tests

	Mean	SD	Min	Max
RNDLCF300	3.37	7.01	-0.08	18.00
Asym_LEF_60	13.82	32.79	0.00	106.10
Asym_LCF_60	36.92	52.25	-148.74	127.85
Asym_LEF_300	700.43	2634.58	-10.54	10578.93
Asym_LCF_300	-132.9	490.22	-1522.39	145.86

Note. SJ: Squat Jump; CMJ: Countermovement Jump; EINDEX: Elasticity Index; RDLEF60: Right Dominant Leg Extension Force at 60°/s; RNDLEF60: Right Non-Dominant Leg Extension Force at 60°/s; RDLCF60: Right Dominant Leg Curl Force at 60°/s; RNDLCF60: Right Non-Dominant Leg Curl Force at 60°/s; RDLEF300: Right Dominant Leg Extension Force at 300°/s; RNDLEF300: Right Non-Dominant Leg Extension Force at 300°/s; RDLCF300: Right Dominant Leg Curl Force at 300°/s; RNDLCF300: Right Non-Dominant Leg Curl Force at 300°/s; Asym_LEF_60: Asymmetry in Leg Extension Force at 60°/s; Asym_LCF_60: Asymmetry in Leg Curl Force at 60°/s; Asym_LEF_300: Asymmetry in Leg Extension Force at 300°/s; Asym_LCF_300: Asymmetry in Leg Curl Force at 300°/s.

Table 1 above illustrates the mean values of calculated asymmetry (%) between the dominant and non-dominant leg across four isokinetic strength tests: Leg Extension at 60°/s; Leg Curl at 60°/s; Leg Extension at 300°/s; and Leg Curl at 300°/s.

A closer examination of the data reveals that the mean asymmetry in Leg Curl at 60°/s (Asym_LCF_60=36.92%) and Leg Extension at 300°/s (Asym_LEF_300=700.43%). The standard deviations for these variables were large, indicating substantial variability across participants.

Interestingly, while Leg Extension at 60°/s showed a moderate asymmetry (mean=13.82%), the average asymmetry in Leg Curl at 300°/s was negative (-132.9%), indicating that in some cases, the non-dominant leg produced higher force than the dominant leg.

The red dashed line (Figure 1) indicates the clinical threshold for meaningful asymmetry (10%).

Asymmetry levels in the Leg Curl tests (at both 60°/s and 300°/s) exceeded the 10% threshold, In contrast, Leg Extension asymmetries remained below the threshold

Table 2 presents the statistical comparison between the dominant and non-dominant legs across the tested isokinetic strength parameters. It includes t-values and p-values derived from paired sample t-tests (or non-parametric alternatives when applicable), assessing whether the differences observed are statistically significant ($p<0.05$).

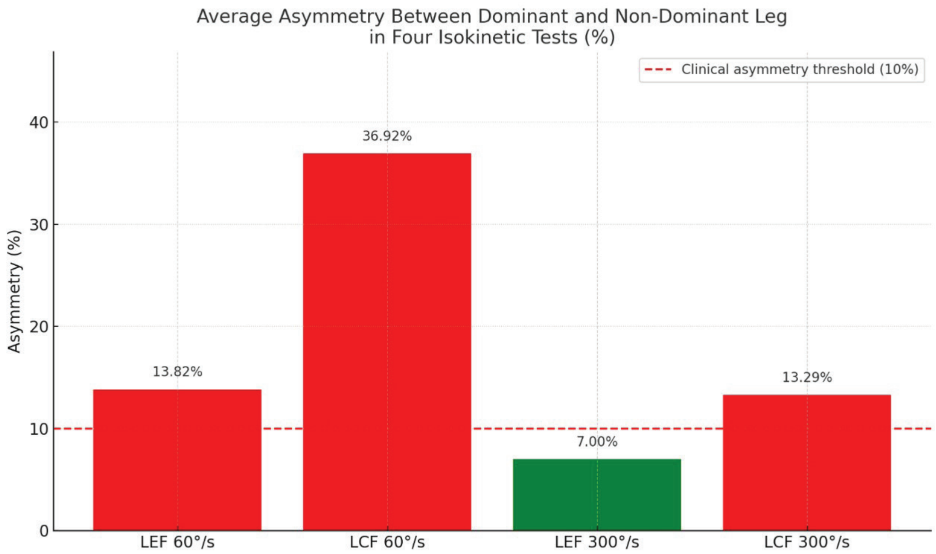

FIGURE 1. Average Asymmetry Between Dominant and Non-Dominant Leg in Four Isokinetic Tests (%)

