Effects of a Back Squat Training Program on Leg Power, Jump, and Sprint Performances in Junior Soccer Players

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Abstract

Chelly, MS, Fathloun, M, Cherif, N, Amar, MB, Tabka, Z, and Van Praagh, E. Effects of a back squat training program on leg power, jump, and sprint performances in junior soccer players. *J Strength Cond Res* 23(8): 2241–2249, 2009—The aim of the present study was to investigate the effects of voluntary maximal leg strength training on peak power output (Wpeak), vertical jump performance, and field performances in junior soccer players. Twenty-two male soccer players participated in this investigation and were divided into 2 groups: A resistance training group (RTG; age 17 ± 0.3 years) and a control group (CG; age 17 ± 0.5 years). Before and after the training sessions (twice a week for 2 months), Wpeak was determined by means of a cycling force-velocity test. Squat jump (SJ), countermovement jump (CMJ), and 5-jump test (5-JT) performances were assessed. Kinematics analyses were made using a video camera during a 40-m sprint running test and the following running velocities were calculated: The first step after the start ($V_{first\ step}$), the first 5 m ($V_{first\ 5\ meters}$), and between the 35 m and 40 m (V_{max}). Back half squat exercises were performed to determine 1-repetition maximum (1-RM). Leg and thigh muscle volume and mean thigh cross-sectional area (CSA) were assessed by anthropometry. The resistance training group showed improvement in Wpeak ($p < 0.05$), jump performances (SJ, $p < 0.05$ and 5-JT, $p < 0.001$), 1-RM ($p < 0.001$) and all sprint running calculated velocities ($p < 0.05$ for both $V_{first\ step}$ and $V_{first\ 5\ meters}$, $p < 0.01$ for V_{max}). Both typical force-velocity relationships and mechanical parabolic curves between power and velocity increased after the strength training program. Leg and thigh muscle volume and CSA of RTG remained unchanged after strength training. Back half squat exercises, including adapted heavy loads and only 2 training sessions per week, improved athletic performance in junior soccer players. These specific dynamic constant external resistance exercises are highly recommended as part of an annual training program for junior soccer players.

Key Words muscle, peak power, strength training, running velocity

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Introduction

Many studies have reported that in soccer games, aerobic and anaerobic power are important features (4,11,17,34,42). Players of a Danish first-division junior soccer team performed 76 high-intensity runs of 12 to 15 m during a soccer match (4). Therefore, sprint running performance, with or without the ball, is an important factor that may explain the superiority of a winning team. In addition, Stolen et al. (34) reported that 96% of sprint bouts during a soccer game are shorter than 30 m, with 49% being shorter than 10 m. In this context, it must be emphasized that the 10-m performance (or even shorter distances such as 5 m or power production from a stationary start) is a relevant test variable in modern soccer. This may be crucial in critical ball duals. Similarly, jumping performances might be considered as determinant of physical demands during soccer duals. Testing soccer players, it has been reported that squat jump (SJ) and countermovement jump (CMJ) height could attain high values such as 40.4 cm and 64.8 cm, respectively (34).

In many situations, to score goals or to stop goals being scored, the player should be faster and more powerful than the opponent. Moreover, by increasing force in appropriate muscles or muscles groups, acceleration and speed may improve in skills critical to soccer such as turning, sprinting, and changing pace (3). Soccer is becoming more and more athletic and to win a running or jumping dual or to catch the ball before the opponent and to score, high short-term muscle power is necessary. The power produced depends on both force and velocity. In adults, linear force-velocity relationships and parabolic force-power and velocity-power relationships have been obtained during cycle ergometer tests using friction-loaded ergometers or isokinetic cycle ergometers (21,31). Similar relationships have been obtained in children and adolescents (12). Some reports have suggested that resistance training facilitates the increase of short-term peak power, whereas muscle contraction velocity seems less sensitive to training (36). Submaximal loads between 60 and 90% of the maximal dynamic strength, with 8 to 12 repetitions, are used to enhance muscle mass and consequently muscular anaerobic power (36). In fact, the physiological adaptations to resistance training depend on the type of contraction, duration, and intensity used during the program. There are several types of strength training, including isometrics, dynamic constant external resistance (DCER) training, plyometrics, or isokinetics (41). The most important variable in increasing strength is the load applied to the muscles. However, velocity-specific training has also been shown to maximize strength and power gains for athletes (14). Resistance training has the potential of improving sport performances and reducing the rate of sport injury and rehabilitation time following injury (6). The incidence of injuries decreased following strength training, from 15.15 to 7.99 per 1,000 exposures in a men's college soccer team (19). Moreover, it was recommended that to reduce the risk of injuries, athletes should have a high level of strength and power to enhance performances in jumps, kicks, tackles, and sprints (42). We hypothesized that a DCER program with relatively high loads performed twice a week and over 8 weeks could enhance leg strength, leg power, and performance tasks in junior soccer players. To our knowledge, no studies have examined the effect of back half squat training on the lower body in junior soccer players. The aim of the present study was therefore to assess the effects of a 2-month resistance training program on a variety of strength, power, and performance tasks in this age group.

