

Original Research

Strength, Agility, and Cardiorespiratory Fitness in Elite Male Futsal Players

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Keywords: Functional strength, muscle imbalance, agility, dynamic balance, futsal

<https://doi.org/10.26603/001c.144051>

International Journal of Sports Physical Therapy

Vol. 20, Issue 10, 2025

Background

Characterized by intense efforts and rapid changes of direction, futsal performance relies on strength, agility and dynamic balance. Isokinetic testing evaluates neuromuscular strength and asymmetry, providing insights into their relationships with functional strength, aerobic capacity and performance outcomes for elite players.

Objective

This study examined the relationships between lower-limb isokinetic strength and key performance measures, including functional strength (3RM leg extension and leg curl), maximal oxygen uptake, agility and balance, as well as isokinetic asymmetry indices and performance-related asymmetry variables in elite male Vietnamese futsal players.

Study Design

Observation cohort study

Methods

Eighteen elite male futsal players (20.8 ± 3.2 years) were underwent isokinetic strength testing of the hip flexion/extension ($45^\circ \cdot s^{-1}$), knee ($60^\circ \cdot s^{-1}$) and ankle plantar /dorsi flexion ($60^\circ \cdot s^{-1}$), along with 3RM tests for leg extension and leg curl, maximal oxygen uptake (yoyo IR-1 test), agility (arrowhead agility test), and the Y- Balance Test for neuromuscular control/balance. The Pearson product-moment correlation analysis was employed to investigate the correlations among these variables.

Results

Significant positive correlations were found between knee flexor asymmetry index and 3RM leg extension ($r = 0.66$, $p < 0.01$) and leg curl ($r = 0.59$, $p < 0.01$). A negative association was found between 3RM asymmetry index and hip flexor peak torque in dominant ($r = -0.57$, $p < 0.05$) and non-dominant limbs ($r = -0.52$, $p < 0.05$) and knee extensor peak torque in non-dominant limb ($r = 0.50$, $p < 0.05$). Lower limb isokinetic asymmetry index and its associated asymmetry index was found between the knee flexors and arrowhead agility ($r = -0.53$, $p < 0.05$).

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Conclusion

The findings indicate that interlimb strength asymmetries, especially at the knee, correlate with functional strength outcomes in elite male futsal players, potentially guiding future strategies for monitoring and addressing muscular imbalances to enhance performance and potentially reduce injuries.

Level of Evidence

3b

INTRODUCTION

Futsal is a high-intensity team sport marked by frequent short bursts of effort and rapid directional changes. To perform at high level during training and competition, players must possess a combination of physical, neuromuscular, physiological, technical, and tactical abilities.¹⁻³ Due to the sport's demanding nature, especially the repeated execution of sprints and agility-based actions, neuromuscular strength, power, speed, and coordination are essential for optimal performance.^{2,4,5}

In the physiological context, aerobic capacity plays a key role, especially in elite-level competition, where approximately 80 % of maximal oxygen uptake ($\dot{V}O_{2max}$) may be required.³ Likewise, lower limb strength is critical, as it directly influences an athlete's ability to generate explosive force, maintain balance, and perform complex technical movements.^{1,5-7} Therefore, neuromuscular strength and power are increasingly recognized as central attributes for enhancing performance and reducing injury risk in futsal.⁸

From a neuromuscular standpoint, lower limb strength, power, agility, and dynamic balance are linked components that collectively support physical performance in the sport. Previous authors have shown remarkable associations between strength and sprinting, jumping, and change of direction (COD) ability.^{1,7,9-11} Strength has also been linked to enhancements in both static and dynamic balance.¹² However, there remains a lack of clarity regarding how these qualities interact, particularly in the elite-level futsal context.

The strength qualities of futsal players have been widely investigated using isokinetic dynamometry, which measures variables such as peak torque,¹³⁻¹⁵ hamstring-to-quadriceps (H/Q) ratios,¹⁵ unilateral and bilateral strength asymmetry indices.^{16,17} In addition, one-repetition maximal performance in the half-squat exercise has been examined as a complement measure of functional lower-limb strength.¹⁸ Futsal performance of elite players is highly connected to the ability to sustain high levels of strength and power during a match. Additionally, the three-repetition maximum (3RM) test (approximately 93 % of 1RM) is considered an interesting functional measure of strength, as it involves lifting a substantial load for multiple repetitions.¹⁹

