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Associations between maximal strength, sprint, and jump height and match physical performance in high-level female football players

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Studies on females' decisive physical components to physical match-play performance are sparse and only emphasize endurance tests. Thus, the influence of maximal strength and power on physical performance during match-play is currently unknown. The aim of this study was to assess the association between one repetition maximum (1RM) half squat strength, 5-, 10-, and 15-m sprint times, countermovement jump (CMJ) height, and physical high-intensity match-play performance in high-level female football players. Thirty-seven female high-level football players completed 1–2 football matches with physical performance measured by local positioning tracking. Correlations were assessed between physical match-play performance variables (total distance covered, running distance, high-intensity running distance, sprinting distance as well as acceleration and deceleration counts, and peak speed) and laboratory tests (half squat 1RM, 15-m sprint, and CMJ). We found no correlation between 1RM and physical match-play performance. Further, 10-m- and 15-m sprint time ($r = -0.56$, $r = -0.56$, $p < 0.001$) and CMJ jump height ($r = 0.50$, $p < 0.01$) strongly correlated with peak match speed. Further, there was a moderate correlation between 15-m sprint time and ACC ($r = -0.43$, $p < 0.05$). 5-m sprint time did not correlate with physical match-play performance. Laboratory-based sprint and jump performance, but not maximal half squat strength, showed moderate to large correlations with high-intensity physical match-play performance measures in high-level female football players.

KEYWORDS

exercise physiology, external load, local positioning system, neuromuscular performance, one repetition maximum, power, resistance training, Soccer

1 | INTRODUCTION

Important physical capacities in football include aerobic and anaerobic endurance, strength and power, and their derivatives acceleration, sprinting, and jumping.[1] The association between tests of these capacities and physical match-play performance could provide important information for players and coaches and may be a standardized and relevant practice for tracking development of physical capacities in football players. For male players, endurance field tests,[2,3] jump tests,[4,5] and sprint performance tests[6] are all associated with physical match-play performance assessments, whereas strength associations are only studied during small-sided games [7] and for the ability to resist fatigue during match-play.[8]

Females have different body composition than males, where especially males have more muscle mass than females.[9] Additionally, these body compositional differences also comprise different distribution of muscle fiber types, where males inherent greater proportion of the higher threshold, fast twitch fibers,[10] and a lower proportion of slow twitch fibers[11] than females. Consequently, in general, males are stronger,[10] sprint faster, and jump higher[12-14] than females. This also results in different physical match-play performance outputs likely due to lower peak running speed and lower anaerobic power and capacity in females. Hence, it may also result in different associations between laboratory and field-based tests and physical match-play performance assessments. For example, while maximal oxygen uptake is found to be of lower importance for physical match-play performance in male football players, it is correlated with high-intensity running in female football.[15]

In a recent systematic review evaluating the association between laboratory and field-based tests and match-play physical performance, 27 (two studies) out of the 991 players included were females,[16] which highlights the importance of evaluating field-based tests and match-play performance in female football players. Moreover, these two studies assessed associations between endurance-related tests and match-play physical performance.[15,17] Thus, associations between strength and strength derivatives tests, and match-play physical performance can only be generalized from male to female football players. Consequently, studies on strength and strength derivatives for female football players are warranted.[18,19] Considering the inherent differences in body compositional nature between females and males, sex differences between power performance and physical match-play may also be evident, such as observed for maximal oxygen uptake.[15] Consequently, the aim of this study was to assess associations between (1) maximal strength (one repetition maximum (1RM) half squat strength), (2) 5-, 10-, and 15-m sprint, and (3) countermovement jump (CMJ), and physical high-intensity match-play performance assessed as total distance covered, running distance, high-intensity running distance, sprinting distance as well as acceleration and deceleration counts, and peak speed in high-level female football players.

