Functional Performance, Maximal Strength, and Power Characteristics in Isometric and Dynamic Actions of Lower Extremities in Soccer Players

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[1]*Faculty of Sport, University of Pablo de Olavide, Sevilla, Spain;* [2]*Medical Services, Sevilla Football Club, Sevilla, Spain; and* [3]*Institute of Exercise Biology and Physiotherapy, University of Tartu, Tartu, Estonia*

Abstract

Requena, B, González-Badillo, JJ, Saez de Villareal, ES, Ereline, J, García, I, Gapeyeva, H, and Pääsuke, M. Functional performance, maximal strength, and power characteristics in isometric and dynamic actions lower extremities in soccer players. *J* Strength *C*ond *R*es 23(5): 1391–1401, 2009—The purposes of the present study were to determine muscle strength and power output characteristics in a group of professional soccer players and to identify their relationships with 2 functional performance tests (vertical jumping height and 15-m sprint time). Maximal strength and power indices attained against different loads in barbell back squat exercise, isometric maximal force of the knee extensor and plantar flexor muscles, isokinetic peak torque of the knee extensors muscles, vertical jumping height in squat and counter-movement jumps, and 15-m sprint time tests were assessed in 21 semiprofessional soccer players (age 20 ± 3.8 years). Correlation analyses were performed to examine the relationship between each of these measures. The main results of the present study were that (a) maximal power in concentric half-squat exercise was attained with a load of 60% of 1 repetition maximum, representing 112% of body weight; (b) the performance in the functional tests selected was significantly related with all the half-squat variables measured, especially with loads of 75–125% of body weight; and (c) low to nonsignificant correlations were found between functional tests performance and isometric and isokinetic muscle strength measures. It was concluded that in semiprofessional soccer players (a) isometric and isokinetic muscle strength assessed in an open kinetic chain were not movement-specific enough to predict performance during a more complex movement, such as jump or sprint and (b) concentric half-squat exercise was principally related with the functional tests selected when it was performed against external loading within the range of the load in case of which the maximal power output was attained.

Key Words soccer, muscle strength, squat, sprinting, jumping

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Introduction

Soccer is one of the most widely played sports in the world (35). From a physiological point of view, soccer is a high-intensity, long-lasting intermittent exercise (2 parts of 45–50 minutes interspersed by 15-minute rest) that relies predominantly on aerobic energy pathways (39). Players cover about 10–12 km during a soccer match and need to generate high-intensity actions repeatedly within irregular intervals (6,39). For example, during a game a sprint bout occurs approximately every 90 seconds, each lasting for 2–4 seconds (6). In the last decades, numerous studies have tested soccer players with different competitive levels in field and laboratory conditions with the aim of giving clues to the talent detection, identification and development training programmes (35,39). Most of these studies have measured anthropometric and endurance-related variables and few of them have focused on muscle strength characteristics. However, muscle strength is generally accepted to be a major factor influencing success in sport. In track athletes, explosive muscular contractions (particularly by the knee extensors) have been identified to be a crucial component of sprint performance (2,15,48). In soccer, the ability of the neuromuscular system to produce maximal force and power output appears to be as important as endurance.

During a soccer game, the most decisive skills (e.g., the ability to jump high, kick, turn and sprint fast in duels against opponents) are directly related with the power production capacity of the neuromuscular system. In this sense, several studies have identified isokinetic strength of knee extensor and flexor muscles, vertical jump and short-distance sprinting speed as differentiating factors between soccer players of different practice levels (11,24). However, there is a paucity of research on examining soccer players' strength and power characteristics. Cross-sectional studies evaluating soccer players' strength and power characteristics have generally used knee and hip isokinetic muscle actions and functional tests such as vertical jump and maximal short-distance sprinting (39). Recent studies include information about maximal squat strength performance in professional (46,47) and elite youth (26) soccer players. However, practically no information is available about other strength-power indicators extensively used in the literature, such as the maximal isometric strength of lower extremities or the power production in weight-training movements (i.e., squat or power clean) against different external resistances. Indeed, only one study (42) has measured maximal power at different percentages of 1 repetition maximum (1RM) in the squat jump, bench throw, and hang-pull exercises in a group of soccer players. Overall, this research observed maximal power values in squat jump and bench throw exercises ranging 30–40% of 1RM. These results are in agreement with the related literature who proposes the range of 30–45% of 1RM as optimum resistance for maximal power outputs in ballistic exercises (5,31,38).

Typically, a correlational approach applying isokinetic or isoinertial (constant gravitational load) dynamometry has been used to elucidate the relationship between strength/power measures and functional performance tests such as sprint time, kicking velocity, or vertical jumping. In elite soccer players, a positive relationship between peak isokinetic knee flexion (11) or maximal dynamic strength in squat (46) and 10-m sprint time has been showed. This procedure may offer information about the underlying determinants of some decisive high-intensity actions in soccer (i.e., short-distance sprint) and as a result improve strength and conditioning practice in terms of assessment and exercise prescription (13). However, our understanding of the relationships between isometric, isokinetic and isoinertial measures with functional performance tests in soccer players is still rudimentary.

The purposes of the present study therefore were 1) to determine muscle strength and power output characteristics in a group of professional soccer players, including measures which have not been previously published with soccer players, as isometric maximal force of lower limbs and maximal power output in traditional squat exercise against different external loads; and 2) to identify the relationships between the muscle strength and power output measures in the isometric, isokinetic and isoinertial exercises selected and 2 functional performance tests extensively used in the literature (15-m sprint time and vertical jumping).