Although recent studies highlight the link between various determinants of lower limb neuromuscular performance, there remains a lack of research examining the interrelationships among these parameters in high-performance athletes, particularly elite male futsal

players. Therefore, this study aims to examine the relationships between lower-limb isokinetic strength and key performance measures, including functional strength (3RM leg extension and leg curl), maximal oxygen uptake ($\dot{V}O_{2max}$), agility and balance, as well as isokinetic asymmetry indices and performance-related asymmetry variables in elite male Vietnamese futsal players. A deeper understanding of these factors and their interactions could inform training strategies designed to enhance futsal performance and reduce the risk of injury. It was hypothesized that greater neuromuscular and functional strength in the lower limbs is associated with improved change of direction ability and dynamic balance in elite male futsal players.

METHODS

STUDY DESIGN

A single cohort study was conducted to evaluate the relationship among neuromuscular strength characteristics of the lower limbs at the hip, knee, and ankle joints, employing an isokinetic dynamometer, and functional strength assessed through the three-repetition maximum (3RM) leg extension and leg curl, maximal oxygen uptake (YO-YO IR1 test), the arrowhead agility test (AAT), and the Y-Balance Test (YBT). In order to eliminate any residual fatigue, the tests were conducted two weeks before the first match of the National Futsal League season. Furthermore, the participants were familiarized with the tests, which were administered at the same time of day to avoid systematic bias due to circadian variation. Following a standardized order, 18 elite male futsal players from the same professional futsal club competing in the Vietnamese National League completed the tests within a five consecutive days period: Day one: anthropometric and the lower limb dynamic YBT; Day two: isokinetic muscle strength; Day three: 3RM leg extension, leg curl; Day four: the AAT; Day five: YO-YO intermittent recovery test.

PARTICIPANTS

The software G*Power 3.1.9.2 was used to do an a priori power analysis in order to calculate the sample size. Preliminary assumptions included a Type I error rate of 5 % and a Type II error rate of 5 % (or 95 % power). Based on these calculations, a minimum sample size of $n = 13$ was required to achieve a power of 0.95, an error probability of 0.05, and a high effect size of 0.70. Eighteen elite male futsal players from the same professional futsal club competing in the Vietnamese National League, of which five

were regular members of the national futsal squad, volunteered as subjects. The following determined inclusion: (i) had at least three years of national competition experience, (ii) qualified for the national futsal league team, and (iii) was injury-free for six months. Players with inappropriate health status or any medical conditions that could affect performance or test participation were excluded from the study. The study satisfied the World Medical Association's Declaration of Helsinki at the local University Ethics Committee.

EXPERIMENTAL PROCEDURES

ANTHROPOMETRIC MEASUREMENTS

Anthropometric measurements including body mass, stature, and body mass index, were obtained utilizing the Body Composition Analyzer: X-CONTACT 357S (Jawon Medical Co., Ltd., South Korea), in accordance with the endorsement from the International Society for the Advancement of Kinanthropometry.²⁰

MAXIMAL OXYGEN UPTAKE ($\dot{V}O_{2\text{MAX}}$)

The YO-YO IR1 was used to estimate maximal oxygen uptake ($\dot{V}O_{2\text{max}}$).^{20,21} The test comprised two sets of 20 m shuttle runs at an incrementally increased pace regulated by an audible metronome. The testing terminated when the players failed to sustain the required speed twice to reach the finish line on time.²¹ The distance covered at that point was recorded and further considered to estimate $\dot{V}O_{2\text{max}}$ using the equation previously provided by Krusturp et al.²² Verbal encouragement was continuously provided throughout the tests.

THE LOWER LIMB DYNAMIC Y-BALANCE TEST

The lower limb dynamic YBT was performed using standardized methods using the YBT Kit.²³ After practice trials, the first test trial assessed the distance from the YBT apex of the most proximal reach indication as participants moved anterior (ANT), posteromedial (PM), and posterolateral (PL).²⁴ For normalization, participants' supine lower-limb lengths were bilaterally measured to the nearest half centimeter from the anterior superior iliac spine to the ipsilateral medial malleolus. Furthermore, the subsequent formula was employed to compute the YBT test asymmetries for each direction, defining the dominant (D) limb (the limb exhibiting greater functional performance) and the non-dominant (ND) limb^{16,17}:

$$\text{Asymmetry index} = (D-ND)/D \times 100$$

THE ARROWHEAD AGILITY TEST

The change of directional performance was assessed through the AAT.²⁵ utilizing the kinematic measuring system (KMS) infrared timed light system integrated into compatible computer software (Fitness Technologies, Adelaide, Australia). The participants were required to sprint and change direction at a maximum speed during the test, en-

suring that they did not step over or around the markers. If the participants failed to comply, the trial stopped and re-attempted after a complete recovery, which took approximately three minutes. The AAT results encompassed the fastest and slowest timings between sides, with the sum times of both sides retained for further investigation.²⁵ The change of direction asymmetry index was computed as the percentage difference between the fastest and slowest timings, utilizing the formula established by Impellizzeri et al.¹⁶