Methods

Experimental Approach to the Problem

This study was designed to address the following question: Does a resistance training program with heavy loads performed twice a week for 2 months enhance physical performances for soccer players? For these reasons 2 groups of soccer players within the same team were chosen: A resistance training group (RTG) and a control group (CG). All subjects completed the following tests at 2 separate periods: First the baseline period before the start of the training program and the second after 2 months of resistance training. The tests comprised a force-velocity test to evaluate leg muscle power, 3 different jump tests, a 40-m dash, a 1-RM back half squat, and anthropometric measurements to assess leg muscle volume. The effectiveness of the applied resistive training program was evaluated with pretraining and posttraining testing.

Subjects

The physical characteristics of RTG ($n = 11$) and CG ($n = 11$) are displayed in Table 1. Subjects were all junior soccer players who trained for more than 4 years (mean training period 4.7 ± 0.8 years) and were injury free for almost 2 years before participation in this study. Both groups had no experience in strength training and there was no strength training performed as part of their normal training routine. Individuals were classified by a physician for their sexual maturation in the fifth stage described by Tanner (35). Coach and parents were informed about the different tests procedures performed during the study. A parental/guardian consent for all players involved in this investigation was obtained. The study was reviewed and approved by the Committee on Research for the Medical Sciences of the University of Sousse.

All individuals were tested twice, with 2 months between each test. The resistance training program was performed twice per week over 2 months.

Evaluation and Procedure

All subjects completed 2 familiarization sessions to eliminate learning effects and to be informed about pretest instructions. The same order of testing was followed after the pre- and posttraining program. All tests were performed over 2 days separated by 48 hours of rest. All testing procedures were done in the morning at a laboratory temperature of approximately 20–22°C (except sprint running, which was done in an outdoor track with wind velocity not exceeding 0.5 m/s^{-1}). Individuals were asked to abstain from physical exercise 1 day before testing and from drinking caffeinated beverages in the last 4 hours preceding the test. The total duration of the resistance training program was 8 weeks (from February until March). All the players (RTG and CG) trained 4 times per week to develop their technical and tactical skills. Each training session lasted about 2 hours and comprised various skill activities at different intensities, offensive and defensive strategies, and finally 30 minutes of continuous play. During the competition season (from October until March) they participated each week in the official national junior soccer championship.

Table 1. Participant's physical characteristics.

Groups	Age (years)	Mass (kg)	Height (cm)
CG (n = 11)	17 ± 0.5	60 ± 7	174 ± 8
RTG (n = 11)	17 ± 0.3	59 ± 6	173 ± 3

CG = control group; RTG = resistance training group.

Day 1

Force-Velocity Test. The cycling force-velocity test was performed on a mechanically braked cycle ergometer (Monark 894 E Peak Bike, Weight Ergometer, Sweden). A familiarization session was conducted on a separate day. Individuals completed 5 short maximal sprints against consecutive braking forces of 2.5%, 5%, 7.5%, 9%, and 11.5% of the individual's body mass, with resting intervals of at least 5 minutes between trials. The cycle ergometer was equipped with an incremental digital encoder to calculate the velocity of the flywheel. Software allowed estimation of the velocity at each pedal stroke, and the product of braking force and pedaling velocity indicated the power output during each trial. The maximal power output during a given trial was defined by the individual's peak pedaling velocity. During the sprint, the pedaling rate was continuously screened on the computer and subjects were asked to stop sprinting as soon as it was clear that the velocity had reached its peak value. The sprints lasted about 5 to 7 seconds. Peak power (Wpeak) was reached when additional loading induced a decrease in power output. The corresponding braking force and pedaling velocity are respectively called optimal force and optimal velocity. Parabolic relationships were obtained only if we observed a decline of maximal power over 2 successive braking forces. Linear relationships between braking force and the corresponding pedaling velocity for all trials was plotted for each individual. Maximal pedaling velocity (V_0) and maximal force (F_0) were calculated using a regression equation (2,39).