Table 2. Statistical Comparison of Dominant and Non-Dominant Limbs Across Isokinetic Tests

Test	t-value	p-value	Significant Difference
RDLEF60 vs RNDLEF60	-1.16	0.274	No
RDLCF60 vs RNDLCF60	0.08	0.939	No
RDLEF300 vs RNDLEF300	0.46	0.652	No
RDLCF300 vs RNDLCF300	-0.29	0.776	No

Note. RDLEF60 vs RNDLEF60: comparison between dominant and non-dominant leg extension force at 60°/s; RDLCF60 vs RNDLCF60: comparison between dominant and non-dominant leg curl force at 60°/s; RDLEF300 vs RNDLEF300: comparison between dominant and non-dominant leg extension force at 300°/s; RDLCF300 vs RNDLCF300: comparison between dominant and non-dominant leg curl force at 300°/s.

This analysis provides insight into limb asymmetry, with an emphasis on whether any of the strength variables differ significantly between limbs. Although notable asymmetries were observed in some tests, particularly in hamstring-related movements, none of the comparisons reached statistical significance, possibly due to high interindividual variability or the limited sample size, particularly in hamstring-related movements, none of the comparisons reached statistical significance, possibly due to high interindividual variability or the limited sample size.

Figure 2 illustrates the inter-limb asymmetry values across different muscle groups and contraction velocities, highlighting the variability among individual players.

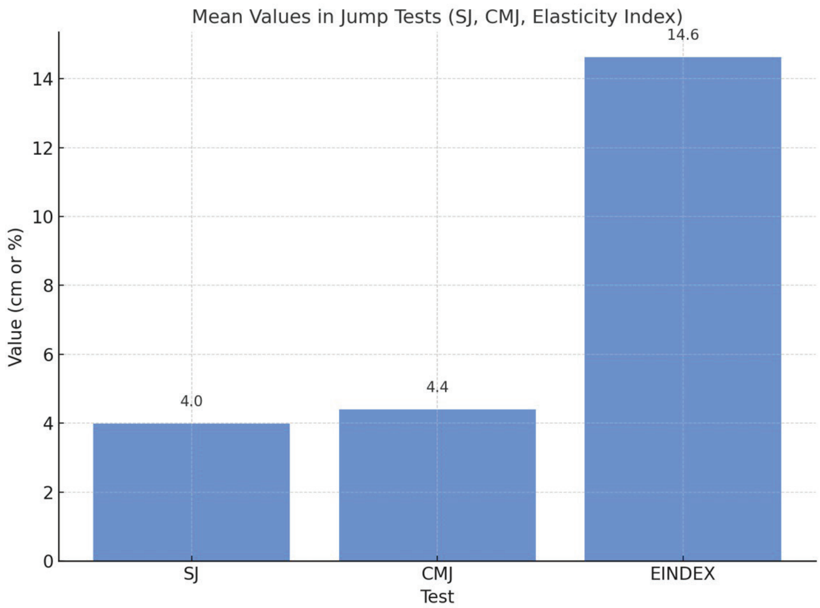

FIGURE 2. Mean Values in Jumping Tests

The correlation analysis revealed weak to negligible associations between jump height in the Squat Jump (SJ) and Countermovement Jump (CMJ) and isokinetic muscle strength parameters (r≈-0.15 to 0.13).

In contrast, the Elasticity Index (EI) demonstrated moderate positive correlations with specific strength variables (Figure 3), including knee extensor strength at 60°/s (RDLEF60; r=0.51) and knee flexor strength at 300°/s (RDLCF300; r=0.53).

