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RELATIONSHIP BETWEEN ISOKINETIC STRENGTH, VERTICAL JUMP, SPRINT SPEED, AGILITY AND YO-YO INTERMITTENT RECOVERY TEST PERFORMANCE IN SOCCER PLAYERS

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Abstract:
The current study investigated the relationship between isokinetic knee strength, jump performance, agility, linear and repeated sprinting capacity and Yo-Yo IR1 test performance and the fatigue indices of some of these variables in semi-professional soccer players. Twenty semi-professional soccer players participated in this study, performing 6 tests: bilateral concentric isokinetic strength tests of the knee extensors and flexors (60◦.s-1 and 300◦.s-1), jump tests (countermovement, squat and repeated jumping), linear sprints (10 and 30 m), agility (Illinois test), Bangsbo repeated sprints (7 x 34.2 m), and Yo-Yo IR1 tests. While no isokinetic variables were significantly correlated with field test results, some jump test results correlated with AgiWB, 10- and 30-m sprint times, RSTMEAN and FIRS. Furthermore, the knee isokinetic strength (60◦.s-1 and 300◦.s-1) indices and jump capacities demonstrated moderate to strong relationships with each other. In addition, AgiWB correlated with the 10-m sprint times and RSTMEAN, 30-m linear sprint times correlated with 10-m sprint times and AgiWB, and FIRS and RSTMEAN correlated with the Yo-Yo IR1 test results. The results suggest that power output during CMJ and RJ tests and not isokinetic knee strength are informative in determining field conditioning parameters for semi-professional soccer players.

Keywords: isokinetic, jump, lower extremity, field test, soccer

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1. Introduction

Soccer is an intermittent sport that requires different types of physical activities and a variety of skills. Some movements involved in the game are relatively explosive, such as sprints, jumps and kicking [1], whereas others involve low-intensity activities, such as walking, shuffling, standing and jogging [2].

Time-motion analyses have shown that most of the distance in a game is covered via walking and other low-intensity activities. Moreover, top-level players cover approximately 10-13 km during a soccer game [3,4], and the number of high-intensity activities performed can be used to identify the skill level of a player and categorize them into upper or lower levels. In fact, international players engage in 28% more ($P < 0.05$) high-intensity running (2.43 vs. 1.90 km) and 58% more sprinting (650 vs. 410 m) than professional players at lower levels of competition [5]. Furthermore, Mohr et. al. found that top-class soccer players perform 150–250 intense actions per game [5] and perform a high-intensity run (≥19.8 kmh^{-1}) every 72 s [6]. These efforts are particularly dependent on the maximal strength of the lower limbs and their ability to generate anaerobic power [1].

Evaluating the physical capacities of soccer players is a vital issue in modern soccer; hence, objective and reliable diagnostic tools are necessary for these evaluations. To assess dynamic muscle strength, isokinetic dynamometry is often applied as a laboratory test [7], and to evaluate anaerobic power, vertical jump tests are used as both laboratory and field assessments [8]. These tests help determine muscle strength and anaerobic capacity in the lower extremities of soccer players [9,10]. However, these tests are generally considered laboratory tests and are not available to all soccer teams because the state-of-art technology required is quite expensive. Moreover, there has been discussion in the literature about whether they are appropriate for testing dynamic activities that include acceleration, deceleration, changes in direction and sprinting power that is involved in soccer. Therefore, several field tests, such as single or repeated sprint, agility and Yo-Yo Intermittent Recovery (IR) tests have been used in some studies and are thought to better reflect the strength, power and aerobic and anaerobic capacities of soccer players.

For these reasons, several studies have been conducted to investigate the relationship between the results of laboratory tests and field tests to evaluate soccer players, but these studies have provided contradictory findings. For instance, Newman et al. found a strong relationship between knee extensor and flexor peak torques and 10- to 20-m sprint times [11], whereas Cometti et al. did not find any significant relationship between those parameters [1]. Furthermore, Atabek et al. found that countermovement jump (CMJ) height showed a significant and moderate relationship with isokinetic knee strength during extension measured at 120° and 180°/s, whereas squat jump (SJ) height was not correlated with any of the isokinetic strength parameters [12], which is in agreement with the findings of some studies [13–15] but contradicts those of others [16].