Table 2. Intraclass correlation coefficients for relative reliability and coefficient of variation of track running velocities and jump tests.

	ICC	95% CI	CV (%)
Track running velocity			
$V_{first\ step}$ (m/s)	0.96	0.90–0.98	5.3
$V_{first\ 5\ meters}$ (m/s)	0.82	0.56–0.92	4.4
V_{max} (m/s)	0.85	0.62–0.94	4.4
Jump tests			
Squat jump height (cm)	0.96	0.90–0.98	4.6
Countermovement jump height (cm)	0.97	0.93–0.99	3.9
5-jump test (m)	0.89	0.74–0.96	2.7

ICC = intraclass correlation coefficient; CI = confidence interval; CV = coefficient of variation.

Squat Jump and Countermovement Jump. Squat jump and countermovement jump performances were measured using a contact mat (ErgojumpP apparatus, Globus Italia, Codogne, Italy). The calculation method and the apparatus have been previously described (7). The displacement of the center of gravity during the flight (*h*) corresponds to the jumping height and is calculated using the recorded flight time (t_f) as follows (7):

$$h = \frac{gt_f^2}{8}$$

where "g" is the acceleration of gravity (9.81 m/s^2).

In short, this apparatus comprises a digital timer (accuracy 0.001 second) connected to a resistive platform. The timer is triggered by the feet of the individual at the moment of release from the platform and is stopped at touch down. Thus, the flight time during the jump is recorded and allows the determination of the height reached during the jump. This method of calculation assumes that the positions of the jumpers on the apparatus were the same on take-off and on landing. Because the flight time is used to calculate the jump height, strict instructions were addressed to all subjects to keep their legs straight during the flight time of the jump. During the CMJ, the subject starts from an upright standing position on the contact mat, makes a downward movement until approximating a knee angle of 90 degrees, and subsequently begins to push off. During the SJ, the subject starts from a knee angle of 90 degrees and performs a vertical jump by pushing on his legs. During SJ, all subjects were instructed to avoid any downward movement before the pushing phase. For both jumps (SJ and CMJ), all subjects performed familiarization trials before doing 3 consecutive experimental trials for each jump. The highest value for each jump was retained.

Table 3. Anthropometric parameters before and after resistance training.

	Test	RTG ($n = 11$)	CG ($n = 11$)
Leg muscle volume (liter)	Pre	7.3 ± 0.6	7.2 ± 1.2
	Post	7.4 ± 0.7	7.1 ± 1.4
Thigh muscle volume (liter)	Pre	5.0 ± 0.4	4.9 ± 0.9
	Post	5.1 ± 0.5	4.8 ± 1
Mean thigh CSA (cm^2)	Pre	162 ± 13	160 ± 24
	Post	168 ± 16	160 ± 28

RTG = resistance training group; CG = control group.

TABLE 4. Force-velocity test calculated parameters before and after resistance training.

	Test	RTG ($n = 11$)	CG ($n = 11$)
Absolute power (W)	Pre	631 ± 90	590 ± 106
	Post	677 ± 102	596 ± 115
Power (W/kg)	Pre	10.6 ± 0.9	9.8 ± 0.9
	Post	11.0 ± 1.0	10.0 ± 1.0
Power (W/Leg muscle volume)	Pre	87 ± 8	82 ± 9
	Post	91 ± 8	84 ± 9
Power (W/thigh muscle volume)	Pre	126 ± 11	121 ± 13
	Post	133 ± 12	125 ± 15
Power (W/CSA) (W/cm^2)	Pre	3.9 ± 0.4	4.0 ± 0.4
	Post	3.7 ± 0.4	3.8 ± 0.5
Maximal pedaling velocity (rpm)	Pre	192 ± 18	197 ± 13
	Post	205 ± 12	207 ± 17
Maximal force (N)	Pre	115 ± 20	102 ± 18
	Post	116 ± 19	104 ± 17

RTG = resistance training group; CG = control group.

