RELATIONSHIPS OF PEAK LEG POWER, 1 MAXIMAL REPETITION HALF BACK SQUAT, AND LEG MUSCLE VOLUME TO 5-M SPRINT PERFORMANCE OF JUNIOR SOCCER PLAYERS

MOHAMED SOUHAIEL CHELLY,1,2 NAJET CHÉRIF,3 MOHAMED BEN AMAR,1 SOUHAIL HERMASSI,1 MOURAD FATHLOUN,4 EZDINE BOUHLEL,3 ZOUHAIR TABKA,3 and ROY J. SHEPHARD5

1Research Unit Evaluation and Analysis of Factors Influencing Sport Performance, ISSEP of Ksar Said, Tunis, Tunisia; 2High Institute of Sport and Physical Education of Ksar Said, Tunis, Tunisia; 3Laboratory of Physiology, Faculty of Medicine Ibn-El-jazzar, Sousse, Tunisia; 4High Institute of Sport and Physical Education, El Kef, Tunisia; and 5Faculty of Physical Education & Health, University of Toronto, Toronto, Canada

ABSTRACT
Chelly, MS, Chérif, N, Ben Amar, M, Hermassi, S, Fathloun, M, Bouhlel, E, Tabka, Z, and Shephard, RJ. Relationships of peak leg power, 1 maximal repetition half back squat, and leg muscle volume to 5-m sprint performance of junior soccer players. J Strength Cond Res 24(1): 266–271, 2010—Performance over very short distances (1–5 m) is important in soccer. We investigated this in 23 male regional-level soccer players aged 17.2 ± 0.7 years, filming body markers to determine the average velocity and acceleration over the first step ($V_s$ and $A_s$) and the first 5 m ($V_5$, $A_5$). Data were related to scores on a force-velocity test, squat jump (SJ), countermovement jump (CMJ), and 1 maximal repetition (1 RM) half back squat. Leg and thigh muscle volumes were also assessed anthropometrically. $V_5$ was positively correlated with leg and thigh muscle volumes ($r = 0.61$, $p < 0.05$; $r = 0.43$, $p < 0.05$, respectively), SJ power (absolute and relative to body mass, $r = 0.45$, $p < 0.05$; $r = 0.43$, $p < 0.05$, respectively), absolute force-velocity leg power ($r = 0.49$, $p < 0.05$), and 1 RM half back squat ($r = 0.66$, $p < 0.001$). The use of dimensional exponents did not change coefficients materially. $V_s$ was also correlated with leg muscle volume and 1 RM back half squat ($r = 0.56$, $p < 0.01$; $r = 0.58$, $p < 0.01$, respectively) and more weakly with force-velocity leg power and SJ force ($r = 0.49$, $p < 0.05$; $r = 0.46$, $p < 0.5$, respectively). However, the CMJ was unrelated to velocity or acceleration. Sprinting ability is correlated with measures of power and force such as the force-velocity test, SJ, and 1 RM half back squat; such measures thus offer useful guidance to soccer coaches who wish to improve the short-distance velocity of their players.

KEY WORDS velocity, acceleration, force-velocity test, squat jump, countermovement jump, leg force

INTRODUCTION
A soccer match makes heavy demands on both aerobic and anaerobic metabolism (7,14,17). Elite players run 8–12 km during a game, with aerobic metabolism predominating (2,14). Nevertheless, anaerobic metabolism is also crucial in sprints, jumps, and tackles (17). Up to 50 rapid turns are made during a match, initiated by sustained and forceful concentric muscle contractions. Moreover, sprints account for 1–11% of the distance covered, typically lasting 2–4 seconds and occurring every ~90 seconds (2,12). Professional players can run faster than amateurs over 10 m but have no advantage in a 30-m sprint (6). Sprints range from 1.5 to 105 m, and the ability to accelerate and sustain very short sprints is important to success in soccer (1).

