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The Relationship Between Lower Extremity Strength Asymmetry and Vertical Jump Performance: A Study on Female University Athletes in Different Sports

Alt Ekstremite Kuvvet Asimetrisi ile Dikey Sıçrama Performansı Arasındaki İlişki: Farklı Spor Dallarındaki Kadın Üniversite Sporcuları Üzerine Bir Çalışma

Research Article / Araştırma Makalesi

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Abstract

The purpose of this study is to examine the relationship between lower extremity strength asymmetry and vertical jump performance in female university athletes participating in different team sports (basketball, handball, volleyball). A total of 64 female athletes (basketball: 22, handball: 24, volleyball: 18) enrolled at Mersin University participated in the study. Participants' body composition, isokinetic knee strength (using a Cybex dynamometer), and vertical jump performance (using a force platform) were measured. Bilateral (Q/Q, H/H) and ipsilateral (H/Q) strength asymmetry percentages were calculated. The findings of the study showed that there were negative significant correlations between bilateral quadriceps (Q/Q) and hamstring (H/H) strength asymmetry and vertical jump performance in all three sports. As the strength difference between muscle groups increased, jump height decreased. In contrast, a positive significant relationship was found between the ipsilateral hamstring/quadriceps (H/Q) strength ratio and jump performance. Fisher's z-transformation analysis revealed no statistically significant difference in the magnitude of these relationships among the three sports ($p>0.05$). In conclusion, this study supports the notion that lower extremity strength asymmetries have the potential to negatively impact performance parameters requiring explosive strength, such as vertical jump. Coaches and sports practitioners are advised to regularly assess athletes for strength asymmetries and H/Q ratios and to include exercises in training programs aimed at correcting these imbalances in order to optimize performance and reduce the risk of injury.

Keywords: Strength asymmetry, Bilateral, Ipsilateral, Vertical jump, University athletes

Öz

Bu çalışmanın amacı, farklı takım sporlarında (basketbol, hentbol, voleybol) yer alan kadın üniversite sporcularında alt ekstremite kuvvet asimetrisi ile dikey sıçrama performansı arasındaki ilişkiyi incelemektir. Çalışmaya Mersin Üniversitesi'nde öğrenim gören 64 kadın sporcu (basketbol: 22, hentbol: 24, voleybol: 18) katılmıştır. Katılımcıların vücut kompozisyonları, izokinetik diz kuvvetleri (Cybex dinamometresi kullanılarak) ve dikey sıçrama performansları (kuvvet platformu kullanılarak) ölçülmüştür. Bilateral (Q/Q, H/H) ve ipsilateral (H/Q) kuvvet asimetri yüzdeleri hesaplanmıştır. Çalışmanın bulguları, her üç spor dalında da bilateral quadriceps (Q/Q) ve hamstring (H/H) kuvvet asimetrisi ile dikey sıçrama performansı arasında negatif yönde anlamlı korelasyonlar olduğunu göstermiştir. Kas grupları arasındaki kuvvet farkı arttıkça sıçrama yüksekliği azalmıştır. Buna karşılık ipsilateral hamstring/quadriceps (H/Q) kuvvet oranı ile sıçrama performansı arasında pozitif yönde anlamlı bir ilişki bulunmuştur. Fisher'ın z-dönüşüm analizi, bu ilişkilerin büyüklüğünde üç spor dalı arasında istatistiksel olarak anlamlı bir fark ortaya koymamıştır ($p>0,05$). Sonuç olarak, bu çalışma, alt ekstremite kuvvet asimetrilerinin dikey sıçrama gibi patlayıcı kuvvet gerektiren performans parametrelerini olumsuz etkileme potansiyeline sahip olduğu görüşünü desteklemektedir. Antrenörlere ve spor uygulayıcılarına, sporcuları kuvvet asimetrileri ve H/Q oranları açısından düzenli olarak değerlendirmeleri ve performansı optimize etmek ve sakatlık riskini azaltmak için bu dengesizlikleri düzeltmeyi amaçlayan egzersizleri antrenman programlarına dâhil etmeleri önerilmektedir.