Day 2

Sprint Running Performance. Subjects sprinted at maximal velocity over a 40-m distance on an outdoor grass track. This playing field is familiar and specific for soccer players and is used for their habitual training sessions. Starting blocks were used to avoid slipping during the first step. All subjects were accustomed to the use of starting blocks for several days during the week before the definitive testing sessions. In preference to a radar system (10), performance was filmed by 2 video cameras (Sony Handycam, DCR-PC105E, Japan) placed perpendicularly to the running lane at selected positions along the track. The first camera was used to film the individual from the start until the first 5 m indicated by markers (part of the acceleration phase). The second camera was placed to monitor the sprint during the last 5 m (from 35 m until 40 m) also indicated by markers (phase of maximal running velocity (10,23). Therefore, the average running velocity during the first step after the start ($V_{first\ step}$), the average running velocity during the first 5 m ($V_{first\ 5\ meters}$), and the average running velocity between the 35 m and 40 m was calculated. The latter was considered as the individual maximal running velocity (V_{max}). Subjects wore dark cycling shorts, allowing the investigator to film displacement of the hip, marked with white tape; hip displacement was considered to be representative of the total displacement of the subject. Each participant performed 2 consecutives trials, separated by a recovery interval of at least 5 minutes; the highest velocity of the 2 values was retained. Data processing software (Regavi & Regressi, Micrelec, Coulommiers, France) converted measures of hip displacement to the corresponding velocities ($V_{first\ step}$, $V_{first\ 5\ meters}$, and V_{max}). The reliability of the camera and the data processing software in our working conditions was verified by measuring given speeds of moving rolling balls (2–14 m/second) by the camera (V_c) and checking them over a given distance (3 m) using photoelectric cells (V_{pc}) (GLOBUS-REHAB and Sports High Tech, Articolo ERGO TIMER, Italy). The linear relationship between the 2 estimates of the speed ($V_c = 0.9936 \times V_{pc} + 0.65$) showed that they were well correlated ($r = 0.99$; $p < 0.0001$).

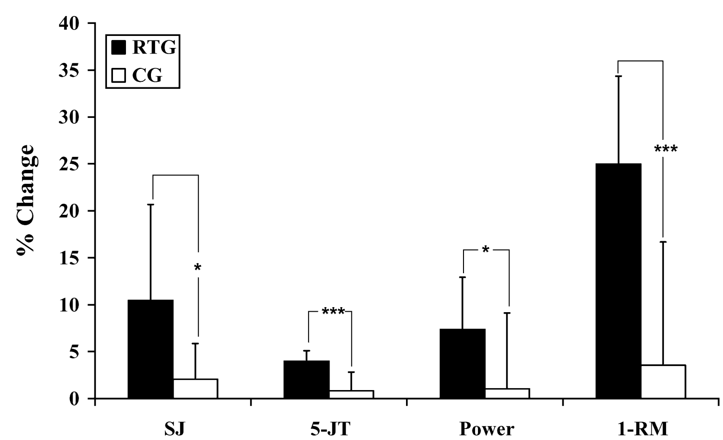

Figure 1. Comparison in percentage change in squat jump performance (SJ), 5-jump test (5-JT), force-velocity test power, and 1-repetition maximum half back squat (1-RM) from pretest to posttest between resistance training group (RTG) ($n = 11$) and control group (CG) ($n = 11$). *Nonpaired student test significantly different at $p < 0.05$. ***Nonpaired student test significantly different at $p < 0.001$.

1-RM Back Half Squat at 90 Degrees. Each participant kept an upright position, looking forward and firmly grasping the bar with both hands. The bar was also supported on the