Methods

Experimental Approach to the Problem

To determine the relationship between isometric and dynamic muscle strength variables in a group of professional soccer players, various isometric and dynamic strength and power output measures of the lower extremities were assessed. These included maximal strength (1RM) and power attained against different loads in traditional barbell back squat exercise, isometric maximal force (MF) of the knee extensor (KE) and plantar flexor (PF) muscles, isokinetic peak torque (PT) of the KE muscles, vertical jumping height in squat (SJ) and counter-movement (CMJ) jumps, and 15-m sprint time. Correlation analyses were performed to examine the relationship between each of these measures. The results were then analyzed to determine the degree of relation between each of the studied measures. The experimental phase took place during the end part of the preseason period.

Subjects

A total of 21 male soccer players from Tammeka JK (Tartu, Estonia) who played in the First Estonian Soccer Division took part in the study, and performed all tests described below. Their mean (*SD*) age, height, and body mass were 20 (3.8) years, 178.5 (6.7) cm, and 71.5 (6.7) kg, respectively. The players studied were all semiprofessionals who trained on a daily basis (2–4 hours per day). Their experience in soccer practice was 12–15 years. Moreover, all subjects had been undertaking a continual resistance training program incorporating strength and power training exercises for at least a year. All the subjects were informed of the procedures and the purpose of the study and their written informed consent was obtained. The study carried the approval of the University of Tartu Ethics Commitee and was performed in accordance with the Helsinki Declaration.

Muscle Strength and Power Output Tests

One repetition concentric maximum (1RM), maximal peak power output (MPP), and the peak power attained with an external load equivalent to the 50, 75, 100, and 125% of the body weight (MP_{50BW}, MP_{75BW}, MP_{BW}, and MP_{125BW}, respectively) were tested in half-squat exercise. These variables were measured by means of 2 different half-squat tests performed on separate days. During both squat tests, the shoulders of the subjects were in contact with a bar positioned so that the knee starting angle was 90 degrees (measured manually with goniometer). On command, the subject performed a concentric leg extension as fast and forcefully as possible starting from the flexed position to reach the full extension of 180 degrees against the resistance determined by the weight plates added to both ends of the bar, whereas the trunk was kept as straight as possible. The tests were performed on Smith́s machine in which the barbell was attached to both ends, with linear bearings on 2 vertical bars allowing only vertical movements.

In both tests, the subjects were instructed to move the load as fast as possible. Before testing, warm-up consisted of a set of 5 half-squat concentric leg extensions at loads of 40–50% of their perceived 1RM. The first test was designed to measure half-squat 1RM and MPP. The first load selected was 20 kg (barbell load) and next the resistance was gradually increased by 10 kg (i.e., 10 kg, 20 kg, 30 kg, etc.) until the MPP was reached. We considered that MPP was reached when the

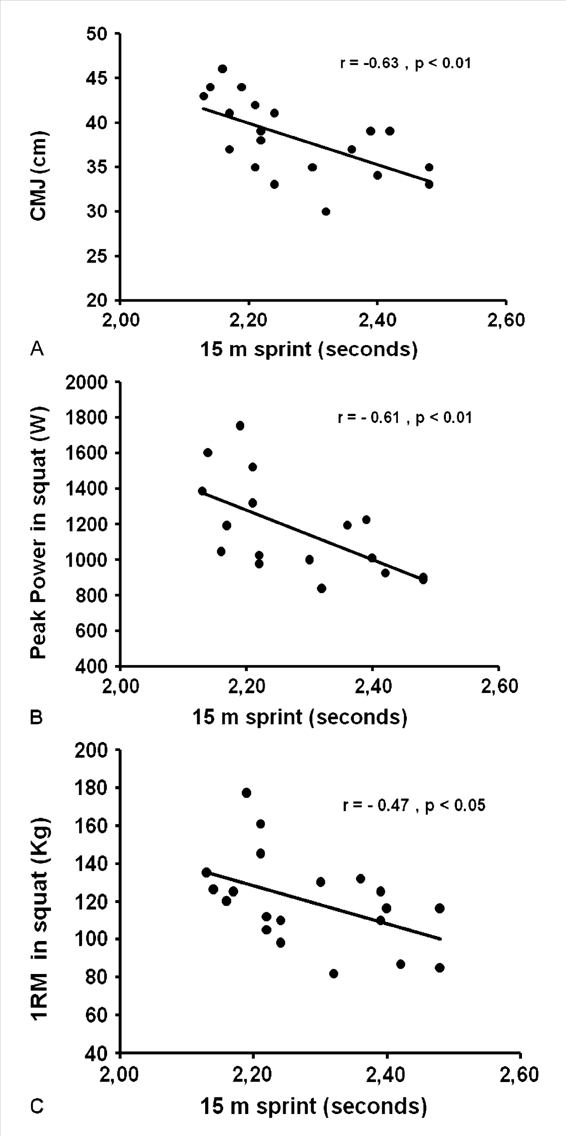

Figure 1. Relationships between counter-movement vertical jump height (a), maximal peak power (a), and 1 repetition maximum (1RM) (b) in concentric half-squat exercise with 15-m sprint time.

peak power attained with 1 load (i.e., 80 kg) was lower than the PP of the previous load (i.e., 70 kg; Figure 1). From this moment, 3–4 attempts were performed until the subject was unable to extend the legs to the required position. The last acceptable extension with the highest possible load was determined as 1RM. A 3-minute rest between sets was employed. The second test was designed to measure the MP_{50BW}, MP_{75BW}, MP_{BW}, and MP_{125BW}. After warm-up, 2 test actions were recorded for each external load and the best reading (with the highest velocity) was taken for further analysis. The time for rest between each trial and set was always 1.5 minutes.