Anahtar Kelimeler: Kuvvet asimetrisi, Bilateral, İpsilateral, Dikey sıçrama, Üniversite sporcuları

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Introduction

Athletes are guided to develop their physical and physiological capacities through sport-specific programs under the supervision of expert coaches. Although each sport has its own specific requirements, certain common elements are important for sustainable performance. These elements include lower and upper extremity strength, explosive power, jumping ability, aerobic endurance, and functional capacity (Stradijot et al., 2012). Particularly in team sports (soccer, basketball, handball, volleyball, etc.), where competition is paramount, lower extremity strength and the performance elements associated with it become critical. Therefore, lower extremity strength and performance indicators have become an area of intense interest for researchers in terms of monitoring athletes' performance, determining injury risks, and evaluating the effects of different training methods on these variables (Barendrecht et al., 2011; Hegedus et al., 2015; Hermassi et al., 2014).

In team sports, lower extremity muscle strength plays a critical role in the effective execution of sport-specific movements such as sprinting, jumping, changing direction, passing, and shooting. Numerous studies in the literature indicate that muscle strength imbalances or asymmetries predispose athletes to sports injuries (Bishop et al., 2018; Vargas et al., 2020). Strength asymmetry is typically defined by comparing the maximal strength levels of both legs relative to a specific reference point. This comparison is made using either contralateral (e.g., between the right and left hamstring or quadriceps muscles) or ipsilateral (between the hamstring and quadriceps muscles on the same side) ratios (Bishop et al., 2016). Strength imbalances in the lower extremities can directly affect athletic performance and play an important role in determining strategies for preventing injuries in the long term (Daneshjoo et al., 2013). Lower extremity strength balance has a decisive effect on vertical jump performance and power production (Impellizzeri et al., 2007). Strength differences between muscles can negatively affect jump height and explosive power output by reducing the optimal strength production capacity of the lower extremity muscles (Bishop et al., 2016). It has been reported that female athletes, in particular, are more prone to lower extremity strength asymmetry and sports injuries than males (Deda and Kalaja, 2015). The literature reports inconsistent findings regarding the relationship between interlimb asymmetries and vertical jump, change of direction speed, sprint performance, and sport-specific motor skills. (Bishop et al., 2018; Holm and Vollestad, 2007; Maly et al., 2021). Furthermore, the existing literature shows that the relationship between lower extremity strength asymmetry and performance has mostly been studied in male athletes, while data specific to female athletes is limited. Moreover, there are very few studies that adopt a comparative approach across different team sports (Maly et al., 2021; Tarakcı et al.,2025). Therefore, this study aimed to examine the relationship between lower extremity strength asymmetry and vertical jump performance in female university athletes from three different team sports (volleyball, basketball, and handball) using the same methodological framework. The hypothesis of the study is that an increase in lower extremity strength asymmetry will negatively affect vertical jump performance. This study aims to contribute to the literature by revealing the relationship between muscle strength imbalances and vertical jump performance in female athletes participating in different team sports, thereby highlighting the importance of considering asymmetries in training planning.

Method

Research Design

This study was conducted using a correlational survey model. Correlational survey models aim to determine possible relationships between variables and examine the direction and degree of these relationships (Cohen, 2018). The athletes visited the laboratory three times. On the first day, training sessions were held to introduce the test equipment, and body composition measurements were taken using the bioelectrical impedance method. On the second visit day, following a warm-up protocol, isokinetic strength testing was performed according to the protocol. Forty-eight hours later, on the third test day, vertical jump measurements were performed following the warm-up protocol. Participants were instructed to avoid intense physical exercise and alcohol and caffeine consumption for 24 hours prior to the tests.

Research Group

To determine the sample size, G*Power analysis was performed, referencing the study by Michailidis (2023) (5% margin of error, 95% power), and the sample size was determined to be at least 16 for each group, totaling 48 participants for the three groups. The population of this study consisted of female athletes at Mersin University, while the sample group consisted of a total of 64 female athletes studying at the Faculty of Sports Sciences at Mersin University who agreed to participate in the study: basketball=22; handball=24 and volleyball=18 athletes. Participants actively involved in university teams during the data collection process, averaging 5 training sessions per week. Weekly training programs generally include sport-specific technical and tactical drills, game-based workloads, on-field conditioning exercises, and high-intensity interval training.