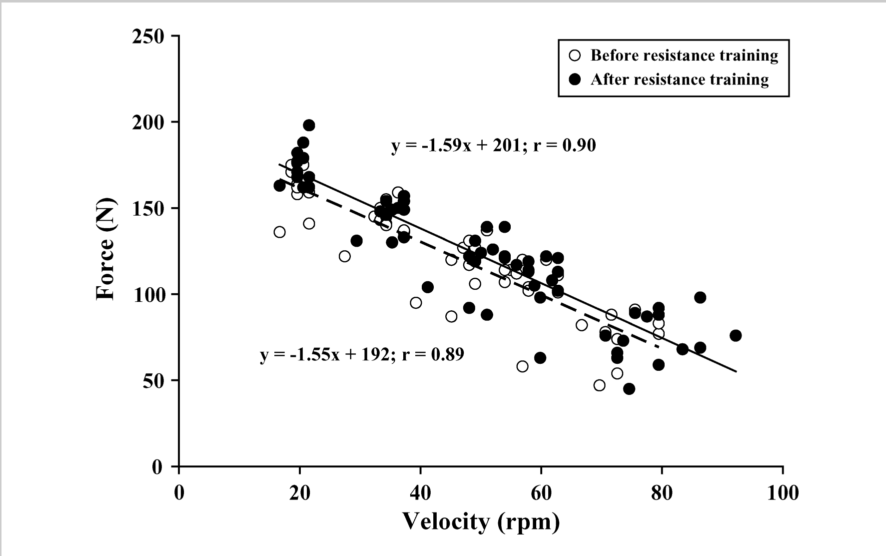

Figure 2. Resistance training group (n = 11) force-velocity relationship before (dotted line) and after (solid line) resistance training. This relationship is slightly moved up after strength training.

shoulders. Then the subject bent his knees until he reached the limit of 90 degrees. After that the subject raised himself to the upright position with the lower limbs completely extended. Because this technique was unfamiliar for the participants in this study, an instructor explained and demonstrated this lifting technique. All subjects performed 8 technical training sessions during the month preceding the 1-RM measurements. During the familiarization session, a pretest RM was done to determine the approximate RM value. To measure the experimental RM values, a barbell was loaded with free weights across the upper back of the participant and using an initial loading corresponding to 90% of the pretest RM. Two consecutive loaded flexion–extensions were performed at 90 degrees of knee flexion (a back half squat). Each time the 2 repetitions were mastered, a load of 5 kg was added after allowing a recovery interval of at least 5 minutes. When the subject performed 2 successful repetitions with his pretest RM value, a load of 1 kg was added after the recovery period. If the individual was unable to successfully complete the second repetition with the new loading, the corresponding load was considered as the individual's 1-RM. The average number of lifting actions before reaching 1-RM was 3 to 6.

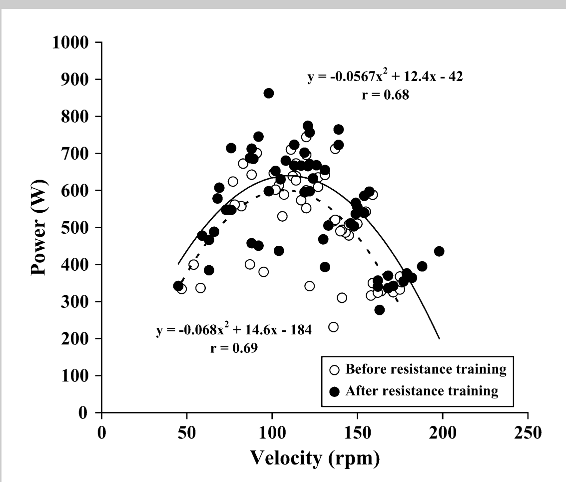

Figure 3. Resistance training group (n = 11) figure drawn of the all power and velocity data before (dotted line) and after (solid line) resistance training. The fitting of a second-order function allows us to identify the increase of the power production for all friction loads.

Five Jump Test. The 5 jump test (5-JT) consists of 5 maximal bouncing strides (27,34) from a standing position. The instructions given to all subjects were to avoid any back steps before the first bouncing stride and to land with both legs on the fifth one. The total distance covered by the subject was measured and considered as an individual performance. Each subject performed 3 consecutive trials separated by at least 1 minute of recovery. The longest distance performed by the subject was retained.

Anthropometry. To measure thigh muscle volume, circumferences (tape measure), and skinfold thicknesses (Harpenden caliper, United Kingdom) at different levels of the thigh, the length of the thigh and the width of the condyles of the knee (anthropometrical kit, SiberHegner, Zurich, Switzerland) were measured to estimate the thigh muscle volume.

The measurements of the circumferences at the maximal level of the calf just above the ankle and skinfolds on the back and each side of the calf plus leg length (from trochanter major to lateral malleolus) were added to those of the thigh to calculate the leg muscle volume (16). The accuracy of this anthropometrical method was recently challenged and validated by comparison with the dual-energy x-ray absorptiometry (DEXA) method (9).