Some studies have been conducted to determine the correlation between field performance tests, such as repeated sprint, linear sprint, agility, and jumping performance, or Yo-Yo IR1 test results and the fatigue indices (FIs) of some of those variables, which are estimated via established formulas. However, the correlation between these variables shows a wide variability in the reported findings and, in particular, the correlation of the isokinetic knee strength FI with field test results has seldom been reported.

1.1 Purpose of the Study

It is considered essential that fitness testing should be administered before an athlete begins a strength and conditioning programme and/or a competitive season [17]. For this reason, the assessment of different types of performance outcomes for soccer players could be important for coaches to (i) evaluate and improve their training programmes and (ii) assess player progress during the pre- and mid-training periods. Therefore, the purpose of the current study was to investigate the relationship between isokinetic knee strength, jump performance, agility, linear and repeated sprint capacity, Yo-Yo IR1 test performance and the FIs of some of these variables in semi-professional soccer players.

2. Material and Methods

2.1. Subjects

Twenty semi-professional soccer players (age: 22.55 years ± 2.70; height: 175 cm ± 5.35; weight: 72.70 kg ± 6.74; body mass index: 23.71 ± 2.05; body fat percentage: 13.45 ±4.54) volunteered to participate in the current study. None of the subjects had experienced any previous injuries in their lower limbs. Only one player did not attend to Yo-Yo IR1 test, because of personal issues. Tests were performed at the beginning of the season and were completed over six days, and no training was performed during this period. Tests performed on each day were as follows: (1^{st} day) anthropometric measurements, agility and linear sprint test; (2^{nd} day) repeated sprint test; (3^{rd} day) jump tests; (4^{th} day) isokinetic strength tests; and (6^{th} day) Yo-Yo IR1 test. Electronic timing gates and mats (Smartspeed, Fusion Sport, Australia) were used to perform the sprint, repeated sprint, jump, agility, and Yo-Yo IR1 tests. Standardized progressive warm-up activities were performed prior to all tests to control for potential variables and improve the reliability of all tests. Fifteen minutes of warm-up activities, including jogging, dynamic activities and soccer-specific movements, were performed. The experiments were undertaken with the understanding and written consent of each subject, and the study conforms to The Code of Ethics of the World Medical Association (Declaration of Helsinki), with the approval of the Ethics committee of Osmangazi University, Turkey.

2.2. Test Protocols of Isokinetic Measurements

The bilateral concentric isokinetic strength of the knee extensors and flexors was measured using an isokinetic dynamometer (Cybex, Humac Norm Testing and

Rehabilitation System, USA). Muscle strength was measured at angular velocities of $60^{\circ}.s^{-1}$ (5 repetitions) and $300^{\circ}.s^{-1}$ (30 repetitions). Concentric strength at $60^{\circ}.s^{-1}$ was considered to be representative of a player's maximal strength, while 30 concentric repetitions at $300^{\circ}.s^{-1}$ were considered representative of a player's strength endurance. The dynamometer was calibrated prior to the testing session according to the procedures prescribed by the manufacturer. Players performed three submaximal trials at $60^{\circ}.s^{-1}$ and five submaximal trials at $300^{\circ}.s^{-1}$ to familiarize themselves with the protocol before the maximal tests. The tests at $60^{\circ}.s^{-1}$ were performed first, followed by those at $300^{\circ}.s^{-1}$. For the tests at $60^{\circ}.s^{-1}$, a 30-s rest period was allowed between the submaximal tests and a 2-min rest period was allowed before tests at $300^{\circ}.s^{-1}$. Five trials at $60^{\circ}.s^{-1}$ were performed, and the maximal peak torques for knee extension where flexion was registered via computer (Humac, 4.5.5 version, CSMI, USA). The highest value was used as the outcome measure. Thirty trials at $300^{\circ}.s^{-1}$ were performed, and the data were exported as an excel file to calculate the FI using the following equation: FI_{ISO} = 100 – ((Average performance of last 3 reps/Average performance of first 3 reps) x 100) [18].

