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Key words
- under-15 soccer players
- full squat
- sprint
- strength
- jump ability
- velocity-based resistance training

Abstract

This study aimed to determine the effects of combined resistance training and plyometrics on physical performance in under-15 soccer players. One team (n=20) followed a 6-week resistance training program combined with plyometrics plus a soccer training program (STG), whereas another team (n=18) followed only the soccer training (CG). Strength training consisted of full squats with low load (45–60% 1RM) and low-volume (2–3 sets and 4–8 repetitions per set) combined with jumps and sprints twice a week. Sprint time in 10 and 20 m (T_{10}, T_{20}, T_{10-20}), CMJ height, estimated one-repetition maximum ($1RM_{est}$), average velocity attained against all loads common to pre- and post-tests (AV) and velocity developed against different absolute loads ($MPV_{20,\ 30,\ 40\ \text{and}\ 50}$) in full squat were selected as testing variables to evaluate the effects of the training program. STG experienced greater gains ($P<0.05$) in T_{20}, CMJ, $1RM_{est}$, AV and $MPV_{20,\ 30,\ 40\ \text{and}\ 50}$ than CG. In addition, STG showed likely greater effects in T_{10} and T_{10-20} compared to CG. These results indicate that only 6 weeks of resistance training combined with plyometrics in addition to soccer training produce greater gains in physical performance than typical soccer training alone in young soccer players.

Introduction

In modern soccer, having a well-developed physical fitness is considered an essential prerequisite to yield high performance during a match [18,42]. Many studies have reported that endurance capacity is an important feature to obtain high performance in soccer players [42,43]. However, although high-speed actions only contribute to ~1 − 11% of the total distance covered [42], they constitute the most decisive events of the game [18]. In fact, most goals are preceded by a straight sprint, jump or change of direction by either the scoring or the assisting player [7]. Such actions require high strength generation by the muscles of the lower limbs [26]. Therefore, within the aerobic context of the match, strength is also one basic quality that influences game performance [42].

The neuromuscular system's ability to produce maximal leg strength distinguishes high level soccer players from those of lower levels [43]. In addition, significant relationships have been observed between lower limb strength and sprint time, vertical jumps and changes of direction [4]. Moreover, a recent study has shown that lower limb strength was related to a higher ability to maintain performance during the game [41]. Thus, by a suitable strength training (ST) that increases the available force of muscle contraction in the appropriate muscle groups, acceleration and speed may improve in skills critical to soccer such as turning, sprinting, jumping and changing pace [42].

Short- and long-term ST have been shown to improve maximal strength of lower limb muscles with concurrent enhancement of jumping ability, rate of force development, intermittent endurance performance and sprint times in adult soccer players [17,18]. However, little information is available in the literature concerning young soccer players, although ST is deemed to be safe and effective to improve muscular strength and motor skill performance in children and adolescent athletes [14]. Thus, using appropriate training stimuli linked to natural growth and maturation processes could accelerate and enhance physical development [10]. However, there is a lack of empirical knowledge on the effects and optimization of training during

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Bibliography
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Group	Age (years)	Mass (kg)	Height (m)	BMI ($kg \cdot m^{-2}$)	MO	PAS (%)
CG	14.7 ± 0.5	63.5 ± 6.9	1.70 ± 0.06	21.9 ± 1.7	1.00 ± 0.48	95.3 ± 2.0
STG	14.7 ± 0.5	60.3 ± 6.6	1.71 ± 0.05	20.7 ± 1.6	1.04 ± 0.45	95.4 ± 1.7

CG: Control group; STG: Strength training group; BMI: Body mass index; MO: Maturity offset; PAS: Predicted adult stature

Table 1 Participant's physical characteristics (mean ± SD).

growth and maturation in young soccer players. Previous studies conducted with young soccer players have used heavy-load resistance training (RT) [5,6,25] or a combination of heavy-load RT and plyometrics [8,21,29] in order to improve strength and power characteristics. These investigations have demonstrated the positive effects that result from the application of these methods, reporting significant increases in vertical jump and sprint time [5,6,21,25]. However, RT performed with heavy loads and repetitions to muscular failure or close to it seems to be associated with a high fatigue degree [38], which may hamper the effective ball practice during subsequent technical-tactical field training [1] and may have a greater risk of injury. Thus, what type of ST produces the greatest gains with the lowest possible degree of fatigue in order to produce the minimal interference with the specific soccer training in young players remains unclear.

