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Section III – Sports and Physical Activity

Strength and Speed-Strength Qualities Underpinning Curve Sprint Performance: A Comparative Analysis in Junior Soccer Players

by
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Curve sprinting is crucial in soccer, yet the strength and speed-strength qualities distinguishing fast from slow curve sprint performers remain understudied. This study investigated whether junior soccer players classified as fast in curve sprinting exhibited greater strength and speed-strength qualities compared to their slower counterparts. Forty-eight male junior soccer players (age: 15.3 ± 1.1 years) completed a standardized curve sprint test along the penalty arc and a linear sprint test, with split times recorded at 5 m, 8.5 m, and 17 m. Strength and speed-strength qualities were assessed using countermovement jump, drop jump, and isometric mid-thigh pull tests performed on a force plate. Statistical analyses included independent-samples t-tests for group comparisons with Hedges' g and rank-biserial correlation (rB) for effect sizes, complemented by Bayesian independent-samples t-tests with Bayes factors (BF10) to quantify evidence strength for alternative versus null hypotheses. Participants were median split into fast and slow groups based on 17-m curve sprint times. The fast group demonstrated greater speed across all split times in both curve and linear sprints and exhibited greater fast maximal dynamic and reactive strength measured by jump height ($p < 0.001$, $rB = 0.734$) and the reactive strength index ($p = 0.002$, $g = 0.853$). Bayesian analysis provided very strong ($BF_{10} = 29{,}750$) and strong evidence ($BF_{10} = 18.933$) supporting improved fast maximal dynamic and reactive strength in the fast group. However, no significant differences were found in maximal isometric or explosive strength between groups. These findings suggest that fast maximal dynamic and reactive strength qualities, rather than maximal isometric and explosive strength, distinguish between curve sprint performances in male junior soccer players.

Keywords: *running; team sports; exercise test; youth sports; Bayes' theorem*

Introduction

Sprinting speed is a critical factor in performance in many sports. While its importance is well-established in track and field, sprint performance is equally critical in team sports, where players dynamically adjust their running speed, trajectory, and movement strategies based on their physical capacities and the sport-specific biomechanical and contextual demands (Filter et al., 2023). Soccer, characterized by its intermittent nature with repeated cycles of high-intensity actions like sprinting and tackling intertwined with lower-intensity activities such as jogging and walking, depends on a combination of biomechanical, tactical, mental, and physiological attributes for effective performance (Gualtieri et al., 2023). Although sprints account for only a small fraction of the total distance covered in a match, they are crucial during decisive moments, such as quick attacking plays and defensive recoveries (Caldbeck and Dos'Santos, 2022). Moreover, as Faude et al. (2012) noted, sprinting is the most frequent action in soccer goal-scoring and assisting

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situations. However, unlike linear sprinting, which is commonly trained and tested, most high-speed maneuvers in soccer involve curvilinear sprints (i.e., curve sprints (CSs)), critical for evading opponents or navigating the field (Caldbeck and Dos'Santos, 2022; Filter et al., 2023).

The CS, also known as bend sprints in track and field, involves athletes running along a curved path, unlike the straight path of linear sprints. Body kinematics and kinetics during running on a curved path differ significantly from those in linear sprints, because, unlike linear sprints, the body experiences a centripetal force, which is directed orthogonal to the body's motion and causes the body to follow a curved path (Churchill et al., 2015). These differences require distinct kinematic and kinetic patterns and impose unique mechanical and neuromuscular demands (Churchill et al., 2015; Filter et al., 2020b). While track events have been extensively studied for decades (Churchill et al., 2015; Jain, 1980), these findings may not fully apply to team sport players, whose dynamic game contexts differ from track events. Moreover, Meng et al. (2024) observed that team sport players adopted a more ground-based running strategy with longer ground-contact times compared to track and field athletes, highlighting the need for sport-specific technical models. Until recently, the absence of a standardized CS test for team sport settings limited such analyses, a critical gap addressed by Filter and colleagues' development of a team sport-specific CS test (Filter et al., 2020a).

Filter et al. (2020a) developed a new CS test for soccer players that has been well received in sports science research. The test, conducted on a 17-m curved path along the penalty arc of a regulation soccer field, demonstrates high reliability and mirrors the curvilinear sprinting patterns prevalent in soccer matches. Filter et al. (2020a) suggested that CS and linear sprint abilities were distinct physical attributes, requiring separate assessment and training (Filter et al., 2020a). Despite the importance of CSs in soccer, research on the biomechanical and neuromuscular characteristics underpinning CS performance remains limited.

Cronin and Hansen (2005) conducted one of the foundational studies investigating the relationship between strength qualities and linear sprint performance in team sport players. They assessed strength in professional rugby league players using measures from three repetition maximum (RM) squat, isokinetic, and jump tests. Players were categorized into fast and slow groups based on linear sprint performance (5 m, 10 m, and 30 m), with results showing that faster players exhibited significantly greater fast maximal dynamic strength, defined as the ability to produce high force rapidly during dynamic movements (James et al., 2023), particularly in jump tests, compared to slower players (Cronin and Hansen, 2005). Given the shared high intensity demands of team sports like rugby and soccer, these findings suggest that similar force production capabilities may influence CS performance. However, the CS requires unique biomechanical adaptations, such as lateral force production and body lean (Churchill et al., 2015), limiting the direct applicability of these linear sprint findings. Further research is needed to identify the specific strength qualities that differentiate between players who excel in CS tasks in soccer and other team sports.