2.3. Squat, Countermovement and Multiple Jump Measurements

The players performed SJs, CMJs and 30 sec of repeated jumps (RJs) with their arms akimbo to minimize their contribution to the movement [1]. Three tests were carried out for the SJ and CMJ tests, but only the best results were taken into account for the evaluation process. A 2-min rest was allowed between jumps to minimize the effect of fatigue. Two RJ tests were performed, and 5 minutes were allowed between each test, with the highest values for RJ_{MAX} and RJ_{MEAN} used for further analysis. Peak power (PJ_{POW}) in the CMJ tests was estimated using the formula from Johnson and Bahamonde: PJpow (W) = 78.6 CMJ (cm) + 60.3 mass (kg) - 15.3 height (cm) - 1,308 [19].

2.4. Agility Test

Illinois agility performance tests were used to evaluate each player's agility skills. The data were collected in accordance with established methods [20]. "With Ball" (Agi_{B}) and "Without Ball" (Agi_{WB}) agility tests were performed, and three repetitions were performed for each test with a three-min rest between each repetition. Furthermore, a five-min rest was allowed between the Agi_{B} and Agi_{WB} sessions. The best scores for each test were used for further analysis.

2.5. Sprint Test

Tests of 10- and 30-m sprint speeds, as suggested by Svensson and Drust, were used to evaluate linear speed [21]. Electronic timing gates were placed at the start line (0 m) and at 10 (T10M) and 30 m (T30M), at approximately 0.6 m from the ground. The soccer players performed two maximal sprints over each distance, and their best individual results were used for analysis in this study [22].

2.6. Repeated Sprint Test (Bangsbo Sprint Test)

The protocol for the Bangsbo repeated sprint test (RST) consists of seven maximal 34.2-m sprints. During each sprint, changes in direction (< 90°) to the right and left sides are made, as previously described by Pasquarelli et al. [22]. This protocol showed good reproducibility [coefficient of variation = 1.8% (95% confidence interval = 1.5 – 2.4%)] [23]. The mean time (RST_{MEAN}) and the shortest time (RST_{SHORT}) among the seven sprints were recorded [22]. During the test, heart rate was recorded at 5-s intervals via the Polar Team 2 system. Moreover, the FI (FI_{RS}) during the test, which allows for the evaluation of the percentage by which performance is reduced between the sprints, was calculated using the following equation [22]: $FI_{RS} = (RST_{MEAN} / RST_{SHORT} \times 100) - 100$.

2.7. Yo-Yo IR1 Test

Yo-Yo IR1 tests were conducted on grass fields using previously described procedures [24]. Sprint times and total metres covered were calculated automatically by the electronic timing gates, and estimated VO2 max was calculated using the following equation for the Yo-Yo IR1 test: VO2max (mL/min/kg) = IR1 distance (m) × 0.0084 + 36.4. During the test, heart rate was recorded at 5-s intervals via the Polar Team Pro system. The Yo-Yo IR1 test consists of 2 x 20-m shuttle-runs at increasing velocities, with 10 s of active recovery between the shuttles [24]. The test was started at a speed of 10 $km.h^{-1}$, and speed increments were adjusted automatically using the electronic timing gates. The test was finished when all participants either failed to reach the line twice at the test speed or felt too exhausted to continue at the required speed.

2.8. Statistical Analyses

Descriptive statistics were produced to describe the characteristics of the subjects. All data are expressed as the mean ± SD. To evaluate the relationship between parameters, Pearson's correlation coefficients were calculated. The level of significance was set at $p < 0.05$.

3. Results

The isokinetic knee strength measurements and jump test results of the soccer players in the study are displayed in Table 1. Table 2 shows the results of the field test scores (agility, linear and repeated sprint and Yo-Yo IR1 test results).