3RM LEG EXTENSION AND LEG CURL TEST

Estimated one-repetition maximum (1RM) before assessing functional strength through the three-repetition maximum (3RM) leg extension and leg curl using the leg extension and leg curl machine (Technogym BV, Rotterdam, The Netherlands). Following a two to five minute rest interval, a set of 3 repetitions was executed at 60 – 90 % of the estimated one-repetition maximum (1RM), continuing until a three-repetition maximum (3RM) was attained.^{19,26} The bilateral strength asymmetry index was calculated as the percentage difference between leg extension and leg flexion, employing an equation established by Impellizzeri et al.¹⁶

LOWER LIMB ISOKINETIC STRENGTH TEST

All isokinetic assessments were performed individually for each leg using a Biodex System 4-PRO® (Biodex Medical Systems Inc., Shirley, NY) dynamometer to determine the peak torque of the hip flexors and extensors at a slow angular velocity of 45 deg.s⁻¹,²⁷ as well as the peak torques for knee flexion and extension at 60 deg.s⁻¹,^{15,27} and for ankle plantar and dorsiflexion at 60 deg.s⁻¹.²⁸ The hamstring to quadriceps strength ratio (H/Q ratio), associated with knee function prediction and muscle strength imbalance, was employed to examine bilateral and unilateral strength asymmetries.^{15,27} The unilateral strength asymmetry index for the hip, knee, and ankle joints was calculated as the percentage difference between the dominant limb and the non-dominant limb, where the dominant (D) limb is defined as the limb exhibiting greater peak torque, and the non-dominant (ND) limb: asymmetry index = (D-ND)/D × 100.^{16,17}

STATISTICAL ANALYSIS

The normality of the distribution was assessed using the Shapiro-Wilk test. Descriptive analysis obtained the mean and standard deviation (SD) for all variables. Absolute reliability was assessed by calculating the coefficient of variation (CV) and reported as follows: poor > 10%, moderate 5–10 %, or good < 5 %.²⁹ Network plots were used to explore the correlation patterns by visual inspection. Subsequently, Pearson's correlation coefficients was computed to analyzed the associations among absolute and asymmetry index of lower limbs neuromuscular isokinetic strength and functional strength of the three-repetition maximum (3RM) leg extension and leg curl, maximal oxygen uptake ($\dot{V}O_{2\text{max}}$), agility, and dynamic balance. The magnitude of

associations was reported as follows: trivial $r < 0.1$, small $0.1 < r < 0.3$, moderate $0.3 < r < 0.5$, large $0.5 < r < 0.7$, very large $0.7 < r < 0.9$, $0.9 < r < 1.0$, nearly perfect.³⁰ The alpha level for evaluation of statistical significance was set at $p < 0.05$. All analyses were conducted in SPSS Statistics for Windows Version 24.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Eighteen elite male futsal players from the same professional club in the Vietnamese National League, with a mean age of 20.8 ± 3.2 years, height of 1.69 ± 4.2 m and body mass of 59.8 ± 6.4 kg, participated in the study. The descriptive statistics for all variables are presented in [Table 1](#). Good absolute reliability (CV) was found in the maximum oxygen consumption ($\dot{V}O_{2max}$) and the arrowhead agility test performance in each direction and asymmetry index (CV=1.48–4.21). Good to moderate absolute reliability were found in the functional strength of 3 RM leg extension, leg curl and asymmetry index, and the absolute values of hip and knee extensors (CV=3.95–5.81), respectively. On the other hand, the unilateral strength asymmetry index of the hip, knee, and ankle joints in both flexors and extensors movements, dominant and non-dominant H/Q ratio and lower limb dynamic YBT depicted poor reliability (CV=20.24 – 78.59), highlighting very high variability in the selected performance.

