Upper-Body Isometric Strength Qualities Are Associated With Faster High-Intensity Running Performances in Professional Soccer Players: A Cross-Sectional Study

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Abstract

Curovic, I, Toskic, L, Markovic, M, Alexander, J, Suzovic, D, Grecic, D, and Harper, DJ. Upper-body isometric strength qualities are associated with faster high-intensity running performances in professional soccer players: A cross-sectional study. *J Strength Cond Res* XX(X): 000–000, 2026—Despite being highlighted as potentially important, the relationship between greater upper-body (UB) strength and lower-body–dominant high-intensity actions (HIA) in professional soccer players remains unknown. The aim of this study was to examine the associations between relative UB isometric strength qualities and HIA [i.e., sprinting, repeated sprint ability (RSA), change of direction (COD), vertical jumping] while controlling for leg power influence in 63 male professional players. Statistical significance was set at $p \leq 0.05$. Results identified that handgrip strength (HGS), particularly rate of force development (RFD), demonstrated significant large correlations with faster 30-m sprints ($r \approx -0.52$, $p < 0.001$) and RSA ($r \approx -0.55$, $p < 0.001$). Upper-body maximal strength capacity (push-pull composite score) exhibited significant moderate correlations with faster RSA ($r = -0.36$, $p = 0.004$) and COD 505 test ($r = -0.30$, $p = 0.019$). Hierarchical regression analysis showed that, after controlling for leg power, UB strength accounted for an additional 12.1% of the variance in RSA performance ($\Delta R^2 = 0.121$, $p = 0.004$), while HGS added a further 12.4% ($\Delta R^2 = 0.124$, $p = 0.002$), with the full model explaining 29.3% of total variance. In conclusion, greater relative UB strength appears to be linked to superior high-intensity running performances in professional soccer players, especially during RSA tasks. Future research should investigate the effects of UB strength training through longitudinal interventions and further explore the role of UB-derived RFD metrics for HIA while accounting for horizontal lower-body force-generating capacities.

Key Words: handgrip strength, sprinting, acceleration, repeated sprint ability, change of direction, speed

Introduction

Soccer is a sport in which linear sprinting speed, jumping, change of direction (COD), and repeated sprint ability (RSA) are essential contributors to success (32,38). The rising tactical demands and fixture congestion in modern soccer make enhancing and maintaining the capacity to repeat these specific high-intensity actions (HIA) a priority for training practices (37). Numerous studies have shown that leg muscle strength can enhance HIA performances (39,78,96,112). However, there is a paucity of research investigating how various upper-body (UB) strength qualities could influence these actions (21), and no studies have investigated this link specifically for soccer players. That said, soccer strength and conditioning coaches have expressed a strong belief that UB strength plays an important role in supporting the performance of HIA in professional soccer players (22).

The potential for a stronger and more powerful UB to improve HIA may lie in its ability to augment kinetic energy transfer and impulse generation (26,50,71,90,111). In jumping, arm swing contributes to performance by increasing the center of mass velocity through additional work performed by the shoulder and trunk extensors (14,55). This action enhances force production around the hip joint and improves stretch-shortening cycle utilization through greater downward momentum and more effective proximal-to-distal sequencing for generating force (i.e., reduced antagonist co-contraction) (18,35). In sprinting, the contribution of the upper limbs appears more indirect, as opposing arm movements do not directly increase forward momentum during the upward running phases (34,47). During acceleration, however, forward body lean alters the orientation of force application, enabling the vertical component of arm swing to contribute to horizontal propulsion through a forward shift of the center of mass (4). In this phase, coordinated rapid actions of the shoulder and humerothoracic joints (73,95) assist lower-limb force production and sprint acceleration (95). In COD performance, UB

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musculature may contribute by supporting force transmission and trunk control across key movement subphases (i.e., acceleration, deceleration, and re-acceleration), where rapid upper-limb actions and trunk positioning assist the lower body (LB) in maintaining balance and initiating momentum in the desired direction (33,40). These effects are likely mediated by coordinated trunk-pelvic interactions and may be influenced by neuromuscular adaptations such as enhanced rate of force development (RFD) and central neural drive (44,62), which could facilitate whole-body power expression (25).

The extent to which UB strength contributes to HIA performances remains unclear. Research has shown moderate-to-large positive associations between UB strength measured by 1 repetition maximum (1RM) bench press and sprinting speed (i.e., 30-m flying times) in Australian footballers (116), as well as improved RSA in various athletes (6,28,48), although the relationship to accelerative abilities and jumping appeared insignificant (48,109,116). Soccer players frequently execute HIA in rapid succession (32,80), and evidenced potential of non-specific UB strength to mitigate fatigue associated with these actions (6,28,48) could become important for overall on-field performance. Notably, most studies have predominantly utilized dynamic 1RM bench press testing (6,48,116), neglecting other muscle groups and critical strength qualities like the RFD, which may be more relevant for the rapid force-generating requirements of HIA (54,62,67,94). Furthermore, pulling strength may represent a more specific contributor than pushing patterns due to the activation of the latissimus dorsi and posterior deltoid muscles, which exhibit high activation during submaximal running (45) and predominantly consist of fast-twitch muscle fibers optimized for powerful, explosive movements (74). Their positive contribution to whole-body displacements might be mediated through powerful contractions of trunk extensors during activities such as sprinting (4) and jumping (13,76). This link is explained by the posterior oblique sling system involving the interaction between the latissimus dorsi and the opposite gluteus maximus (91,108), optimizing power transfer between the upper and lower extremities (45,74,91,108).