Several authors have suggested that it is not necessary to cause excessive fatigue to improve strength performance [11,20] and that lifting velocity is more or at least as important as the magnitude of the load *per se* [31]. Therefore, the combination of moderate loads and few repetitions in the set, lifting the load at maximal voluntary velocity, could be a sufficient stimulus to induce relevant neuromuscular adaptations in young soccer players without previous experience in RT. Despite this, few studies [11,13,23,24] have used a combined RT with plyometrics in which weight lifting exercises were performed with moderate loads and low volume. These studies [11,13,23,24] were conducted with adolescent soccer players (18–20 years of age) and training intervention resulted in significant improvements in jump height, whereas the effects on acceleration capacity were unclear. Furthermore, in 2 of these investigations [13,24], the training load (% of 1RM) of weight lifting exercise was not specified, which may hinder the interpretation of the results.

To the best of our knowledge, only 2 previous studies [11,23] have used lifting velocity as a reference to prescribe RT. This is possible because there is a very close relationship ($R^2 = 0.98$) between movement velocity and relative load (%1RM) [12]. This novel evaluation method based on lifting velocity enables the assessment of the athlete's strength without the need to perform a one-repetition maximum test (1RM) or maximum repetitions test (XRM). Thus, in the study performed by López-Segovia et al. [23] the training load in the squat exercise ranged from $1.20\,m \cdot s^{-1}$ (~45% 1RM) to $0.80\,m \cdot s^{-1}$ (~70% 1RM) and the training volume was low (4–8 repetitions per set). However, no significant improvements in either jump, sprint or strength performances were observed after the training period. These authors [23] suggested that the high-volume of endurance training performed during the intervention might have attenuated the effects of ST. On the other hand, a recent study performed by González-Badillo et al. [11] showed that 26 weeks of a combined velocity-based RT and plyometrics in young soccer players resulted in the same or even greater gains in leg strength, jumping and sprinting than 5 years (from 15–16 to 20–21 years of age) of only typical soccer training. However, several studies have indicated that improvements in strength and power are related to maturity status and the baseline strength levels [10,27]. Therefore, despite these findings, there is no information concerning the effectiveness of short-term RT combined with plyometrics on physical performance in young soccer players. In light of the aforementioned considerations, the main aim of the present study was to analyze the effect of adding to the typically technical-tactical soccer training a RT program with low loads and low number of repetitions per set combined with jumps and sprints on lower limb muscle strength, jumping ability and sprint performance among post-pubertal (14–15 years) soccer players during the first 6 weeks of season phase. We hypothesize that this type of strength training would enhance muscular strength and other factors critical to soccer performance with no concomitant interference on technical-tactical soccer training.

Materials and Methods

▼

Participants

Forty-four male, young male soccer players belonging to 2 different teams voluntarily participated in this study. A team was assigned to perform a combination of RT and plyometric exercises (STG; $n = 22$), while the other team merely conducted typical soccer training (CG; $n = 22$). 6 players were excluded from the study because they were injured or were absent from the post-testing session. As a result, the training program was completed by 20 and 18 players for the STG and the CG, respectively. Participant characteristics are displayed in ○ **Table 1**. Both teams had a similar age, weight, maturity offset and predicted adult stature, and they competed in the same group of the under-15 Spanish first division. All participants had trained for more than 5 years and were injury free for at least 6 months before participation in this study. Neither group had any experience in strength training. Coach and parents were informed about the different tests procedures performed during the study. Parental/guardian consent for all players involved in this investigation was obtained. The present investigation met the ethical standards of this journal [15] and was approved by the Research Ethics Committee of Pablo de Olavide University.

Experimental procedure

In this study a quasi-experimental design was undertaken to examine the effect of a resistance training program with low loads combined with plyometrics exercises on the physical performance of young soccer players. Two U-15 soccer teams (STG and CG) were used to examine this question over the course of 6 weeks (September–October) of training and soccer competition. The STG performed 2 RT sessions per week along with the regular soccer training, while CG continued the typical soccer training alone. Both groups performed 4 sessions of soccer training per week and played a 90-min match. Each training session lasted about 2 h and comprised various skill activities at different intensities, small-sided games, and finally 30 min of continuous play or high-intensity interval training. Except for strength training, the training contents were similar for all players of both STG and CG. All participants were tested before (Pre) and after

(Post) the 6-week experimental period using identical protocols: 1) 20-m all-out running sprints; 2) countermovement vertical jumps (CMJ); and 3) a progressive isoinertial loading test for the individual load-velocity relationship in full squat (FS) exercise. In the preceding 2 weeks of this study, 4 preliminary familiarization sessions were undertaken with the purpose of emphasizing proper execution technique in the FS exercise as well as CMJ.

