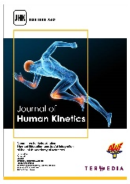

Relationship of Isometric Strength and Curve Sprint Performance in Female Soccer Players

by
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Sprint performance is critical in soccer, with most sprints following a curvilinear rather than a linear path. While isometric strength (IS) has been linked to linear sprint (LS) and change of direction (COD) performance, its relationship with curve sprint (CS) performance remains unclear. Hence, in this study, we analyzed the relationship between IS and CS performance in elite female soccer players. Nineteen elite female soccer players (age: 25.32 ± 4.18 years; body height: 167 ± 6.0 cm; body mass: 59.26 ± 5.34 kg; body fat percentage: 12.70 ± 2.18%) participated in a pre-season testing protocol. Following a standardized warm-up, players performed assessments of isometric hamstring strength (ISO), the isometric mid-thigh pull (IMTP), and CS performance. IS was measured using a portable force plate, which is the gold standard for such assessments. Pearson correlation analysis examined the relationship between IS variables and CS performance. No significant correlations were found between IS measures and CS performance (r = −0.198 to 0.296, $p \geq 0.05$), indicating that IS tests may not accurately reflect force production during velocity-specific activities, such as the CS, in elite female soccer players. Further studies should examine other neuromuscular and biomechanical factors affecting CS performance.

Keywords: *acceleration; athletic performance; hamstring muscles; maximal velocity; peak force*

Introduction

Women's soccer involves intermittent effort, requiring players to cover long distances and frequently run at high speeds (Trewin et al., 2018). On average, players cover 9–11.5 km per match, with high-speed running (>19.8 km/h) distances of 344–867 m. Researchers have observed significant changes in the game between the 2015 and 2019 FIFA Women's World Cups. High-intensity running (19–23 km/h) and sprinting (>23 km/h) increased significantly by 15% and 29%, respectively, underlining their importance (Beato et al., 2025). However, while sprints are essential, approximately 85% of maximal sprints in soccer follow a curvilinear path (Caldbeck and Dos' Santos, 2022).

High-intensity linear and multidirectional speed actions such as sprinting, change of direction, acceleration, and deceleration are essential for female soccer players (Beato et al., 2025). Linear sprinting (LS) plays a vital role in many match scenarios; however, curved sprinting (CS) is particularly crucial because it allows players to evade defenders, track opponents, and create space during play (Bloomfield et al., 2007; Fitzpatrick et al., 2019). Unlike LS, CS requires specific biomechanical adaptations that significantly affect performance, including reduced maximum speed (Sašek et al., 2025), increased trunk inclination (Brice et al., 2008) and rotational control to maintain balance, and enhanced inter-limb coordination and stability

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(Paz Paz et al., 2024).

Understanding the factors influencing sprint performance is important for developing better training programs and improving players' performance (Cronin and Sleivert, 2005). In addition to maximal velocity, key contributors to sprint performance include acceleration, ground reaction forces, and biomechanical factors (Nagahara et al., 2018). While previous studies have shown that strength, power, reactive strength, and inter-limb asymmetries are indeed associated with linear and multidirectional sprint performance (Northeast et al., 2019), their direct contribution to CS performance is less established and may involve additional demands, such as trunk control (Kobal et al., 2021), mediolateral force generation (Churchill et al., 2015), and inside-outside leg coordination (Filter et al., 2020).

Identifying factors that optimise training programs can enhance on-field players' performance (Rumpf et al., 2016). As previously known, LS performance is a function of lower-body strength and posterior chain function as measured using assessments such as the isometric mid-thigh pull (IMTP) and isometric hamstring strength (ISO) tests (Thomas et al., 2015; Whyte et al., 2024). Although Šašek et al. (2024) reported strong correlations between isometric knee extensor and flexor strength and CS performance in student-athletes, it remains unclear whether these findings can be generalized to elite female soccer players. This highlights the need for further research to determine the factors influencing CS performance in this population, considering the distinct motor requirements of both CS and LS.

Therefore, the aim of the study was to analyse the relationship between IS and CS performance in elite female soccer players. We hypothesised that greater maximal IS would be related to better CS performance. To the best of our knowledge, this study is the first to explore the association between maximal IS and CS performance in female soccer players.