James et al. (2023) proposed a framework classifying five distinct strength and speed-strength qualities. In principle, maximal strength, encompassing maximal isometric and heavy maximal dynamic strength qualities, involves producing high force during relatively slow or isometric muscle-tendon unit (MTU) contractions, whereas speed-strength, including explosive, fast maximal dynamic, and reactive strength qualities, emphasizes rapid force production in dynamic movements (James et al., 2023). These qualities are assessed using specific tests: the isometric squat or the isometric mid-thigh pull (IMTP) for maximal isometric and explosive strength, 1RM or 3RM lifts for heavy maximal dynamic strength, the countermovement jump (CMJ) or the squat jump (SJ) for fast maximal dynamic strength, and the drop jump (DJ) for reactive strength (James et al., 2023). Fast maximal dynamic strength and reactive strength are particularly relevant for sprinting due to the time constraints of generating force rapidly (James et al., 2023).

Several studies have investigated the relationship between sprint performance and strength capabilities in soccer players. López-Segovia et al. (2011), for instance, examined the relationships between strength qualities, assessed through vertical jump tests and the maximal full squat, and linear sprint performance with split

times at 10 m, 20 m, and 30 m in U21 soccer players. Their results indicated significant correlations between these sprint times and measured power metrics. Similarly, Barrera et al. (2023) found that peak torque at higher angular velocities during isokinetic strength assessments, along with jump height (JH) from CMJ and SJ tests, significantly correlated with linear sprint performance. However, their reliance on a portable optical measurement system limited the detailed analysis of force production mechanics. With the increasing use of force plates in sports science research, deeper insights into athletes' force production capabilities have become achievable. While these studies predominantly focused on linear sprinting, research examining CSs demonstrates comparable limitations. For instance, Loturco et al. (2020) reported significant correlations between JH from CMJ and SJ tests and both linear sprint (with split times at 5 m, 10 m, and 17 m) and CS performances in U20 soccer players. Recent studies involving youth female soccer players have similarly employed optical measurement systems during SJ, CMJ, and DJ tests to investigate sprint correlations (Sašek et al., 2025). However, these investigations have not thoroughly analyzed the distinct strength qualities identified by James et al. (2023). Given the limited research focusing on junior soccer players, further investigation is warranted to better understand the sprint performance and strength qualities specific to this developmental stage.

Studies cited previously suggest that sprinting performance generally improves as strength capabilities increase, yet recent research indicates that speed does not always scale proportionally with strength gains, potentially due to a saturation effect where further increases in certain strength qualities yield diminishing returns (Vial et al., 2025). Additionally, Donaldson et al. (2025) reported inconsistent relationships between strength qualities and sprint acceleration, possibly due to interactions between strength expression and coordination patterns. These findings challenge the notion that greater strength always enhances sprinting, suggesting that once key thresholds are met, training may shift toward sprint-specific technique and coordination. This shift becomes particularly pertinent during the specialization of developing soccer players, where CS and linear sprint performance become increasingly dissociated with age, accompanied by greater inter-limb asymmetries and a heightened demand for specific intra- and inter-muscular coordination (Filter et al., 2022). Additionally, Sal-de-Rellán et al. (2026) reported that different physical qualities showed varying relationships with repeated sprint ability in elite youth soccer players. These findings are particularly relevant for junior soccer players, building on prior research in youth populations, where sprint performance is critical, as sprint speed and strength qualities distinguish elite junior players from their sub-elite and recreational peers (Gissis et al., 2006).

This study aimed to determine whether significant differences existed in strength and speed-strength qualities between junior soccer players classified as fast or slow in a soccer-specific CS task (Filter et al., 2020a). These qualities were assessed using CMJ, DJ, and IMTP tests, conducted with a portable force plate, following the framework of James et al. (2023). This approach sought to elucidate strength and speed-strength qualities by distinguishing between fast and slow players in CS performance. We hypothesized that junior soccer players classified as fast in the CS test would exhibit significantly greater strength and speed-strength qualities than those classified as slow, with varying effect sizes and evidence levels depending on the quality assessed.

Methods

Participants

Forty-eight junior male soccer players participated in the experiments (Table 1) with no major neuromusculoskeletal problems that would affect their test performance at the time of the measurements. Participants were players of a local soccer club and in season at the time of data collection. All participants played soccer at a competitive level for at least two years and practiced at least five days and nine hours per week. Participants had refrained from high-intensity strength training 48 h prior to data collection. All participants and legal guardians provided written informed consent to take part in the study. This study was conducted following the principles of the Declaration of Helsinki, and approved by the Ethics Committee of ODTÜ, Ankara, Türkiye (protocol code: 0593-ODTUİAEK-2022; approval date: 01 December 2022).