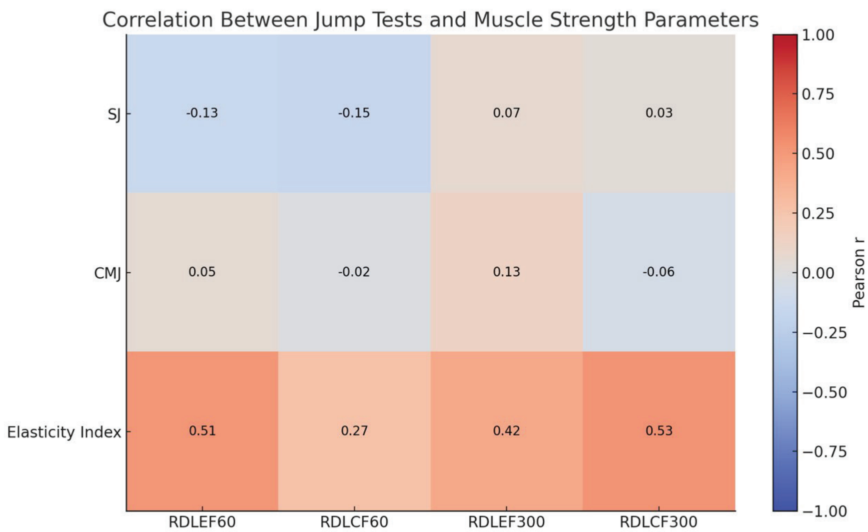

FIGURE 3. Pearson Correlation Coefficients between Jump Test Metrics and Muscle Strength Parameters (n=18)

The correlations were strongest at moderate angular velocity (60°/s) and during eccentric contraction of the hamstrings (Curl at 300°/s). While overall muscular strength may not predict jump height directly, the efficiency of SSC utilization, as reflected by the Elasticity Index.

Discussion

The current study aimed to assess inter-limb asymmetry in elite U16 football players using a combination of jump performance tests (Squat Jump [SJ] and Countermovement Jump [CMJ]) and isokinetic strength assessments via the Kineo Training System. Additionally, the relationship between explosive power and lower-limb muscle strength parameters was investigated. Considering the age group (U16), biological maturation and growth spurts could contribute to temporary neuromuscular imbalances, warranting age-specific interpretation. In this context, the findings suggest that isolated strength, as measured via Kineo (e.g., Leg Extension/Curl), is not a direct predictor of vertical jump performance. This is mirrored by Kozinc et al. (2020), who reported that no significant associations between unilateral jump and isokinetic knee extension and flexion FVP parameters were found (all $r \leq 0.26$; $p > 0.05$). Instead, jumping ability appears to be a multifactorial quality, influenced by neuromuscular coordination, jump technique, and the effective utilization of the stretch-shortening cycle (SSC), in addition to raw muscular strength. This underscores the importance of integrated training approaches that target not only force production but also technical and neuromuscular factors essential for explosive movements. The cutoff values of SSC efficiency to be considered for male and female elite-standard players were 1.73% and 2 cm for the relative (ΔCMJ-SJ) and absolute (CMJ-SJ) variables, respectively (Castagna & Castellini, 2013).

Isokinetic Asymmetry

These values substantially exceed the commonly accepted clinical threshold of 10%, which is associated with an elevated risk of musculoskeletal injury (Bishop et al., 2018; Croisier et al., 2008), indicating a high level of inter-limb imbalance, particularly under eccentric and high-velocity movement conditions. This was most evident in the Leg Curl (hamstring) test, where mean asymmetry exceeded 10% at both 60°/s and 300°/s angular velocities (Croisier et al., 2008), indicating a heightened risk of muscular injuries, particularly during dynamic and eccentric movements typical of football. These results align with previous literature, which highlights the hamstrings as more susceptible to asymmetry, especially in adolescent football players undergoing growth and neuromuscular development. This emphasizes the importance of targeted posterior chain training interventions, particularly for youth athletes exhibiting such asymmetrical tendencies. However, no statistically significant differences were found between the dominant and non-dominant legs ($p > 0.05$), potentially due to the small sample size or high individual variability.