[Table 2](#) depicts the correlations between lower limb isokinetic strength and its associated factors and performance measures. The knee flexors ASI presented positive large correlations with the 3 RM functional strength of leg extension ($r=0.66$, $p<0.01$), leg curl ($r=0.59$, $p<0.01$) and negative large correlations with the AAT_ASI ($r=-0.53$, $p<0.05$). A large negative association was identified between ankle dorsiflexion peak torque in the dominant limb and 3RM leg curl ($r=-0.53$, $p<0.05$), with a moderate negative association between ankle dorsiflexion peak torque in the non-dominant limb and 3RM leg extension ($r=-0.49$, $p<0.05$). The ASI of 3 RM functional strength exhibited a substantial large negative correlation with the dominant limb of the hip flexors peak torque ($r=-0.57$, $p<0.05$), a large negative correlation with the non-dominant limb of the hip flexors peak torque ($r=-0.52$, $p<0.05$), and a moderate positive correlation with the non-dominant limb of the knee extensors peak torque ($r=0.50$, $p<0.05$), respectively. The AAT presented positive large correlations with the dominant limb of the knee flexors peak torque ($r=0.52$, $p<0.05$) and negative large correlations with ankle dorsiflexion peak torque in the dominant limb ($r=-0.57$, $p<0.01$).

The correlation results between the lower limb isokinetic asymmetry index and its associated asymmetry index of 3 RM functional strength, lower limb dynamic balance, and directional change performance revealed a large negative correlation only between the knee flexors ASI and the AAT_ASI ($r=-0.53$, $p<0.05$).

DISCUSSION

This study examined the correlation between essential neuromuscular strength characteristics of the lower limbs, as measured by isokinetic dynamometry, three-repetition maximum (3RM) leg extension and leg curl, maximal oxygen uptake ($\dot{V}O_{2max}$), agility, and dynamic balance of lower limb in elite male Vietnamese futsal players. Furthermore, the correlation results between the lower limb isokinetic asymmetry index and its corresponding asymmetry index of 3 RM functional strength (leg extension, leg curl), change of directional performance (arrowhead agility) and dynamic balance of the lower limbs (YBT) were evaluated.

Overall, knee flexor asymmetry index (ASI) demonstrated large positive correlations with 3 RM functional strength in both leg extension and leg curl, while exhibiting a negative correlation with the AAT asymmetry index. Nevertheless, most of the lower limb isokinetic asymmetry index, H/Q ratio, and its associated asymmetry index of 3 RM functional strength did not exhibit a correlation with lower limb dynamic balance and directional change performance. Additionally, no correlations were identified between the lower limb isokinetic and 3 RM functional strength, aerobic performance and lower limb dynamic balance. Consequently, the hypothesis was partially validated. Specifically, these results could provide significant insights into the relationship among strength, asymmetry, and dynamic performance, possibly informing future training and evaluation strategies in sports and rehabilitation scenarios.

Upon considering the descriptive statistics and coefficient of variation for all performance indicators, moderate to good absolute reliability was noted in maximum oxygen consumption, arrowhead agility performance across all directions, asymmetry index, functional strength of the 3 RM leg extension and leg curl, as well as the asymmetry index for hip and knee extensors, highlighting the reliability of these evaluations. However, the study identified poor reliability in the unilateral strength asymmetry indices for the hip, knee, and ankle joints, as well as the dominant and non-dominant hamstring/quadriceps (H/Q) ratios and the YBT. These findings suggesting that unilateral strength assessments, particularly for asymmetry indices, can be highly variable due to differences in limb dominance, muscle flexibility, and dynamic balance, leading to a higher degree of inconsistency across trials.^{17,31}

Regarding the isokinetic profiling, the present study reported consistent with the results in elite Brazilian futsal players for dominant and non-dominant knee peak torque concentric in extensors (214.7 – 216.5 vs 217.1 – 201.6 Nm)¹⁵ but lower than the result from professional Brazilian futsal players (224.0 – 223.9 Nm).¹³ The concentric knee peak torque of the flexors (105.2 – 97.3 Nm) was lower than that shown in previous studies on Brazilian futsal players (136.6 – 135.8 Nm)¹⁵ and professional futsal players (128.6 – 124.1 Nm), professional soccer players (131.1 – 127.6 Nm) and, professional beach soccer players (140.5–132.6 Nm), respectively.³ Furthermore, the current study revealed a higher unilateral strength asymmetry index for the knee extensors (6.99 %) and knee flexors (7.74 %) compared to

Table 1. Results of descriptive statistics and coefficient of variation for all performance measures.