Methods

Participants

Nineteen female soccer players (age: 25.32 ± 4.18 years; body height: 167 ± 6.0 cm; body mass: 59.26 ± 5.34 kg; body fat percentage: 12.70 ± 2.18%) volunteered to participate in this study during their pre-season period. Per the classification framework proposed by McKay et al. (2022), all participants were identified as Tier 3 elite female soccer players. Additionally, all athletes had completed at least a secondary-level education (McKay et al., 2022). According to a previous study (Thomas et al., 2015), large correlation coefficients were observed. Considering these coefficients and assuming a large coefficient (r = 0.57), a power analysis (G*Power version 3.1.9.7, Universität Kiel, Düsseldorf, Germany) was conducted before the study. The analysis showed that including at least 19 participants in the study would yield 80% power with a 95% confidence level (5% type 1 error rate).

All participants met the following inclusion criteria: 1) active participation in the Women's Super League, 2) regular training (> four times per week), 3) no medical conditions that could affect assessments, and 4) no hamstring-related injuries within the past 6 months before participation. Informed consent was obtained from all the participants. The study adhered to the tenets of the Declaration of Helsinki and was approved by the Hacettepe University Health Sciences Research Ethics Committee (approval code: 2024/01-59; approval date: 09 January 2024).

Measures

Familiarisation and Anthropometric Measurements

Anthropometric data were collected, including standing height using a stadiometer to the nearest 0.1 cm (SECA, 321, Vogel & Halke, Hamburg, Germany) and body mass using scales to the nearest 0.1 kg (SECA, 321, Vogel & Halke, Hamburg, Germany). The body fat percentage was assessed using skinfold calipers (Holtain Ltd.), measuring seven sites (abdominal, axilla, chest, subscapular, supra-iliac, thigh, and triceps) per the Jackson-Pollock method (Jackson and Pollock, 1978). All participants underwent a familiarisation session 48 h before the test day to ensure familiarity with the testing protocol, during which they practiced the test protocols until the lead researcher confirmed technical competence.

Warm-Up Protocol

Before the IS tests, each participant completed a standardised 10-min warm-up on a cycle ergometer, comprising 7 min of pedalling at 90 W and subsequently 3 min at 120 W (McCall et al., 2015). After the cycling session, participants performed dynamic lower-body stretching, including multidirectional lunges, inchworms, and body-weight squats (Fílter et al., 2020).

Isometric Strength Measurements

Isometric Hamstring Strength Test

The ISO test (Figure 1) was performed 5 min after the warm-up using a force plate (Kistler 9260AA6, Winterthur, Switzerland) with a sampling rate of 1000 Hz. Data were collected using Kistler's BioWare software. Testing included both dominant and non-dominant limbs at ISO 30° and 90° of knee flexion, selected based on muscle activation research (Onishi et al., 2002).

Participants were in the supine position, facing a box supporting the force plate with the testing leg positioned using a goniometer (Lafayette Instrument Company, Lafayette, IN, USA) at 90° or 30° knee flexion (Figure 1). The heel rested on the force plate, while the non-working leg remained extended alongside the box. Each participant performed three trials of a 3-s maximal voluntary contraction per leg, following the verbal command '3, 2, 1, drive'. They exerted force through the heel into the platform, 'as hard and as fast as possible' without lifting their buttocks, hands, or head off the mat (McCall et al., 2015). A 30-s rest interval was allowed between contractions, with participants completing three contractions at each knee angle per limb. A 2-min rest interval was allowed when switching limbs. The order of testing (dominant vs. non-dominant limbs and 90° vs. 30° position) was randomised across participants using a block design to minimise the influence of fatigue or learning effects on test outcomes.

Participants were instructed to keep their arms across their chest while the practitioner applied pressure to the contralateral hip, ensuring a fixed position of the buttocks on the ground to maintain standardised testing conditions. All participants performed the tests wearing shoes, and standardised verbal encouragement was provided during contractions. Participants were required to repeat the trials when their hips lifted off the ground or when a counter-movement was detected, the latter identified through the inspection of force traces following each repetition. Absolute peak force (PF, measured in N) data, categorised by dominant and non-dominant legs, were recorded for each contraction. Absolute PF values were obtained for both the dominant and non-dominant limbs; however, average limb values were used in statistical analyses to provide a general indicator of bilateral strength. Additionally, all PF (N) values from ISO tests were normalised to body mass (N/kg) to account for individual differences in body size, and these relative strength metrics were included in subsequent statistical analyses.