These findings align with prior research indicating that asymmetry may often remain undetected when assessed solely using traditional paired t-tests (Bishop et al., 2018), emphasizing the importance of individualized profiling for athletes. These results align with previous literature, which highlights the hamstrings as more susceptible to asymmetry, especially in adolescent football players undergoing growth and neuromuscular development. This emphasizes the importance of targeted posterior chain training interventions, particularly for youth athletes exhibiting such asymmetrical tendencies. Red bars indicate test conditions in which the mean inter-limb asymmetry exceeds the critical threshold of 10%, suggesting a heightened risk of muscular imbalance and potential injury. Green bars represent conditions where the mean asymmetry remains below 10%, values considered acceptable within sports science practice and unlikely to pose a significant risk to performance or injury.

Recent systematic evidence suggests that inter-limb asymmetries greater than 15% in hamstring eccentric strength and greater than 10% in quadriceps concentric torque significantly increase the risk of non-contact muscle injuries in professional soccer players (Fousekis et al., 2011; Liporaci et al., 2019).

Jump Performance and Elasticity Index

The average Elasticity Index (EI) in this study fell within expected normative ranges (~20%), suggesting normal utilization of the stretch-shortening cycle (SSC) among participants. The observed difference between SJ and CMJ confirmed that players were able to effectively capitalize on stored elastic energy during dynamic movement execution. The Elasticity Index values fall within the expected normative range (15–25%), indicating that players are effectively utilizing the SSC mechanism during jumps (Petridis et al., 2019). As expected, CMJ height exceeded SJ height. A substantially lower EI could indicate neuromuscular fatigue or functional asymmetry, but this was not observed in the current sample. These results align with previous literature, which reports normative EI values between 15–25% in trained youth athletes and supports the role of CMJ-SJ differences as a valid indicator of SSC efficiency and neuromuscular function (Bishop et al., 2022; Impellizzeri et al., 2008; Kozinc et al., 2021).

Relationship Between Strength and Jump Performance

Correlation analysis showed weak associations between absolute muscular strength (Leg Extension and Curl) and jump height (SJ and CMJ), supporting existing literature that suggests that vertical jumping ability is multifactorial affected by coordination, technique, rhythm, and SSC efficiency (Cormie et al., 2011). The Elasticity Index showed moderate positive correlations with strength measures, particularly with Leg Extension at 60°/s ($r=0.51$) and Leg Curl at 300°/s ($r=0.53$). This suggests that enhanced strength in knee extensors and flexors at specific contraction speeds may improve SSC efficiency. These findings are in line with Michailidis et al. (2025), who reported that "a significant positive correlation between the CMJ Bilateral Asymmetry Index and the BAI Anterior Quadriceps at 60°/s ($r=0.262$, $p=0.038$) was identified, while a moderate inverse correlation was found with posterior hamstrings ($r=-0.319$, $p=0.011$)," indicating differential contributions of muscle groups to jump asymmetry.

These results corroborate the findings of Impellizzeri et al. (2008), who emphasized the importance of lower-limb symmetry for maintaining optimal performance and reducing injury risk in youth athletes. Similarly, Bishop et al. (2018) reported that asymmetries exceeding 10% are associated with increased injury risk, particularly within the hamstring muscle group. In our study, values above this threshold were observed in the Leg Curl test, reinforcing the need for targeted screening and corrective interventions. Croisier et al. (2008) demonstrated that untreated strength imbalances increase the risk of hamstring injuries by over fourfold. However, when corrected through targeted preseason interventions, this elevated risk was effectively mitigated.

Functional Implications of Asymmetry and Injury Risk

Although no statistically significant differences were detected, the absolute asymmetry values observed in the hamstring musculature raise functional and preventative concerns. These asymmetries may contribute to altered neuromuscular control and compensatory movement patterns, which in turn can increase spinal and hip joint loading. Consequently, athletes may face a heightened risk of hamstring strains, muscular overload, and acute injuries—particularly during high-intensity actions such as sprinting and change-of-direction tasks (Croisier et al., 2008). Therefore, inter-limb asymmetry serves as a valuable screening tool for identifying at-risk athletes and informing injury prevention strategies. The direction of asymmetry was rarely consistent across groups, suggesting that limb dominance is task- and population-specific (Bishop et al., 2021).