During half-squat testing, bar displacement (mm) and maximal power (Watts) were recorded by linking a rotary encoder to the end of the bar. The rotary encoder (Computer Optical Products, Chatsworth, Los Angeles, CA) recorded the position and direction of the bar within an accuracy of 0.2 mm and time events with an accuracy of 1 ms. Customized software (JLML I+D, Madrid, Spain) was used to calculate power output for each repetition of half squat performed throughout the whole range of motion.

Isometric Force Testing

During the measurement of isometric MF of the KE muscles the subjects sat in a custom-made dynamometric chair with the knee and hip angles equal to 90 and 110 degrees, respectively. The body position of the subject was secured by Velcro belts placed over chest, hip and thigh. The unilateral knee extension isometric force of the dominant leg was recorded by standard calibrated strain-gauge transducer DST 1778 (Russia) mounted inside a metal frame which was placed around the distal part of the ankle above the malleoli using a Velcro belt. Signals from the strain-gauge transducer were linear from 0 to 2500 N. The force signals were sampled at the frequency of 1 kHz and stored on computer hard disk, using software WSportLab (Urania, Estonia). The reproducibility of the force measurement was calculated with repeated static loads on the dynamometer. The relative error between the trials was less than 1%, while the relative difference was less than 0.7%. The high reliability of isometric strength measurements using the strain-gauge transducer mentioned earlier was demonstrated in the previous study, which indicated that test-retest correlations with a 5-day interval between measurements was $r = 0.92$ (34).

During testing, the subjects were asked to exert isometric knee extension against the belt of the strain-gauge transducer as forcefully as possible during 2–3 second. Strong verbal encouragement and visual feedback were used to motivate the subjects. The force-time curve was analyzed by personal computer and the greatest force of the three maximal knee extensions was taken as the isometric MF. Two-minute rest periods were allowed between trials.

During the measurement of isometric MF of the PF muscles, the subjects were seated in a custom-made dynamometer with the dominant leg flexed 90 degrees at the knee and ankle angles, and mounted inside a metal frame. The foot was strapped to an aluminium foot plate. The inclination of the foot could be altered by rotating the foot plate about an axis that corresponded to that of the ankle joint (i.e., the medial malleolus). The knee cap and front side of the thigh were held down by an adjustable pad. Torques acting on the foot plate were sensed by a standard strain-gauge transducer connected with the foot plate by rigid bar. The electrical signals from the strain-gauge transducers were amplified and displayed with special amplifier. The system was linear from 10 to 1600 N. The point of application of force to the foot plate was located on articulation regions between the metatarsus and ossa digitorum pedis. The force signals were sampled at a frequency of 1 kHz and stored on hard disk for further analysis.

During testing, the subjects were instructed to push the foot plate as forcefully as possible for 2–3 seconds. Strong verbal encouragement and visual feedback were used to motivate the subjects. The force-time curve was analyzed by personal computer and the greatest force of the 3 maximal plantar flexions was taken as isometric MF. Two-minute rest periods were allowed between trials.

Isokinetic Peak Torque Measurement

Isokinetic concentric knee extension PT was measured using a Cybex II dynamometer and manual (Lumex Inc., Ronkonkoma, NY). After calibration of the dynamometer, subjects were seated in the adjustable chair and thigh, hip, and chest were stabilized using straps. The axis of rotation of the knee joint was aligned with axis of the dynamometer lever arm. The force pad was placed 3–4 cm superior to the medial malleolus with the foot in plantigrade position. The knee and hip of the dominant leg was positioned at 90 and 110 degrees of flexion, respectively. Range of motion during testing was set using the goniometer through an arc from 90 degrees of knee angle to full extension. Subjects were instructed to hold their arms across the chest to isolate extension movements in knee joint. During the testing the subjects were asked to perform knee extension as forcefully and quickly as possible through a complete range of motion. Three attempts were carried out at low (60 degrees$\cdot$s^{-1}) and moderate (180 degrees$\cdot$s^{-1}) angular velocities, and the one with the highest PT value was used for further analysis. The trial proceeded from the lower to the higher angular velocity. Verbal encouragement was provided during the trials. A rest period of 2 minutes was allowed before and between the attempts. All torque measurements were gravity corrected.

Vertical Jump and Sprint Performance Testing

Vertical jump height was determined using a force platform with specifically designed software (Bioware, Kistler, Switzerland). Jumping height was determined as the center of mass displacement calculated from force development and measured body mass. Two types of vertical jumps were performed: SJ and CMJ. Squat jump was started from static semisquatting position with the knee angle of 90 degrees of flexion, followed by subsequent action, during which the leg and hip extensor muscles contracted concentrically. In case of CMJ, each subject stood erect on the force platform and performed a preparatory movement down to approximately 90 degrees of the knee flexion, stretching the leg extensor muscles (eccentric contraction), followed by explosive maximal extension in the opposite direction (concentric contraction).

Fifteen-meter sprint time was measured using photocells (Brower Timing, Fairlee, VT) at the start and finish lines. The players performed 20 minutes of individual warm-up including several accelerations. They then carried out 4 trials separated by a 3-minute rest interval, and the best trial was used for the subsequent statistical analysis. The players decided themselves when to start each test from the static position 30 cm behind the photocell, with the time being recorded from when the subjects intercepted the photocell beam.