Outcome variables	Mean±SD	95% CI	CV (%)
$\dot{V}O_{2\max}$ (ml·min ⁻¹ ·kg ⁻¹)	52.66 ± 0.13	(51.55–53.76)	4.21
3RM Leg extension (kg)	115.03 ± 4.54	(112.77–117.29)	3.95
3RM Leg curl (kg)	66.39 ± 4.79	(64.01–68.77)	7.22
3RM ASI (%)	42.31 ± 2.89	(40.88–43.75)	6.83
Hip extensors dominant PT 45 deg·s ⁻¹ (Nm)	153.10 ± 13.08	(146.60–159.61)	8.54
Hip extensors non-dominant PT 45 deg·s ⁻¹ (Nm)	137.57 ± 9.97	(132.62–142.53)	7.25
Hip extensor ASI 45 deg·s ⁻¹ (%)	9.77 ± 6.98	(6.30–13.24)	71.44
Hip flexors dominant PT 45 deg·s ⁻¹ (Nm)	116.99 ± 12.65	(110.70–123.28)	10.81
Hip flexors non-dominant PT 45 deg·s ⁻¹ (Nm)	103.91 ± 11.19	(98.34–109.47)	10.77
Hip flexors ASI 45 deg·s ⁻¹ (%)	10.88 ± 7.05	(7.37–14.39)	64.81
Knee extensors dominant PT 60 deg·s ⁻¹ (Nm)	217.05 ± 18.39	(207.91–226.19)	8.47
Knee extensors non-dominant PT 60 deg·s ⁻¹ (Nm)	201.58 ± 17.21	(193.02–210.14)	8.54
Knee extensor ASI 60 deg·s ⁻¹ (%)	6.99 ± 5.18	(4.41–9.57)	74.13
Knee flexors dominant PT 60 deg·s ⁻¹ (Nm)	105.22 ± 8.22	(101.13–109.30)	7.81
Knee flexors non-dominant PT 60 deg·s ⁻¹ (Nm)	97.03 ± 9.52	(92.30–101.77)	9.81
Knee flexors ASI 60 deg·s ⁻¹ (%)	7.74 ± 6.01	(4.71–10.76)	78.59
Dominant H/Q ratio 60 deg·s ⁻¹	0.45 ± 0.10	(0.40–0.50)	22.46
Non-dominant H/Q ratio 60 deg·s ⁻¹	0.40 ± 0.08	(0.36–0.44)	20.24
Ankle plantar flexion dominant PT 60 deg·s ⁻¹ (Nm)	85.09 ± 6.45	(81.89–88.30)	7.58
Ankle plantar flexion non-dominant PT 60 deg·s ⁻¹ (Nm)	72.37 ± 7.38	(68.70–76.04)	10.19
Ankle plantar flexion non-dominant ASI 60 deg·s ⁻¹ (%)	14.56 ± 10.16	(9.50–19.61)	69.78
Ankle dorsi flexion dominant PT 60 deg·s ⁻¹ (Nm)	31.58 ± 4.26	(29.46–33.70)	13.49
Ankle dorsi flexion non-dominant PT 60 deg·s ⁻¹ (Nm)	26.07 ± 4.93	(23.61–28.52)	18.92
Ankle dorsi flexion non-dominant ASI 60 deg·s ⁻¹ (%)	17.39 ± 12.75	(11.05–23.73)	73.30
Y-balance anterior ASI (%)	5.11 ± 2.42	(3.90–6.31)	47.33
Y-balance posteromedial ASI (%)	4.77 ± 1.95	(3.80–5.74)	40.89
Y-balance posterolateral ASI (%)	5.31 ± 2.48	(4.08–6.55)	46.66
Fastest arrowhead agility performance (s)	8.09 ± 0.25	(7.96–8.21)	1.49
Slowest arrowhead agility performance (s)	8.33 ± 0.12	(8.27–8.39)	3.14
Sum of arrowhead agility performance (s)	16.41 ± 0.32	(16.26–16.57)	1.95
ASI of arrowhead agility performance (%)	12.01 ± 0.18	(11.92–12.10)	1.48

SD—standard deviation; 95%CI—confidence interval for each mean parameter estimate; CV—the mean coefficient of variation; RM—repetitive maximum; ASI—asymmetry index; PT—peak torque; * $p < 0.05$; ** $p < 0.01$

the previously data obtained in elite Brazilian futsal players (2.5 vs. -1.40 %).¹⁵