Isometric strength testing offers a practical and sensitive alternative for assessing maximal and explosive strength qualities, demonstrating strong correlations with dynamic athletic performance, including jumping (36), sprinting (102,115), COD (65,101), and kayaking (106). Furthermore, UB strength assessments in an isometric regime have demonstrated high validity when compared with dynamic UB strength tests (7,60,92), thereby eliminating potential confounding variables associated with technique and range of motion. Similarly, the reliability of UB isometric push and pull tests that measure peak force has been consistently reported as excellent across multiple studies (1–3,7,60,76,77,80,114). Similarly, handgrip strength (HGS) assessment is established as a reliable and practical isometric tool (9,67) frequently used as a proxy for general UB strength (30,83,100). Force-generating metrics obtained from HGS tests, including maximal force and RFD, have been found to significantly correlate with HIA, including jumping and reactive COD (i.e., agility) performances (66,67,76,85,89). For example, Schulz et al. (89) investigated the HGS of elite youth soccer players and observed a strong association with sprinting ($r = -0.62$ to 0.73) and vertical jumping ability ($r = 0.69$ to 0.75) (89). This relationship may be explained by the emerging concept of vertical strength transfer, whereby strength training for one body region can enhance performance in another body region through neurophysiological adaptations, including increased central neural drive, and systemic circulating factors that facilitate anabolic adaptations at the whole-body level (25).

The potential for UB strength to enhance performance of HIA has been highlighted in a scoping review (21). This review emphasized methodological shortcomings of current research such as the predominant use of dynamic 1RM bench press tests, inconsistent body mass standardization, and a neglect of UB explosive strength qualities such as the RFD. The authors suggested future studies to address these gaps, thereby highlighting that UB strength could be particularly important for HIA in sports such as soccer, where players appear to lack significant neuromuscular adaptations from UB strength training plans (43,84). From a strength and conditioning perspective, establishing whether UB strength is associated with HIA represents an important preliminary step before longitudinal intervention-based studies are recommended to inform more targeted training strategies and monitoring approaches in professional players. Therefore, the aim of this study was to investigate associations between UB strength qualities and HIA in professional male soccer players. We hypothesized that UB strength would exhibit moderate positive influence on HIA performances, with stronger relationships expected for the measures of explosive strength (i.e., RFD).

Methods

Experimental Approach to the Problem

A cross-sectional study design was used to examine the relationship between isometric UB strength qualities and HIA performances in professional male soccer players. Testing was divided into 2 parts on the same day. In the first part, subjects performed isometric seated push and pull strength tests followed by the maximal HGS test. The second part assessed performance of HIA in the following order: (a) maximal concentric-only vertical squat jump (SJ) with restricted arms, (b) maximal vertical countermovement jump (CMJ) and free arms, (c) 505 COD test, and (d) 30-m RSA test. To minimize potential performance decrements associated with fatigue, subjects were instructed to abstain from strenuous physical activity for at least 48 hours before testing, and researchers coordinated with the teams' strength and conditioning coaches to ensure that no intense training sessions occurred within this period.

Subjects

Sixty-three male professional soccer players (age: 22 ± 3.2 years; height = 181 ± 6.3 cm; body mass = 75 ± 7 kg) from 3 First Serbian League (second tier) clubs participated in this study. Subjects were all outfield players aged 18 years or older (range 18–25), with no injuries and fully engaged in training. Goalkeepers were excluded due to distinct movement patterns (53). Before data collection, a power analysis (HHU, Düsseldorf, Germany) was conducted for a correlation and regression model (27,47,56). It was determined that at least 23 subjects for correlation and 18 subjects for regression (3 predictors) were required to achieve a statistical power of 0.80 with an alpha level of 0.05. This study was approved by the Institutional Review Board/Ethics Committee of the University of Lancashire (HEALTH 0330 Phase_5) and conducted in accordance with the Declaration of Helsinki. All subjects were informed of the risks and benefits of this study before data collection and provided written informed consent in accordance with institutional guidelines.

Procedures

Subjects were familiarized with all testing protocols immediately before testing to ensure proper execution and maximal effort. This included familiarization with the isometric push and pull exercises, during which they performed 2 submaximal practice efforts (approximately 50 and 75% of perceived maximum (60)) for each movement, focusing on correct posture and bracing, followed by a single maximal effort to establish a movement-specific reference. A rest period of 15 minutes was provided between this final familiarization trial and the commencement of the experimental trials to ensure full recovery.

The testing occurred in an indoor athletic arena on a rubber track surface to ensure all conditions were the same for each subject, thereby avoiding potential interference by external weather conditions. The subjects were accustomed to the field testing protocols, as they were part of the clubs' routine performance assessments. Before data collection, each subject's age, height, and body mass were recorded. Height was measured barefoot using a portable stadiometer (Seca 213, Seca GmbH & Co. KG., Hamburg, Germany), and body mass with a body composition analyzer (InBody 270, Biospace Co., Ltd., Seoul, Republic of Korea). Subjects first completed the UB isometric strength assessments before proceeding to the HIA tests. This consisted of 2 trials on seated UB push and pull tests using a custom rig with an attached dynamometer (DynaMo Max, VALD, Queensland, Australia) sampled at 1,200 Hz (23). Handgrip force data were collected using a wireless K-Grip dynamometer (Kinvent Biomechanics, Montpellier, France; 1,000 Hz) with data visualized and exported using the Kinvent application (version 2.23.0) (24).

Testing of HIA progressed from the least to the most fatiguing, starting with the vertical jumps, followed by the 505 test, and concluding with RSA. Before all testing, subjects completed a standardized RAMP-based warm-up (i.e., raise, activate, mobilize, and potentiate), starting with 5 minutes of jogging, followed by 5 minutes of dynamic activities such as high knees and jumping jacks, and 5 minutes of mobility exercises (e.g., calf walks and lunges). Subsequently, they progressed to 5 minutes of plyometric drills such as single-leg hops and linear/lateral runs over 20 m with increasing intensity. This warm-up type has been shown to effectively prepare for sprinting and agility-based actions in soccer players (107) and has been previously used in similar testing studies (56,58). If the wait time was longer than 15 minutes, subjects engaged in a 2-minute active re-warm-up involving brief sprints and jumps 2–3 minutes before their turn (93). They rotated by the numbers assigned beforehand, ensuring recovery periods of at least 3 minutes between tests (56).