Experimental Protocol

During testing, the players participated in their regular conditioning, sport, and strength training routines. This entailed 2 times per week of explosive-strength training sessions. The main exercises of these sessions were the traditional squat-lift, power clean, vertical SJ and CMJ to box, hurdle vertical jumps, and sprints. Thus, all players were familiar with traditional squat and vertical jump testing exercises, which they had performed regularly as part of their training. Adequate rest of 48 hours was allowed between testing and any training session to allow for optimal recovery before the next testing session. Each player was tested separately, instructed, and verbally encouraged to give maximal effort on all tests. Players attended 6 testing sessions at approximately the same time of the day. The first 4 sessions were designated as familiarization sessions in the course of which the players were carefully familiarized with the testing procedure of voluntary force production of the lower extremity muscles during several submaximal and maximal actions. Testing was conducted over 2 sessions separated by 5–7 days. During the first testing occasion, each subject was tested for his isometric MF of the KE and PF muscles, and 1RM and MPP in the traditional half-squat exercise. In the second test session, each subject was tested for vertical jumping and 15-m sprint performance, isokinetic PT of the KE muscles and, MP_{50BW}, MP_{75BW}, MP_{BW} and MP_{125BW} in traditional half-squat exercise. Data obtained from the last 2 sessions of the familiarization period and both testing sessions allowed us to calculate the reproducibility of the measurements of 1) maximal strength and muscle power output in the traditional half-squat exercise, 2) isometric MF of the KE and PF muscles, 3) vertical jump height and sprint time, and 4) isokinetic PT of the KE muscles. Test-retest reliabilities for the experimental tests demonstrated intraclass correlations ranging from 0.8 to 0.95.

Statistical Analyses

Values are expressed as means $\pm$ *SD*. Pearson correlation coefficients were used to determine the interrelationships between variables. A one-factor analysis of variance was used to determine the effect of relative load on power during half-squat test. Scheffé post-hoc analyses were then used to identify the loads or loading range at which maximum power occurred. To examine the importance of the strength and power measures on sprint performance, the 11 subjects with the fastest 15-m times ($\pm$ seconds) and the 11 subjects with the slowest 15-m times ($\pm$ seconds) were compared using independent sample t-test. A level of $p \leq 0.05$ was used for establishing statistical significance.

Results

Half-Squat, Vertical Jump and 15-m Sprint Performance

The 1RM in half-squat exercise was 119.5 $\pm$ 26.2 kg that represented the 166 $\pm$ 27% of body mass. Figure 1 shows a representative case of a player power production during the

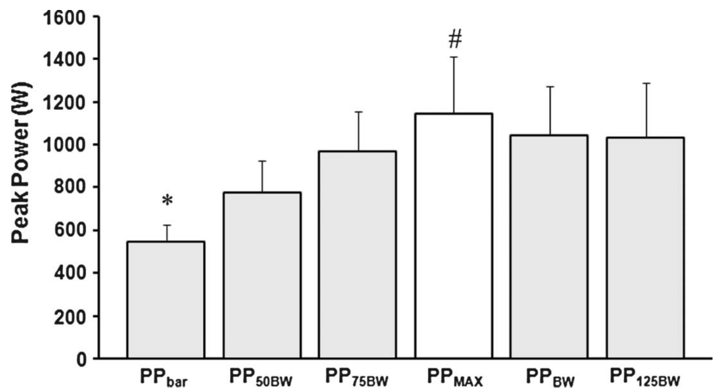

Figure 2. Absolute peak power output across the loading spectrum in the concentric half-squat exercise. PP_{bar} = peak power attained with the barbell (20 kg); PP_{50BW}, PP_{75BW}, PP_{100BW}, PP_{125BW} = peak power attained with an external load equivalent to 50, 75, 100, and 125% of the body weight, respectively. MPP = maximal peak power value obtained in half-squat exercise (see text for details). #*Significant ($p \leq 0.05$) difference with the rest of power values attained with the loads selected. §Significantly lower than PP_{75BW}, PP_{100BW}, PPMAX, and PP_{125BW}.

traditional half-squat exercise against different external loads (interspersed by 10 kg) until the MPP was attained. For the entire sample analyzed, MPP was 1148.6 ± 301 W and was performed with an external load equivalent to 112.5% of body weight and 60.3% of 1RM. Mean barbell displacement and velocity values when MPP was reached were 23.1 ± 3.9 cm and 1.06 ± 0.12 $m \cdot s^{-1}$, respectively. MPP was significantly greater across the loading spectrum selected (MP_{50BW}, MP_{75BW}, MP_{BW} and MP_{125BW}, see Figure 2). Moreover, no significant differences were observed between MP_{75BW}, MP_{BW} and MP_{125BW} values (Figure 2). Vertical jump height was 37.3 ± 5.6 and 32.3 ± 4.9 cm for CMJ and SJ, respectively. The mean (*SD*) time for the 15 m sprint test was 2.28 ± 0.16 seconds.

Isokinetic and Isometric Muscle Strength

Isokinetic PT of the KE muscles significantly decreased ($p < 0.01$) as the test velocity was increased (265.6 ± 42.8 vs. 134.3 ± 29.7 Nm for 60- and $180° \cdot s^{-1}$, respectively). Isometric MF was significantly greater in PF compared with KE muscles (348.1 ± 40 vs. 228.5 ± 41 Nm, $p < 0.05$).