2 | MATERIALS AND METHODS

2.1 | Design and procedure

In this cross-sectional study, the associations between laboratory tests of maximal strength, jump height, and sprint times, and physical performance during friendly 11 vs 11 football match-play were examined. The laboratory tests were carried out over two separate days where 15-m sprint time with 5-m and 10-m split times and CMJ height were tested at day 1, and maximal half squat strength 1RM was tested at day 2. Test days were separated by at least three days. Following all laboratory tests, matches were played with at least 48 h of recovery and within maximum four weeks. Participant inclusion criteria for our analyses were (1) 90 min of playing time in at least one match and (2) complete at least one of the laboratory tests between >48 h to four weeks before the matches.

2.2 | Subjects

Thirty-seven outfield players were included, where 25 players completed one, and 12 players completed two 90-min friendly matches in one given position. One player lost the first 5 min of the match due to error with the tracking device, and for this participant, only peak speed was carried forward for analysis. Additionally, 34 players completed all three laboratory tests, while three participants only completed the CMJ and sprint test. The teams were playing at level two and three in Norway. We contacted the teams' coaches and invited their teams to participate. When informing the players about the study's purpose and the associated risks and benefits, all eligible players who were invited accepted the request to participate. Exclusion criteria were players with injuries making them unable to perform the matches and/or tests, as well as players performing <90 min of playing time. The players' characteristics are described in Table 1. The study complied with the Declaration of Helsinki. All participants gave written informed consent.

2.3 | Sprint test

Prior to each test day, the players refrained from high-intensity exercise for 48 h. On their first visit to the laboratory, the players arrived in the afternoon, where body mass (Seca 813, Seca GmbH & Co.) and height (Seca 217, Seca GmbH & Co.) were measured before they performed a warmup consisting of 14 min of self-selected, self-perceived low-intensity cycling (7 min) and running (7 min). Thereafter, three sprint acceleration attempts of 15 m at approximately 95% of maximal effort were carried out on artificial grass, with an easy walk back to start. Single-beam photocells (ATU-X, IC control AB) mounted to the wall at every 5-m split recorded the sprint times. The first photocell was placed 20 cm above the ground with the following 5-m, 10-m, and finishing 15-m photocells placed 100 cm above the ground. The players

TABLE 1 Descriptive characteristics of the study participants (mean ± SD)

Age (years)	18.4 ± 3.6
Body mass (kg)	61.8 ± 5.4
Height (cm)	167 ± 5
Positions	
Full backs (n)	5
Center backs (n)	7
Center midfielders (n)	12
Wide midfielders (n)	9
Center forwards (n)	4
Variables	
CMJ (n)	37
15-m sprint test (n)	37
1RM (n)	34
TD, RD, HIR, Sprinting, ACC/DEC (n)	36
Peak speed (n)	37

Data are shown as mean ± SD and frequency (n).

Abbreviations: 1RM, 1 repetition maximum; ACC, acceleration counts; CMJ, countermovement jump; DEC, deceleration counts; HIR, high-intensity running distance; TD, total distance.

started 30 cm behind the first photocell, initially triggering the timer when breaking the sensor. The players decided when to start the sprint, and a minimum of three minutes were given between in total three attempts. The fastest 15-m sprint with its split times was carried forward for final analyses.

2.4 | Countermovement jump test

Following >3 min rest from the sprint trials, a CMJ test was performed on a portable force platform (Hur-Labs, ALU4, Finland), connected to a computer, and recorded in the manufacturer´s software (Force platform software suite, HURlabs oy, Kokkola, Finland). All players carried out two jumps with their hand placed on the hips, with a self-selected depth of the countermovement, interspersed by minimum three minutes rest. Each player was verbally encouraged to perform the jump with maximal effort. The highest jump was recorded as their CMJ height.

2.5 | Maximal half squat strength

On their second visit to the laboratory, following the same warmup as prior to the sprint test (14 min self-selected low intensity), maximal strength was assessed by 1RM in half squat. An Olympic Bar (20 kg, T-100G; Eleiko, Halmstad, Sweden) and a squat rack were used for 1RM testing. Prior to starting their 1RM trials, the players warmed up with 10 repetitions at − 50% 1RM. A sports scientist (SP) used a hand-held goniometer to ensure a − 90° knee angle between femur and tibia on every 1RM trial. An image of the − 90° knee angle squat exercise is illustrated in Supplementary Materials. The trials started in standing position with a weight decided by the researcher. For every approved set, the weight was increased with 5–10 kgs. Recovery between every set was set to >3 min, and the highest accepted lift was recorded as 1RM.