Isometric Upper-Body Push and Pull Strength Tests. The setting for the isometric UB push and pull test was identical to the formerly described protocol (Figure 1) (23). It has been proposed that the optimal joint angle for accurately assessing maximal isometric push and pull strength is the one where peak force is generated at 90° (61,71,92). Furthermore, both the isometric bench press and bench pull tests have demonstrated high reliability in previous studies for measuring peak force at 90° angles (1,23,60,71,114). Each player therefore performed 2 trials with 3 seconds of maximal effort in both the push and pull tests, respectively, with the elbow angles set at 90°. At least 2 minutes of rest was allowed between attempts (60). Peak force, defined as the maximum force value achieved ($F_{\max}$), was chosen based on its previously demonstrated high test-retest reliability using the same instrument (ICC = 0.97–0.99; CV < 6%) (23).

Force signals were baseline-corrected using the mean force during a 500-ms preinitiation period (23). Contraction onset was defined as the first sample exceeding 30 N above baseline (23). No additional filtering was applied to the force-time data (23).

To derive a single indicator of UB strength capacity (UBSC), peak force values from the UB push and UB pull tests were averaged to form a composite score. This UBSC variable was used in all subsequent analyses alongside the individual push and pull metrics, providing an overall representation of UB strength that was independent of the intended movement pattern.

Handgrip Strength Test. The setting for the HGS test was identical to the formerly described protocol (Figure 2) (24). Each

Figure 1. A) Isometric pull test, and B) isometric push test using the DynaMo Max dynamometer attached to the custom-built metal rig.

Figure 2. Handgrip strength test using Kinvent K-Force Grip.

player performed 2 maximal 3-second trials with 1-minute rest between attempts (60). Only variables previously shown to demonstrate acceptable test-retest reliability from the same instrument (ICC = 0.88–0.99; CV = 4–14%) (24) were extracted:

- Peak Force (N), defined as the maximum force value achieved (F_{max}).
- Time-specific RFD values ($N \cdot s^{-1}$):
  $RFD_{0–150}$
  $RFD_{0–200}$

Force-time data were processed within the Kinvent software environment using a low-pass Butterworth filter. The cutoff frequency was scaled relative to the device sampling frequency as part of the software's internal signal-processing procedure (24). Contraction onset was subsequently identified automatically from the processed force-time signal, after which time-specific RFD variables were extracted over fixed epochs relative to contraction onset ($RFD_{0–150}$ and $RFD_{0–200}$).

As with the push and pull scores, left- and right-hand values for all handgrip force metrics (i.e., F_{max}, $RFD_{0–150}$, $RFD_{0–200}$) were averaged to create bilateral measures for the subsequent analyses. Hence, maximal force from HGS tests is presented as (bilateral) handgrip strength capacity (HGSC).

Force-Time Data and Allometric Scaling. The selected force-time data were chosen for their relationship to dynamic athletic performance (52,62), offering a greater likelihood of higher reliability compared with earlier time windows (1,20,60,71,114). Previously, both UB push and UB pull tests using the same instrument exhibited excellent reliability for peak force (ICC = 0.97–0.99; CV < 6%) (23). Similarly, the HGS assessment with the Kinvent device demonstrated excellent reliability for peak force (ICC >0.97; CV < 6%) and good-to-excellent reliability for later-phase RFD measures (ICC = 0.88–0.99; CV = 4–14%) (24), justifying their selection as the most robust and reliable metrics for correlation analyses. Importantly, all force variables were normalized to body mass using allometric scaling ($F/Body\ Mass^{0.67}$), in accordance with Jaric's recommendations (49), reflecting the nonlinear relationship between body size and force production. This approach is considered appropriate for force-based measures obtained using dynamometry, as opposed to ratio scaling, which is more suitable for torque-based variables (49). Although it is recognized that population-specific exponents may vary (99), a standardized exponent was applied to ensure consistency with established theoretical models and previous literature. This method has been used in research examining isometric muscle strength in elite athletes (10).

High-Intensity Action Tests. Vertical jumps were performed in 2 different ways. First, to account for the leg muscle contribution to HIA, an arm-restricted concentric-only SJ was used to isolate vertical leg power from any influence of the arm swing-facilitated back extension muscle contribution (13,21). Subjects were required to establish their optimal squat depth and then perform 3 jumps with 1-minute rest between trials (Figure 3A). Second, 3 maximal CMJs with arm swing were performed from an extended leg position (64), with subjects instructed to jump as high as possible with a 1-min rest between trials (Figure 3B) (64). All trials were video-recorded to verify correct technique. For both vertical jumps, the highest jump height (cm) and peak power (W) were measured using force plates (K-Deltas, Kinvent, Montpellier, France) sampling at 1,000 Hz.

The 505 test measuring COD ability was administered following established protocols (57,58). Subjects were instructed to use their preferred foot and turning technique to complete the test as fast as possible. They sprinted through a timing gate (Witty, Microgate, Bolzano, Italy) positioned 5 m before a marked 15-m turning point, planting either foot on or behind this line before turning 180° and sprinting back through the gate (Figure 4). Any trial with premature turns or incorrect foot placement was repeated. The best 505 time was retained for analysis, measured to the nearest 100th of a second.