Using G*Power (v.3.1) (Faul et al., 2007), we performed an a priori statistical power analysis

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of the sample size required for a one-tailed *t*-test to compare differences between two independent means, and based on the effect size of 0.75 from strength and speed characteristics reported by Gissis et al. (2006), a minimum sample size of 46 participants was calculated for alpha = 0.05 and power = 0.80. We recruited 58 volunteers to participate in the experiments and 48 of them completed all tests and sessions.

Measures

Drop Jump Test

The DJ is a common plyometric exercise and test used to assess fast stretch-shortening cycle (SSC) function (Pedley et al., 2017). In a DJ, participants stand on a box, step forward from the box without stepping down, drop onto the ground or a force plate, and immediately perform a maximal vertical jump after landing. During DJs, the MTUs of the lower limb extensors undergo active stretching (braking or eccentric phase) immediately followed by rapid shortening (propulsion or concentric phase) within the SSC, a natural mechanism in running (Komi, 2003). James et al. (2023) recommended the reactive strength index (RSI) as the primary metric, with the constituent RSI metrics (i.e., JH and ground contact time (GCT)) as supplementary metrics.

Participants performed the DJ in the akimbo position on a force plate (Kistler 9260AA6, Switzerland) at a 1000-Hz sampling rate, with a 30-cm drop height to balance external load and injury risk. They were instructed to "imagine the force plate as a hot surface and, upon landing, perform a rebound jump as high and fast as possible" (Flanagan et al., 2008). Testing and analyses were conducted in accordance with the procedures outlined by Celik et al. (2024) and Pedley et al. (2022).

Countermovement Jump Test

The CMJ is a widely used assessment of an athlete's neuromuscular capacity and slow SSC function. During a CMJ, the athlete begins in an upright stance on the ground or a force plate, performs a rapid downward movement, and immediately executes a maximal vertical jump. James et al. (2023) recommended using JH as the primary metric for the assessment of fast maximal dynamic strength, with supplementary metrics such as vertical velocity at takeoff, peak vertical velocity, or relative peak power.

Participants performed two CMJ trials in the akimbo position on the force plate sampling at 1000 Hz. They began with a stationary upright posture with feet placed shoulder width apart and used a self-selected countermovement depth (CMD). Standardized instructions were given to "rapidly lower the body and jump as high and as fast as possible, keeping the hands on the hips throughout the motion, and absorb the landing by flexing at the hips, knees, and ankles" (McMahon et al., 2019). The jump yielding the greatest JH was selected for subsequent analysis. To further explore force production biomechanics in relation to CS performance, secondary variables, such as the modified reactive strength index (mRSI) and CMD, were calculated in accordance with McMahon et al. (2019).

Isometric Mid-Thigh Pull Test

The IMTP test is a reliable method for assessing lower-body force-generating capacity and allows the evaluation of multiple metrics of force, the rate of force development (RFD), and impulse (IMP) across multiple time intervals. The tests were performed on the force plate sampling at 2000 Hz, in accordance with the standardized procedures described by Guppy et al. (2022). Participants completed five maximal-effort IMTPs using the short-duration protocol, with each trial lasting one second and separated by approximately 20 s of rest in one continuous trial without stepping off the force plate. Among several IMTP test protocols, this short-duration protocol particularly emphasizes rapid force generation relevant to sprint running performance. Consistently with James et al. (2023), peak force (PF) represented maximal isometric strength, whereas IMP calculated within the 0–150 ms window served as the metric of explosive strength.

During testing, participants maintained an upright trunk with hip angles between 124° and 150° and knee angles between 120° and 140°, verified with a goniometer (Haff, 2019). Participants were instructed to avoid any countermovement and pull as fast and as hard as possible the fixed bar while pushing their feet into the ground. Unfiltered force-time data were acquired using Kistler MARS software and then exported to MATLAB for further processing. To ensure that the subject's body slack was eliminated immediately prior to the start of a trial, participants

were instructed to apply the minimum required pre-tension (less than 100 N above the subject's body weight) to the bar. Force-time metrics were derived using the manual force-onset identification method evaluated by Guppy et al. (2021). Force onset of each IMTP was defined with MATLAB's *ginput* function as the final peak/trough preceding a clear deflection from baseline noise (Tillin et al., 2010), and the one that produced the highest PF was selected for further analysis. After locating the force onset, 17 force-time metrics were calculated following Guppy et al. (2021, 2022).

Curve and Linear Sprint Tests

To perform the linear sprint test and the CS test, we adhered to the procedures outlined by Filter et al. (2020a). Participants first completed the CS test, followed by the linear sprint test. Standardized instructions were provided, requiring a full-maximal-effort sprint without purposeful deceleration. Participants began behind the start point marked with cones in a standing start posture and followed the penalty arc line (with a radius of 9.15 m) for the CS test or a straight line for the linear sprint test to ensure a valid trial. Participants were instructed to begin at their chosen time after receiving the go-ahead signal from the experimenter. During data collection, four sets of photoelectric timing gates (Fusion Sport Smart Speed, Australia) were used over a 17-m distance, enabling split times to be recorded at 5 m (initial acceleration), 8.5 m (apex of the curve), and 17 m (finish line). The photocells were standardized to a width of 180 cm and a height of 90 cm to allow players to pass through easily, with the start point positioned one meter behind the first set of timing gates at 0 m (start line). The CS test was conducted in both directions (right and left), with two trials per direction; the best performance, based on completion time at 17 m across the four trials, was selected for further analysis. Similarly, for the linear sprint test, each participant completed two trials, with the best performance, based on completion time at 17 m, used for analysis.