Regarding the hamstring to quadriceps (H/Q) strength ratio, mean H/Q ratio values for dominant and non-dominant limbs in elite male Vietnamese futsal players (40–45 %) were lower than those found by Lira et al.¹³ in professional Brazilian futsal players (55–57 %), soccer players (53 %) beach soccer players (53–56 %) and even sub-elite Spanish female futsal players (50 %),³² respectively. The findings reported may suggest that the lower H/Q ratio which has been traditionally associated with a higher incidence of the lower limb injuries and it also may affect sport performance.^{13,33} Additionally, the variation in H/Q ratios may be attributed to variances in the training and muscle development of futsal players, with elite and professional players typically benefiting from a more holistic approach to developing both the quadriceps and hamstrings.^{3,13,33}

However, it is important to note that recent research has questioned the predictive value of muscle strength specifically hamstring strength and H/Q ratio for injury occurrence. For instance, the evidences suggests that muscle strength alone is not a consistent or sufficient predictor of injury risk.^{34,35} Thus, while H/Q ratio remains a relevant performance metric, its role in injury prevention should be considered in the context of multifactorial risk models that include neuromuscular control, fatigue, movement quality, and training [load.As](#) emphasized by Bahr,³⁶ screening should be used to guide individualized training, rehabilitation, and injury reduction strategies, enabling practitioners to tailor interventions based on an athlete's specific profile rather than relying on universal thresholds or normative cutoffs. Beside, future integrative approaches to athlete assessment and performance enhancement should incorporate not only biomechanical and neuromuscular param-

Table 2. Results of correlations between lower limb isokinetic strength and its related variables and performance measures.

Performance measures	3 RM functional strength			$\dot{V}O_{2max}$	ANT_ASI	PM_ASI	PL_ASI	AAT	AAT_ASI
	Leg Extension	Leg Curl	ASI						
Hip extensors dominant PT 45 deg·s ⁻¹ (Nm)	-0.04	-0.02	-0.01	0.13	-0.02	-0.00	0.13	0.13	0.27
Hip extensors non-dominant PT 45 deg·s ⁻¹ (Nm)	0.16	-0.06	0.21	0.20	0.22	0.24	0.37	0.14	0.06
Hip extensor ASI 45 deg·s ⁻¹ (%)	-0.20	0.02	-0.19	-0.01	-0.22	-0.22	-0.19	0.05	0.24
Hip flexors dominant PT 45 deg·s ⁻¹ (Nm)	0.06	0.42	-0.57*	0.17	0.24	0.15	0.31	0.31	-0.19
Hip flexors non-dominant PT 45 deg·s ⁻¹ (Nm)	-0.10	0.30	-0.52*	0.13	0.22	0.17	0.24	0.25	0.07
Hip flexors ASI 45 deg·s ⁻¹ (%)	0.24	0.20	-0.10	0.10	0.24	-0.02	0.19	0.13	-0.38
Knee extensors dominant PT 60 deg·s ⁻¹ (Nm)	-0.07	-0.34	0.43	0.09	-0.07	0.12	-0.07	0.10	-0.24
Knee extensors non-dominant PT 60 deg·s ⁻¹ (Nm)	-0.08	-0.41	0.50*	0.19	-0.11	0.05	-0.14	0.13	-0.20
Knee extensor ASI 60 deg·s ⁻¹ (%)	-0.00	0.11	-0.15	-0.13	0.08	0.12	0.11	-0.04	-0.03
Knee flexors dominant PT 60 deg·s ⁻¹ (Nm)	0.24	0.36	-0.34	-0.05	0.16	0.26	0.19	0.52*	-0.07
Knee flexors non-dominant PT 60 deg·s ⁻¹ (Nm)	-0.24	-0.11	-0.05	0.06	0.13	0.15	0.23	0.16	0.29
Knee flexors ASI 60 deg·s ⁻¹ (%)	0.66**	0.59**	-0.32	-0.14	-0.02	0.08	-0.13	0.41	-0.53*
Dominant H/Q ratio 60 deg·s ⁻¹	-0.23	0.29	-0.27	0.32	-0.02	-0.06	0.02	-0.09	-0.11
Non-dominant H/Q ratio 60 deg·s ⁻¹	-0.09	-0.05	-0.13	-0.09	0.06	-0.01	0.22	0.13	-0.04
Ankle plantar flexion dominant PT 60 deg·s ⁻¹ (Nm)	0.17	0.29	-0.27	0.29	-0.02	0.04	-0.03	-0.09	-0.02
Ankle plantar flexion non-dominant PT 60 deg·s ⁻¹ (Nm)	-0.26	-0.05	-0.13	-0.04	0.04	0.12	0.14	-0.11	-0.20
Ankle plantar flexion non-dominant ASI 60 deg·s ⁻¹ (%)	0.31	0.22	-0.01	0.23	-0.06	-0.10	-0.15	0.04	0.16
Ankle dorsi flexion dominant PT 60 deg·s ⁻¹ (Nm)	-0.23	-0.53*	0.26	-0.33	-0.08	-0.09	0.02	-0.57*	0.37
Ankle dorsi flexion non-dominant PT 60 deg·s ⁻¹ (Nm)	-0.49*	0.44	0.36	-0.01	0.12	0.07	0.22	-0.38	0.44
Ankle dorsi flexion non-dominant ASI 60 deg·s ⁻¹ (%)	0.44	0.07	-0.27	-0.27	-0.27	-0.20	-0.31	-0.01	-0.25