Testing procedures

Anthropometric measurements were taken prior to the physical testing. The standing height (cm) and body mass (kg) were measured and the body mass index (BMI) was calculated. The maturity status of the participants was determined using years from/to peak height velocity (PHV) (i.e., maturity offset = −7.999994 + (0.0036124 × age × height) [30] as well as the percentage of predicted adult stature (PAS) [40]. Neuromuscular performance was assessed at pre- and post-training using a battery of tests performed in a single session in a fixed sequence as described below. At least 2 days before the test time, there were no fatiguing training sessions. Testing sessions were performed at the same venue and time of day (± 1 h) for each participant under the same environmental conditions (21 °C and 60% humidity). Strong verbal encouragement was provided during all tests to motivate participants to give a maximal effort.

Running sprints: Two 20-m sprints, separated by a 3-min rest, were performed in an indoor running track. Photocell timing gates were placed at 0, 10 and 20 m so that the times to cover 0–10 m (T_{10}), 0–20 m (T_{20}) and 10–20 m (T_{10-20}) could be determined. A standing start with the lead-off foot placed 1 m behind the first timing gate was used. Participants were required to give an all-out maximal effort in each sprint and the best of both trials was kept for analysis. The same warm-up protocol, which incorporated several sets of progressively faster 30-m running accelerations, was followed in the pre- and post-tests. Sprint times were measured using photocells (Polifemo Radio Light, Microgate, Bolzano, Italy). Test-retest reliability for T_{10}, T_{20} and T_{10-20} as measured by the coefficient of variation (CV) was 2.55%, 1.67% and 1.40%, respectively. The intraclass correlation coefficients (ICC) were 0.78 (95% confidence interval, CI: 0.59 − 0.89) for T_{10}, 0.90 (95% CI: 0.82 − 0.95) for T_{20} and 0.96 (95% CI: 0.92 − 0.98) for T_{10-20}.

Vertical jump: Each player performed 5 maximal jumps with their hands on their hips separated by 45 s rests. The highest and lowest values were discarded, and the resulting mean value was kept for analysis. CMJ height was determined using an infrared timing system (Optojump, Microgate, Bolzano, Italy). The CV for test-retest reliability was 2.14% and the ICC was 0.99 (95% CI: 0.98 − 1.00).

Isoinertial squat loading test: The assessment consisted of an isoinertial test with increasing loads using the full squat exercise performed in a Smith machine (Multipower Fitness Line; Peroga, Murcia, Spain) with no counterweight mechanism. A detailed description of the testing procedures used in this study has recently been reported elsewhere [11, 38]. Initial load of test was set at 20 kg and was progressively increased in 10 kg increments until the attained mean propulsive velocity (MPV) was $< 1.10\,m\cdot s^{-1}$. Thereafter, the load was individually adjusted with smaller increments (5 down to 2 kg) so that the movement velocity was $\sim 1.00\,m\cdot s^{-1}$ (range: $0.96–1.04\,m\cdot s^{-1}$). This value was chosen for several reasons: a) there is a strong relationship between the load that elicited a bar velocity of $\sim 1.00\,m\cdot s^{-1}$ ($V1_{LOAD}$) and 1RM in FS exercise [37]; b) maximal load used in FS exercise during RT was the load that elicited a $\sim 1.00\,m\cdot s^{-1}$ (~56% of 1RM [37]), thereby, when this load was obtained, we had enough information for a training prescription; c) heavier loads may also predispose to a higher risk of ventral flexion of the lumbar spine while squatting [22]; d) this load has already been used as a reference to prescribe RT [11]. The players performed 3 repetitions with each load. Only the best repetition at each load, according to the criteria of fastest MPV [39], was considered for subsequent analysis. The participants were required to always execute the concentric phase of each repetition at maximal intended velocity. Three minutes of recovery were taken between each series of repetitions. Feedback based on eccentric distance traveled and concentric velocity was provided during every repetition. This was accomplished by using a linear velocity transducer (T-Force System, Ergotech, Murcia, Spain) that registered the kinematics of every repetition and whose software provided visual and auditory feedback in real time. Characteristics and reliability of this system have recently been reported elsewhere [38]. Warm-up consisted of 5 min of joint mobilization exercises, followed by 2 sets of 8 and 6 repetitions (separated by 3-min rests) with loads of 10 and 20 kg, respectively. The exact same warm-up and progression of absolute loads were repeated in the post-test for each participant. The following variables derived from this test were used for analysis: a) estimated 1RM ($1RM_{est}$) calculated from the MPV with the last load (kg) of the test, as follows: $100 \times LOAD / -2.185 \times MPV^2 - 61.53 \times MPV + 122.5$ [37]; b) average MPV attained against all absolute loads common to pre- and post-tests (AV) [31]; c) MPV attained against 20 kg (MPV_{20}), 30 kg (MPV_{30}), 40 kg (MPV_{40}) and 50 kg (MPV_{50}).