Pearson's Product Moment Correlation Matrix

Table 1 represents the relationship between the variables selected. A significant negative correlation was found between 15-m sprint time and vertical jump height (CMJ, $r = -0.63$, $p < 0.01$; SJ, $r = -0.57$, $p < 0.05$; Figure 3). Half-squat variables showed significant relationships with the functional tests selected (CMJ and SJ height and 15-m sprint time) ($r = 0.47$ to 0.65). The only half-squat measure that was not significantly related to vertical jump measures was

Table 1. Intercorrelation matrix between muscle strength, power, and speed measures.

	1RM	MPP	PP_{50BW}	PP_{75BW}	PP_{BW}	PP_{125BW}	IMF_{KE}	IMF_{PF}	IPT_{KE60}	IPT_{KE180}	SJ	CMJ	ST15
1RM	1.00												
MP	0.82**	1.00											
MP_{50BW}	0.59**	0.82**	1.00										
MP_{75BW}	0.66**	0.90**	0.90**	1.00									
MP_{BW}	0.83**	0.94**	0.80**	0.86**	1.00								
MP_{125BW}	0.75**	0.95**	0.73**	0.82**	0.85**	1.00							
IMF_{KE}	0.58**	0.64**	0.60*	0.65**	0.67**	0.58*	1.00						
IMF_{PF}	0.43	0.50*	0.61**	0.49*	0.57**	0.39	0.51*	1.00					
IPT_{KE60}	0.38	0.50*	0.42	0.43*	0.53*	0.40	0.46*	0.29	1.00				
IPT_{KE180}	0.37	0.40	0.30	0.34	0.38	0.36	0.31	0.02	0.87**	1.00			
SJ	0.50*	0.56*	0.42	0.65**	0.56**	0.51*	0.55**	0.30	0.39	0.48*	1.00		
CMJ	0.50*	0.56*	0.42	0.65**	0.56**	0.51*	0.57**	0.14	0.40	0.48*	1.00	1.00	
ST15	−0.47*	−0.62**	−0.49*	−0.61**	−0.62*	−0.49*	−0.42	−0.35	−0.31	−0.22	−0.57	−0.64**	1.00

Values represents means (*SD*). 1RM = 1 repetition maximum in half-squat; CMJ = countermovement vertical jump; IMF_{KE} and IMF_{PF} = isometric maximal force of the knee extensors and plantar flexors, respectively; IPT_{KE60} and IPT_{KE180} = isokinetic peak torque of knee extensor muscles at 60- and 180 $° \cdot s^{-1}$. MPP = maximal peak power value obtained in half-squat exercise (see text for details); PP_{50BW}, PP_{75BW}, PP_{100BW}, PP_{125BW} = peak power attained with an external load equivalent to the 50-, 75-, 100- and 125% of the body weight in half-squat exercise, respectively; SJ = squat vertical jump; ST15 = 15-m sprint time.

*Denotes significance at $p \leq 0.05$. **Denotes significance at $p \leq 0.01$.

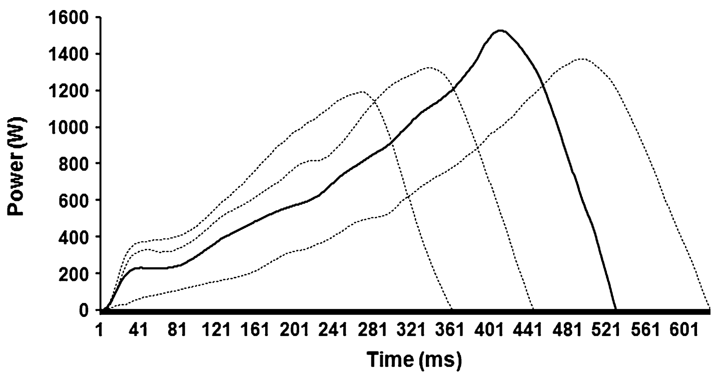

Figure 3. Power-time curves measured in one subject during concentric half-squat exercise with barbell loads of 40, 60, 80, and 100 kg. The maximal power output for this subject was attained in testing with barbell load of 80 kg.

MP_{50BW}. All the half-squat measures correlated significantly with 15-m sprint time. The strongest relations between vertical jump (CMJ and SJ) height and half-squat variables were observed for MP_{75BW}. The strongest relation between 15-m sprint time and half-squat variables were observed for MPP and MP_{75BW} (Figure 3). However, from the coefficients of determination ($R^2 = 24.2$–42.3%), it appears that there is a great deal of unexplained variance between the tests (half-squat vs. functional performance). With regard to the interrelationship between half-squat measures, all the measures were significantly correlated ($r = 0.59$–0.94) with the strongest relationship observed between MPP in half-squat and MP_{75BW}, MP_{100BW}, and MP_{125BW}.

Isometric MF of the KE muscles significantly correlated with vertical jump height; however, this relation was not significant for PF muscles. Isometric maximal muscle strength was not significantly related to 15-m sprint time. Yet, isometric maximal muscle strength characteristics were moderately correlated with half-squat measures ($r = 0.44$–0.67). In respect of the isokinetic measures, only the isokinetic PT of the KE muscles at $180°s^{-1}$ was significantly related with vertical jump height. However, this measure only accounted for 22% of the common variance associated with vertical jump performance. No isokinetic measures was significantly related to 15-m sprint time ($r = -0.31$ and -0.22). Moreover, isokinetic PT at $180°\cdot s^{-1}$ did not correlate significantly with any half-squat and isometric measures. However, isokinetic PT at $60°\cdot s^{-1}$ was significantly related with MPP, MP_{75BW} and MP_{100BW} measures in half-squat and isometric MF of the KE muscles.