Procedures

Participants' body composition measurements, isokinetic strength and vertical jump tests were performed by the same researcher at the Physical Profile, Performance, and Biomechanics Laboratories within the Faculty of Sports Sciences at Mersin University. To ensure the reliability of the test results, the ambient temperature was kept constant at 21–22 °C and the humidity at 45–55%, and all measurements were performed under controlled laboratory conditions. The inclusion criteria for the study were: (i) individuals volunteering for the study, (ii) having at least three years of sports history, (iii) actively continuing to participate in sports, (iv) not having experienced any health problems or injuries that could negatively affect performance in the last six months or during the study, and (v) regularly participating in all test procedures in the study. All participants completed the Physical Activity Readiness Questionnaire (PAR-Q) and a health history form to assess their suitability for the exercise program before being included in the study. Any "yes" answer to the questions in the questionnaire was considered a criterion for exclusion from the study.

Body Composition Measurements: The Bioelectrical Impedance Analysis method was used to determine the parameters related to the participants' body composition, and measurements were performed using the Tanita BC418 (Japan) device. Before the measurements, participants were given detailed information about the procedure and were asked to participate in the assessments wearing sportswear (shorts and a T-shirt) and without shoes. Height was measured using a Holtain Ltd. (U.K.) stadiometer.

Isokinetic Strength Measurements: Participants' knee joint extensor and flexor isokinetic strength measurements were performed using a Cybex II Norm isokinetic dynamometer (Humac Norm CSMI, USA). Prior to the test, participants underwent a 10-minute warm-up consisting of 5 minutes of running on a treadmill and 5 minutes of dynamic movements. The test protocol was set at 10 repetitions at an angular velocity of 180°/s, followed by 3 sets of 5 repetitions at an angular velocity of 60°/s. The reason for selecting angular velocities of 60°/s and 180°/s was that muscle fibers produce more force at lower angular velocities (Gregor et al., 1979). A 30-second rest interval was provided between sets. The tests were performed using only concentric contractions (Con/Con) to prevent hamstring injuries in participants (Bennett and Stauber, 1986). The seat angle was set to 85°, as recommended by the manufacturer's protocol. The torso and thigh were secured to the seat with straps, and the ankle joint was attached to the dynamometer arm via a padded pad. The range of motion was standardized at 90° for all participants (Maly et al., 2017). Calibration and gravity correction were adjusted to match the values provided by the isokinetic dynamometer. Participants were provided with the necessary information and detailed instructions about the test prior to testing. Verbal motivation was also provided during the test. Measurements were taken between 9:00 a.m. and 1:00 p.m. in a laboratory environment with constant humidity and temperature. Peak torque (PT) values obtained in all tests were recorded in Newton meters (Nm). The bilateral and ipsilateral strength asymmetries of the athletes were calculated using the formulas below.

Bilateral (contralateral) strength asymmetry refers to the comparison of strength between two limbs. In this study, isokinetic peak torque data for the quadriceps and hamstrings were obtained by flexing and extending the knee joint at 60 °/s. The force asymmetry between the two limbs was calculated for both the quadriceps and hamstring muscles (Q/Q and H/H) using the formula:

(High peak torque - low peak torque) / high peak torque x 100.

Ipsilateral strength asymmetry is the imbalance in agonist and antagonist muscle strength in the same limb. In this study, isokinetic peak torque data for the quadriceps and hamstrings were obtained and the ipsilateral strength difference (H/Q) between the right and left legs was calculated as a percentage using the following formula.

It was calculated using the formula (Hamstring peak torque/Quadriceps peak torque) x 100 (Gleim et al., 1978).

Vertical Jump (CMJ) Test: Participants' vertical jump performance was assessed using a dual-plate force platform system (Hawkin Dynamics, Westbrook, USA). During the test, athletes were asked to stand on the platform with their hands on their hips, then perform a 90° rapid squat movement and jump as high as possible. Each individual performed two trials with 30-second rest intervals, and the highest value obtained was recorded in centimeters (cm) (Badby et al., 2023).