Strength training program

The strength training program in the STG group consisted of 2 times per week, on non-consecutive days, for a period of 6 weeks. These ST sessions lasted ~35 min. The main exercises of the training program were full squats, jumps, sprints, step phase triple jumps and changes of direction. **Table 2** shows in detail the characteristics of the ST program. The loads used by each player were assigned according to the movement velocity of the Smith machine bar obtained in the initial isoinertial squat loading test. Thus, relative intensity of the squat exercise progressively increased from $\sim 1.20\,m\cdot s^{-1}$ (~45% 1RM) to $\sim 1\,m\cdot s^{-1}$ (~58% 1RM). RT was combined with displacements with changes of direction without extra loads in series of 10 s, series of 6–12 executions of the step phase of the triple jump, and lineal sprint of 20 m. Approximately 3-min rest periods were allowed between each set and each exercise, except for the step phase triple jump where the rest period was around 1–2 min. The participants were instructed to perform all exercises as fast as possible in order to obtain the highest possible gains [31]. At least 2 trained researchers supervised each workout session and recorded the compliance and individual workout data during each training session. In all sessions, warm-up consisted of 5 min of jogging and 3 min of joint mobilization exercises. Then, 2 sets of 8 and 6 repetitions (separated by 3-min rests) of FS with lower loads at maximal scheduled load in each session were performed.

Table 2 Strength training program.

Exercises	Sessions 1	2	3	4	5	6	7	8	9	10	11	12
FS (S×R) (m·s^{-1})	2×8 (1.20)	3×8 (1.20)	3×8 (1.20)	3×6 (1.12)	3×6 (1.12)	3×8 (1.12)	2×6 (1.06)	3×6 (1.06)	3×6 (1.06)	2×4 (1.00)	3×4 (1.00)	3×4 (1.00)
CMJ		3×5		3×5		3×5		3×5		3×5		3×5
SPTJ (S×J)	6×8	6×6	6×8	6×6	6×10	6×6	6×10	6×6	6×12	6×6	6×12	6×6
COD (R×T)	3×10s		3×10s		4×10s		4×10s		5×10s		3×10s	
Sprint (R×D)		3×20m		4×20m		3×20m		4×20m		4×20m		3×20m

FS: full squat; CMJ: countermovement jump; SPTJ: step phase triple jump; COD: changes of direction; S×R: sets×repetitions; S×J: sets×number of jumps; R×T: repetitions×duration. R×D: repetitions×distance

Statistical analysis

The values are expressed as mean ± standard deviation (SD). The reliability was assessed by intraclass correlation coefficients and coefficients of variation. Homogeneity of variance across groups (CG vs. STG) was verified using the Levene's test, whereas the normality of distribution of the data was examined with the Kolmogorov-Smirnov test. A 2 (group: CG, STG)×2 (time: Pre, Post) repeated measures analysis of variances (ANOVA) was calculated for each parameter. Bonferroni post-hoc tests were used when the interaction was significant. Effect sizes (ES) were calculated using Hedge's *g* [16] in order to estimate the magnitude of the training effect on the selected neuromuscular variables within each group, as follows: g=(mean STG – mean CG)/combined SD. The standardized difference for changes between the STG and CG in each dependent variable was calculated on log-transformed values using the pooled pre-training SD [19]. Probabilities were also calculated to establish whether the true (unknown) differences were lower, similar or higher than the smallest worthwhile difference or change (0.2 multiplied by the between-subject standard deviation [19]). Quantitative chances of higher or lower differences were evaluated qualitatively as follows: < 1 %, almost certainly not; 1–5 %, very unlikely; 5–25 %, unlikely; 25–75 %, possible; 75–95 %, likely; 95–99 %, very likely; > 99 %, almost certain. If the chances of having higher or lower values than the smallest worthwhile difference were both > 5 %, the true difference was assessed as unclear. Pearson's correlation coefficients were calculated to establish the respective relationships between the changes of all measured variables. Inferential statistics based on interpretation of magnitude of effects were calculated using a purpose-built spreadsheet for the analysis of controlled trials [Hopkins WG. Analysis of a pre-post controlled trial (December, 2006). On the Internet: http://www.sportsci.org; (retrieved 10 February, 2012)]. The statistical analyses were performed using SPSS software version 18.0 (SPSS Inc., Chicago, IL). Statistical significance was established at the $P<0.05$ level.