Leg power is important to both the initial acceleration and maximal velocity (4). The maximal half squat strength of elite players is significantly correlated with their times over 10 and 30 m and maximal jump heights (19). However, no studies have previously investigated acceleration and velocity over distances <9 m. Such information seems critical to the training for soccer and other team sports. We have thus examined relationships of velocity and acceleration during the first steps ($V_s$ and $A_s$, respectively) and the first 5 m of a sprint ($V_5$ and $A_5$, respectively) to leg power, jump height, leg muscle volume, and 1 maximal repetition (1 RM) back half squat strength.
METHODS

Experimental Approach to the Problem

Our aim was to examine the relationships of velocities and accelerations in very short sprints to leg power, jump height, leg muscle volume, and 1 RM half back squat in soccer players. Subjects performed a 10-m sprint. $V_0$, $V_s$, $A_0$, and $A_s$ were assessed by filming over the first 5 m. Other laboratory and field tests included a force-velocity test, squat and countermovement jumps (CMJs), and a 1 RM half back squat at 90° to assess leg power, leg force, and jump height. Values were correlated with standard anthropometric assessments of leg muscle volumes.

Subjects

Subjects were 23 male players from a top regional soccer team (mean age: 17.2 ± 0.7 years; body mass: 64.7 ± 6 kg; height: 1.75 ± 0.04 m; body fat: 14.2 ± 2.4%; soccer experience: 5.4 ± 1.9 years). Procedures were approved by the institutional ethics review committee. Parental/guardian and participant informed consent was obtained from all involved. All were examined by the team physician and were in good health. All had trained 4 times per week for at least 4 years. Typical 2-hour training sessions included skill activities at various intensities, offensive and defensive tactics, and a final 30 minutes of continuous play. During the competitive season (September to June), subjects also participated in the national junior championship league each week. They abstained from exercise on the previous day and drank no caffeine beverages for 4 hours before testing.

Test Procedures

Two preliminary familiarization sessions minimized any effects of learning and habituation for the cycle ergometer and jump tests. Definitive tests were performed on 2 days, separated by 48 hours of rest.

Cycle Ergometer Force-Velocity Test. The cycle ergometer force-velocity test was performed on a mechanically braked cycle ergometer (Monark 894 E Peak Bike, Weight Ergometer, Vansbro, Sweden). Software allowed estimation of the velocity at each pedal stroke; the product of braking force and pedaling velocity indicated power output, and maximal velocity at each pedal stroke; the product of braking force and maximal pedaling velocities $(V_0)$ and $(V_s)$ and accelerations $(A_0)$ and $(A_s)$. The reliability of the camera and the data processing software was previously checked (5).

In actual play, a sprint usually has a standing (SS) or jogging (JS) start. Preliminary trials thus compared 3 types of sprint in 13 players (SS, JS, and crouching start with starting blocks [CS]), according to a random block design. $V_s$ values for the 3 starting modes differed significantly from each other (for the JS, 6.05 ± 0.30 m/s; for the SS, 4.95 ± 0.55 m/s; and for the CS, 4.52 ± 0.28 m/s). However, we adopted CS for our definitive tests because of its greater reliability (intraclass correlation coefficient [ICC] of 0.82, in contrast to the JS and SS ICC of 0.74 and 0.69, respectively).

One Maximal Repetition Back Half Squat at 90°. Participants maintained an upright position. The bar was grasped firmly with both hands and was also supported on the shoulders. The knees were bent to 90° and the subject then regained the upright position, with the legs fully extended. Eight technical training sessions were performed during the month preceding definitive measurements. After 2 successful repetitions at the pretest RM, a further 1-kg load was added. If the second repetition could not be completed at the new loading, this was accepted as the individual’s 1 RM. Typically, 3 to 6 lifts were needed to reach the 1 RM.

Anthropometry. Both thigh and leg muscle volumes were estimated using the equations of Jones and Pearson (8). Circumferences (steel tape measure) and skinfold thicknesses (Harpenden Skinfold Caliper, CE 0120, baty, British Indicators, West Sussex, United Kingdom) were measured at appropriate levels of the lower limbs, and the intercondylar widths were determined using a standard anthropometry kit (SiberHegner, Zurich, Switzerland).

Statistical Analyses

All values are expressed as mean ± SD. Relationships between variables were tested by least squares linear regression analyses, with $p ≤ 0.05$ as the threshold of significance.