The mean value of thigh CSA was calculated from the maximal and mid-thigh circumferences according to the following formula (9):

Circumference (C) = 2p • Radius (R)
R = C/2p

Training Program. The resistance training program for the experimental group (RTG) was carried out twice a week, immediately before the regular soccer training session, and lasted 2 months. The strength training sessions were performed on Tuesday and Thursday. Back half squat was used as a training exercise. The loads were calculated using the individual 1-RM previously measured. This 1-RM value was reassessed at the fourth week and the strength loads used for training sessions were updated. The strength training session consisted of 7 repetitions at 70%RM, 4 repetitions at 80%RM, 3 repetitions at 85%RM, and 2 repetitions at 90%RM. The load of 70% is considered as a warm-up exercise. The aim of the resistance training program was to obtain an optimal increase in muscle strength followed by a delayed increase in muscle power. For review, see Blimkie and Sale (6).

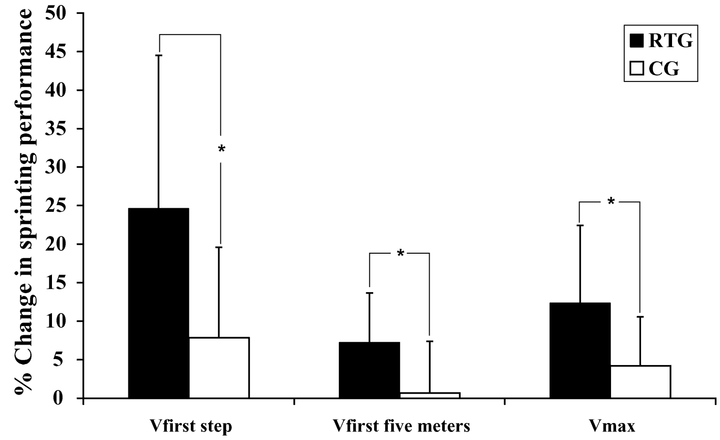

Figure 4. Comparison in percentage change in sprint running velocity variables from pretest to posttest between resistance training group (RTG) ($n = 11$) and control group (CG) ($n = 11$). *Nonpaired student test significantly different at $p < 0.05$.

The training protocol used in this study was based on the 1-RM performance of each individual. It is well known that motivation of the individual plays an important role in muscle strength improvement. Verbal encouragements were constantly given to maintain high motivation in this particular group of soccer players. Furthermore, familiarization training sessions were carried out to obtain "true" RM measurements.

Statistical Analyses

Values are expressed as mean ± standard deviation (m ± SD). Comparison between the 2 test sequences (pre- and posttest) for the 2 groups (RTG and CG) was conducted using a nonpaired Student *t*-test. The Pearson product-moment correlation was also used to determine the relationship between braking force and pedaling velocity in the force-velocity test. $p < 0.05$ was taken as the limit of significance in all statistical tests. To determine the reliability of sprint running velocities and the jump tests, the data of both groups were analyzed. We used a 1-way analysis of variance (ANOVA) to obtain the intraclass correlation coefficients (ICC) of repeated interval scale measures (29). Ninety percent confidence intervals were used to determine all the ICC. As a general rule, an ICC of more than 0.90 is considered high, between 0.80 and 0.90 moderate, and less than 0.80

Table 5. Jumps and fields tests values before and after resistance training.

	Test	RTG ($n = 11$)	CG ($n = 11$)
Jump tests			
Squat jump height (cm)	Pre	31.5 ± 4	30.8 ± 3.6
	Post	34.6 ± 3	31.4 ± 3.5*
Countermovement jump height (cm)	Pre	33.8 ± 4	33.8 ± 3.7
	Post	36.3 ± 3	34.5 ± 4.2
5-jump test (m)	Pre	10.6 ± 0.3	10.7 ± 0.6
	Post	11.1 ± 0.2	10.8 ± 0.7
Track running velocity			
$V_{first\ step}$ (m/s)	Pre	1.76 ± 0.2	1.78 ± 0.27
	Post	2.16 ± 0.2	1.91 ± 0.28*
$V_{first\ 5\ meters}$ (m/s)	Pre	3.5 ± 0.18	3.51 ± 0.13
	Post	3.75 ± 0.13	3.53 ± 0.24*
V_{max} (m/s)	Pre	7.84 ± 0.53	7.93 ± 0.27
	Post	8.77 ± 0.44	8.26 ± 0.39†
1-RM			
1-RM half back squat (kg)	Pre	105 ± 14	108 ± 11
	Post	142 ± 15	112 ± 18*

RTG = resistance training group; CG = control group.
*Student nonpaired test significantly different at $p < 0.05$.
†Student nonpaired test significantly different at $p < 0.01$.

insufficient for physiological field tests (40). The coefficient of variation (CV) was established to reflect intrasubject reproducibility for sprint running measurements and jump performances. The CV, defined by Schabort et al. (32) as the intrasubject variation expressed as a percent of the subject's mean, is based on the change in mean performance over consecutive pairs of trials for individual participants.