Isometric Mid-Thigh Pull Test

All participants performed the IMTP test, as illustrated in Figure 2, following established methodological guidelines (Comfort et al., 2019), including standardised joint angles, trial repetition criteria, and familiarisation procedures. The bar height was predetermined based on the body posture, specifically the knee angle (125–145°) and the hip angle (140–150°), which replicated the start of the second pull phase of the clean. Participants were secured to the bar using lifting straps, and a standardised command was given: 'Push your feet into the ground as fast and as hard as possible' (Comfort et al., 2019). A portable force plate sampling at 1000 Hz (Kistler 9260AA6, Winterthur, Switzerland) was incorporated into a portable IMTP rack and interfaced with computer software (Kistler's MARS [ver. 5.2.1.237]) to measure force-time characteristics directly.

Athletes performed two warm-up pulls at 50%, 75%, and 90% of their perceived maximum effort, with a 1-min rest interval between each attempt. Once a stable body position was established, athletes received a countdown ('3, 2, 1, Push') before initiating the pull. Each trial needed to maintain a 250-N difference between attempts (Comfort et al., 2019).

Certain conditions that might compromise the accurate identification of the pull's initiation, such as the absence of a stable weighing period (indicated by apparent fluctuations in the force-time data) or the presence of a counter-movement, were considered for invalid trials. Trials were repeated if a counter-movement was detected before initiating the isometric contraction, as evidenced by a noticeable drop in the force-time trace. Such counter-movements were considered violations of isometric conditions and were excluded from the analysis. Additionally, trials were repeated if PF was recorded at the end of the trial (Comfort et al., 2019).

Participants performed three maximal IMTP trials to achieve their maximal PF. Each trial lasted 5 s and was accompanied by robust verbal encouragement. A 1- to 2-min rest interval was provided between maximal effort pulls. All IMTP measurements were recorded both in absolute terms and relative to body weight (R IMTP) (Comfort et al., 2019). The IMTP trial was reported as the PF (N), with the highest PF data from the three trials used for subsequent analysis.

Curve Sprint Performance Test (CS)

The CS test was conducted on an official natural grass soccer field using the goalkeeper area arc under consistent environmental conditions (13–16ºC and 30–35% of relative humidity) (Figure 3). To ensure ecological validity and familiarity, all participants wore their own standard football boots (moulded cleats), replicating typical match-day conditions. The key variables included a 9.15-m radius from the penalty spot, a 14.6-m straight line distance, a 105.84° angle, and a total distance of 17 m (obtained through trigonometric analysis) (Fílter et al., 2020).

Before the CS test, participants completed a thorough warm-up consisting of 5 min of self-selected pace jogging, dynamic stretching, and three practice sub-maximal trials for CS.

Two pairs of photocells (Smart Speed, Fusion Sport, Brisbane, Australia) were placed 90 cm above the ground at both the start and end points of the curved trajectory on each side to ensure precise measurements and consistency along the sprint path. Additionally, cone markers were placed along the curve to guide participants.

Participants were briefed on the sprint procedure and instructed to sprint with maximum effort while maintaining the curve. The trial was considered successful when the participant sprinted along the guidelines (arc of the area). Each player performed three sprint trials on both their preferred and non-preferred sides. The starting position was standardised, with each participant beginning 1 m behind the timing gates. A 3-min rest interval was observed between trials to minimise fatigue. The fastest recorded time from each side was taken, and the mean of these values was calculated for statistical analysis.

Statistical Analyses

Descriptive statistics were used to analyse the data, with results presented as mean ± standard deviation (SD), median (IQR: Interquartile range), and minimum-maximum values. Intraclass correlation coefficients (ICCs; two-way mixed consistency), the coefficient of variation (%CV), and their 95% confidence intervals (CIs) were calculated to assess the inter-trial reliability of performance between trials for the CS, IMTP, and ISO tests (%CV ± S.E; 95% CI). For the IS assessments, within-session reliability (ICC and CV) was calculated using all three repetitions per limb and per condition (i.e., six trials total for each ISO position). The minimum acceptable reliability was set at ICC > 0.7 and CV < 15%. The CV was classified as follows: < 5.00%, excellent; 5.00–9.99%, good; 10.00–14.99%, moderate; > 15%, poor (Baumgartner and Chung, 2001). In the ICC assessments, reliability ranges were classified according to Koo and Li (2016) as follows: ICC<0.5, poor reliability; 0.5≤ICC<0.75, moderate reliability; 0.75≤ICC<0.9, good reliability; and ICC≥0.9, excellent reliability. Data normality was checked using the Shapiro-Wilk test and Q-Q plot analysis. Spearman's and Pearson's correlation coefficients were used to analyse relationships between variables. Correlations were classified as small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.70–0.89), nearly perfect (0.90–0.99), or perfect (1.0). All statistical analyses were performed using IBM SPSS Statistics 25 for Windows (IBM Corp., Armonk, NY, USA).