Differences Between Fast and Slow Subject Groups

The values for each of the variables for the fast and slow subject groups are listed in Table 2. One repetition maximum, MPP, MP_{75BW} and MP_{100BW} in half-squat, isometric maximal strength of knee extensors and vertical jumping height (SJ and CMJ) were significantly different between the fast and slow subject groups. Concerning the other variables, no discrimination could be made between fast and slow subject groups.

Table 2. Differences between the fast and slow group of players based on 15-m rankings.*

Variable	Fast	Slow	T-test	*p*-value
1RM in half-squat (kg)	128.5	108.6	2.11	0.048
MP in half-squat (W)	1313	984.3	3.18	0.008
MP in half-squat with 50% of body weight (W)	832.4	716.4	2.05	0.060
MP in half-squat with 75% body weight (W)	995.6	926.4	2.45	0.041
MP in half-squat with 100% body weight (W)	1117.1	923	2.24	0.038
MP in half-squat with 125% body weight (W)	1033.5	1026.3	2.05	0.091
Isometric MF of the KE muscles (Nm)	244.3	209.5	2.21	0.039
Isometric MF of the PF muscles (Nm)	363.7	330.0	1.98	0.067
Isokinetic PT of the KE muscles $60°\cdot s^{-1}$(Nm)	280.7	247.6	1.99	0.061
Isokinetic PT of the KE muscles $180°\cdot s^{-1}$(Nm)	140.4	125.5	1.22	0.236
SJ height (cm)	36.9	32.8	2.91	0.009
CMJ height (cm)	40.3	35.6	2.97	0.008
15-m sprint time (s)	2.19	2.39	−8.62	0.000

*1RM = 1 repetition maximum; CMJ = countermovement vertical jump; KE = knee extensors; MF = maximal force; MP = maximal power; PT = peak torque; SJ = squat vertical jump.

Discussion

The main findings of the present study were that (1) maximal power in traditional half-squat exercise (MPP) in semi-professional soccer players was attained with a load of ~60 % of 1RM, representing 112% of body weight; (2) the performance in the functional tests selected (vertical jumping height and 15-m sprint time) was significantly related with all the traditional half-squat variables measured but specially with loads of 75–125% of body weight; and (3) low to nonsignificant correlations were found between functional tests performance and isometric and isokinetic muscle strength measures.

Traditional Half-Squat Performance

The 1RM in concentric half-squat observed in our study was similar to that observed in professional Tunisian youth players (less than 19 years old) (26) or in male players from the National Collegiate Athletic Association Division I (42). However, our results were lower than the published data of first-division Norwegian (21,46,47) and Greek (25) players. For example, a 1RM value of 170 kg (2.2 vs. 1.8 kg/kg body weight observed in the present study) was reported in concentric half-squat in seventeen elite Norwegian players (46). Long-term training adaptations induced by the previous participation in strength training programs, especially against heavy resistance loads, may explain the lower levels in maximal strength observed in our study. In this sense, the players selected performed explosive-type strength training by means of squat with loads ranging 40–70% 1RM, vertical jumps and sprinting exercises preferably in the pre-season period, including this type of stimulus during the season.

To our knowledge, this is the first study that has measured muscle power output at different loads during the traditional half-squat exercise in soccer players. We found that MPP was attained with an external load equivalent to the 112% of body weight that represented 60.3% of the 1RM. In general, these results are in agreement with previous studies performed with athletes of different sports (12,22,38,40). Izquierdo et al. (22) showed that the load in which the MPP in the traditional half-squat occurred was at 60% of 1RM for handball players, middle-distance runners, and untrained subjects. Similarly, Cormie et al. (12) observed that MPP was attained with an external load equivalent to the 56% of 1RM in a group of football players, sprinters and long jumpers. However, differences in samplés resistance training background, the measurement procedure for maximum power capability, such as the mode of exercise used during testing (i.e. ballistic vs. traditional squat) or the methods of calculating maximal power (i.e. average power per load vs. maximal power per load), make the comparison between the published results difficult. For example, it has been suggested that the range of percentage of 1RM that leads to MPP is related with the amount of velocity specific training performed previously by the sample analyzed (5). Baker et al. (5) concluded that simultaneously strength- and power-trained athletes maximize their power output at higher percentages of 1RM (60–70%) than unaccustomed or power-trained athletes by means of high-velocity exercises. Moreover, several studies (5,38,42) have analyzed MPP during the ballistic mode of the squat exercise (half-squat jump). From these studies, it is important to highlight the experiment of Thomas et al. (42) who measured MPP in soccer players also. These authors observed that MPP during the half-squat jump was attained at loads of 30 and 40% of 1RM. However, the comparison between these studies and the present research it is difficult because of differences in the mode of squat exercise analyzed (traditional vs. ballistic). Exercise as half-squat jump does not entail a large deceleration period, as occurs during the traditional half-squat (31). Consequently, half-squat jump results in greater power output, velocity, and muscle activation level compared with its traditional strength training counterpart (31). Indeed, Thomas et al. (42) showed higher MPP values than those obtained in the present study (~1750 vs. 1153w). Similarly, Sleivert and Taingahue (38) reported a higher level of MPP relative to body mass (17.58 vs. 15.9) in squat jump exercise performed by rugby and basketball players.