2.6 | Physical performance during match-play

Prior to each match, the players refrained from high-intensity exercise for 48 h. All matches were played on artificial grass at the same football stadium (105 × 68 m) during pre-season at 69 degrees north in temperatures varying from −12 to 5 degrees Celsius. All matches started between 19:00 and 21:00. The two halves were 45 min with no added time. The coaches decided on the tactical systems, and positions for the players. Each match was monitored using a stationary radio-based tracking system capturing positional data at 20 Hz (ZXY Sport Tracking System, Trondheim, Norway) as described earlier.[20,21] The system is found reliable and has a good coefficient of variation (CV) being 1% for total distance and 3.1% for high-intensity running distance.[20] Our selected physical match-play performance variables total distance (TD), running distance (RD), high-intensity running distance (HIR), sprinting distance (SD), acceleration counts (ACC) deceleration counts (DEC), and peak speed were chosen for further analysis. The following locomotion speed and acceleration cutoffs were applied: RD (>12km h^{-1}), HIR (>16 km h^{-1}), sprinting (>20 km h^{-1}),[22] accelerations/ decelerations (ACC/DEC; a positive or negative change of speed more than 2 m s^{-2}, lasting more than 0.5 seconds).[23] For players performing two matches, the data were averaged except for peak for peak match speed, where the highest speed was included for the final analyses. For positional characteristics, players were divided into central (center backs, center midfield, forwards) and lateral (full backs, wide midfielders) positions for correlational analysis.

2.7 | Statistical analyses

Normality distribution was examined with visual inspection of Q-Q plots together with the Shapiro-Wilk normality test (all $p > 0.05$ except for high-intensity running distance ($p = 0.007$) and sprint distance (p=0.034). Pearson's correlation coefficients (r) were used to assess the association between physical match-play performance (total distance,