Results

Table 1 shows the mean ± SD values for absolute PF in IS tests and timings for CS performance during within-session assessments. The data showed acceptable to excellent reliability within sessions, with ICC values ≥ 0.928 (95% CI ≥ 0.846) and CV values classified as moderate to excellent for most measures, except ISO 90°, which exceeded the threshold of 15%.

Table 2 presents the descriptive statistics for the relative PF in IS assessments. Relative values were calculated based on the corresponding maximum absolute values; therefore, ICC values were not reported for these measures.

Figure 4 shows the correlation between athlete measurements. The analysis revealed a statistically significant, strong positive relationship between

IMTP PF (N) and R IMTP PF (N/kg). Additionally, a statistically significant, positive, and very large relationship was found between the ISO 30° and 90° values. However, no statistically significant correlations were observed among the other variables examined.

Table 1. Within session reliability of absolute isometric strength assessments and curve sprint performance.

	Mean (± SD)	Median (IQR)	Min-Max	% CV± SE (95% CI)	ICC (95% CI)
CS (s)	2.79 ± 0.09	2.82 (2.76–2.87)	2.6–2.9	3.2 ± 0.5 (2.2–4.3)	0.944 (0.858–0.972)
IMTPa (N)	1433.67 ± 147.25	1446.45 (1310.52–1546.95)	1190.72–1725.64	10.3 ± 1.7 (7.0–13.5)	0.946 (0.881–0.978)
ISO 30a (N)	223.04 ± 31.69	224.34 (199.13–237.13)	170.14–281.37	14.2 ± 2.3 (9.7–18.7)	0.932 (0.846–0.974)
ISO 90a (N)	236.92 ± 40.29	224.59 (206.41–261.42)	187.95–340.01	17.0 ± 2.8 (11.6–22.4)	0.947 (0.878–0.98)

CS = Curve Sprint; IMTP = Isometric Mid-Thigh Pull; ISO = Isometric Hamstring Strength; 95% CI: 95% Confidence interval; CV = Coefficient of variation; ICC = Intraclass correlation coefficient; SD = Standard deviation; SE = Standard error; Med (IQR)= Median (25th–75th percentiles); N = Newtons; s = seconds; a = absolute

Table 2. Descriptive statistics for the relative isometric strength assessments.

	Mean ± SD	Median (IQR)	Min-Max	% CV± SE (95% CI)
IMTPr (N/kg)	2.472 ± 0.215	2.444 (2.309–2.647)	2.087–2.920	8.7 ± 1.4 (5.9–11.5)
ISO 30r (N/kg)	0.386 ± 0.061	0.366 (0.341–0.437)	0.303–0.512	15.8 ± 2.6 (10.6–21.0)
ISO 90r (N/kg)	0.410 ± 0.077	0.391 (0.348–0.449)	0.325–0.587	18.8 ± 3.2 (1.3–2.5)

IMTP = Isometric Mid-Thigh Pull; ISO = Isometric Hamstring Strength; 95% CI: 95% Confidence interval; CV = Coefficient of variation; SD = Standard deviation; SE = Standard error; Med (IQR)= Median (25th–75th percentiles); N = Newtons; kg = kilogram; r = relative

Figure 1. Illustration of isometric hamstring strength tests: ISO 90 (a) and ISO 30 (b).

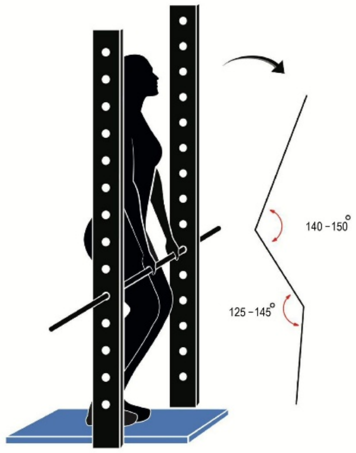

Figure 2. Illustration of the isometric mid-thigh pull test.