On the other hand, Izquierdo et al. (22) showed that in weightlifters and handball players the velocities that elicited maximal power in the lower extremities were higher (1.06- and 0.96 ms, respectively) than those recorded for road cyclists and middle distance runners (0.75-, 0.72 ms, respectively). In the present study, MPP was attained at similar velocity than was showed by weightlifters (1.06 ms). This similar behavior could be argued on lower body patterns of long-term training adaptation in muscle power between weightlifters and soccer players. During soccer training sessions and competitive games, of frequent strenuous activities of the lower muscles, such as short sprint accelerations and repetitions of various kicks are conducted. Additionally, we observed that MPP was performed at 23.14 cm of distance (from 90 degrees of flexion). No previous studies were found, reporting the distance at which MPP is attained. In the present study, this distance was not correlated with the players' height ($r = 0.34$, $p =$ NS). This could be explained by the homogeneity of body height in the sample selected (coefficient of variation [CV] was 3.3%). The velocity at which MPP was attained, in contrast with the heterogeneity observed in MPP values, was similar for all the subjects (CV was 11.5%).

Functional Performance Tests

Numerous studies (21,37,39) have measured vertical jump height as an indicator of muscle power of the lower limbs in soccer players. The respective results obtained in the present study were similar (3) to or lower (37,46) than those published previously in articles on professional soccer players. Differences in soccer playerś training history (21,46) (i.e., with or without systematic strength training), competitive level (39) and the procedures applied to measure vertical jumping performance may explain these discrepancies.

To our knowledge, only 2 studies (8,17) have measured 15-m sprint time in elite soccer players. Both studies reported similar values (2.30 and 2.35 seconds, respectively) to those obtained in the present study (2.28 seconds). In several studies, 10-m or 30-m distances have been selected for sprint testing (39). In the present study, 15-m distance was selected because during an elite soccer game, each sprint bout lasts on an average for 2–3 seconds (21,39) and with an average distance between 12 and 16 m (6).

In the present study, a significant negative correlation was found between vertical jumping height in CMJ and SJ and 15-m sprint time. This is in accordance with previous studies in senior (46) and young (10,17) elite soccer players. For example, Wisloff et al. (46) observed in Norwegian senior elite players a significant correlation between vertical jumping height and 10-m and 30-m sprint time. These results confirm the relation between vertical jump height and short-duration sprint time and agree with those biomechanical analyses of sprinting which have shown that short-distance sprint are highly dependent on the subject's ability to generate powerful extensions of the KE, hip extensor, and PF muscles (27,48).

Relationships Between Traditional Half-Squat and Functional Performance Tests

In the present study, all the traditional half-squat variables measured (with the exception of MP_{50BW}) were moderately related with the functional tests selected (vertical jumping height and 15-m sprint time). Because the movement patterns are similar between the half-squat and the jumps, a greater relationship between squat and jump than between squat and sprint exercises might be expected. However, this was not the case, both functional tests offered similar relations with the half-squat exercise performance (Table 1). The strongest relationships between both functional tests and half-squat variables were observed for MP_{75BW}, MP_{100BW}, and MPP half-squat variables ($r = 0.56$–0.65, $p < 0.01$). Thus, the stronger relationship between half-squat exercise and functional performance tests was attained in the range of loads between 75% to about 115% of body weight. In addition, only in this range of loading in half-squat exercise significant differences between faster and slower subjects were found (Table 2). The stronger relationship within this range of external loads may be explained by several biomechanical and physiological processes not measured in the present experiment. It may be speculated that during this range of external resistance loading in which the maximal power output is attained, neural drive (fast twitch motors units recruitment and firing rate) will be optimal for this exercise. Thus, explosive movements such as sprint running or jumping depending on fast twitch motor units activation from lower limb extensor muscles (27,48) would be principally related with squat exercise when this exercise is performed with the aforementioned range of loading.

On the other hand, the correlation coefficients observed between these squat variables and the performance in 15-m sprint time were similar to that which Sleivert and Taingahue (38) reported between peak power in split-squat and traditional squat-jump with 5-m sprint time ($r = -0.65$ and -0.66, respectively). Similarly, Young et al. (48) reported a significant relationship between average power in a concentric squat jump with an external load of 19 kg and 2.5-m sprint time ($r = -0.74$). However, differences in the mode of exercise (i.e., jump squat with or without countermovement vs. traditional half-squat) and differences in procedures used (i.e., methods for calculating power or external loads selected to measure power) make it difficult to compare the conducted studies. To our knowledge, no previous studies have measured the relationship between functional tests as vertical jump or sprint performance with the maximal power attained against different external loads in the traditional half-squat exercise in soccer players. Although the relations observed between MP_{75BW}, MP_{100BW}, and MPP and functional performance tests were significant, the associated coefficients of determination ($R^2 = 31$–42%) indicate a great deal of unexplained variance between tests. Traditional concentric half-squat, 15-m sprint, and vertical jump are high-intensity multijoint activities in which knee extensors, plantar flexors and hip extensor muscle groups have been described as principally agonist muscles (27). However, biomechanical differences (i.e., joints range of movement, time of force application) exist between them that explain the moderate correlations observed in the present study.