Design and Procedures

The experiments were conducted across three sessions within one week. The first and second authors performed all measurements. The initial session involved anthropometric assessments and familiarization with the tests. Junior soccer players practiced sprint and force plate-based tests for at least two trials each, with additional trials provided until they felt comfortable and competent. Reliability analysis, based on two recorded trials per participant on the first session, confirmed high to very high trial-to-trial reliability for all test metrics (Celik et al., 2024). During the second session, the CS test and the linear sprint test were conducted on the club's training field. The final session, held in the indoor clubhouse, included DJ, CMJ, and IMTP tests. Participants were instructed to abstain from food and beverages (except water) for two hours prior to testing. The warm-up protocol comprised five minutes of jogging followed by dynamic stretching of major lower-limb muscle groups (Flanagan et al., 2008), after which participants practiced the tests, rested for five minutes, and then completed recorded trials. A standard rest interval of three minutes was provided between trials.

Statistical Analysis

Participants were ranked according to their best 17-m CS times and divided into fast and slow groups at the median. Descriptive statistics for these groups were reported as mean (M) ± standard deviation (SD).

In null hypothesis significance testing (NHST), test selection was based on assumption checks for the standard (frequentist) approach. The assumptions of equality of variances and normality were evaluated using the Brown-Forsythe and Shapiro-Wilk tests, respectively. Independent samples Student's t-test was applied when assumptions of normality and equality of variances were satisfied, whereas the Mann-Whitney test was used when one or two assumptions were violated. Location parameter was given by mean difference for the Student's t-test and by the Hodges-Lehmann estimate for the Mann-Whitney test. For strength qualities in NHST, the tests were directional, hypothesizing (H_1) that male junior soccer players in the fast group would exhibit greater strength (reactive, fast maximal dynamic, maximal isometric, and explosive). For all other metrics, the data analysis was exploratory in nature (Ditroilo et al., 2025), and tests were two-tailed. Statistical significance was set at $p < 0.05$. For effect sizes, when the Mann-

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Whitney test was used, the rank-biserial correlation (r_B) was employed and interpreted similarly to Pearson's *r*: <0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; and >0.5, large. Otherwise, Hedges' *g* (denoted as *g*) was used to quantify the magnitude of observed effects, interpreted as trivial (0.00–0.19), small (0.20–0.59), moderate (0.60–1.19), or large ($g \geq 1.20$) (Hopkins, 2002).

For the Bayesian approach, independent samples *t*-tests were conducted using a one-sided alternative hypothesis. Given the limited prior knowledge regarding strength comparisons among junior soccer players in the context of a CS test, a default prior was selected, employing a Cauchy distribution with a scale of 0.707. Due to the one-sided alternative hypothesis, the prior distribution was truncated at zero, permitting only positive effect size values. Bayes factor classifications were as follows: BF_{10} = 1–3 indicated weak evidence; 3–10, moderate evidence; 10–30, strong evidence; and >30, very strong evidence in favor of the alternative hypothesis (H_1). Conversely, support for the null hypothesis (H_0) was classified as: BF_{10} = 1.00–0.33, weak evidence; 0.33–0.10, moderate evidence; and 0.09–0.03, strong evidence favoring the null hypothesis (Van Doorn et al., 2021). All statistical analyses were performed using JASP software, version 0.19.3.

Results

Table 1 presents descriptive statistics and comparative analyses for the participants' age, body height and mass as well as CS and linear sprint split times at 5 m, 8.5 m, and 17 m. The mean age, body height and mass of the junior players in fast and slow groups were not significantly different from each other. The fast group was significantly faster on all split times in both the CS and the linear sprint. For instance, on average, junior soccer players in the fast group completed the 17-m CS test significantly faster (2.66 ± 0.10 s) than those in the slow group (2.96 ± 0.13 s).

Table 2 presents descriptive statistics and NHST outcomes for the classical and Bayesian approaches for the strength and speed-strength qualities. On average, junior soccer players in the fast group exhibited greater fast maximal dynamic strength (primary metric: JH = 29.6 ± 3.3 cm) than those in the slow group (22.4 ± 5.2 cm). According to the Mann-Whitney test, this difference was statistically significant and represented a large effect size. The Bayesian independent samples *t*-test revealed very strong evidence supporting the alternative hypothesis (H_1) for fast maximal dynamic strength (BF_{10} = 29,750).

Regarding reactive strength (Table 2), the fast group demonstrated significantly higher reactive strength than the slow group, with a moderate effect size. The Bayesian independent samples *t*-test provided strong evidence in favor of the alternative hypothesis (H_1) for reactive strength (BF_{10} = 18.933).