The RSA test utilized in this study consisted of 7 30-m sprints with 20-second recovery periods between each sprint, similar to protocols previously used with male soccer players (56,57). Sprint times were recorded to the nearest 100th of a second using timing gates (Witty, Microgate, Bolzano, Italy) (42). After each sprint, subjects jogged back to the start line for the next sprint. They were required to maintain a stationary position for 5 seconds before starting each sprint and received feedback on the recovery period. Constant verbal encouragement was provided to help subjects maximize their effort on each sprint. Two performance metrics were calculated for the RSA test: (a) total time (RSAtt), which was a measure of cumulative time (s) for all 7 sprints (56,57), and (b) performance decrement (fatigue index; RSAf) calculated as [(mean sprint time − best sprint time)/best sprint time] × 100, as described by Impellizzeri et al. (12,27).

From the RSA test, 10-m and 30-m sprint times were recorded using gates positioned at 0, 10, and 30 m, measuring 0–10 m and 0–30 m intervals. These sprint distances have been previously employed in the assessment of soccer players (56,63), revealing their acceleration performance (15) and sprinting velocity specific to this sport (97).

Statistical Analyses

All statistical analyses were conducted using IBM SPSS Statistics (version 25.0, SPSS Inc., Chicago, IL). Statistical significance was set a priori at $p < 0.05$. The assumption of normality for all variables was confirmed using the Shapiro-Wilk test. Pearson's

Figure 3. A) Starting position for arm-restricted vertical squat jump, and B) arm-swing countermovement vertical jump.

bivariate correlations were first used to examine the relationships between relative SJ peak power and all performance outcomes. Subsequently, partial correlations were used to examine the relationships between UB strength qualities and all HIA outcomes with relative SJ power (W/kg$^{0.67}$) included as a covariate to control for the influence of LB power capacity. The UB metric included peak force (i.e., F_{max}) for both UB push and UB pull. Handgrip force metrics included peak force (i.e., F_{max}) and time-specific RFD (i.e., $RFD_{0–150}$, $RFD_{0–200}$). For all correlation analyses, the magnitude of associations was interpreted using Hopkins' scale (47): trivial (<0.10), small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.70–0.89), and nearly perfect (≥0.90). Given the exploratory nature of this study, we initially report uncorrected p-values to minimize type II error. However, to address concerns regarding multiple comparisons, we additionally apply the Benjamini-Hochberg False Discovery Rate (FDR) procedure with $q = 0.05$ across all partial correlations (8). Although the a priori sample size calculation was based on $\alpha = 0.05$, the FDR correction effectively required a per-test significance level of $p \leq 0.02$ for the partial correlations to remain significant. To confirm that the obtained sample of 63 subjects provided sufficient statistical power under this more stringent threshold, a post hoc sensitivity analysis was conducted using G*Power (29), showing that the required sample size was calculated to be 49 subjects.

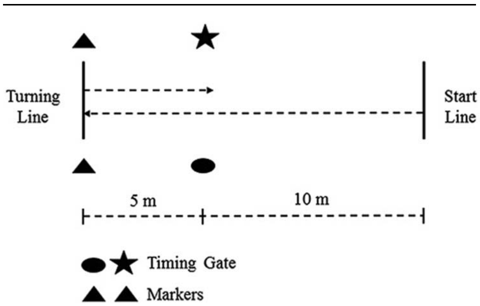

Figure 4. 505 test measuring change-of-direction performance (Loturco et al. [59])

Hierarchical multiple regression analysis was used to evaluate the influence of UBSC and HGSC on RSA performance. The sequence of entry included 3 steps:

- Step 1: SJ power.
- Step 2: UBSC.
- Step 3: HGSC.

This approach allowed us to quantify the incremental variance explained by UBSC and HGSC beyond the primary contribution of leg power for each variable. Repeated sprint ability outcome was chosen for its most consistent positive relationship with greater UB strength (21). The order of entry was determined based on theoretical considerations. Leg power was entered first because SJ performance is a significant correlator with sprinting (110). Upper-body strength capacity (push-pull composite peak force) was entered second as the primary measure of UB strength with a noted potential to enhance RSA (21). HGSC (bilateral peak force) was entered last as a secondary, more distal measure of general neural drive (89) to assess whether it adds explanatory power beyond the UBSC.

To provide an exploratory illustration of the differences in HIA between players with very high vs. very low UB strength, we conducted an extreme-groups comparison as a supplementary descriptive analysis. The top 10% ($n = 6$) with the highest UBSC were compared against the bottom 10% ($n = 6$). Given the small sample sizes, normality was assessed using the Shapiro-Wilk test and visual inspection of distributions. Independent samples t-tests were used to compare groups on key performance variables. The primary focus of this analysis was on the magnitude of the differences, which was quantified using effect sizes (Cohen's d) interpreted according to the expanded thresholds proposed by Sawilowsky (88), where $d \approx 0.01$ = very small, 0.20 = small, 0.50 = medium, 0.80 = large, 1.20 = very large, and ≥2.00 = huge. The alpha level for statistical significance was set at $p < 0.05$. Importantly, this analysis is presented only as hypothesis-

Table 1

Descriptive statistics for isometric push, pull, and handgrip strength tests.*

Test	UB push F_{max} (N/kg$^{0.67}$)	UB pull F_{max} (N/kg$^{0.67}$)	UBSC F_{max} (N/kg$^{0.67}$)	Bilateral handgrip F_{max} (N/kg$^{0.67}$)	Bilateral handgrip RFD_{0-150} (N·s^{-1}/kg$^{0.67}$)	Bilateral handgrip RFD_{0-200} (N·s^{-1}/kg$^{0.67}$)
Mean ± *SD*	57.30 ± 8.25	50.10 ± 7.02	53.70 ± 7.28	20.60 ± 2.40	69.01 ± 17.37	56.1 ± 13.33
95% CI						
Lower bound	55.22	48.40	51.88	20.06	64.63	52.80
Upper bound	59.38	51.94	55.54	21.27	73.38	59.52

*UB = upper body, UBSC = upper-body strength capacity.

generating and should not be overinterpreted due to very small subsamples, which can produce unstable estimates, inflated effect sizes, and dichotomization bias.