Elite youth soccer players in younger age categories exhibit greater bilateral strength asymmetry in both knee extensors and flexors, which may elevate the risk of injury during developmental stages (Kalata et al., 2021).

Role of Kineo in Injury Prevention and Athletic Development

The Kineo system offers a precise, safe, and versatile platform for evaluating muscle function, including isokinetic and eccentric loading—capabilities that are rarely achievable with traditional equipment. Among its key advantages is the ability to measure peak force objectively across a range of velocities, allowing for detailed profiling of neuromuscular performance. Moreover, it enables accurate detection of inter-limb strength imbalances and supports the creation of personalized loading protocols tailored to individual deficits. Finally, the system allows for longitudinal monitoring of performance, which is particularly valuable for guiding rehabilitation and tracking developmental progress in youth athletes. Regular integration of Kineo testing into performance monitoring frameworks may serve both diagnostic and prescriptive functions, guiding training interventions related to explosiveness, eccentric strength, and muscular symmetry.

Isokinetic testing provides a reliable and objective method for assessing knee extensor and flexor strength, offering valuable benchmarks for training and rehabilitation in elite and youth soccer players (Bishop et al., 2021).

Furthermore, the importance of eccentric training in injury prevention and strength development has been supported not only by sports science but also by engineering-based research. Zivanovic (2020) emphasizes that eccentric overload, achieved through greater muscular force over a reduced angular displacement, results in significant improvements in strength and neuromuscular efficiency. This supports the value of intelligent resistance technologies like Kineo, which allow precise control and monitoring of eccentric loading parameters during sport-specific movements. Evaluation of muscle strength imbalance can be an important element in optimizing the training process of soccer players (Śliwowski et al., 2024).

Limitations

Like all applied studies, this research presents several limitations. First, the small sample size (n=18), although composed of elite-level players, reduces the statistical power of the findings. Second, the sample included only male participants, which limits the generalizability of the results to female football populations. Third, the study focused solely on a single age category (U16), where physiological variations related to puberty may influence performance outcomes. Finally, the cross-sectional design of the study did not allow for longitudinal tracking, thereby limiting insights into the progression or changes in asymmetry over time.

Conclusion and Practical Implications

The present study identified pronounced inter-limb asymmetries in a portion of the examined elite U16 football players, particularly in the hamstring muscle group, as measured by isokinetic testing with the Kineo system. Although group-level mean values did not reveal statistically significant differences between the dominant and non-dominant limbs, individual cases exceeded the clinically relevant threshold of 10%, warranting attention for potential injury risk. In addition to neuromuscular profiling, monitoring body composition is considered a crucial element in performance optimization and injury prevention. According to Ivanov and Gutev (2024), controlling body composition not only enhances performance but also plays a role in identifying and developing young talent in professional football (Ivanov et al., 2022).

The combination of jump tests (Squat Jump, Countermovement Jump, and Elasticity Index) with isokinetic assessments provides a comprehensive overview of lower-limb explosive strength, muscular symmetry, and functional status. The Elasticity Index, in particular, emerged as a valuable indicator, demonstrating associations with strength performance under eccentric and slow-speed conditions. This dual assessment approach enhances the diagnostic resolution compared to either method alone, reinforcing its use in youth football development programs.

Practical Recommendations:

Several practical recommendations emerge from the present findings. First, it is advisable to implement regular monitoring of inter-limb asymmetry using systems like Kineo or comparable technologies at intervals of approximately every 6–8 weeks throughout the competitive season. Second, individualized training interventions should be designed to target specific deficits, particularly for players exhibiting asymmetries greater than 10%, ensuring the corrective load is tailored accordingly. Third, the integration of eccentric and unilateral strength exercises can support improved muscular symmetry and help mitigate injury risk. Fourth, the use of the Elasticity Index (EI) is encouraged as a practical tool for monitoring stretch-shortening cycle (SSC) efficiency during dynamic movements and tracking explosive performance development over time. Finally, establishing normative age-specific reference values for both asymmetry and jump performance may guide more precise training and talent development strategies. Furthermore, longitudinal research is warranted to determine whether targeted asymmetry interventions can effectively reduce injury incidence in elite youth athletes.

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Conflict of interest

The authors declare that there are no conflict of interest.

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