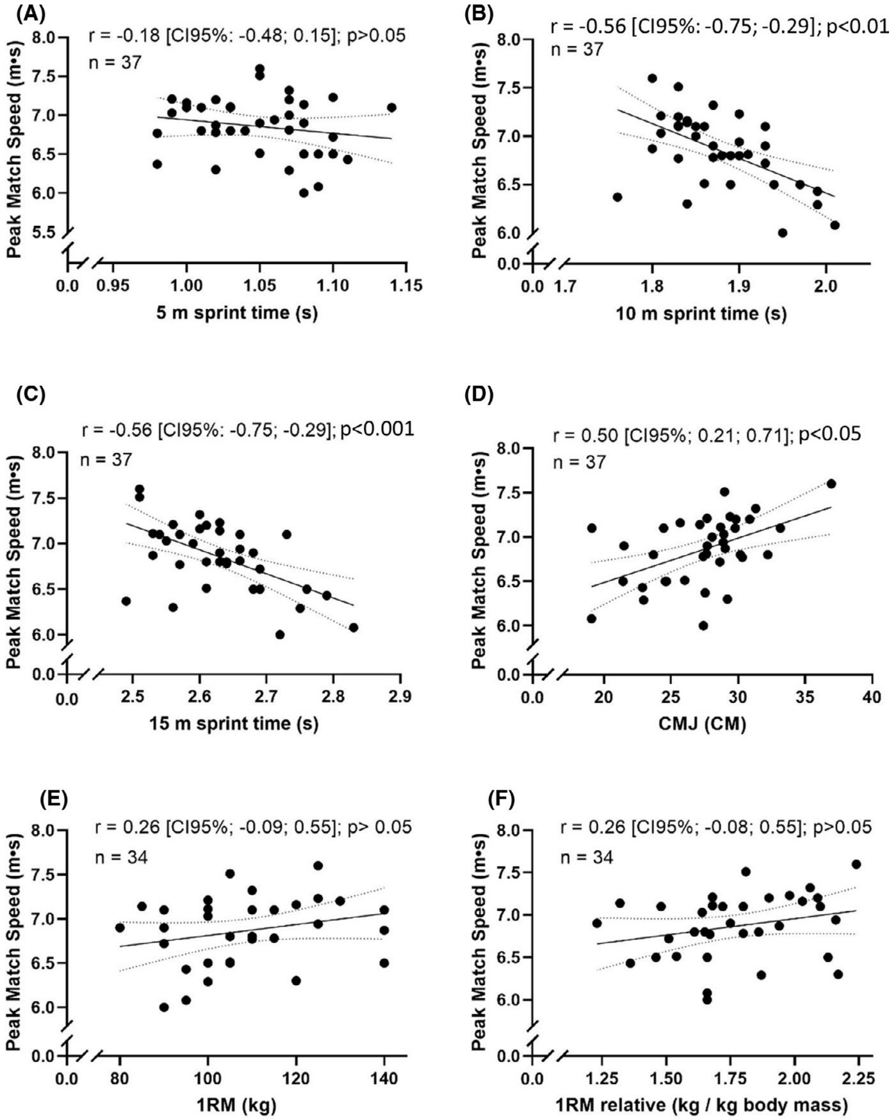

FIGURE 1 Scatterplots with regression lines with 95% CI, and correlation coefficients between peak match speed and 5-m sprint time (A), 10-m sprint time (B), 15-m sprint time (C), CMJ (D), 1RM half squat strength (E), and scaled 1RM / body mass (F), for players of both lateral and central positions pooled. CI, confidence interval; CMJ, countermovement jump; 1RM, one repetition maximum

high-intensity running distance, sprint distance, acceleration counts, decelerations counts, and peak match speed) and laboratory-based assessments (1RM, CMJ, and 5-, 10-, and 15-m sprint times), as well as between the laboratory tests (15-m sprint test, CMJ, and 1RM). In the non-normally distributed variables (high-intensity running distance and sprint distance), Spearman´s rho (ρ) correlation was used. A correlation (r/ρ) of ≥ 0.1 was considered small, ≥ 0.3 moderate, and ≥ 0.5 large.[24] To test for significance of the difference between two correlation coefficients (ie, central vs. lateral positions on the same variables), the Fisher r-to-z transformation was used. This was also used for Spearman´s rho in accordance with others.[25] To decrease the false discovery rate, the p-values were adjusted using the Benjamini-Hochberg method for each laboratory variable (7 pairwise comparisons in each test) for both pooled group correlations, correlations within positions, and for z comparisons between positions.[26] All data are presented as mean ± standard deviations (SD) or r and ρ unless otherwise is stated. The Statistical Package for Social Sciences (version 26.00; IBM Corporation) and the functions r.test and p.adjust (packages psych and stats in R) (R core team, 2021)[27] were used for all statistical analyses.

3 | RESULTS

For the pooled sample, we found no correlation between 1RM and physical match-play performance. Further, 10-m- and 15-m sprint time (r = −0.56, r = −0.56, $p < 0.001$), and CMJ jump height (r = 0.50, $p < 0.01$) strongly correlated with peak match speed (Figure 1). Further, there was a moderate correlation between 15-m sprint time and ACC (r = −0.43, $p < 0.05$). 5-m sprint time did not correlate with physical match-play performance. Stratified analyses of lateral and central positions are presented in Table 2 (descriptive characteristics) and Table 3 (correlation analyses). There were no differences in correlations between positions for any of the variables (all $p > 0.05$).