In terms of maximal isometric strength (Table 2), junior soccer players in the fast group showed marginally higher values (primary metric: PF = 1,629.5 ± 220.0 N) than their counterparts in the slow group (1,570.1 ± 366.4 N). However, the Mann-Whitney test revealed that this difference was not statistically significant and yielded only a small effect size. The Bayesian analysis indicated weak evidence in support of the null hypothesis (BF_{10} = 0.506).

With respect to explosive strength (Table 2), the fast group displayed marginally lower values than the slow group. The Student's *t*-test revealed no significant difference and indicated only a small effect size. The Bayesian independent samples *t*-test suggested moderate evidence in support of the null hypothesis (H_0) for explosive strength (BF_{10} = 0.169).

Tables 3–5 present descriptive statistics and comparative analyses for the metrics of the DJ, CMJ, and IMTP tests, respectively. These analyses were exploratory in nature and employed two-tailed independent samples *t*-tests. For the DJ test (Table 3), among the RSI components, JH differed significantly between the fast and slow groups, whereas GCT did not. For the CMJ test (Table 4), mean and peak propulsion velocity, as well as mean and peak propulsion power, were significantly higher in the fast group, with large effect sizes. Additionally, the mRSI and CMD differed significantly between groups, with moderate effect sizes. For the IMTP test (Table 5), none of the metrics differed significantly between the fast and slow groups.

Discussion

This study investigated whether junior soccer players classified as fast in the CS test exhibited greater strength and speed-strength qualities compared to their slower counterparts. The key findings revealed that the fast group

demonstrated significantly better quality in fast maximal dynamic and reactive strength. However, no significant differences in maximal isometric or explosive strength were observed between groups. The fast group also demonstrated greater speed across all split times in both the CS and the linear sprint.

Our hypothesis was partially supported, as we hypothesized that reactive and fast maximal dynamic strength would differ between fast and slow groups in the CS test. Our findings for reactive and fast maximal dynamic strength were in line with those of previous studies on the strength and sprint performance relationship (Cronin and Hansen, 2005; Loturco et al., 2020). The CMJ test revealed lower-limb SSC function that is particularly relevant to the initial acceleration phase in linear sprints, where relatively longer ground contact times (i.e., slow SSC) (Turner and Jeffreys, 2010) facilitate force generation critical for increasing speed in the initial steps (Cronin and Hansen, 2005). In this context, we used the CMJ test for the assessment of fast maximal dynamic strength (James et al., 2023). Although the CMJ test has been extensively used in previous studies, to the best of our knowledge, this is the first study to employ a Bayesian approach and deliver very strong evidence indicating that male junior soccer players in the fast group on the CS test exhibit greater fast maximal dynamic strength when assessed by CMJ-JH. Similarly, for reactive strength tested using DJs, which resembles rapid force production in the sprinting phases after initial acceleration with relatively shorter ground-contact times (i.e., fast SSC) (Cronin and Hansen, 2005; Turner and Jeffreys, 2010), our data provide strong evidence that male junior soccer players in the fast group on the CS test exhibit greater reactive strength when assessed by the RSI in the DJ test. In sprinting, the natural pattern of the MTU of leg muscles, which undergoes active stretching followed by rapid shortening during the SSC, is known to have force-potentiating effects (Norman and Komi, 1979), and based on our findings, it could be suggested that young soccer players in the fast group utilized the SSC more effectively.

Table 1. Descriptive characteristics and sprint times of the participants.

Metric	Mean ± SD	Test	Location Parameter	*p*	Effect Size (95% CI)
Age (year)	Fast: 15.552 ± 1.087 Slow: 15.023 ± 1.165	Student	−0.529	0.097	−0.462 (−1.011 to 0.091)
Body height (m)	Fast: 1.742 ± 0.065 Slow: 1.743 ± 0.094	Student	0.001	0.973	0.009 (−0.534 to 0.553)
Body mass (kg)	Fast: 60.504 ± 6.961 Slow: 66.469 ± 12.147	Mann-Whitney	4.200	0.057	0.309 (0.003 to 0.562)
17-m CS (s)	Fast: 2.660 ± 0.096 Slow: 2.957 ± 0.129	Student	0.296	<0.001	2.568 (1.821 to 3.301)
8.5-m CS (s)	Fast: 1.375 ± 0.258 Slow: 1.556 ± 0.089	Mann-Whitney	0.120	< 0.001	0.867 (0.763 to 0.927)
5-m CS (s)	Fast: 0.902 ± 0.058 Slow: 0.969 ± 0.052	Student	0.067	< 0.001	1.196 (0.599 to 1.783)
17-m LS (s)	Fast: 2.587 ± 0.142 Slow: 2.817 ± 0.147	Student	0.230	< 0.001	1.568 (0.938 to 2.186)
8.5-m LS (s)	Fast: 1.452 ± 0.064 Slow: 1.570 ± 0.076	Student	0.118	< 0.001	1.651 (1.013 to 2.277)
5-m LS (s)	Fast: 0.948 ± 0.055 Slow: 1.003 ± 0.080	Student	0.055	0.006	0.792 (0.223 to 1.353)

CS: curve sprint, LS: linear sprint. For the Student t-test, effect size is given by Hedges' g. For the Mann-Whitney test, effect size is given by the rank biserial correlation. For the Student t-test, the location parameter is given by mean difference. For the Mann-Whitney test, location parameters are given by the Hodges-Lehmann estimate

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Table 2. Descriptive statistics and null hypothesis significance testing outcomes for classical and Bayesian approaches for the strength and speed-strength qualities.