Data Analysis

The data obtained were analyzed using the JASP program. The Shapiro-Wilk test was used to check whether all variables were normally distributed. Since the data showed a normal distribution, the relationships between the groups were examined using parametric tests. To evaluate the relationship between the athletes' strength asymmetry parameters and their vertical jump performance, the Pearson correlation coefficient (r) was calculated for each group. Correlation coefficients were interpreted to determine the direction and strength of the relationships. When correlations differed significantly between groups, the necessary statistical comparisons were made using Fisher's z-transformation. All statistical results were considered significant at the $p<0.05$ level.

Ethical Statement

This study was ethically approved by the Mersin University Sports Sciences Ethics Committee with decision number 067, dated 18/11/2024. Participants participated in the study voluntarily, and an informed consent form was signed beforehand. Furthermore, the study was conducted in accordance with the Declaration of Helsinki.

Findings

The findings section presents the descriptive characteristics of the participants (Table 1), normality test results (Table 2), the relationships between strength asymmetry and vertical jump performance across sports disciplines (Tables 3–5), and the comparison of correlation coefficients between groups using Fisher's z-transformation (Table 6).

Table 1. Descriptive characteristics of the participants

Variable	*Sports Discipline*	*Min*	*Max*	*X̄*	*SD*
Age (years)	Basketball (n:22)	18,00	24,00	20,32	2,10
	Handball (n:24)	20,00	25,00	23,00	1,35
	Volleyball (n:18)	20,00	28,00	23,76	3,03
Height (cm)	Basketball (n:22)	165,00	189,00	176,20	6,31
	Handball (n:24)	155,00	172,00	164,00	4,16
	Volleyball (n:18)	172,00	188,00	180,40	5,97
Body Weight (kg)	Basketball (n:22)	55,20	88,00	67,44	8,78
	Handball (n:24)	48,60	70,50	55,69	6,25
	Volleyball (n:18)	56,50	73,50	65,42	5,81
Vertical Jump (cm)	Basketball (n:22)	24,80	42,00	32,94	5,81
	Handball (n:24)	27,00	37,40	31,62	4,86
	Volleyball (n:18)	28,20	38,80	33,39	2,97
Right Extension Peak Torque (Nm)	Basketball (n:22)	157,00	255,00	196,3	23,81
	Handball (n:24)	158,00	223,00	183,1	15,76
	Volleyball (n:18)	182,00	242,00	203,8	21,50
Right Flexion Peak Torque (Nm)	Basketball (n:22)	98,00	168,00	114,40	16,72
	Handball (n:24)	89,00	138,00	106,4	11,67
	Volleyball (n:18)	95,00	141,00	118,6	15,30
Left Extension Peak Torque (Nm)	Basketball (n:22)	156,00	232,00	184,40	20,72
	Handball (n:24)	150,00	209,00	174,20	14,70
	Volleyball (n:18)	163,00	262,00	199,20	28,21
Left Flexion Peak Torque (Nm)	Basketball (n:22)	87,00	142,00	107,5	14,51
	Handball (n:24)	86,00	127,00	100,30	10,54
	Volleyball (n:18)	90,00	148,00	114,10	14,82
Bilateral Difference (%) (Q/Q)	Basketball (n:22)	1,88	14,80	9,22	3,12
	Handball (n:24)	2,38	11,17	5,66	2,21
	Volleyball (n:18)	2,51	16,41	7,93	2,72
Bilateral Difference (%) (H/H)	Basketball (n:22)	1,39	20,18	9,61	5,20
	Handball (n:24)	1,04	16,82	6,63	3,71
	Volleyball (n:18)	0,93	13,87	7,39	3,95
Ipsilateral Difference (%) (Right H/Q)	Basketball (n:22)	51,28	65,88	58,28	4,12
	Handball (n:24)	51,38	67,80	58,12	4,10
	Volleyball (n:18)	52,17	66,49	58,24	5,08
Ipsilateral Difference (%) (Left H/Q)	Basketball (n:22)	49,44	66,49	58,35	5,02
	Handball (n:24)	53,37	65,48	57,60	3,38
	Volleyball (n:18)	45,00	66,26	57,56	4,86