Results

Intraclass correlation coefficient values to asses the reliability and the coefficient of variation of track running velocities and jumps tests are displayed in Table 2.

No significant changes were observed in leg or thigh muscle volume after resistance training (Table 3). Wpeak, relative Wpeak (W/kg, W/leg muscle volume, W/thigh muscle volume, and W/CSA), maximal pedaling velocity, and maximal force calculated from the force-velocity test were not statistically different between the 2 groups before and after resistance training (Table 4). However, RTG showed a significant increase in Wpeak when % change is used for comparison (Figure 1). The force-velocity relationship was moved up after strength training (Figure 2). Moreover the fitting of a second order function of the power-velocity relationship illustrates the enhancement of muscle power production for all friction loads (Figure 3).

Wpeak increase was also accompanied by a significant enhancement in the different calculated track running velocities ($p < 0.05$ for $V_{first\ step}$, $V_{first\ 5\ meters}$, and V_{max}) (Figure 4 and Table 5) and 1-RM performance ($p < 0.001$, Figure 1 and Table 5).

Discussion

The main result of this study showed that our resistance training program induced an increase in leg cycling peak power (Wpeak) ($p < 0.05$, Figure 1) in junior soccer players. Moreover, field tests (sprint running, SJ, and 5-JT performances) were significantly improved (Figure 4 and Figure 1).

Strength training with heavy loads (85–100% of 1-RM) induces an optimal increase in strength and then enhances power with minimum effect on muscle volume (1). The present data are consistent with this finding and showed no gain in leg muscle volume (Table 3) in contrast to significant % change in leg Wpeak (Figure 1). However, after the resistance training program, relative leg peak power (W/leg muscle volume, W/thigh muscle volume, and W/CSA) remained statistically comparable between the experimental and the control groups (Table 4). Whether resistance training induced changes in limb morphology in preadolescents and adolescents is still a matter of debate. Despite significant improvements in muscle strength, Ramsay et al. (28) observed no evidence of upper arm or thigh muscle hypertrophy measured by computerized tomography in preadolescent boys following 20 weeks of high-intensity strength training. Conversely, some others studies reported an increase in both strength and muscle cross-sectional area of the thigh (15,25). Given the small samples ($n = 5–10$) in these studies, it is difficult to draw conclusive statements. However, it seems that the magnitude of the morphological adaptation is small in preadolescents and adolescents in comparison to the reported strength gains and in comparison to adults' data.

Therefore, it has been suggested that the increase of leg Wpeak is essentially a result of neuronal adaptations and coordination. In fact, neuronal adaptations include many factors, such as selective activation of motors units, synchronization, selective activation of muscles, and increased recruitment of motor units (5). These authors recommended the use of high loads (85–95% of 1-RM) with rapid actions to cause a maximal neural adaptation. Moreover, in adults, some authors have suggested the use of explosive movements with heavy loads (85–100 of 1-RM) and few repetitions (3–7) (33) to stimulate neuronal adaptations that are in accordance with the strength training program used in the present study. In preadolescent boys, the twitch interpolation technique (28) has been used to assess the contribution of changes in motor unit activation (MUA) to training-induced strength increases (6,28). MUA of the knee extensors increased by 12% after 10 weeks of training. The percentage increase in MUA was, however, less than the increase in leg strength. Another study (26) used electromyography (EMG) to measure resistance training–induced changes in neuromuscular activation of the elbow flexors in preadolescent girls and boys (26). Eight weeks of training resulted in increases of both integrated EMG amplitude (16.8%) and isokinetic strength (27.8%). Results of these studies provide direct evidence that training-induced strength gains in young people are attributable, at least in part, to increases in neuromuscular activation.