Strength Quality	Metric	Mean ± SD	*p*	Effect Size (95% CI)	BF_{10}	Bayes Interpretation
Fast maximal dynamic	JH	Slow: 0.224 ± 0.052 Fast: 0.296 ± 0.033	<0.001	−0.734 (−∞ to −0.579)	29750	Very strong evidence for H_1
Reactive	RSI	Slow: 0.683 ± 0.199 Fast: 0.872 ± 0.236	0.002	−0.853 (−∞ to −0.352)	18.933	Strong evidence for H_1
Maximal isometric	PF	Slow: 1570.130 ± 366.402 Fast: 1629.535 ± 220.046	0.119	−0.201 (−∞ to 0.073)	0.506	Weak evidence for H_0
Explosive	IMP-0-150	Slow: 131.080 ± 21.564 Fast: 125.670 ± 20.668	0.810	0.252 (−∞ to 0.727)	0.169	Moderate evidence for H_0

JH: jump height (m), IMP-0-150: impulse at 0–150 ms window (N·s), PF: peak force (N), RSI: reactive strength index (m/s)

Table 3. Descriptive statistics and comparative analyses for the DJ test metrics.

Metric	Mean ± SD	Test	Location Parameter	*p*	Effect Size (95% CI)
JH	Fast: 27.882 ± 3.238 Slow: 21.117 ± 4.383	Student	−6.765	<0.001	−1.727 (−2.386 to −1.054)
GCT	Fast: 339.583 ± 87.458 Slow: 323.125 ± 79.747	Student	−16.458	0.499	−0.193 (−0.760 to 0.375)
Lpow	Fast: 29.216 ± 6.722 Slow: 29.692 ± 7.309	Student	0.476	0.815	0.067 (−0.500 to 0.632)
Tpow	Fast: 32.799 ± 5.359 Slow: 27.852 ± 6.040	Student	−4.947	0.004	−0.852 (−1.440 to −0.256)
PCOMD	Fast: 24.184 ± 7.394 Slow: 21.844 ± 4.301	Student	−2.340	0.187	−0.381 (−0.950 to 0.193)
pVGRF	Fast: 3.895 ± 1.037 Slow: 4.308 ± 1.245	Mann-Whitney	0.358	0.222	0.208 (−0.118 to 0.494)
LPF	Fast: 3.851 ± 1.055 Slow: 4.280 ± 1.271	Mann-Whitney	0.340	0.230	0.205 (−0.122 to 0.491)
TPF	Fast: 3.586 ± 0.831 Slow: 3.592 ± 0.815	Student	0.007	0.977	0.008 (−0.558 to 0.574)
LTTD	Fast: 24.408 ± 17.234 Slow: 24.592 ± 16.428	Mann-Whitney	−0.048	0.992	−0.003 (−0.322 to 0.315)
Kvert	Fast: 253.379 ± 160.432 Slow: 276.361 ± 132.155	Mann-Whitney	34.115	0.230	0.205 (−0.122 to 0.491)
BPT	Fast: 169.708 ± 53.871 Slow: 158.667 ± 45.290	Student	−11.042	0.446	−0.218 (−0.785 to 0.350)
PPT	Fast: 169.875 ± 36.093 Slow: 164.458 ± 36.833	Student	−5.417	0.609	−0.146 (−0.712 to 0.421)
B-IMP	Fast: 0.386 ± 0.054 Slow: 0.376 ± 0.042	Student	−0.010	0.485	−0.200 (−0.766 to 0.369)
P-IMP	Fast: 0.410 ± 0.041 Slow: 0.374 ± 0.054	Student	−0.036	0.013	−0.734 (−1.316 to −0.145)
SLC	Fast: −0.896 ± 0.059 Slow: −0.869 ± 0.123	Mann-Whitney	0.003	0.829	0.038 (−0.284 to 0.352)

JH: jump height (cm), B-IMP: braking impulse (BW·s), BPT: braking phase time (ms), GCT: ground contact time (ms), Kvert: vertical stiffness (N/m/kg), LPF: landing peak force (BW), Lpow: average power eccentric phase (W/kg), LTTD: landing to take-off time difference (%), PCOMD: peak center of mass displacement (cm), P-IMP: propulsion impulse (BW·s), PPT: propulsion phase time (ms), pVGRF: peak vertical ground reaction force (BW), SLC: spring like correlation (unitless), TPF: take-off peak force (BW), Tpow: average power concentric phase (W/kg)

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Table 4. Descriptive statistics and comparative analyses for the CMJ test metrics.