Table 1: Knee isokinetic strength and jump test results for soccer players

			Mean	SD
Knee Isokinetic Strength	$60^0.sn^{-1}$	R_{EXT}	217.43	34.39
		R_{FLEX}	157.33	25.58
		L_{EXT}	217.52	49.60
		L_{FLEX}	154.62	34.25
	$300^0.sn^{-1}$	R_{EXT}	112.19	16.59
		R_{FLEX}	98.72	14.93

		L_{EXT}	112.74	22.68
		L_{FLEX}	99.77	17.08
	$300^0.sn^{-1}$ (FI_{ISO})	R_{EXT}	42.42	7.13
		R_{FLEX}	36.46	10.32
		L_{EXT}	43.83	9.66
		L_{FLEX}	36.36	11.09
Jump	SJ (cm)		36.49	5.04
	CMJ (cm)		38.44	5.12
	PJ_{POW} (W)		4696.40	573.91
	RJ_{MAX} (cm)		40.79	4.84
	RJ_{MEAN} (cm)		35.89	4.5

R_{EXT}: Right extensor; R_{LEX}: Right flexor; L_{EXT}: Left extensor; L_{FLEX}: Left flexor; FI_{ISO}: Isokinetic fatigue index. SJ: Squat jump; CMJ: Countermovement jump; PJ_{POW}: Peak jump power; RJ_{MAX}: Repeated jump max; RJ_{MEAN}: Repeated jump mean.

Table 2: Field test results for soccer players

		Mean	SD
Illinois	Agi_B (s)	21.12	1.07
	Agi_{WB} (s)	16.17	0.64
Linear Sprint	10-m (s)	1.57	0.09
	30-m (s)	4.05	0.27
Repeated Sprint	RST_{MEAN} (s)	7.18	0.26
	FI_{RS}	8.99	2.71
	RS_HR	186.20	6.83
Yo-Yo IR 1	YoYo IR1 (m)	1939.05	574.68
	VO_{2Max} (ml/kg/dk)	52.69	4.83
	YoYo IR1_HR	191.00	5.48

Agi_B: Agility with ball; Agi_{WB}: Agility without ball; RST_{MEAN}: Repeated sprint mean time; FI_{RS}: Repeated sprint fatigue index; HR: Heart rate.

Table 3 shows the correlations between the isokinetic knee strength and jump test results and the field test results. Table 4 shows the correlations among the laboratory test results, while Table 5 shows correlations among the field test results.

Table 3: Correlations between isokinetic knee strength and jump test results and field test results for soccer players

	Agi_B	**Agi_{WB}**	**10 m**	**30 m**	**RST_{MEAN}**	**FI_{RS}**	**Yo-Yo IR1**
R_{EXT} ($60^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS
R_{FLEX} ($60^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS
L_{EXT} ($60^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS
L_{FLEX} ($60^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS
R_{EXT} ($300^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS
R_{FLEX} ($300^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS
L_{EXT} ($300^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS
L_{FLEX} ($300^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS
FIR_{EXT} ($300^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS

FIR_{FLEX} ($300^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS
FIL_{EXT} ($300^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS
FIL_{FLEX} ($300^0.s^{-1}$)	NS	NS	NS	NS	NS	NS	NS
SJ	NS	-.504*	NS	-.522*	-.466*	NS	NS
CMJ	NS	-.516*	NS	NS	-.537*	NS	NS
PJ_{POW}	NS	-.539*	-.542*	NS	NS	.465*	NS
RJ_{MAX}	NS	-.548*	NS	NS	-.686**	NS	NS
RJ_{MEAN}	NS	-.669**	NS	NS	-.769**	NS	NS

*: p<0.05; **: p<0,001
SJ: Squat jump; CMJ: Countermovement jump; PJ_{POW}: Peak jump power; PJ_{MAX}: Peak jump max; PJ_{MEAN}: Peak jump mean; Agi_{B}: Agility with ball; Agi_{WB}: Agility without ball; RST_{MEAN}: Repeated sprint mean time; FI_{RS}: Repeated sprint fatigue index; R_{EXT}: Right extensor; R_{LEX}: Right flexor; L_{EXT}: Left extensor; L_{FLEX}: Left flexor; FIR_{EXT}: Right extensor fatigue index; FIR_{FLEX}: Right flexor fatigue index; FIL_{EXT}: Left extensor fatigue index; FIL_{FLEX}: Left flexor fatigue index.