Results

Descriptive statistics for all UB strength metrics and HIA performance variables are presented in Tables 1 and 2, respectively. Pearson's correlation analysis revealed that SJ peak power had significant large associations with CMJ height ($r = 0.60$, $p < 0.001$), significant small associations with 10-m sprint acceleration ($r = -0.29$, $p = 0.02$), and significant moderate associations with 30-m sprint performance ($r = -0.34$, $p = 0.007$). Notably, SJ peak power demonstrated no significant correlations with COD ability ($r = 0.01$, $p = 0.94$) or RSAtt ($r = -0.22$, $p = 0.08$).

After controlling for SJ peak power using partial correlations, multiple UB strength metrics demonstrated significant associations with improved HIA performance (Table 3). Upper-body strength capacity showed moderate associations with faster COD 505 times ($r = -0.30$, $p = 0.02$) and RSAtt ($r = -0.36$, $p = 0.004$), along with a small association with faster 30-m sprint performance ($r = -0.27$, $p = 0.03$). Similarly, individual push and pull F_{max} metrics demonstrated small but significant associations with faster COD 505 times ($r = -0.29$, $p = 0.02$; $r = -0.28$, $p = 0.03$, respectively) and significant moderate associations with faster RSAtt ($r = -0.36$, $p = 0.004$; $r = -0.33$, $p = 0.01$, respectively).

Handgrip force metrics, particularly RFD, emerged as the strongest unique correlates of 30-m and RSAtt after accounting for leg power (Table 4). For 30-m sprint time, significant moderate-to-large associations were found between faster times and F_{max} ($r = -0.39$, $p = 0.002$), RFD_{150} ($r = -0.49$, $p < 0.001$), and RFD_{200} ($r = -0.52$, $p < 0.001$). Similarly, significant moderate-to-large associations were observed between F_{max} ($r = -0.44$, $p < 0.001$), RFD_{150} ($r = -0.53$, $p < 0.001$), and RFD_{200} ($r = -0.55$, $p < 0.001$) and faster RSAtt. Both RFD metrics also displayed moderate associations with faster 505 test times ($r = -0.34$, $p = 0.006$), suggesting that rapid force-generation capacity was linked to improved COD performance. Finally, 10-m sprint times demonstrated significant small-to-moderate correlations with higher F_{max} ($r = -0.26$, $p = 0.04$), RFD_{150} ($r = -0.28$, $p = 0.03$), and RFD_{200} ($r = -0.30$, $p = 0.02$). By contrast, CMJ height and the RSAf showed no significant relationships with any handgrip metric.

Notably, after applying the Benjamini-Hochberg procedure ($q = 0.05$) across all partial correlations ($n = 36$), only those with original $p \leq 0.02$ remained significant after correction, while those with original $p \geq 0.03$ did not. Hence, the borderline significance observed in the correlations between the 30-m sprint and UBSC ($r = -0.27$, $p = 0.03$), COD and pull F_{max} ($r = -0.28$, $p = 0.03$), the 10-m sprint and HGSC ($r = -0.26$, $p = 0.04$), and RFD_{150} ($r = -0.28$, $p = 0.03$) should be interpreted with caution.

The hierarchical regression analysis revealed a distinct predictive hierarchy for RSAtt (Tables 5–7). SJ power alone explained 4.8% of the variance in RSAtt, although this effect did not reach statistical significance ($R^2 = 0.048$, $p = 0.083$). Nevertheless, the addition of UBSC at Step 2 significantly improved the model, increasing explained variance by 12.1% to a total of 17.0% ($\Delta R^2 = 0.121$, $p = 0.004$), and the subsequent inclusion of HGSC at Step 3 further increased explained variance by 12.4% to a total of 29.3% ($\Delta R^2 = 0.124$, $p = 0.002$).

The exploratory extreme-groups analysis revealed that the top 10% of players with the highest UB strength outperformed those with the lowest UB strength in all performance metrics despite having a small disadvantage with leg power (Supplementary Table 1, https://links.lww.com/JSCR/A908). Most notably, they demonstrated a large advantage in RSAtt, completing the RSA test significantly faster ($d = -1.92$, $p = 0.006$). Similarly, the high-strength group was significantly faster in both a 505 COD test ($d = -0.72$, $p = 0.002$) and a 30-m sprint ($d = -0.77$, $p = 0.002$), with both differences representing moderate-to-large effects. However, with only 6 players per group, these estimates are inherently unstable, effect sizes may be inflated, and extreme-group dichotomization is prone to bias, so this analysis should be treated as purely exploratory.

Discussion

This is the first study, to the authors' knowledge, to investigate the relationship between isometric UB strength, as assessed using horizontal push-pull maximal force and handgrip force-time metrics, and high-intensity running and jumping actions in professional soccer players after controlling for body mass and SJ power. The results show that UB strength (i.e., push-pull

Table 2

Descriptive statistics for high-intensity actions.*

Test	SJp (W/kg$^{0.67}$)	CMJ-A (cm)	COD 505 (s)	Sprint 10 m (s)	Sprint 30 m (s)	RSAtt (s)	RSAf (%)
Mean ± *SD*	206.04 ± 23.90	42.10 ± 4.58	2.40 ± 0.11	1.82 ± 0.07	4.27 ± 0.14	31.40 ± 0.98	5.37 ± 1.60
95% CI							
Lower bound	200.00	40.98	2.38	1.79	4.23	31.23	4.97
Upper bound	212.07	43.29	2.43	1.83	4.30	31.72	5.78

*SJp = squat jump power; CMJ-A = countermovement jump with arm swing; COD = change of direction; RSAtt = repeated sprint ability total time; RSAf = repeated sprint ability fatigue.