Metric	Mean ± SD	Test	Location Parameter	*p*	Effect Size (95% CI)
TTT	Fast: 0.691 ± 0.092 Slow: 0.638 ± 0.113	Student	−0.053	0.081	−0.507 (−1.079 to 0.071)
FT	Fast: 0.491 ± 0.027 Slow: 0.425 ± 0.050	Mann-Whitney	−0.066	<0.001	−0.734 (−0.853 to −0.543)
RSI	Fast: 0.722 ± 0.108 Slow: 0.681 ± 0.118	Student	−0.041	0.210	−0.361 (−0.930 to 0.211)
mRSI	Fast: 0.436 ± 0.081 Slow: 0.357 ± 0.087	Student	−0.079	0.002	−0.923 (−1.515 to −0.322)
UPT	Fast: 0.325 ± 0.063 Slow: 0.313 ± 0.067	Mann-Whitney	−0.012	0.458	−0.127 (−0.428 to 0.200)
BPT	Fast: 0.147 ± 0.034 Slow: 0.123 ± 0.039	Student	−0.024	0.027	−0.648 (−1.225 to −0.063)
PPT	Fast: 0.219 ± 0.033 Slow: 0.202 ± 0.045	Student	−0.017	0.134	−0.434 (−1.004 to 0.141)
MBF	Fast: 1.714 ± 0.205 Slow: 1.768 ± 0.217	Student	0.054	0.380	0.252 (−0.318 to 0.818)
MPF	Fast: 2.135 ± 0.175 Slow: 2.082 ± 0.226	Mann-Whitney	−0.063	0.149	−0.245 (−0.523 to 0.080)
MBP	Fast: 9.965 ± 2.737 Slow: 8.911 ± 2.462	Student	−1.054	0.168	−0.398 (−0.967 to 0.176)
MPP	Fast: 28.665 ± 3.005 Slow: 24.971 ± 3.650	Mann-Whitney	−3.912	<0.001	−0.599 (−0.771 to −0.347)
MBV	Fast: 0.659 ± 0.130 Slow: 0.577 ± 0.125	Student	−0.082	0.031	−0.632 (−1.209 to −0.049)
MPV	Fast: 1.559 ± 0.098 Slow: 1.421 ± 0.107	Student	−0.138	<0.001	−1.326 (−1.947 to −0.693)
PBF	Fast: 2.483 ± 0.321 Slow: 2.576 ± 0.440	Student	0.094	0.404	0.239 (−0.330 to 0.806)
PPF	Fast: 2.740 ± 0.323 Slow: 2.814 ± 0.546	Mann-Whitney	0.026	0.829	0.038 (−0.284 to 0.352)
PBP	Fast: 13.008 ± 3.871 Slow: 11.804 ± 3.587	Student	−1.204	0.270	−0.317 (−0.885 to 0.254)
PPP	Fast: 50.546 ± 5.299 Slow: 43.114 ± 5.857	Mann-Whitney	−7.259	<0.001	−0.677 (−0.819 to −0.457)
PBV	Fast: 0.976 ± 0.218 Slow: 0.865 ± 0.210	Student	−0.111	0.079	−0.511 (−1.084 to 0.067)
PPV	Fast: 2.561 ± 0.125 Slow: 2.252 ± 0.224	Mann-Whitney	−0.310	< 0.001	−0.799 (−0.891 to −0.644)
CMD	Fast: 0.227 ± 0.047 Slow: 0.181 ± 0.062	Student	−0.046	0.006	−0.821 (−1.407 to −0.227)
Kvert	Fast: 6.880 ± 2.451 Slow: 11.237 ± 6.679	Mann-Whitney	2.660	0.019	0.396 (0.088 to 0.634)

BPT: braking phase time (s), CMD: countermovement depth (m), FT: flight time (s), Kvert: absolute vertical stiffness (kN/m), MBF: mean braking force (BW), MBP: mean braking power (W/kg), MBV: mean braking velocity (m/s), MPF: mean propulsion force (BW), MPP: mean propulsion power (W/kg), MPV: mean propulsion velocity (m/s), mRSI: modified reactive strength index (m/s), PBF: peak braking force (BW), PBP: peak braking power (W/kg), PBV: peak braking velocity (m/s), PPF: peak propulsion force (BW), PPP: peak propulsion power (W/kg), PPT: propulsive phase time (s), PPV: peak propulsion velocity (m/s), RSI: reactive strength index (s/s), TTT: time to take-off (s), UPT: unweighting phase time (s)

Table 5. Descriptive statistics and comparative analyses for the IMTP test metrics.