None of the isokinetic results was significantly correlated with the field test results. Some of the jump parameters were correlated with AgiWB, 10-30 m sprint times, RSTMEAN and FIRS (Table 3). Furthermore, while none of the isokinetic strength parameters showed a correlation with the SJ results, Pearson's correlation coefficients between some measures of isokinetic strength and the results of the jump performance tests showed moderate to strong correlations, as displayed in Table 4.

Table 4: Correlations among isokinetic knee strength and jump test results for soccer players

	$60^0.s^{-1}$				**$300^0.s^{-1}$**				**$300^0.s^{-1}$**			
	R_{EXT}	**R_{FLEX}**	**L_{EXT}**	**L_{FLEX}**	**R_{EXT}**	**R_{FLEX}**	**L_{EXT}**	**L_{FLEX}**	**FIR_{EXT}**	**FIR_{FLEX}**	**FIL_{EXT}**	**FIL_{FLEX}**
SJ	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CMJ	**.439***	NS	NS	NS	**.527***	NS	NS	NS	NS	NS	NS	NS
PJ_{POW}	**.498***	**.601****	NS	NS	**.740****	**.792****	**.578***	**.628****	NS	NS	NS	NS
RJ_{MAX}	**.494***	**.522***	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
RJ_{MEAN}	**.495***	**.467***	NS	NS	NS	NS	NS	NS	**.475***	NS	NS	NS

*: p<0.05; **: p<0,001
R_{EXT}: Right extensor; R_{LEX}: Right flexor; L_{EXT}: Left extensor; L_{FLEX}: Left flexor; FIR_{EXT}: Right extensor fatigue index; FIR_{FLEX}: Right flexor fatigue index; FIL_{EXT}: Left extensor fatigue index; FIL_{FLEX}: Left flexor fatigue index; SJ: Squat jump; CMJ: Counter movement jump; PJ_{pow}: Peak jump power; PJ_{Max}: Peak jump max; PJ_{Min}: Peak jump minimum; PJ_{Mean}: Peak jump mean.

Table 5: Correlations among field test results for soccer players

	Agi_{B}	**Agi_{WB}**	**10-m**	**30-m**	**RST_{mean}**	**$FI_{RS)}$**
Agi_{WB}	NS					
10 m	NS	**.457***				
30 m	NS	NS	**.522***			
RST_{mean}	NS	**.704****	NS	NS		
FI_{RS}	NS	NS	NS	NS	NS	
Yo-Yo IR1	NS	NS	NS	NS	**-.621***	**-.551***

*: p<0.05; **: p<0,001
Agi_{B}: Agility with ball; Agi_{WB}: Agility without ball; RST_{Mean}: Repeated sprint mean time; FI_{RS}: Repeated sprint fatigue index.

Based on the correlations among the field tests, while AgiB did not correlate with any field test results, AgiWB correlated with the 10-m sprint times and RSTMEAN. Furthermore, the 30-m linear sprint times were correlated with the 10-m sprint times and AgiWB. In addition, FIRS and RSTMEAN were correlated with the Yo-Yo IR1 test results.

4. Discussion and Conclusion

In the present study, the relationships between isokinetic knee strength, jump performance, linear and repeated sprint capacity, agility with and without a ball and Yo-Yo IR1 test performance in semi-professional soccer players were analysed, and the main findings were that (a) AgiB, AgiWB, RSTMEAN, and Yo-Yo IR1 test results did not correlate with any of the isokinetic strength results. However, some important correlations were identified among the jump parameters measured and the field test results. (b) Furthermore, isokinetic strength and jump test results showed moderate to strong correlations with each other. (c) In addition, important correlations were identified among field test results.