Age- and gender-associated changes in muscle size and strength during puberty have been attributed largely to hormonal influences and more specifically to changes in testosterone secretion that occur during this period. Testosterone, which is a potent anabolic agent, increases moderately (4-fold) during the early stages of puberty and then increases rapidly by another 20-fold between mid and late puberty in males (6,38). However, the influence of the effect of testosterone secretion during and just after puberty is not fully understood. Kraemer et al. (18) reported that 14- to 17-year-old male strength trainees with less than 2 years of experience did not show an increase in serum testosterone after a training period, whereas strength trainees with more than 2 years of experience did show, after training, an increase in serum testosterone. Training experience, therefore, may have an impact on the hormonal responses to training in young male athletes. Moreover, muscle fiber size, mean cross-sectional area, and morphological characteristics, which are closely related to force generation, increase during growth and have a tendency to plateau at the age of 16 to 17 years (38). In the present study, we assumed that the influence of growth parameters in resistance training is minimized as a result of the short period of our investigation

(2 months). The typical linear force-velocity relationship was observed before and after strength training. The force-velocity relationship changed upward after strength training (Figure 2). This result is in agreement with some previous studies done on isolated muscle fibers (13,20). The typical mechanical parabolic curve between power and velocity is shown in Figure 3. The latter illustrates an overall increase after strength training. Such enhancement in the muscle fiber power-force relationship after dynamic strength training was reported in previous studies (13). The same alteration also occurred on skinned fibers after a stretch-shortening cycle training program (20).

Resistance training induced improvements in jump performances, such as SJ (+10%, $p < 0.05$), and the 5-JT (+4%, $p < 0.001$) (Figure 1). However, CMJ performance showed no statistically difference after resistance training.

A strength training program on a leg press machine produced an increase in SJ performance (+9.1%, $p < 0.01$) (37), which is in accordance with our results. Nevertheless, CMJ performance remains constant and increases only when individuals performed a combined training program (strength training program on a leg press machine and jump exercises) (37). In the present study, subjects performed muscle actions against high loads (80–90% of 1-RM), which presumably involve neuronal adaptations and more specifically an increase in the rate of force development (33). Sale (30) reported increases in EMG activity after jump and strength training probably as a result of an increase of motor units' activation or an increase in their firing frequency. Several factors may contribute to changes in muscle performance during CMJ, such as an increase in muscle capacity to develop higher tension, to add more contractile elements, or to store and reuse elastic energy (37).

The 5-JT performance was highly improved after strength training ($p < 0.001$). A previous study (8) observed a strong relationship between the force-velocity test and the 5-JT. It has been suggested that an increase in Wpeak production in the force-velocity test may improve the 5-JT performance.

All track running velocities increased after the specific strength program ($p < 0.05$). In junior soccer players, the improvement in track running velocity after strength training was demonstrated by a recent study (17). In a 5-year-follow-up study of children, running speed increased by 3 to 5% a year in athletic boys (24). It is suggested that this increase was partly a result of growth and maturation and of improvement of stride length after a specific strength training program (22). Explosive efforts such as sprints or jumps play a major role in performance during soccer matches. These efforts depend essentially on maximal strength and leg peak power output. Bangsbo et al. (3) showed that high speed and moderate speed sprints were more frequent among Danish first-division players than in lower divisions. However, sprinting with a ball differs from running without a ball. There is a velocity-specific effect, and training velocity in soccer should simulate the sport movements as close as possible. Almasbakk and Hoff (1) suggested the development of the neuromuscular coordination as the crucial factor in early velocity-specific strength enhancements.

It is surprising that we did not observe significant correlations between Wpeak and velocities, which is in disagreement with data reported by Chelly and Denis (10). This might be related to the limited number and/or a selection bias of our young individuals. Furthermore, different testing methodology and thereby differences in muscular activation may explain this discrepancy. In the study reported by Chelly and Denis (10), Wpeak was measured using a specific treadmill sprinting test, which involves more muscle mass and implies the stretch-shortening cycle and therefore increases leg Wpeak. In contrast, Wpeak measured during the cycling force-velocity test does not imply the stretch-shortening cycle and muscle mass is lower (essentially the quadriceps muscle). Similarly, in elite adult soccer players Cometti et al. (11) did not report significant correlations between maximal strength and anaerobic power performances. They suggested that isokinetic tests do not reflect the same limb movement involved during sprinting, kicking a ball, or jumping.

Practical Applications

The current study indicated that 8 weeks of back half squat training with adapted heavy loads and with only 2 sessions per week elicited enhancements in peak power output, dynamic strength, jump, and sprint performances in junior soccer players. For practical purposes, this type of resistance training can be introduced preceding the habitual technical and tactical soccer training sessions. To protect young players from possible injuries, we also recommend back half squat training, even for players who are still regularly involved in strength training programs. The neuronal adaptations and force increase as a result of comparable resistance training programs in postadolescent soccer players have to be verified and necessitate further investigations.

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