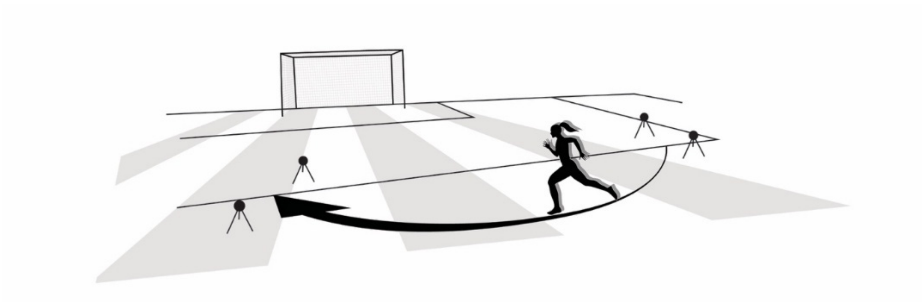

Figure 3. Illustration of the curve sprint performance test.

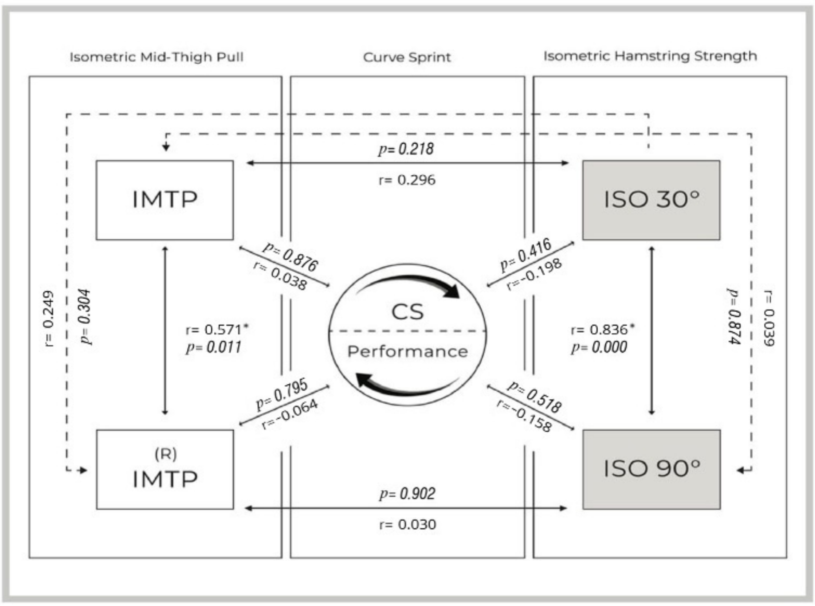

Figure 4. Correlation analyses between CS performance and IS measurements.
** = statistically significant difference (p < 0.05)*

Discussion

The key findings of this study included: (1) very large correlations observed between ISO 30° and 90°, (2) moderate correlations observed between ISO 30° and IMTP, and (3) non-significant correlations observed between CS performance tests and isometric muscle strength measures.

The strong correlations observed between ISO 30° and 90° indicate that isometric hamstring strength remained consistent across different knee angles. This finding supports the reliability of IS measures in assessing overall hamstring strength (Higbie et al., 1996). However, the absence of significant correlations between CS-ISO 30° and 90° suggests that while isometric hamstring strength is important, it may not be the primary determinant of sprinting ability. This aligns with the view that sprint performance is a function of muscle strength, power, and coordination rather than strength alone (Horníková and Zemková, 2021).

Moderate correlations were observed between the absolute and relative PF values in the ISO 30° and IMTP tests, which simply reflects that both tests assess general lower-limb IS across multiple joints. The IMTP is a well-established measure of lower-limb force production, particularly relevant to LS performance, because of its focus on hip and knee extensors in a vertical, sport-specific posture (Sheppard et al., 2011). In contrast, the ISO 30° test primarily targets hip extensor strength in a supine position, which may not biomechanically align with the demands of sprinting (Whyte et al., 2024). These tests share some variance; however, this correlation does not imply specific transferability. Rather, each test provides distinct and complementary information regarding an athlete's isometric force profile.

One of the most significant findings of this study is the lack of evidence supporting the relationship between IMTP strength measures and CS performance. This contrasts with previous research that uniformly showed strong correlations between IMTP PF and LS performance. For instance, prior research has established a negative correlation between IMTP and short-distance sprint times (Thomas et al., 2015; Wang et al., 2016). However, the lack of a relationship between IS and CS performance in this study indicates that CS imposes different biomechanical and neuromuscular demands than LS (Alt et al., 2015; Filter et al., 2020).