Results

Significant differences between groups were found at baseline for $1RM_{est}$, AV, MPV_{20}, MPV_{30} and MPV_{50} in favor of CG. Compliance with the ST program was 95.7 % in all sessions scheduled for STG. Mean values, percent changes from pre- to post-training and ES for all variables analyzed are reported in **Table 3**.

Vertical jump and sprint time: Significant time × group interactions in favor of STG were observed for T_{20} ($P<0.04$) and CMJ ($P<0.001$), whereas there was no time × group interaction for T_{10} ($P=0.25$) and T_{10-20} ($P=0.18$). Training resulted in a significant improvement ($P<0.05$) in T_{10-20}, T_{20} and CMJ, and a trend toward a significant improvement in T_{10} ($P=0.083$) for STG. No significant pre-post changes were found in either CMJ or sprint time performance for CG. Greater intra-group ES were found for STG when compared to CG in all variables. Furthermore, STG presented *almost certainly* greater effect on CMJ (with chance for greater/similar/lower scores than CG of 100/0/0 for STG) than CG, whereas the beneficial effects of STG compared to CG on T_{10}, T_{10-20} and T_{20} were *possible* (66/32/3), *possible* (58/41/1) and *likely* (80/20/0), respectively (**Fig. 1**).

Isoinertial strength assessments: Large significant time × group interactions in favor of STG were observed for $1RM_{est}$, AV, MPV_{20},

Table 3 Changes in selected neuromuscular performance variables from pre- to post-training for each group.

	CG				STG			
	Pre	**Post**	**Δ (90% CI)**	**ES (90% CI)**	**Pre**	**Post**	**Δ (90% CI)**	**ES (90% CI)**
T_{10} (s)	1.79 ± 0.08	1.79 ± 0.06	+0.0 (−1.3 to 1.2)	−0.01 (−0.28 to 0.27)	1.76 ± 0.06	1.74 ± 0.06	−1.3 (−2.5 to 0.0)	−0.35 (−0.71 to 0.0)
$T_{10–20}$ (s)	1.33 ± 0.06	1.32 ± 0.06	−0.1 (−1.5 to 1.2)	−0.03 (−0.31 to 0.25)	1.33 ± 0.06	1.31 ± 0.06 $^{\#}$	−1.3 (−2.0 to −0.5)	−0.25 (−0.40 to −0.11)
T_{20} (s)	3.13 ± 0.12	3.13 ± 0.10	+0.2 (−0.6 to 1.0)	−0.05 (−0.14 to 0.25)	3.10 ± 0.11	3.07 ± 0.10 $^{\#\S}$	−1.1 (−1.7 to −0.4)	−0.29 (−0.47 to −0.11)
CMJ (cm)	33.2 ± 3.7	33.4 ± 3.7	+0.6 (−0.8 to 2.0)	0.05 (−0.07 to 0.17)	33.2 ± 4.8	36.2 ± 5.8 $^{\#\#\#\S\S\S}$	+9.0 (6.4 to 11.3)	0.58 (0.41 to 0.72)
$1RM_{est}$ (kg)	76.8 ± 15.3 *	78.6 ± 15.3	+2.4 (−1.4 to 2.6)	0.11 (−0.07 to 0.29)	65.2 ± 13.0	84.0 ± 17.3 $^{\#\#\#\S\S\S}$	+28.5 (22.5 to 34.9)	1.16 (0.93 to 1.38)
AV ($m \cdot s^{-1}$)	1.20 ± 0.06 **	1.23 ± 0.05	+2.1 (0.6 to 3.6)	0.31 (0.08 to 0.53)	1.12 ± 0.09	1.31 ± 0.12 $^{\#\#\#\S\S\S}$	+18.9 (15.5 to 22.3)	1.78 (1.49 to 2.08)

Data are mean ± SD; Pre: initial evaluation; Post: final evaluation; ES: intra-groups effects size; Δ: Pre-Post Change; CI: Confidence Interval; T_{10}: 10 m sprint time; $T_{10–20}$: 10–20 m sprint time; T_{20}: 20 m sprint time; CMJ: countermovement jump; $1RM_{est}$: estimated one-repetition maximum; AV: average velocity attained against all loads common to pre- and post-tests; Differences between groups at Pre: $^{*}P<0.05$, $^{**}P<0.01$; Differences intra-groups: $^{\#}P<0.05$, $^{\#\#\#}P<0.001$; Significant group × time interaction: $^{\S}P<0.05$, $^{\S\S\S}P<0.001$. *Note*: The negative ES in sprint time variables represent a positive training effect, due to improvements in sprint performance are represented by a decrease in sprint time, which result in a negative ES