There were moderate to large correlations between CMJ and the split times during the 15-m sprint test: 5 m

TABLE 2 Match and laboratory variables for lateral, central, and all players

Variable	Lateral players (*N* = 14)	Central players (*N* = 23)	All (*N* = 37)
TD (m)	9927 ± 1026	10051 ± 848#	10003 ± 909
Running (m)	1726 ± 433	1790 ± 414#	1765 ± 417
HIR (m)	1099 ± 375	792 ± 266#	912 ± 343
Sprinting (m)	272 ± 112	171 ± 125#	211 ± 129
ACC (counts)	31 ± 14	22 ± 9#	26 ± 12
DEC (counts)	41 ± 17	29 ± 10#	34 ± 14
Peak match speed (m·s)	6.94 ± 0.25	6.80 ± 0.43	6.86 ± 0.38
15-m sprint			
5-m sprint time (s)	1.05 ± 0.03	1.05 ± 0.04	1.05 ± 0.04
10-m sprint time (s)	1.89 ± 0.05	1.87 ± 0.07	1.88 ± 0.06
15-m sprint time (s)	2.63 ± 0.06	2.63 ± 0.09	2.63 ± 0.08
CMJ jump height (cm)	27.32 ± 3.72	27.42 ± 3.90	27.38 ± 3.78
1RM 90° squat (kg)	107 ± 16*	110 ± 16†	109.1 ± 16.1
1RM 90° squat (kg/mb$^{-0.67}$)	6.80 ± 1.03*	6.95 ± 0.95†	6.89 ± 0.97
1RM 90° squat (kg/mb kg^{-1})	1.75 ± 0.28*	1.78 ± 0.25†	1.77 ± 0.26

Data are shown as mean ± SD.

Abbreviations: 1RM, 1 repetition maximum; ACC, acceleration counts; CMJ, countermovement jump; DEC, deceleration counts; HIR, high-intensity running distance; TD, total distance.

* = n 13;

= 22;

† = n 21.

(r = −0.48, p = 0.002), 10 m (r = −0.66, p =< 0.001), and 15 m (r = −0.72, p =< 0.001) (r = −0.72 (p =< 0.001). There were no significant correlations between the split sprint times and 1RM (all $p > 0.05$). There were moderate correlations between CMJ height and scaled 1RM squat (kg/mb$^{-0.67}$) (r = 0.41, p = 0.015) and 1RM (kg/mb kg^{-1}) (r = 0.43, p = 0.011).

4 | DISCUSSION

This cross-sectional study is to our knowledge the first study to assess laboratory-based lower limb strength and strength derivatives, with physical match-play performance in high-level female football players. We found large correlations between peak match speed, and 10-m and 15-m sprint time, as well as CMJ height. A moderate correlation was found between 15-m sprint time and ACC. These findings are applicable to physical coaches of female football teams, which should focus on relevant assessment tools to monitor the players' physical condition and development.

5 | STRENGTH

There were no associations between maximal half squat strength and physical match-play performance. Thus, it seems that dynamic lower limb muscle strength does not play a central role in physical match-play performance.

A previous study in male football players reported a moderate correlation between isometric maximal strength and small-sided games performance.[7] They assessed physical performance in the playing formats 8 v 8 and 4 v 4, while we assessed it during 11 v 11 matches. The above-mentioned previous study found a moderate correlation between strength and acc.[7] When the number of players involved, and field size during game play decrease, there is an increase in the number of accelerations/decelerations.[28] Decelerations are shown to be muscularly taxing,[29] and therefore, a high strength level could potentially be related to the ability to perform decelerations. However, their findings are in contrast to ours as we did not observe a positive correlation between accelerations/decelerations and maximal strength. Another study reported isokinetic strength to be correlated with match-play physical performance in the context of fatigue parameters, where greater levels of strength were related to an ability to maintain performance toward the end of matches.[8] This suggests that strength may be related to the ability to perform accelerations during small-sided games, as well as the ability to resist physical performance fatigue during match-play, at least in males.