Sprint Running Performance. After familiarization, subjects made a maximal 10-m sprint on an outdoor tartan surface. Body displacement was filmed by cameras (Digital Handy cam, DCR-PC105E, 25 frames per second, Sony Corporation, Tokyo, Japan) placed at 10 m perpendicular to the running lane. Participants performed 2 definitive trials, separated by an interval of at least 5 minutes, the fastest trial being recorded. The software (Regavi & Regessi; Mireelec, Coulommiers, France) converted measurements of hip displacement to the corresponding velocities $(V_s$ and $(V_o)$ and accelerations $(A_0$ and $(A_s)$. The reliability of the camera and the data processing software was previously checked (5).

In actual play, a sprint usually has a standing (SS) or jogging (JS) start. Preliminary trials thus compared 3 types of sprint in 13 players (SS, JS, and crouching start with starting blocks [CS]), according to a random block design. $V_s$ values for the 3 starting modes differed significantly from each other (for the JS, 6.05 ± 0.30 m/s; for the SS, 4.95 ± 0.55 m/s; and for the CS, 4.52 ± 0.28 m/s). However, we adopted CS for our definitive tests because of its greater reliability (intraclass correlation coefficient [ICC] of 0.82, in contrast to the JS and SS ICC of 0.74 and 0.69, respectively).
throughout. The reliability of the sprint velocities and jump tests was assessed by calculating ICC and their 95% confidence intervals.

**RESULTS**

The ICC for sprint velocities and accelerations ranged from 0.87 to 0.96 and for CMJ height, force, and power from 0.95 to 0.99. Intraclass correlation coefficient for SJ height, force, and power was similar (ICC = 0.96). Absolute values for the running velocities and accelerations were $V_S = 2.16 \pm 0.5 \text{ m/s}$, $V_S = 4.12 \pm 0.5 \text{ m/s}$, and $A_S = 5.34 \pm 2.1 \text{ m/s}^2$, and $A_S = 2.99 \pm 0.6 \text{ m/s}^2$. As expected, the CMJ height (0.40 ± 0.03 m) and power relative to body mass (24.4 ± 1.7 W·kg$^{-1}$) were

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**TABLE 1.** Coefficients of correlation between track sprinting velocities, anthropometric, and performance variables ($n = 23$).†

<table>
<thead>
<tr>
<th></th>
<th>Velocity first step (m·s$^{-1}$)</th>
<th>Velocity first 5 m (m·s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass (kg)</td>
<td>0.43*</td>
<td>0.51*</td>
</tr>
<tr>
<td>Height (m)</td>
<td>0.20</td>
<td>0.29</td>
</tr>
<tr>
<td>Total leg muscle volume (L)</td>
<td>0.56**</td>
<td>0.61**</td>
</tr>
<tr>
<td>Total leg muscle volume/kg body mass</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>Total leg muscle volume/m height</td>
<td>0.54**</td>
<td>0.59**</td>
</tr>
<tr>
<td>Thigh muscle volume (L)</td>
<td>0.40</td>
<td>0.43*</td>
</tr>
<tr>
<td>Thigh muscle volume/kg body mass</td>
<td>0.12</td>
<td>0.09</td>
</tr>
<tr>
<td>Thigh muscle volume/m height</td>
<td>0.38</td>
<td>0.40</td>
</tr>
<tr>
<td>Thigh cross-sectional area (cm$^2$)</td>
<td>0.43*</td>
<td>0.48*</td>
</tr>
<tr>
<td>Force-velocity power (W)</td>
<td>0.49*</td>
<td>0.58**</td>
</tr>
<tr>
<td>Force-velocity power (W·kg$^{-1}$)</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Maximal pedaling velocity ($V_0$)</td>
<td>0.43*</td>
<td>0.38</td>
</tr>
<tr>
<td>Maximal pedaling force ($F_0$)</td>
<td>0.30</td>
<td>0.46*</td>
</tr>
<tr>
<td>SJ height (m)</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>SJ power (W)</td>
<td>0.31</td>
<td>0.45*</td>
</tr>
<tr>
<td>SJ power (W·kg$^{-1}$)</td>
<td>0.33</td>
<td>0.43*</td>
</tr>
<tr>
<td>SJ force (N)</td>
<td>0.48*</td>
<td>0.56**</td>
</tr>
<tr>
<td>CMJ height (m)</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>CMJ power (W)</td>
<td>0.25</td>
<td>0.34</td>
</tr>
<tr>
<td>CMJ power (W·kg$^{-1}$)</td>
<td>0.26</td>
<td>0.28</td>
</tr>
<tr>
<td>CMJ force (N)</td>
<td>0.32</td>
<td>0.34</td>
</tr>
<tr>
<td>1 RM half back squat (kg)</td>
<td>0.58**</td>
<td>0.66***</td>
</tr>
</tbody>
</table>

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.
† SJ = squat jump; CMJ = countermovement jump.