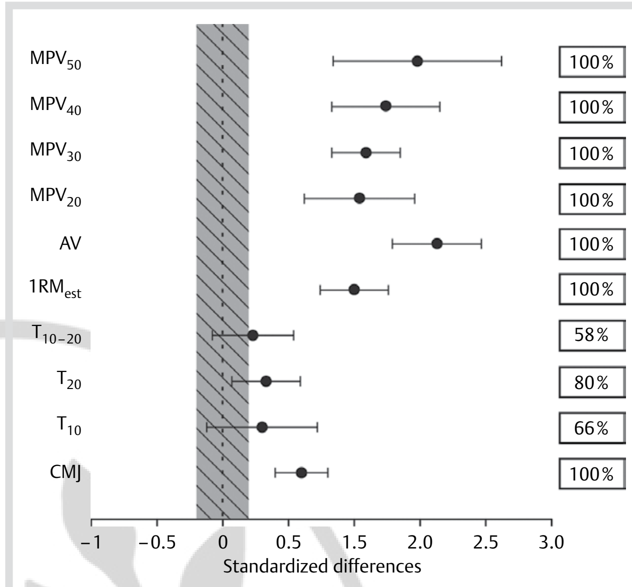

Fig. 1 Differences scores (90% confidence intervals) for changes from pre- to post-test in 10 m (T_{10}), 10–20 m ($T_{10–20}$) and 20 m (T_{20}) sprint time, countermovement jump performance (CMJ), estimate one repetition maximum ($1RM_{est}$), average velocity attained against all absolute loads common to pre- and post-tests (AV) and velocity developed against different absolute loads ($MPV_{20, 30, 40 \text{ and } 50}$) when comparing the STG and CG. Gray areas represent trivial differences. The probability of the effect being practically relevant in favor of STG compared to CG is additionally given in the boxes.

MPV_{30}, MPV_{40} and MPV_{50} ($P<0.001$, in all cases). STG showed significant improvements in all variables measured during the isoinertial progressive loading test, whereas no significant pre-post changes were observed for CG (▶ **Table 3 and** ▶ **Fig. 2**). Practically worthwhile differences between STG and CG showed that STG resulted in an *almost certainly* better effect on $1RM_{est}$ (100/0/0) and AV (100/0/0), as well as on MPV_{20} (100/0/0), MPV_{30} (100/0/0), MPV_{40} (100/0/0) and MPV_{50} (100/0/0) than CG.

Correlations: When the data from both groups were pooled, significant negative correlations were observed between the individual relative changes in CMJ and the individual relative changes in T_{10} ($r=-0.49$; $P<0.01$) and T_{20} ($r=-0.59$; $P<0.001$) (▶ **Fig. 3a, b**). Furthermore, significant positive correlations were observed between the individual relative changes in CMJ and the individual relative changes in $1RM_{est}$ ($r=0.63$; $P<0.001$), AV ($r=0.68$; $P<0.001$) (▶ **Fig. 3c**), MPV_{20} ($r=0.56$; $P<0.01$), MPV_{30} ($r=0.72$; $P<0.001$), MPV_{40} ($r=0.62$; $P<0.001$) and MPV_{50} ($r=0.69$; $P<0.001$). The individual relative changes in $1RM_{est}$ also showed a significant negative correlation with the individual relative changes in T_{20} ($r=-0.37$; $P<0.05$). No significant correlations were found between the individual relative changes in isoinertial strength parameters and the individual relative changes in T_{10} and $T_{10–20}$.

Discussion

The main finding of this study was that a RT with low loads and low volume combined with jumps and sprint exercises induced important enhancements in various strength parameters, as well as in vertical jump ability and sprint performance in young