Table 3
Partial correlations between isometric upper-body push/pull strength, isometric upper-body strength capacity and high-intensity actions.*

	CMJ-A (cm)	COD 505 (s)	Sprint 10 m (s)	Sprint 30 m (s)	RSAtt (s)	RSAf (%)
Push F_{max}						
r	0.22	−0.29†	−0.06	−0.29†	−0.36‡	−0.14
p	0.08	0.02†	0.66	0.02†	0.004‡	0.27
95% CI	[−0.17 to 0.56]	[−0.53 to 0.01]	[−0.27 to 0.18]	[−0.57 to 0.09]	[−0.61 to −0.08]	[−0.41 to 0.13]
Pull F_{max}						
r	0.17	−0.28†	−0.06	−0.24	−0.33‡	−0.18
p	0.19	0.03†	0.63	0.06	0.01‡	0.17
95% CI	[−0.34 to 0.48]	[−0.52 to −0.04]	[−0.34 to 0.19]	[−0.58 to 0.11]	[−0.58 to −0.03]	[−0.47 to 0.16]
UBSC F_{max}						
r	0.19	−0.30†	−0.05	−0.27†	−0.36‡	−0.18
p	0.13	0.02†	0.69	0.03†	0.004‡	0.17
95% CI	[−0.27 to 0.53]	[−0.53 to −0.03]	[−0.28 to 0.19]	[−0.55 to 0.07]	[−0.59 to −0.10]	[−0.47 to 0.13]

*CI = bootstrap-derived 95% confidence interval; CMJ-A = countermovement jump with arm swing; COD = change of direction; RSAtt = repeated sprint ability total time; RSAf = repeated sprint ability fatigue; UBSC = upper-body strength capacity.
†$p \leq 0.05$.
‡$p \leq 0.01$.

composite, UBSC) had significant moderate correlations with faster RSAtt and 505 COD, while maximal HGS (i.e., bilateral composite, HGSC) demonstrated significant moderate correlations with faster 30-m sprints and RSAtt. Notably, however, the highest associations were observed for handgrip RFD measures (RFD_{150} and RFD_{200}), which exhibited significant large correlations with faster RSAtt and 30-m sprints, complemented by significant moderate correlations with faster COD times. Hierarchical regression analysis showed that after controlling for leg influence (i.e., SJ power), RSA was significantly explained by UBSC ($\Delta R^2 = 12.1\%$, $p = 0.004$) and, subsequently, by HGSC ($\Delta R^2 = 12.4\%$, $p = 0.002$). Together, these results suggest that relative UB strength, most notably handgrip RFD, is linked to faster high-intensity running performances, which is especially pronounced for RSA.

Key findings of this study were that UBSC (push-pull composite score) significantly correlated with improved RSAtt ($r = -0.36$, $p < 0.01$), with HGSC (left- and right-HGS composite score) demonstrating the strongest associations, particularly for RFD measures ($r \approx -0.54$; $p < 0.001$). These findings were corroborated by the hierarchical regression analysis, which showed that after controlling for leg power, UBSC independently explained an additional 12.1% of the variance in RSAtt ($p = 0.004$), and HGSC added a further 12.4% ($p = 0.002$), together accounting for 29.3% of the total variance. To the authors' knowledge, no previous work has examined these relationships in soccer players. The link between nonspecific UB strength and RSA is, however, supported in research on other multidirectional sports. For instance, Balsalobre-Fernández et al. (6) reported large-to-very-large correlations between bench press maximal force/power outputs and RSA ($r = -0.61$ to -0.86, $p < 0.05$), indicating that basketball players with greater concentric UB strength and power were able to maintain performance better across repeated sprints. Similarly, Ingebrigtsen and Jeffreys (48) found significant large correlations between 1RM bench press strength and better 10-m RSA performance in elite youth handball players ($r = -0.56$, $p < 0.05$). Together, these findings highlight a consistent pattern linking greater UB strength with enhanced RSA performances across different team sports. The observed results may be attributed to 2 key factors: (a) a protective neural mechanism that enhances motor cortex efficiency, reducing the neural cost of muscle activation (51), and (b) a biomechanical advantage gained from powerful movements with the upper extremities (45). In a sport like soccer, where HIA are performed in rapid succession (32,80), mitigating fatigue in this way could directly translate to improved match performance

Table 4
Partial correlations between bilateral handgrip strength metrics and high-intensity actions.*

	CMJ-A (cm)	COD 505 (s)	Sprint 10 m (s)	Sprint 30 m (s)	RSAtt (s)	RSAf (%)
F_{max}						
r	0.10	−0.02	−0.26†	−0.39‡	−0.44‡	−0.11
p	0.44	0.87	0.04†	0.002‡	0.000‡	0.39
95% CI	[−0.18 to 0.39]	[−0.29 to 0.25]	[−0.50 to −0.01]	[−0.58 to −0.17]	[−0.64 to −0.19]	[−0.44 to 0.22]
RFD_{150}						
0.15	−0.34‡	−0.28†	−0.49‡	−0.53‡	−0.07	0.15
0.23	0.006‡	0.03†	0.000‡	0.000‡	0.58	0.23
95% CI	[−0.34 to 0.46]	[−0.52 to −0.10]	[−0.45 to −0.02]	[−0.66 to −0.18]	[−0.70 to −0.21]	[−0.42 to 0.23]
RFD_{200}						
r	0.15	−0.34‡	−0.30†	−0.52‡	−0.55‡	−0.07
p	0.24	0.007‡	0.02†	0.000‡	0.000‡	0.60
95% CI	[−0.30 to 0.47]	[−0.52 to −0.08]	[−0.46 to −0.03]	[−0.67 to −0.21]	[−0.72 to −0.22]	[−0.41 to 0.23]

*CI = bootstrap-derived 95% confidence interval; CMJ-A = countermovement jump with arm swing; COD = change of direction; RFD = rate of force development; RSAtt = repeated sprint ability total time; RSAf = repeated sprint ability fatigue.
†$p \leq 0.05$.
‡$p \leq 0.01$.