PT—peak torque; 3RM—three repetitive maximum; $\dot{V}O_{2max}$ —maximum oxygen consumption; ASI—asymmetry index; ANT_ASI— anterior asymmetry index of YBT; PM_ASI—posteromedial asymmetry index of YBT; PL_ASI— posterolateral asymmetry index of YBT; AAT— sum of the arrowhead agility test; AAT_ASI — asymmetry index of arrowhead agility test * p < 0.05; ** p < 0.01.

Table 3. Results of correlations between lower limb isokinetic asymmetry index and its related asymmetry index variables.

Lower limb isokinetic asymmetry	Asymmetry index (ASI)				
	3 RM	ANT	PM	PL	AAT
Hip extensors ASI 45 deg·s ⁻¹ (%)	-0.19	-0.22	-0.22	-0.19	0.24
Hip flexors ASI 45 deg·s ⁻¹ (%)	-0.10	0.04	-0.02	0.12	-0.38
Knee extensors ASI 60 deg·s ⁻¹ (%)	-0.15	0.08	0.12	0.11	-0.03
Knee flexors ASI 60 deg·s ⁻¹ (%)	-0.32	-0.02	0.08	-0.13	-0.53*
Dominant H/Q ratio 60 deg·s ⁻¹	-0.05	-0.06	-0.06	-0.02	-0.11
Non-dominant H/Q ratio 60 deg·s ⁻¹	-0.14	-0.05	-0.01	0.22	-0.04
Ankle plantar flexion non-dominant ASI 60 deg·s ⁻¹ (%)	-0.06	-0.06	-0.10	-0.15	0.16
Ankle dorsi flexion non-dominant ASI 60 deg·s ⁻¹ (%)	-0.28	-0.27	-0.20	-0.31	-0.25

ASI—asymmetry index; ANT— anterior asymmetry index of YBT; PM—posteromedial asymmetry index of YBT; PL— posterolateral asymmetry index of YBT; AAT— asymmetry index of arrowhead agility test * $p < 0.05$; ** $p < 0.01$

ters, but also neurocognitive components—such as reaction time, decision-making, and visual-motor processing which are increasingly recognized as critical determinants of both athletic performance and injury resilience.³⁷

It should be emphasized that the results of the present study suggest that the positive correlations between the knee flexor asymmetry index (ASI) and 3 RM functional strength in leg extension and leg curl exercises indicate that athletes with greater strength asymmetry in the hamstrings tend to possess higher functional strength in these lower limb exercises. This finding corroborates the idea that strength asymmetries may reflect an athlete's potential for maximal strength.^{13,19} An elevated asymmetry index indicates that one side (dominant or non-dominant) is considerably stronger than the other, potentially due to compensatory mechanisms affecting the development of functional strength.^{19,38} However, the lack of correlation between lower limb isokinetic asymmetry indices (including the H/Q ratio), 3 RM functional strength, and dynamic balance or directional change performance suggests that strength imbalances do may not impair dynamic performance.