One of the most important findings of the present study is that linear sprint times did not correlate to any of the isokinetic strength (60°.s-1 x 5 repetitions) or isokinetic strength endurance (300°.s-1 x 30 repetitions) results. In line with our results, Alemdaroğlu [7] and Kin İşler et al. [25] also found no significant correlations between linear sprint performance and isokinetic knee strength; however; Dowson et al. [26] and Metaxas et al. [27] have reported a significant correlation between these parameters at lower angular velocities.

In addition, the results of another important sprint performance assessment, repeated sprint tests (RSTs), which evaluate an individual's anaerobic capacity via repeated, short, maximal efforts [10], did not demonstrate a significant correlation with the 60◦.s-1 or 300◦.s-1 isokinetic knee strength test results in the current study, which is consistent with previous findings [10,27]. One plausible explanation for this lack of association may be because the tests reflect different physiological requirements: power output requirements are higher in RSTs [28], while maximal concentric dynamic strength and strength endurance have greater effects on the results of isokinetic tests [29]

The other running-based performance assessed was agility, which is defined as "*a rapid whole-body movement with change of direction or velocity in response to a stimulus*" [30]. Therefore, the characteristics of a player's leg muscles are essential for agility. However, isokinetic indices did not significantly correlate to either of the agility performance measures (AgiB and AgiWB) in the current study. Young et al. found low and non–significant correlations ($r = 0.34$) between an 8-m sprint with directional changes and power output during sets of isokinetic squats at 40◦.s-1 [31]. In contrast to these results, Negrete and Brophy found moderate and significant ($r = –0.60$, $p < 0.05$) relationships between single-leg isokinetic squat strength and a complex multidirectional change-of-direction speed task [32]. The results of the current study are in line with the study performed by Young et al. in that none of the concentric isokinetic knee strength indices significantly correlated with agility ($P > 0.05$). Agility is one of the components of velocity, and is based on the role of stretch-shortening cycles (SSCs) of muscles in generating rapid power increases and the transfer of power, as reflected by a power-time curve, in a lateral and upward direction [33]. To change directions, the centre of gravity needs to be lowered by bending both knees, shortening the stride length and rapidly pushing with one leg, which is affected by the phase of muscle contraction in relation to the SSC mechanism [30]. In the current study, there was no significant correlation between the 60◦.s-1 and 300◦.s-1 isokinetic knee strength and agility results (AgiB and AgiWB). Because agility and maximal leg strength are both based on the generation of high forces and explosive movements [29], these results may be somewhat surprising. The observed results may have occurred due to the lack of the SSC under the isokinetic test conditions [34] because isokinetic leg strength tests are performed while sitting rather than running; therefore, power estimates in these tests may differ from those of field-based agility (Illinois) tests, which are more representative of team sports activities [35,36].

Even though isokinetic knee strength test results did not correlate with those of running-based activities, some of the vertical jump indices, which measure anaerobic power output and leg strength [37] showed moderate to high correlations with most of the running-based (10- and 30-m linear sprint times, RST indices and AgiWB) performance measures assessed in the semi-professional soccer players in the current study.

Studies investigating the relationship between vertical jumping performance and linear sprint speed generally emphasize the effects of body weight on the correlation coefficients. For instance, some studies have found correlations between linear sprint speed and absolute jumping performance in SJ and CMJ tests [38,39], but others have only found correlations with jump performance when expressed relative to body weight and have interpreted their results as reflecting the fact that sprinting involves high-force production to support the weight of the body [40–42]. In the current study, the 30-m sprint results showed a significant negative correlation ($r = -.522$, $p < 0.05$) with absolute SJ performance, whereas the 10-m sprint results were significantly and negatively correlated ($r = -.542$, $p < 0.05$) with PJPOW (as measured in the CMJ tests).