Table 2. Normality Test Results

Sports Discipline	*Variable*	*W*	*p*
Basketball	Bilateral Q/Q	0,963	0,560
	Bilateral H/H	0,964	0,584
	Ipsilateral Right H/Q	0,967	0,636
	Ipsilateral Left H/Q	0,952	0,344
	Vertical Jump	0,957	0,440
Handball	Bilateral Q/Q	0,959	0,421
	Bilateral H/H	0,943	0,191
	Ipsilateral Right H/Q	0,974	0,321
	Ipsilateral Left H/Q	0,931	0,101
	Vertical Jump	0,949	0,259
Volleyball	Bilateral Q/Q	0,937	0,280
	Bilateral H/H	0,931	0,227
	Ipsilateral Right H/Q	0,965	0,456
	Ipsilateral Left H/Q	0,975	0,345
	Vertical Jump	0,895	0,089

Table 3. Relationship between strength asymmetry and vertical jump in basketball players

	Variable		Vertical Jump	Bilateral Q/Q	Bilateral H/H	Ipsilateral Right H/Q
Basketball	Bilateral Q/Q	r	-0,420*			
		p	0,032			
	Bilateral H/H	r	-0.380*	0,720**		
		p	0,047	0,001		
	Ipsilateral Right H/Q	r	0,510**	-0,310	-0,280	
		p	0,008	0,089	0,115	
	Ipsilateral Left H/Q	r	0,480*	-0,290	-0,260	0,850**
		p	0,015	0,104	0,132	0,001

Significant relationships have been found between strength asymmetries and vertical jump performance in basketball. A moderate negative correlation was found between bilateral Q/Q asymmetry and vertical jump (r= -0.420, p = 0.032). Similarly, a negative correlation was also found with bilateral H/H asymmetry (r= -0.380, p = 0.047). These findings indicate that jump performance decreases as bilateral asymmetry in the quadriceps and hamstring muscles increases. When examining the relationships between ipsilateral asymmetry and jumping performance, statistically significant moderate positive correlations were found between the right H/Q ratio (r= 0.510, p = 0.008) and the left H/Q ratio (r= 0.480, p = 0.015) and vertical jump. These findings reveal that the hamstring/quadriceps strength ratio is an important determinant of jumping performance in basketball players.

Table 4. Relationship between strength asymmetry and vertical jump in handball athletes

	Variable		Vertical Jump	Bilateral Q/Q	Bilateral H/H	Ipsilateral Right H/Q
Handball	Bilateral Q/Q	r	-0,350*			
		p	0,041			
	Bilateral H/H	r	-0,340*	0,680**		
		p	0,047	0,001		
	Ipsilateral Right H/Q	r	0,450*	-0,270	-0,230	
		p	0,012	0,095	0,134	
	Ipsilateral Left H/Q	r	0,410*	-0,240	-0,210	0,820**
		p	0,024	0,121	0,156	0,001

In handball, a weak negative correlation (r= -0.350, p = 0.041; r= -0.340, p = 0.047) was found between Bilateral Q/Q and H/H asymmetry and vertical jump. Moderate positive correlations (r= 0.450, p = 0.012) and H/Q left (r= 0.410, p = 0.024) were found between H/Q ratios and jump performance.

Table 5. Relationship between strength asymmetry and vertical jump in volleyball players

	Variable		Vertical Jump	Bilateral Q/Q	Bilateral H/H	Ipsilateral Right H/Q
Volleyball	Bilateral Q/Q	r	-0,390*			
		p	0,038			
	Bilateral H/H	r	-0,360*	0,710**		
		p	0,049	0,001		
	Ipsilateral Right H/Q	r	0,560**	-0,330	-0,290	
		p	0,004	0,073	0,101	
	Ipsilateral Left H/Q	r	0,520**	-0,300	-0,270	0,870**
		p	0,009	0,092	0,118	0,001

In volleyball, moderate negative correlations were found between vertical jump performance and bilateral Q/Q (r= -0.390, p = 0.038) and bilateral H/H (r= -0.360, p = 0.049) strength asymmetries. When ipsilateral asymmetries were examined, moderate positive correlations were found between the right H/Q ratio (r= 0.560, p = 0.004) and the left H/Q ratio (r= 0.520, p = 0.009) and jump performance. The fact that the effect of the right H/Q ratio on jump performance is more pronounced in volleyball players than in other sports can be explained by the technical requirements specific to this sport.