From the perspective of lower-limb functional strength and performance, understanding the relationship between balance capacity and change-of-direction ability is essential for enhancing athletic performance, preventing injuries, and informing rehabilitation strategies, as both are fundamental to many different sports. The present findings indicate that imbalances in knee flexor strength are connected with coordination deficits in dynamic activities and may correlate with a reduced ability to generate efficient and symmetrical acceleration movements. This finding aligns with research suggesting that strength imbalances can affect movement efficiency and muscle coordination during dynamic tasks.^{38,39} The absence of associations between lower limb isokinetic strength asymmetry (including the H/Q ratio) and dynamic balance or directional change performance was unexpected. A possible explanation for this might be dynamic tasks that involve balance or rapid directional changes may not be affected by isokinetic strength, especially muscle asymmetry. These relationships

characteristics may partly be explained by the complex interactions of proprioception, joint stability, neuromuscular control, and movement style determine dynamic balance and agility directional changes.³⁸⁻⁴⁰

Importantly, the interpretation of asymmetries in elite athletes should be made with caution. Recent evidence from a systematic review has demonstrated that even in healthy individuals when evaluated using ACL return-to-sport test batteries—a side-to-side strength difference of up to 10% is considered normative.⁴¹ In this context, the asymmetry values observed in the current sample may reflect natural interlimb differences rather than dysfunction or injury risk. Therefore, while elevated asymmetry indices may correlate with strength capacity, they should not be universally viewed as detrimental. These findings highlight the necessity of contextualizing asymmetry thresholds within the specific demands of sports and individual performance profiles, particularly in elite players.

A significant finding, aligning with previous studies, is the lack of correlations between lower-limb isokinetic strength and 3RM functional strength with aerobic performance, underscoring the concept that strength and aerobic capacity interact as predominantly independent attributes.³⁶ The absence of correlation between strength and aerobic performance in this study is consistent with the findings of previous studies in professional soccer players that have shown that aerobic capacity does not necessarily correlate with strength, sprint, anaerobic, or jumping performance.³⁹ Therefore, it is reasonable to assume that aerobic capacity is influenced by different physiological mechanisms than those that determine maximal strength and strength imbalances.

Future research should consider a number of potential limitations that should be taken into account when interpreting the results. Firstly, the current study is constrained by a limited sample size due to restricted access to professional futsal players, necessitating validation in a larger cohort, despite many associations being notably robust. Secondly, the current study was conducted with only elite male futsal players. Therefore, the results are not easily generalizable to all levels of futsal players. To ensure that these re-

sults are comparable in a larger population, a similar study should be conducted with players of different levels of experience and performance (young-age futsal players, recreational, and international level players). Thirdly, it is important to note that this study exclusively involved elite male futsal players, which may not guarantee applicability to female players. Finally, a methodological limitation is the exclusive evaluation of muscle strength in the sagittal plane specifically flexion and extension movements while other significant muscle groups essential to multiplanar control, such as hip abduction/adduction and internal/external rotation, were not evaluated. Consequently, the contribution of these muscles to functional performance and potential injury mechanisms remains unknown within the context of this study.

CONCLUSION

The results of the present study demonstrate that while the knee flexors asymmetry index (ASI) correlates positively with functional strength, it does not have a direct association with lower limb dynamic balance, directional change, or aerobic performance. These findings indicate that strength asymmetries, while reflective of functional strength capacity, may not significantly influence performance in dynamic activities. However, the findings of this study suggest several practical implications for strength training and performance optimization in elite male futsal players. First, while strength imbalances, as indicated mainly by the knee flexors asymmetry index (ASI), may have a significant relationship with maximal functional strength, they do not appear to be directly related to per-

formance in dynamic tasks such as balance, agility, or aerobic endurance. Therefore, strength and conditioning coach and sports scientists may need to focus on a comprehensive training approach that includes not only strength but also motor control, agility, and endurance to improve overall elite male futsal players performance.

ACKNOWLEDGEMENTS

This work is supported by funding of the Danang Sport University, Vietnam. Phornpot Chainok and Rangarit Jamroen are founded by the faculty of Sport Science, Burapha University, Thailand under the project HS025/2567. Rodrigo Zacca is founded by the Research Center in Physical Activity, Health, and Leisure—CIAFEL—Faculty of Sports (FADEUP), University of Porto, Portuguese Foundation for Science and Technology (UIDB/00617/2020: doi: 10.54499/UIDB/00617/2020 and UIDP/00617/2020: doi: 10.54499/UIDP/00617/2020), and the Laboratory for Integrative and Translational Research in Population Health (ITR), Porto, Portugal (LA/P/0064/2020).

CONFLICT OF INTEREST

the authors declare no conflict of interests regarding the publication of this manuscript.

Submitted: April 29, 2025 CDT. Accepted: August 16, 2025

CDT. Published: October 01, 2025 CDT.

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