Table 5

Model summary for hierarchical regression (squat jump power → upper-body strength capacity → handgrip strength capacity) predicting repeated sprint ability total time.*

Model	R	R^2	Adjusted R^2	Std. error	F	df1	df2	Sig	ΔR^2	ΔF	Δdf1	Δdf2	Sig. ΔF	Durbin-Watson
1	0.220	0.048	0.033	0.96057	3.101	1	61	0.083	0.048	3.101	1	61	0.083	
2	0.412	0.170	0.142	0.90470	6.131	2	60	0.004	0.121	8.767	1	60	0.004	
3	0.542	0.293	0.257	0.84163	8.166	3	59	0.002	0.124	10.329	1	59	0.002	1.885

*Durbin-Watson = 1.885 indicates independence of errors.

(70). Notably, however, while UB strength significantly influenced RSAtt in this study, no significant associations were found for the RSAf. This discrepancy may be attributable to the considerably lower reliability of RSA fatigue measures (CVs = 11–50%) compared with the cumulative time (CVs <3%) (105).

Our results also showed that UBSC was moderately associated with faster COD 505 times ($r = -0.30$, $p < 0.05$). Similarly, handgrip RFD demonstrated a significant moderate relationship with this test ($r \approx -0.34$, $p < 0.01$). Although no other studies seem to have directly investigated the link between general UB strength and COD ability, greater maximal isometric trunk strength has been assessed as a key force transmitter in COD movements by linking the upper torso with the lower extremities (21,41,86). This connection between UB, trunk, and LB muscles could be explained by shared central neural drive that facilitates rapid activation of all extremities (25). In this context, effective bracing and rapid activation of strong upper-limb musculature may contribute to coordinated whole-body force production, thereby positively influencing COD performance through improved force transfer (85). Mechanistically, this link could be realized by the integrated myofascial pathways involving the latissimus dorsi, thoracolumbar fascia, and contralateral gluteus maximus (91) with dissipating rotational and propulsive forces across the trunk during the deceleration and re-acceleration phases (87). This interconnected system likely supports synchronized activation of UB and LB musculature, improving trunk stiffness, pelvic stability, and the arm-leg coordination required for rapid directional changes (21).

Using partial correlation analyses, this study showed that HGSC and RFD measures were significantly associated with faster 30-m sprint performance ($r = -0.39$ and $r \approx -0.50$, respectively; $p < 0.001$) with weaker associations observed for 10-m sprints ($r = -0.26$ and $r \approx -0.29$, respectively; $p < 0.05$). There were no significant associations between the measures of UB strength and sprinting times. Evidence from other soccer-specific research is somewhat congruent, though mixed in scope. Tunçel et al. (104) reported significant large correlations between maximal shoulder press strength and faster 10-m and 30-m sprint times ($r = -0.50$ and $r = -0.60$, $p < 0.05$), although no significant associations were observed for 1RM bench press or Lat pulldown (104). Similarly, HGS displayed large correlations with improved 30-m sprinting in elite youth soccer ($r = -0.62$ to -0.73), explaining up to 67% of sprint variance when combined with age (89). In other multidirectional sports, a significant moderate association has been observed between 3-RM bench press strength and flying 30-m sprint performance for Australian football players (116), yet other findings failed to observe significant relationships with 10-m or 30-m sprints (48,116). Taken together, these findings indicate that general unspecific UB strength may not have significant relevance for maximum sprinting performance, while neuromuscular qualities reflected in handgrip force capacity may be helpful. It is possible that players with greater exposure to frequent HIA are more likely to benefit from improved UB strength qualities due to more pronounced transfer compared with those with less frequent engagement in these actions, which could have influenced the noted relationships; however, this remains speculative and should be examined in future research.

Interestingly, there were no significant correlations found between UBSC or HGS and vertical jumping performance in this study. This is consistent with research showing the lack of relationship between greater UB strength (measured by 1RM bench press) and jumping height in collegiate basketball players (109). Although arm swing can facilitate higher activation and contribution of back extensors to vertical propulsion (13,14,21), it seems that nonspecific UB strength has no significant role for this action. In contrast to findings of this study, however, HGS metrics have been found to significantly correlate with improved jumping performances across athletic populations (67,76,85,89). For example, Schulz et al. (89) reported large correlations between HGS and both vertical and horizontal jumps in elite youth soccer players ($r = 0.69$–0.75, $p < 0.01$). The absence of similar relationships in our data likely reflects the fact that we controlled for LB power, a dominant confounding factor not adjusted for in

Table 6

Coefficients and collinearity diagnostics for hierarchical regression (squat jump power → upper-body strength capacity → handgrip strength capacity) predicting repeated sprint ability total time.*†

Model	Predictor	B	SE	β	t	p	95% CI lower	95% CI upper	Tolerance	VIF
1	Constant	33.327	1.056	—	31.554	0.000	31.215	35.439	—	—
	SJ power	−0.009	0.005	−0.220	−1.761	0.083	−0.019	0.001	1.000	1.000
2	Constant	36.052	1.355	—	26.602	0.000	33.341	38.763	—	—
	SJ power	−0.010	0.005	−0.245	−2.076	0.042	−0.020	0.000	0.995	1.005
3	UBSC F_{max}	−0.047	0.016	−0.349	−2.961	0.004	−0.078	−0.015	0.995	1.005
	Constant	37.936	1.390	—	27.285	0.000	35.154	40.718	—	—
	SJ power	−0.008	0.005	−0.186	−1.670	0.100	−0.017	0.002	0.968	1.033
	UBSC F_{max}	−0.033	0.015	−0.250	−2.190	0.033	−0.064	−0.003	0.921	1.085
	HGSC F_{max}	−0.150	0.047	−0.369	−3.214	0.002	−0.243	−0.057	0.908	1.102

*CI = confidence intervals; VIF = variance inflation factor; SJ = squat jump; UBSC = upper-body strength capacity; HGSC = handgrip strength capacity.
†Dependent variable = RSAtt (s). VIF values <1.2 indicate no multicollinearity concerns.