Metric	Mean ± SD	Test	Location Parameter	*p*	Effect Size (95% CI)
F-50	Fast: 763.108 ± 93.962 Slow: 802.680 ± 126.642	Student	39.572	0.225	0.349 (−0.223 to 0.917)
F-90	Fast: 861.923 ± 179.446 Slow: 907.432 ± 166.478	Mann-Whitney	56.740	0.192	0.222 (−0.104 to 0.505)
F-150	Fast: 1041.652 ± 240.862 Slow: 1046.241 ± 220.322	Student	4.589	0.945	0.020 (−0.546 to 0.585)
F-200	Fast: 1195.476 ± 272.139 Slow: 1183.962 ± 253.038	Student	−11.514	0.880	−0.043 (−0.609 to 0.523)
F-250	Fast: 1286.991 ± 291.103 Slow: 1279.840 ± 255.623	Student	−7.150	0.928	−0.026 (−0.591 to 0.540)
pRFD-20	Fast: 4424.818 ± 2743.251 Slow: 3947.465 ± 2683.456	Mann-Whitney	−491.585	0.519	−0.111 (−0.415 to 0.215)
RFD-0-50	Fast: 1339.327 ± 1861.676 Slow: 1109.886 ± 986.155	Mann-Whitney	−9.960	0.992	−0.003 (−0.322 to 0.315)
RFD-0-90	Fast: 1842.001 ± 2015.189 Slow: 1780.521 ± 1548.542	Mann-Whitney	140.935	0.721	0.063 (−0.261 to 0.374)
RFD-0-150	Fast: 2303.392 ± 1600.586 Slow: 1993.705 ± 1320.448	Mann-Whitney	−185.600	0.602	−0.090 (−0.397 to 0.235)
RFD-0-200	Fast: 2496.668 ± 1333.337 Slow: 2183.882 ± 1142.289	Student	−312.786	0.387	−0.248 (−0.815 to 0.322)
RFD-0-250	Fast: 2363.393 ± 1151.577 Slow: 2130.620 ± 880.018	Student	−232.773	0.435	−0.223 (−0.790 to 0.345)
IMP-0-50	Fast: 36.175 ± 3.483 Slow: 38.363 ± 6.199	Mann-Whitney	1.590	0.255	0.194 (−0.132 to 0.483)
IMP-0-90	Fast: 68.571 ± 8.276 Slow: 72.495 ± 11.265	Student	3.923	0.176	0.390 (−0.183 to 0.960)
IMP-0-200	Fast: 181.635 ± 32.635 Slow: 186.916 ± 32.513	Student	5.281	0.577	0.159 (−0.408 to 0.725)
IMP-0-250	Fast: 244.066 ± 46.381 Slow: 248.910 ± 44.189	Student	4.844	0.713	0.105 (−0.462 to 0.671)

F-50: force at 50 ms (N), F-90: force at 90 ms (N), F-150: force at 150 ms (N), F-200: force at 200 ms (N), F-250: force at 250 ms (N), IMP-0-50 ms: impulse at the 0–50-ms window (N·s), IMP-0-90 ms: impulse at the 0–90-ms window (N·s), IMP-0-200 ms: impulse at the 0–200-ms window (N·s), IMP-0-250 ms: impulse at the 0–250-ms window (N·s), pRFD-20: peak rate of force development with a 20-ms window (N/s), RFD-0-50 ms: rate of force development at the 0–50-ms window (N/s), RFD-0-90 ms: rate of force development at the 0–90-ms window (N/s), RFD-0-150 ms: rate of force development at the 0–150-ms window (N/s), RFD-0-200 ms: rate of force development at the 0–200-ms window (N/s), RFD-0-250 ms: rate of force development at the 0–250-ms window (N/s)

On the other hand, our hypothesis was not supported by maximal isometric and explosive strength. Our data provide weak to moderate evidence supporting the null hypothesis that male junior soccer players in the fast and slow groups exhibit no differences in maximal isometric or explosive strength when assessed by the IMTP test. In a scoping review of IMTP test performance relationships to dynamic sport performance assessments, Giles et al. (2022) compiled several studies showing a spectrum of linear associations from none to strong between IMTP and sprint test metrics. Several possible explanations may account for these conflicting results, ranging from differences in testing conditions and populations studied to coordination patterns and strength saturation effects. First, the contraction specificity and temporal demands of IMTP and sprint tests may not align, as sprinting and most locomotor movement patterns follow an SSC pattern,

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whereas countermovement is generally not allowed in IMTP tests. Additionally, recent research indicates that speed does not always scale linearly with strength gains, potentially due to a saturation effect where further increases in certain strength qualities yield diminishing returns (Vial et al., 2025), and there may be complex nonlinear interactions between strength expression and coordination patterns (Donaldson et al., 2025). However, this study, like many others, assumed a linear model for strength qualities and sprinting performance, which represents a limitation of the current and preceding studies.

Our study has also other limitations. For instance, the cross-sectional design precludes causal inferences about whether greater strength qualities lead to faster CS performance. Another limitation was that our sample consisted exclusively of male junior players, limiting generalizability to female players (Korkmaz et al., 2026) or other age groups. Future research with longitudinal designs, inclusion of female players and other age groups could address these limitations.

In conclusion, this study provides evidence that fast maximal dynamic and reactive strength, but not maximal isometric or explosive strength, differ between fast and slow CS performers among male junior soccer players. This study contributes to the growing body of literature emphasizing the unique biomechanical and neuromuscular profiles required for multidirectional speed in soccer. Given the critical role of CSs in decisive soccer moments, developing and monitoring specific strength qualities during the junior development phase may contribute to long-term athletic success in soccer. Thus, sport scientists and practitioners should prioritize designing training programs that target both strength and soccer-specific sprinting skills to optimize junior soccer players' sprint performance and development.

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