Furthermore, AgiWB was negatively correlated with all jump test results, but interestingly, AgiB was not correlated with any of these results in the current study. To our knowledge, only a few studies have examined the correlation of agility with and without a ball with vertical jump capacities. Köklü et al. found similar results: in soccer players, the strongest correlation was found between CMJ capacity and zigzag agility without a ball ($r = -0.769$), and no correlation was found between zigzag agility with a ball and CMJ capacity [39].

However, the absolute vertical jump results (SJ, CMJ, RJ) showed moderate (SJ: $r = -466$, $p < 0.05$; CMJ: $r = -537$, $p < 0.05$) to high (RJMAX: $r = -686$, $p < 0.01$; RJMEAN: $r = -769$, $p < 0.01$) negative and significant correlations to the RST times in the current study. Dardouri et al. did not find any correlations between SJ and CMJ capacities and RST results but did find a significant correlation between the standing five-jump test (5TJ) and

RST results [28], whereas Tonnessen et al. showed a significant, moderate correlation between test performance in 10 x 40-m sprints with 60 s of recovery between trials and CMJ capacities [43]. Two important factors have been suggested to explain why vertical jump tests (SJ and CMJ) do not predict performance in repeated sprints: (a) the influence of changes of direction [44] and (b) the recovery time between sprint repetitions [43]. In the current study, a strong correlation was found between the RJ indices and the results of the RSTs, which also included changes of direction, as did the tests in the study by Tonnessen et al. [43]. Therefore, the findings of our study suggest that recovery time is more likely a better predictive factor for evaluating RST results in relationship to jump performance.

The reason why jumping capacities showed a stronger correlation than the results of the isokinetic tests with the field test results in soccer players might be explained as follows: even though both tests (isokinetic, jump) measure the strength of the lower extremities, there are differences in the tasks involved in each test. Jump tests are closed kinetic chains and include multiple joints, while isokinetic strength tests are open kinetic chains and include the movement of a single joint, which is in contrast to patterns of movement involved in running [15]. This fits with the results showing that jumping capacities showed moderate to strong significant correlations with running-based field test results, whereas isokinetic test results were not correlated with any of those tests. Furthermore, the results of the statistical analysis of the relationship between the isokinetic test results and jump performance illustrate additional important findings. There was a significant, low to moderate correlation (REXT: $r = .498$, $P < 0.05$; RFLEX: $r = .681$, $P < 0.01$) between the 60°.s-1 isokinetic dominant-leg knee extensor and flexor strength test and CMJ capacity, while a moderate to high correlation (REXT: $r = .740$, $p < 0.01$; RFLEX: $r = .792$, $p < 0.01$; LEXT: $r = .578$, $p < 0.05$; LFLEX: $r = .628$, $p < 0.05$) was found between PJPOW, calculated based of CMJ results, and peak isokinetic torque in tests for knee extensor and flexor strength in both legs at 300°.s-1. These results are in agreement with those of other studies in demonstrating (1) an increasing correlation with the increase in angular velocity of the isokinetic tests [45,46] and (2) that when jumping height is expressed relative to the subject's multiplied by the subject's body weight, as in the equation for calculating PJPOW in the current study, the correlation increases [47]. CMJ is mostly related to coordination among muscles and their SSCs. It has been shown that energy is absorbed by the elastic elements of active muscles in the pre-stretched phase and is later utilized in the concentric phase of the muscle [48]. Cerrah et al. investigated EMG activities of the quadriceps and hamstring muscles in amateur and professional soccer players and their results revealed that quadriceps muscles showed higher activation levels in the propulsion phase than in the other phases of the jumping motion [49]. Although isokinetic actions and the biomechanics of jumping involve different movement tasks, the moderate to high correlation between these actions, especially at high angular velocities, may be explained in terms of the role of the isokinetic strength of the knee extensors in providing an explosive take-off during jumping in soccer players.