In addition, low correlations were observed between 1RM in half-squat and the functional performance tests selected. This result contrasts with the strong relationships showed by Wisloff et al. (46) in elite soccer players between 1RM in half-squat and 10- and 30-m sprint ($r = 0.94$ and 0.71, respectively) and vertical jump ($r = 0.78$) performance. However, in the published literature and according to the results observed in our study, most of the experiments report low or non-significant relationships between 1RM in squat exercise and vertical jump or short-distance sprints. Baker and Nance (4) found no relationships between a 3RM squat and 10-m ($r = -0.06$) and 40-m ($r = -0.19$) sprint performance of professional rugby players. Wilson et al. (45) reported a nonsignificant relationship between 1RM in half-squat and 40-m sprint performance. Similarly, Cronin and Hansen (13) in a group of rugby players observed that 3RM in half-squat was not significantly related with vertical jump and 5-, 10-, and 30-m sprint time. In the present study, the 1RM in squat accounts for less than 27% and 22% of the explained variance associated with vertical jump height and 15-m sprint time, respectively. Moreover, in respect to 1RM, there were no significant differences between faster and slower subjects. Thus, in the majority of cases analyzed, the performance in traditional half-squat with maximal external loadings shows low relationships with the performance in functional activities as sprint or vertical jumping. During these functional activities, the time allowed to exert force is limited (<300 ms), whereas during a 1RM in half-squat the time of movement is not a limiting factor and generally is over 500 ms (36).

Thus, different physiological factors may affect the performance of both types of activities. In case of maximal muscle strength, a determinant factor of performance is muscle cross sectional area (1) and in case of rate of force development an important factor is cross bridge cycling rate of type IIA and type IIX muscle fibers in the very early phase of muscle contraction (7,20).

Relationships Between Isometric and Isokinetic Muscle Strength and Functional Performance Tests

In agreement with previous studies (28,45), isometric MF was poorly correlated with the functional tests selected. Indeed, only isometric MF of the KE muscles was significantly related with vertical jumping height. Previous studies that analyzed the relation between maximal isometric muscle strength and vertical jumping height showed significant low (19,23,33) or nonsignificant correlations (28,49). Urgarkovic et al. (43), similar to our study, reported a positive low correlation ($r = 0.52$) between isometric MF of the KE muscles and vertical jumping height in a group of basketball players. In addition, previous studies that analyzed the relation between isometric MF and sprint time reported no statistically significant relationship (45). Numerous researchers have found subsequent differences between dynamic and isometric muscle strength (9,28,41). In general, these low relationships observed have been previously attributed to different motor unit activation patterns between isometric and dynamic muscle contractions (28,45). Nakazawa et al. (29) have reported that specific recruitment patterns are developed for dynamic contractions, and that these patterns differ from motor unit recruitment during maximal isometric contractions. Thus, the isometric MF seems to be characterizing different aspects of voluntary force-generating capacity of the muscles.

In agreement with previous research, no significant relationships were found between isokinetic PT of the KE muscles at low and moderate angular velocities and 15-m sprint time. In literature, between isokinetic knee extension assessment and sprint performance over short distances, nonsignificant to moderate correlations have been reported (11,13,15,30). Similar to our study, Cometti et al. (11) did not observe correlations between PT values (knee extension at 120–300$^\circ\cdot s^{-1}$) and 10- and 30-m sprint times in 95 French soccer players of elite, subelite, and amateur levels. Cronin and Hansen (13) in professional rugby players reported nonsignificant correlations ($r = -0.31$ to -0.08) between isokinetic PT of the KE muscles at 2 velocities (60 and 300$^\circ\cdot s^{-1}$) and 5, 10, and 30-m sprint times. Moreover, the studies that have shown moderate correlations between short-distance sprint and isokinetic PT of the KE muscles ($r = -0.42$ to -0.74) used higher angular velocities than those selected in our study ($>180^\circ\cdot s^{-1}$).

In accordance with the previous studies (32,33,44), a moderate correlation was reported between isokinetic PT of the KE muscles at 180$^\circ\cdot s^{-1}$ and vertical jumping height. In literature, moderate to low correlations between isokinetic testing of the knee extensors and different jump types as one-leg hop (18), vertical jump (33,44), standing long jump, and 5-step jump have been reported (44). Although vertical jumping is a closed chain, multiarticular task involving stretch-shorten cycle type motion and complex muscle coordination; the moderate correlations observed with the isokinetic and isometric knee extension PT reflect the important role of knee extensors strength in its performance (16).

Practical Applications

First, it is important to point out that correlations can only give insights of associations between variables and not into cause and effect. In agreement with previous literature, the present study confirmed as functional performance (especially 15-m sprint time) was poorly related with the isometric and isokinetic muscle strength measurements. It is important to take in account that a limitation of our study was that maximal rate of force development during knee isometric extension and isokinetic PT at higher angular velocities (more than 180$^\circ s^{-1}$) or in eccentric mode was not measured. However, moderate correlations between these variables and vertical jumping (14) or sprinting (11,15) have been established. From our results and in agreement with the previous literature, isometric and isokinetic muscle strength assessments performed in an open kinetic chain are not movement-specific enough to predict performance during a more complex movement such as jumping or sprinting.

On the other hand, all the squat variables measured were moderately related with both functional tests selected. However, the greater relationships were observed when traditional half-squat exercise was performed with the range of loads between 75 to about 115% of body weight (range of resistances in which higher values of peak power were attained; Table 1 and Figure 3). This result may have important implications for the selection of external loads during traditional half-squat training in soccer players. It seems reasonable to train traditional half-squat exercise with the external loads that higher relations offer with the functional performance tests. However, a further longitudinal study measuring the effects of systematic strength training with different external loads (low, medium, and high percentage of 1RM in half-squat) on functional performance is clearly required.

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