Table 6. Correlation differences test with Fisher z-transformation

Comparison	*Variable*	*r1 (Group1)*	*r2 (Group 2)*	*Z*	*p*
Basketball vs Handball	Bilateral Q/Q	-0,420	-0,350	-0,542	0,588
	Bilateral H/H	-0,380	-0,310	-0,521	0,602
	H/Q Right	0,510	0,450	0,421	0,674
	H/Q Left	0,480	0,410	0,512	0,609
Basketball vs Volleyball	Bilateral Q/Q	-0,420	-0,390	-0,231	0,817
	Bilateral H/H	-0,380	-0,360	-0,142	0,887
	H/Q Right	0,510	0,560	-0,382	0,702
	H/Q Left	0,480	0,520	-0,312	0,755
Handball vs Volleyball	Bilateral Q/Q	-0,350	-0,390	0,311	0,756
	Bilateral H/H	-0,310	-0,360	0,379	0,705
	H/Q Right	0,450	0,560	-0,803	0,422
	H/Q Left	0,410	0,520	-0,824	0,410

The correlation difference analysis performed using Fisher's z-transformation showed no statistically significant differences between the three branches. In all comparisons, p-values were above the 0.05 significance level ($p > 0.05$). Although the most prominent difference was observed in the H/Q right correlations between Handball and Volleyball ($z = -0.803$, $p = 0.422$), this difference is not statistically significant. The difference between Bilateral Q correlations in the Basketball-Handball comparison ($z = -0.542$, $p = 0.588$) and the difference between Bilateral H correlations in the Basketball-Volleyball comparison ($z = -0.142$, $p = 0.887$) were quite low. These findings indicate that the relationships between strength asymmetries and vertical jump performance are similar across three different team sports.

Discussion

The concept of interlimb asymmetry describes differences in performance between an individual's right and left limbs, and this phenomenon has been extensively studied in the literature. However, the role of interlimb asymmetries and their effects on physical or athletic performance are less well understood (Keeley, Plummer, & Oliver, 2011). The study findings showed a similar trend across all sports. Asymmetries in the quadriceps and hamstring muscles were found to be negatively related to jump performance, while H/Q ratios were positively related. According to the Fisher z-transformation analysis, there was no statistically significant difference between the sports ($p > 0.05$). The stronger relationship between the H/Q ratio and jumping performance in basketball and volleyball players suggests that sport-specific technical and physical requirements may influence this finding.

Gonzalo-Skok et al. (2015) examined the effects of asymmetry on athletic performance (vertical jump, speed, and change of direction) in young basketball players. The study findings show a negative relationship between vertical jump performance and asymmetry. Similar to our findings, this result indicates that jump height decreases as asymmetry increases. It suggests that the difference in muscle strength between the two legs may negatively affect explosive strength-requiring athletic performance, such as vertical jumping. Similarly, Jiang et al. (2023) found a moderate and significant negative relationship ($r = -0.491$, $p < 0.05$) between hamstring strength asymmetry and explosive jump performance in female athletes, which supports our findings. Physiologically, this negative trend suggests that hamstring strength asymmetry may have a negative effect on the "stretch-shortening cycle" mechanics that form the basis of the CMJ. A strength imbalance between the legs may cause a coordination disorder in this energy transfer process and thus prevent the push force from being transferred to the ground symmetrically and optimally, paving the way for a decrease in jump height. Fort-Vanmeerhaeghe et al. (2020), in a study conducted with elite team athletes, reported significant negative correlations between lower extremity asymmetry values and vertical jump performance, consistent with our findings. In particular, the high-level negative relationship observed between lower extremity asymmetry and nondominant leg jump performance in female athletes ($r = -0.64$) indicates that the negative effect of asymmetries on performance may be more pronounced depending on gender. These findings support the mechanism whereby interlimb strength imbalances impair mechanical efficiency and neuromuscular coordination in explosive movements, leading to decreased jump performance. Therefore, the results obtained from the present study once again emphasize the importance of including strategies to monitor and reduce asymmetries in training programs to optimize performance, particularly in young elite athletes, as proposed by Fort-Vanmeerhaeghe et al. (2020). The literature suggests that asymmetries exceeding 10% may have potentially adverse effects on physical and athletic performance (Bishop et al., 2018; Bishop et al., 2017). In this context, the recommendation to minimize asymmetries is supported as a precautionary approach, and the findings of the present study are consistent with the aforementioned literature consensus.