Moreover, whether strength assessments are evaluated as dynamic or static, isometric, or isokinetic, may influence the interpretation of the importance of strength for football performance. On the one hand, measures of isometric force

TABLE 3 Correlations between physical match-play performance and laboratory tests for lateral and central positions

	5-m sprint time (s)	10-m sprint time (s)	15-m sprint time (s)	CMJ (cm)	1RM (kg)	1RM (kg/mb$^{-0.67}$)	1RM (kg/mb kg^{-1})
Lateral positions							
TD (m)	*r* −0.23 (0.47)	*r* −0.39 (0.17)	*r* −0.20 (0.54)	*r* −0.09 (0.94)	*r* −0.42 (0.49)	*r* −0.21 (0.99)	*r* −0.10 (0.93)
Running (m)	*r* −0.33 (0.47)	*r* −0.41 (0.17)	*r* −0.18 (0.54)	*r* −0.04 (0.94)	*r* −0.34 (0.49)	*r* −0.12 (0.99)	*r* −0.02 (0.96)
HIR (m)	ρ −0.40 (0.16)	ρ −0.58 (0.03)	ρ −0.47 (0.09)	ρ 0.28 (0.34)	ρ −0.37 (0.21)	ρ −0.08 (0.79)	ρ 0.08 (0.79)
Sprinting (m)	ρ −0.21 (0.47)	ρ −0.54 (0.12)	ρ −0.45 (0.15)	ρ 0.32 (0.61)	ρ −0.32 (0.49)	ρ −0.10 (0.99)	−0.12 (0.93)
ACC (counts)	*r* −0.27 (0.47)	*r* −0.47 (0.17)	*r* −0.55 (0.07)	*r* 0.02 (0.94)	*r* −0.33 (0.49)	*r* −0.28 (0.99)	*r* −0.25 (0.93)
DEC (counts)	*r* −0.21 (0.47)	*r* −0.42 (0.17)	*r* −0.55 (0.07)	*r* 0.20 (0.86)	*r* −0.04 (0.89)	*r* 0.04 (0.99)	*r* 0.08 (0.93)
Peak match speed (m·s)	*r* −0.33 (0.47)	*r* −0.76 (0.007)	*r* −0.70 (0.04)	*r* 0.55 (0.28)	*r* −0.22 (0.67)	*r* 0.01 (0.99)	*r* 0.11 (0.93)
Central positions							
TD (m)	*r* 0.45 (0.84)	*r* −0.02 (0.93)	*r* 0.01 (0.96)	*r* −0.23 (0.67)	*r* −0.11 (0.81)	*r* 0.04 (0.86)	*r* 0.12 (0.62)
Running (m)	*r* −0.13 (0.77)	*r* −0.14 (0.63)	*r* −0.12 (0.70)	*r* −0.02 (0.94)	*r* −0.01 (0.99)	*r* 0.16 (0.60)	*r* 0.23 (0.46)
HIR (m)	ρ −0.04 (0.85)	ρ −0.28 (0.21)	ρ −0.25 (0.26)	ρ −0.03 (0.91)	ρ 0.41 (0.08)	ρ 0.45 (0.04)	ρ 0.41 (0.08)
Sprinting (m)	ρ −0.14 (0.77)	ρ −0.37 (0.19)	ρ −0.29 (0.33)	ρ 0.17 (0.67)	ρ 0.47 (0.14)	ρ 0.45 (0.16)	ρ 0.32 (0.37)
ACC (counts)	*r* −0.33 (0.77)	*r* −0.49 (0.07)	*r* −0.46 (0.11)	*r* 0.33 (0.46)	*r* 0.35 (0.30)	*r* 0.41 (0.16)	*r* 0.41 (0.37)
DEC (counts)	*r* −0.22 (0.77)	*r* −0.35 (0.19)	*r* −0.33 (0.33)	*r* 0.09 (0.79)	*r* 0.09 (0.81)	*r* 0.21 (0.53)	*r* 0.25 (0.46)
Peak match speed (m·s)	*r* −0.16 (0.77)	*r* −0.57 (0.04)	*r* −0.55 (0.04)	*r* 0.52 (0.07)	*r* 0.47 (0.14)	*r* 0.42 (0.16)	*r* 0.36 (0.37)

r = Pearson´s correlation, *ρ* = Spearman´s rho. P-values (in brackets) are adjusted for multiple comparisons.