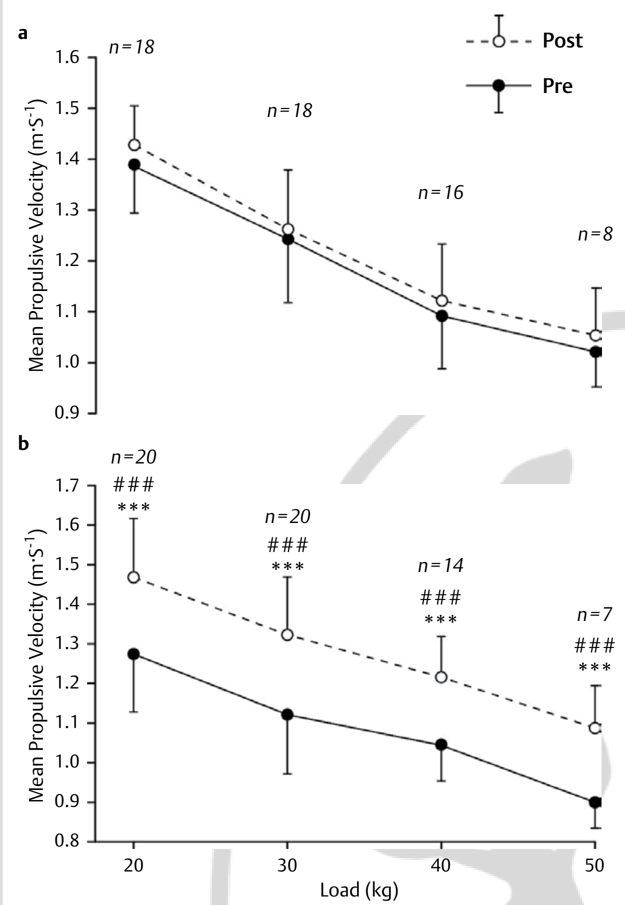

Fig. 2 Load-velocity curve in full-squat exercise obtained in control group **a** and strength training group **b** before and after a 6-week training period. Values are means ± SD. Significant difference within group (* P<0.05; ** P<0.01; *** P<0.001). Significant interaction time × group (# P<0.05; ## P<0.01; ### P<0.001). *Note:* The sample size in each load was decreasing because the participants did not need to progress to that resistance during the initial isoinertial squat loading test.

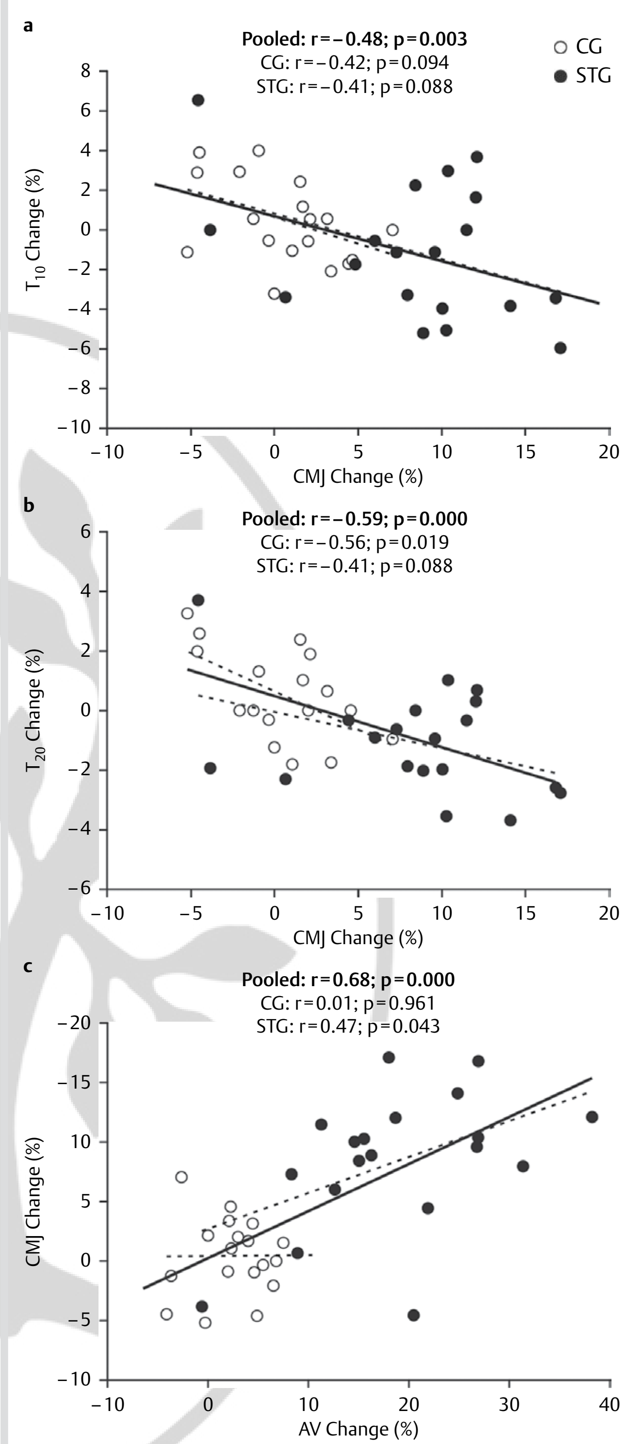

Fig. 3 Relationships between the individual percentage changes in CMJ and the individual percentage changes in 10-m sprint time **a**, 20-m sprint time **b** and average velocity attained against all absolute loads common to pre- and post-tests **c** after 6-week training period in both groups.