LS is primarily determined by maximal horizontal force output, with rapid high-level force production being a key predictor of success (Morin et al., 2011). The IMTP, as a reliable measure of lower-limb force production capacity, is consistent with evidence linking IMTP-PF to LS performance (West et al., 2011). Conversely, CS introduces additional biomechanical challenges that may reduce the role of IS as a direct contributor to performance outcomes (Filter et al., 2020). In CS, athletes must generate a propelling force while simultaneously controlling lateral forces and maintaining stability along a curved path. This requires greater use of mediolateral force, rotational control, and, importantly, different muscle activation patterns than in LS (Churchill et al., 2015).

Based on the findings of a previous study, during CS, the inside leg experiences higher breaking forces and prolonged ground contact time than the outside leg, which plays a more significant role in propulsion (Filter et al., 2020). This unique distribution of forces highlights the distinct nature of CS, suggesting that maximal force production, as measured using the IMTP, may be less critical for CS performance (Alt et al., 2015; Churchill et al., 2015). Furthermore, neuromuscular coordination and technical execution, such as maintaining a good lean angle, controlling ground reaction forces, and managing stride asymmetry, are likely more influential in CS than in LS (Filter et al., 2020). Additionally, previous research has established that CS requires specific muscular and joint biomechanical adaptations that differ from those needed for LS (Churchill et al., 2015). This distinction may explain why IMTP values did not correlate with CS performance in the present study despite their established relationship with LS (West et al., 2011).

The link between IS and LS performance across various populations has been previously examined but with inconclusive findings. For instance, Whyte et al. (2024) found no significant correlation between isometric hamstring strength and 10- and 30-m sprint speeds in female Gaelic footballers. Similarly, Brady et al. (2020) observed significant relationships between IMTP and LS in male sprinters but not in female athletes. These findings show that while IS can affect speed in certain individuals, its impact is not universal, depending not only on individual or population characteristics, but also on the sprint trajectory (i.e., linear or curvilinear).

Conversely, a study focusing on eccentric hamstring strength, primarily assessed through the Nordic Hamstring Exercise (NHE), has shown a positive correlation with LS performance (Timmins et al., 2015). Additionally, in a study involving 40 male sprinters, it was established that increased eccentric hamstring strength was linked to faster sprinting, indicating that eccentric strength training might be more effective for sprint performance than IS training (Timmins et al., 2021). The eccentric phase of sprinting, particularly the late swing phase, is related to the ability to decelerate the limb and transition smoothly into the propulsion phase (Schache et al., 2013). However, CS probably imposes different demands on the hamstrings because of altered stride mechanics, curved trajectories, and asymmetric force production, these factors alone do not fully account for the discrepancy between the ISO test and CS performance observed in this study. Considering the mediolateral force demands during CS, future studies should investigate the potential contributions of hip adduction/abduction and plantar flexion strength, which may be more important for CS than hip extensor strength alone.

Interestingly, recent findings revealed strong correlations between knee extensor and flexor strength and CS performance in student-athletes (Sašek et al., 2024), suggesting that isometric strength plays a more prominent role in certain populations. However, this contrasts with the present study, in which no significant correlations were observed between isometric hamstring strength (ISO 30° and ISO 90°) and CS performance in elite female soccer players. These differing results may be attributed to variations in the athletic level, sex, and neuromuscular characteristics. While the Sašek et al.'s (2024) cohort included student-athletes from mixed backgrounds, our study focused on female athletes with more advanced training backgrounds.

This study has some limitations that should be acknowledged. First, the findings were specific to female athletes in team sports, limiting their generalisability to male athletes and athletes from individual sports. Second, the small sample size (n = 19) may also limit the generalisability of the findings, especially regarding differences in training experience. Third, a correlation design was employed to analyse the relationship between CS performance and IS. Hence, future studies should include other variables, such as LS, NHE, and ISqT, to gain a more holistic view of the analysis. Finally, we focused on PF output without evaluating the rate of force development (RFD), which could provide more detailed insight into the explosive characteristics required for sprinting. Addressing these limitations will help improve future research.

Conclusions

Conclusively, in the present study, no correlation was found between IS and CS performance in female soccer players, likely because of the biomechanical and neuromuscular demands of CS compared with LS. It is important to acknowledge that, owing to the correlational design of this study, definitive causal relations cannot be drawn. Certain associations between strength characteristics and CS performance were observed; however, these do not imply causation. Therefore, the results should be interpreted with caution as they do not conclusively explain the underlying mechanisms of CS performance. Future studies should explore neuromuscular and biomechanical variables, such as joint angles and reactive strength, to help guide specific training for CS.

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