Abbreviations: ACC, acceleration counts; DEC, deceleration counts; HIR, high-intensity running distance; TD, total distance.

development have been reported [7]; on the other hand, isokinetic strength has been applied by researchers.[8] However, it is argued that the most functional strength measurement for football players is dynamic strength, which replicates the movements in match-play.[19] This is in line with findings of dynamic strength being more related to sport-specific sprinting than isometric strength.[30]

6 | SPRINT

For the first time, we display the relationship between a sprint test and physical performance during match-play for female football players. Thus, short sprint assessment in female football may be a relevant assessment tool for monitoring physical capacity and the effect of physical conditioning. Sprinting performance in football is usually divided into an initial acceleration phase (5–10 m) and a longer maximal speed phase (20–40 m).[31] However, most sprints during football match-play are relatively short (Griffin et al, 2020), and our findings indicate that 10-m sprint may be a suitable test relating to peak match speed performance in female football. However, shorter distances during testing are not necessarily better, as 5-m sprint time not was correlated with match-play peak speed in our study, which is consistent with a study in male players.[5] At the same time, the association between sprint performance and physical match-play seems to be inconclusive in the literature.[32,33] Future studies should assess 20–40-meter sprinting time and physical match-play performance to evaluate the importance of testing longer sprint distance in female football.

7 | COUNTERMOVEMENT JUMP

We did not observe any correlation between CMJ and physical match-play performance, which is in contrast to findings in both youth and senior male players,[4,5] except for a strong correlation between CMJ and peak match speed for the players as a pooled group. As we observed a non-significant large correlation ($r > 0.5$) in strata analysis of positions, which was similar to the effect in the pooled group, this may be due to low statistical power, as finding a large effect ($r > 0.5$) with 80% and an alpha of 0.05 would require a sample of 20 players. Thus, we interpret no lower importance of CMJ and peak speed by position in female football. However, large intra-game variations in high-intensity physical performance between positions have been observed previously [34]; thus, our interpretation should be confirmed by future research. Furthermore, although vertical jump and linear sprinting are considered independent skills by some,[35] they are associated in this study. This finding is inconclusive for male players.[6,36] Further, there are contradictive findings on whether CMJ height separates players of different competitive levels in female football.[37,38] It may be that CMJ is more important for other traits than for physical match-play performance, such as headers, which is indicated for youth male players.[39]

Finally, previous studies assessing associations between laboratory-based tests and physical match-play performance have differed between sexes, as described above for maximal oxygen uptake.[15] This indicate that there may be differences in which and how energy systems and neuromuscular factors relates to physical match-play performance between sexes in football, which warrants further and detailed investigations to provide an equal knowledge base for training and performance development for both sexes.

7.1 | Limitations

The relatively small sample size, and low number of matches in this study can be regarded as a limitation, which may be illustrated by a large non-significant correlation between CMJ and peak speed in strata analyses. A large number of players representing all playing positions is important for correlational analysis, since there have been found large inter-game variations in high-intensity physical match-play performance between positions.[34] Further, as team sports with opponents introduces many degrees of freedom, it is important to consider physical performance at best as a proxy, and not a direct measure of football performance (*ie*, wins/losses), or alternative measures that is linked to performance (points, goals scored, *etc*.).

8 | CONCLUSION

In this cross-sectional study, laboratory-based sprint performance, but not maximal half squat strength, was associated with measures of high-intensity physical performance during matches in high-level female football players. CMJ was associated with peak match running speed. These findings suggest that 15-m sprint and CMJ tests can be used with relevance to physical match-play performance in female football players.

9 | PERSPECTIVE

Although not examined here, the physical tests in this study may be relevant for sports performance in other ways, which together with its relationship with physical performance should be recognized by the practitioners. For example, CMJ height is associated with heading success and 1RM squat with tackling success.[39] 1RM squat strength is also found to predict future injuries.[40] Nevertheless, our findings are applicable to practitioners when selecting tests to monitor physical condition of female football players.[6]

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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