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**Figure 1.** Relationship of squat jump force to velocity and acceleration during a 5-m sprint.
significantly greater (p < 0.0001) than for SJ (0.36 ± 0.03 m and 21.3 ± 1.8 W kg⁻¹, respectively). However, jump forces were statistically similar (1,591 ± 239 N and 1,519 ± 152 N for SJ and CMJ, respectively). Absolute and relative leg muscle power, as calculated from the force-velocity test, averaged 907 ± 97 W and 14.1 ± 1.5 W/kg², respectively.

\[ V_0 \text{ and } F_0 \text{ were } 201 \pm 15 \text{ rpm and } 126 \pm 19 \text{ N, respectively.} \]

Leg and thigh muscle volumes averaged 8.4 ± 1.2 L and 5.6 ± 0.8 L, respectively.

\[ V_5 \text{ was significantly correlated with body mass (r = 0.51), total leg, and thigh muscle volumes (r = 0.61 and r = 0.43, respectively) (Table 1).} \]

Other significant relationships were with SJ force (r = 0.56) (Figure 1) and 1 RM back half squat (r = 0.66) (Figure 2). \( A_S \) and \( A_5 \) were positively correlated with leg volume (r = 0.50, 0.66), SJ force (r = 0.44, 0.60), and force-velocity power (r = 0.49, 0.54) (Table 2).

**DISCUSSION**

The leg muscles were relatively well developed; despite an average body mass of only 64 kg, indeed, the total leg volume of 8.4 L exceeded the value of 7.68 L previously estimated for young adult males with a body mass averaging 70.2 kg (15). In terms of the force/velocity test, the average maximal power of French soccer players was 1021 W, but much of their apparent advantage over the present sample was due to a larger body mass; the French group developed an average of 14.7 W/kg² (18) compared with 14.2 W/kg⁻¹ in our players. As in previous studies, CMJ scores exceeded those for the SJ. The CMJ scores also exceed a previous report (13). Although our sample was relatively small, we may thus conclude that the findings are applicable to other soccer players. The observations also have probable relevance to other sports where rapid changes of movement are required.

An allometric adjustment of data is recommended if there are large interindividual differences in body build. However, if differences are small, simple ratios can be used; indeed, if the sample size is small, simple ratios are the preferred approach.

It is commonly argued from dimensional analyses that muscle force should be proportional to the cross-sectional area of the contracting fibers (i.e., to body mass²/³, height², or muscle volume/height), whereas power should be directly proportional to muscle volume, body mass, or height³. In fact, simple correlations of force and power with body mass, height, and muscle volume were affected little by use of the suggested exponents. Although there is theoretical interest in exploring dimensional factors, this seems an unnecessary complication in the practical application of our data.
Although initial velocity and acceleration are important information for a coach, the regular filming of players is hardly practical. Thus, it is important to discern laboratory and field tests correlated with such measurements. The velocity over the first step (\(V_0\)) shows strong positive relationships to total leg muscle volume and 1 RM half back squat, and somewhat weaker positive correlations with thigh cross-sectional area, power estimated from the force-velocity test, \(V_5\) and the SJ force (Table 1). The velocity over the first 5 m (\(V_5\)) is significantly related to these same measurements (with the exception of \(V_0\)), although perhaps \(V_5\) can be measured more accurately, the correlation coefficients are a little larger (Table 1). \(V_5\) is also significantly correlated with absolute SJ power, SJ per kg of body mass, and maximal pedaling force (\(F_5\)) (Table 1). However, neither \(V_5\) nor \(V_5\) is significantly related to CMJ values (Table 1). Acceleration data generally show a similar pattern (Table 2).