The other running-based test performed was the Yo-Yo IR1 test, which also requires endurance. The Yo-Yo IR1 test results were not correlated with those of the isokinetic tests or the jump tests. To the best of our knowledge, there has been only one previous study on the relationship between Yo-Yo endurance test results and isokinetic knee strength, which was performed on handball players. In that study, no significant correlation was found between knee extensor and flexor strength and Yo-Yo performance test results, which is in line with the findings of the current study [50]. The Yo-Yo IR1 Test is frequently used to assess the performance and aerobic capacity of athletes, while isokinetic dynamometry is more frequently used to assess muscle strength in athletes. However, muscle endurance and muscle strength are seldom reported together as they are related to different aspects of muscle performance. In the current study, we did not find any significant correlation between any of the isokinetic performance results (isokinetic strength: 60◦.s-1 x 5 repetitions and isokinetic strength endurance FI: 300◦.s-1 x 30 repetitions) and the Yo-Yo test IR1 test results. Despite the fact that the isokinetic FI was related to strength endurance, it was not correlated with the results of the endurance-based field test (Yo-Yo IR1). Furthermore, none of the jump test results was correlated with the Yo-Yo IR1 test results, which is in contrast to the findings of Hermassi et al. [51]. Although these two measures might be expected to be related because of the similarities in the muscle contraction patterns (i.e., their SSCs), other important factors may explain the results observed. For example, different energy sources during the activities, patterns of fibre-type recruitment requirements and exercise tasks (running versus sitting) may be some of the factors resulting in the lack of a correlation in this study.

For field tests, AgiB did not correlate with any of the variables in the study. However, AgiWB correlated with the 10-m linear sprint and RST results. Both the 10-m sprint and Illinois agility test results may be influenced by the type of running performed in the repeated sprint test protocols because they include linear, unidirectional running or running with a change of direction.

The Yo-Yo IR1 results and the RSTMEAN and FIRS values showed significant, moderate correlations in the current study, thus corroborating the results of Chaouachi et al. [52], who showed a moderate relationship ($r = -0.44$, $p = 0.04$) between tests involving repeated changes of direction and speed (RST) and tests of aerobic endurance with 180◦ turns following linear runs (Yo-Yo IR1). The correlations found in the current study were similar to those found in a previous study (RSTMEAN $r = -.621$, $p < 0.05$; FI: $r = -.551$, $p < 0.05$). The Yo-Yo IR1 test and the RST both include the acceleration and deceleration of the legs and changes of direction during the turns, and these demands possibly result in similar abilities being assessed in these two tests. Another possible factor contributing to the positive correlation between these tests is the physiological process involved as it has been shown that aerobic metabolism contributes more to the significantly increased total energy demand and is more important, relative to the contribution of glycolysis, in maintaining power output during a long series of repeated sprints [10,53].

Finally, for the FIs, the only relevant correlation occurred between the Yo-Yo IR1 results and FIRS. Oliver suggested that the utility of FIs was doubtful and that other measures, such as average time, total time, and best time, are more relevant for assessing performance capacity in RSTs [54]. Therefore, further research is needed to fully understand the relationship between field test results and FI calculation methods.

The present study confirmed that the correlations between the results of the jump tests and field tests (AgiWB, 10- and 30-m sprints, and RSTMEAN) are primarily moderate to strong in semi-professional soccer players. As a result, power output in CMJ and RJ tests may therefore be useful in terms of coaching, especially in making decisions on the parameters for field conditioning in soccer players.

One possible explanation for the lack of relationships between isokinetic strength results and those of field conditioning tests could be due to the different characteristics of running- and sitting-based activities. Because a complex series of synergistic muscle actions involving antagonistic and agonistic muscles are performed during running, sitting-based activities may not be appropriate for assessing performance in soccer players [55], and isokinetic tests may not necessarily reflect the movement of the limbs involved in the different running tasks in soccer [56]. However, studies investigating the relationship between technical components of the game, such as the soccer kick [57,58] and throw-ins [59], and isokinetic strength show moderate to strong positive correlations between these variables. Therefore, isokinetic strength may be a better determinant of technical skills than field conditioning and performance in soccer.

Conflict of Interest Statement
The authors of this manuscript report no conflict of interest. This study did not involve any external research grant support.

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