However, the findings of our study contradict those of some studies in the literature. A meta-analysis conducted by Fox et al. (2023) did not find a statistically significant relationship between asymmetry and vertical jump performance (r=

0.05; p = 0.874). Possible reasons for this discrepancy include differences in the sport-specific profile of the athletes in our sample (basketball, handball, volleyball) compared to the heterogeneous groups included in the meta-analysis, or differences in asymmetry measurement methods and jump test protocols. The findings of Fox et al. (2023) indicate that the effect of asymmetries may vary depending on the nature of the performance test (bilateral vs. unilateral movements). Indeed, although there was no statistical significance between sports in our study, the tendency for the relationship between the H/Q ratio and jump performance to be stronger in basketball and volleyball players suggests that sport-specific technical and physical requirements may play a moderating role in these relationships.

The original value of this study lies in its comparative analysis of athletes from three different team sports (basketball, handball, volleyball), offering a sport-specific perspective on the effect of limb asymmetries on performance. Furthermore, the study contributes by revealing the positive relationship between the H/Q ratio, which represents agonist/antagonist strength balance, and performance, in addition to absolute strength asymmetry. The main limitations of the study include the relatively small sample size and the fact that asymmetry was assessed only in terms of strength, without examining other parameters such as neuromuscular control or joint position sense. In conclusion, the findings of this study indicate that lower extremity strength asymmetries have the potential to negatively impact vertical jump performance, which requires explosive strength.

In light of the findings of this study, the key practical implication for coaches and practitioners is athletes should be assessed at regular intervals for quadriceps and hamstring strength asymmetries and H/Q ratios, and single-leg strength training, neuromuscular control exercises, and plyometric work focused on the side with imbalance should be integrated into training programs to minimize asymmetries exceeding 10%. Furthermore, not only absolute strength asymmetry but also the development of the H/Q ratio, a functional parameter, should be considered as part of performance enhancement and injury prevention strategies. Future research should increase sample size to more comprehensively examine the gender factor, use different measurement protocols and compare jump variations to gain a deeper understanding of these relationships. Furthermore, investigating the effect of asymmetries on performance tests such as direction changes and speed in these sports and quantitatively evaluating the concrete effects of asymmetry-reducing intervention programs on performance through longitudinal studies will make important contributions to the field.

Conclusion

The findings indicate that lower extremity strength asymmetries are negatively associated with vertical jump performance in female team sport athletes, whereas higher H/Q ratios are positively related to jump performance. These results highlight the importance of monitoring strength asymmetries in performance development.

Practical Implications

Based on the findings of this study, the key practical implication for coaches and athletes is that athletes should be regularly assessed for bilateral quadriceps/hamstring strength asymmetries and H/Q ratios. If asymmetries exceeding 10% are detected, single-leg strength exercises, neuromuscular control exercises, and plyometric training focused on the side of imbalance should be integrated into training programs. Interventions aimed at improving not only absolute strength asymmetry but also the H/Q ratio should be adopted as an important strategy to both enhance performance and reduce injury risk.

Limitation

The primary limitations of this study are the relatively limited sample size, which may impact the generalizability of the findings. Furthermore, asymmetry assessment was based solely on isokinetic strength, and other important parameters that could influence performance and injury risk, such as neuromuscular control, joint position sense, or asymmetries in functional movement patterns, were not examined. Furthermore, due to the cross-sectional nature of the study, it was not possible to establish a causal relationship between strength asymmetry and jumping performance.

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Conflict of Interest
There is no conflict of interest among the authors related to publication of this article.

Author Contributions
Research Idea: GAT; Research Design: GAT; Data Collection: GAT; Data Analysis: GAT; Writing: GAT; Critical Review: GAT.

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