Relationships between \(V_5\) and power have not been investigated previously, although such data seem particularly relevant to the very rapid changes of direction developed in soccer and other team sports. The player pushes maximally during the acceleration phase; then, concentric muscle contraction sustains force generation. The ground contact phase of running has 2 phases: braking and propulsive (requiring eccentric and concentric muscle contractions, respectively). The braking phase of male sprinters initially occupies only 12.9% of the total cycle, but when accelerating over a distance of 30 m, it increases progressively, amounting to 43% of the cycle when maximal speed is attained (9,10).

During the first few steps, the main need is for concentric contraction, to generate force and power. Squat jump power and force production are thus strongly correlated with \(V_5\), in contrast to CMJ data. Merlo (9) found a fairly close correlation between the propulsive force and running velocity during the first contact after the blocks in an experienced male sprinter (\(r = 0.74; n = 8\)), further emphasizing the characteristics of the propulsive phase and the importance of force during the acceleration phase of sprinting.

The CMJ seems an appropriate tool when predicting performance over 30- or 100-m sprints (3). However, when predicting acceleration and sprint performance over a distance of 5 m, the SJ provides more relevant information. The CMJ involves a stretch-shortening cycle; it could thus be that over the first 5 m, the braking phase is not long enough to allow full involvement of the stretch-shortening cycle, although the CMJ/power relationship to running velocity emerges over longer distances.

Cycle ergometer force-velocity tests are a little demanding for field-testing, and for soccer players, are a less familiar exercise than jumping. Muscle coordination can influence maximal power output and thus underestimation of performance. Nevertheless, force-velocity tests are helpful in confirming the above reasoning. The power calculated from such exercise reflects largely concentric muscle contraction and is thus analogous to the SJ, despite activation of different muscle groups. The cycle ergometer assessment of absolute leg power is an effective predictor of both velocities (\(V_5\) and \(V_5\)) and accelerations (\(\Delta V_5\) and \(\Delta V_5\)) over a short distance. Both \(V_5\) and \(V_5\) are also related to body velocity (\(V_5\) and \(V_5\)), respectively) (Table 1). Our findings thus support the grading of short-distance sprint performance by the force-velocity test and the SJ in laboratory and field situations, respectively.

Previous studies demonstrated a moderate correlation of 1 RM half back squat scores with velocity over distances of 10–100 m (3,19). The peak forces measured during a split squat and a traditional squat also show a weak correlation with the 5 m sprint time (\(r = -0.49, r = -0.59\), respectively) (16). Our results agree with these findings, showing strong correlations between 1 RM half back squat and both \(V_5\) and \(V_5\) (Table 1 and Figure 2, respectively), offering at least an equally reliable estimate of short-distance sprinting ability in soccer players.

The ability to accelerate over a single step is likely a critical factor in some game situations. \(V_5\) is positively correlated with both muscle volume and thigh cross-sectional area and can be assessed by 1 RM half back squat, force-velocity leg power, and SJ force (Table 1). At first inspection, the finding that a player with more muscle can accelerate and move more rapidly seems logical. Nevertheless, the increase of leg muscle increases body mass and thus inertia, potentially restricting acceleration and the speed attained. The non-significant trend to a positive effect of leg muscle volume after adjusting for body mass (volume/kg) suggests the importance of developing muscle mass locally in the legs rather than in the body as a whole. We can conclude that both leg muscle volume and power are important to acceleration and velocity over short distances. These 2 characteristics must be well developed in junior soccer to allow the quick changes of direction required in a successful player.

**Practical Applications**

Our results indicate that the critical ability of soccer players to accelerate and sustain a high velocity over a distance of 5 m or less can be predicted in the laboratory by the power output achieved in a cycle ergometer force-velocity test and in the field by SJ and more particularly by 1 RM half back squat scores. The volume of the leg muscles seems important to power production and velocity over distances of 5 m and less. The soccer coach who wishes to improve performance over such short distances should seek to increase leg muscle volume and 1 RM half back squat scores. The implication is that specific lower limb strength training to increase 1 RM half back squat scores will enhance sprint velocities over both \(V_5\) and \(V_5\) and thus enhance soccer performance.

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