Table 7

Residual statistics for hierarchical regression (squat jump power → upper-body strength capacity → handgrip strength capacity) predicting repeated sprint ability total time.*

Measure	Minimum	Maximum	Mean	*SD*	*N*
Standardized residual	−1.992	3.310	0.000	0.976	63
Studentized residual	−2.086	3.823	0.005	1.030	63
Mahalanobis distance	0.185	14.551	2.952	2.589	63
Cook's distance	0.000	1.222	0.033	0.154	63
Centered leverage	0.003	0.235	0.048	0.042	63

*Residuals were approximately normally distributed (Shapiro-Wilk $p > 0.05$). Visual inspection indicated homoscedasticity. One case exceeded Cook's distance of 1.0 (1.222), but its removal did not materially affect results.

other investigations. Considering that bilateral CMJ from a standing position rarely reflects a true soccer-specific jumping performance, other approaches to testing this ability may be warranted (31).

Despite heavy physical demands of professional soccer, UB strength training remains surprisingly underdeveloped and undertrained (43,68,69,84,113). Indeed, athletes from other contact-heavy team sports consistently display far superior UB strength levels (5,11,82) along with better HIA results (59) despite similar leg strength (17,19,75,98). In our exploratory supplementary analysis, the top 10% of players with the highest UB strength showed large advantages in RSAtt ($d = -1.92$), 30-m sprint ($d = -0.77$), and COD ($d = -0.72$) over the bottom 10%, despite no significant differences in leg power. Although purely speculative, this stark performance gap may suggest that players who have invested time in UB strength training might have reaped greater benefits for HIA performance compared with those with innately high UB strength levels. However, because we did not measure players' training history, previous UB resistance training exposure, or specific program content, it is impossible to determine whether the observed performance differences are attributable to previous UB strength training exposure. Future intervention studies that directly manipulate UB training and control for baseline strength are needed to test whether UB training can causally improve HIA performance. Notably, a recent systematic review (25) has proposed that repeated high-threshold motor unit recruitment during UB strength training could induce vertical strength transfer through enhanced central neural drive and systemic myokine-mediated adaptations, potentially elevating whole-body neuromuscular capacity independently of direct biomechanical force transfer. Although this mechanism offers a plausible theoretical basis for future investigations, it is not tested by the present data and should be interpreted as hypothesis-generating only.

A principal strength of this investigation, compared with other similar studies, is its methodological rigor, including the use of allometric scaling to account for body mass and control for a direct measure of LB power—critical confounders often overlooked in previous literature. In addition, the selection of force metrics was informed by independently published test-retest reliability studies using the same instruments (23,24). Despite these strengths, certain limitations warrant consideration. The control for LB influence was confined to a metric specific to vertical jumping performance, whereas other leg strength qualities like RFD, particularly in the horizontal direction, were not obtained and accounted for despite being potentially a better determinant of HIA (103,117). Furthermore, the inclusion of players from 3 different clubs, alongside the pooling of outfield positions, may have introduced contextual variability and residual confounding due to differences in training environment, tactical demands, and UB training practices. In addition, differences in playing profiles may influence the observed associations, as players who rely more on HIA (e.g., sprinting and COD) are likely to engage in these actions more frequently, thereby placing UB strength within a more relevant performance context. By contrast, players who are slower and rely more on physical duels or other physical capacities may engage less in HIA, potentially reducing the extent to which nonspecific UB strength relates to HIA performance. Finally, although structured familiarization was provided immediately before testing, all assessments were conducted within a single session. Given that RFD measures are sensitive to familiarization, contraction onset detection, and trial-to-trial consistency, it cannot be confirmed that the values fully reflect stable neuromuscular performance. Future studies should therefore consider multisession familiarization protocols to improve reliability.

In conclusion, this study demonstrates that relative isometric UB strength and handgrip measures were associated with significantly faster RSA and 30-m sprint performance, with less pronounced but still significant associations observed for COD. Handgrip RFD measures emerged as the strongest correlate, demonstrating the largest associations. Future longitudinal studies should compare an intervention group performing targeted UB strength and power training designed to elicit broad neuromuscular adaptations with a control group following an otherwise identical regimen, ideally ensuring that subjects possess comparable performance profiles or are stratified based on their reliance on HIA (e.g., faster players). Such a design would allow isolation of causal effects and directly test the hypothesis that this training approach may enhance HIA, particularly in players who rely on these actions to gain a competitive advantage.

Practical Applications

Strength and conditioning practitioners working in professional soccer may consider UB isometric strength and rapid force production as physical qualities associated with high-intensity running performances. Although the present findings do not establish causality, they suggest that UB strength characteristics reflected in maximal force capacity and RFD qualities may be relevant contributors to HIA and therefore warrant further investigation in longitudinal intervention-based research. There is a preliminary rationale to suggest that short-duration maximal isometric efforts, heavy resisted UB movements, and grip-based strength exercises could provide a low-impact method to enhance sprint-related qualities without increasing mechanical stress on the lower limbs. Integrating targeted UB sessions 1–2 times per week alongside standard soccer conditioning programs may therefore represent a practical and time-efficient strategy to support HIA in professional soccer players.

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