soccer players. Specifically, STG showed significant improvements in all the variables analyzed, except for T_{10} ($P=0.08$), whereas CG remained unchanged after the intervention period. Thus, the results of the present study suggest that young, trained soccer players with low initial strength levels could increase physical performance by adding a low-frequency and low-load RT program combined with plyometrics that accounts for a very low percentage of the total soccer training. Therefore, these results provide relevant evidence to support the need of adding strength and power training within the soccer training program to obtain further development of the physical condition of young players.

Vertical jump and sprint time

After a 6-week intervention, STG showed greater improvement in jumping performance compared to CG (**Table 3** and **Fig. 1**). Previous studies [8,13,24,29] conducted with adults and young soccer players have shown the beneficial effects of RT combined with plyometric exercises on CMJ (1.2–5.1 %; ES: 0.28–0.35), although these improvements were lower than those shown in current study (9 %; ES: 0.58). However, other studies with similar training methods have failed to find significant changes in this variable [23,35]. In one of these studies [35], the weight-lifting exercise was performed with heavy loads and repetitions to failure (6–4RM). Although these training loads have been shown to improve high-explosive actions [6], it seems that lighter, more explosive lifts may be equally or even more effective than heavier lifts that are performed at lower velocities [28]. In the other study, Lopez-Segovia et al. [23] used a training design close to the present study. Nevertheless, in this study the ST program was combined with a large volume of aerobic work. As previous

studies have indicated [34], endurance training could inhibit part of the potential adaptations resulting from ST. This did not occur during the present study, which could explain the differences between the results of both studies.
Regarding sprint time, the training program resulted in significant T_{10}, T_{20} and $T_{10–20}$ improvements for STG whereas CG remained unchanged (▶ **Table 3**). However, the training effect was lower than the effect size (ES: −0.53, 95% CI: 0.23–0.83) and percentage changes (−5.8±2.5%) reported in meta-analyses analyzing the effects of combined training on running sprint times in post-PHV participants [2, 36]. Other studies [8, 13, 23, 24, 32, 35] which analyzed the effects of combined RT and plyometrics on short-distance sprinting in young soccer players have failed to induce a change in this variable despite an increase in strength and/or power. Research into this matter has pointed out that the transfer of strength training effects into sprint performance may be limited when the tasks that supplement the RT are vertical plyometrics only or the volume of specific sprint exercises is too low [8, 13, 21, 29]. However, the content of specific sprint exercises in the aforementioned studies was very similar to that of the present study. Furthermore, except for Ronnestad et al. [35], these studies [8, 13, 23, 24, 32] used the same weight-lifting exercise (squat) with a training volume and intensity very similar to those used in our study. Thus, the greater gains obtained in the present study could be related to other factors, including the maturity status and the baseline strength level of the participants [10]. In fact, it seems that the phase of accelerated adaptation to training for sprint improvements has been suggested to appear at mid- and post-PHV (12–15 years) [36]. Therefore, our results seem to indicate that the same training stimulus could result in greater beneficial effects on sprint and vertical jump in younger players because they might be in more favorable physiological condition (greater hormone levels and incomplete myelination of the nervous system) for strength development than older players.

Strength performance

Strength has usually been measured through the 1RM or XRM tests. However, the direct and precise measure of 1RM can be difficult to obtain if the movement velocity of such 1RM is not adequately controlled [12]. In addition, heavy weights may involve a increased risk of injury, especially for children and participants with no previous experience in strength training. For this reason, we have evaluated the effect of RT on muscle strength through the changes in movement velocity developed against different absolute loads common to pre- and post-tests, as it has been done previously with soccer players [23]. This is possible due to the development of new devices (linear position transducers, rotary encoders, accelerometers, etc.) that enable the direct measuring of many kinematic and kinetic variables that can be used to assess the effects of RT. Since the change of movement velocity against the same absolute load is directly dependent on the force applied, an increment of movement velocity is an indicator of strength improvement. Therefore, it seems that this way of measuring the change in force could prevent any mistakes that may occur during the direct measuring of 1RM.
In connection with the above, the results of our study show that only 6 weeks of RT with low loads (45–60% 1RM) and few repetitions per set produced significant gains in MPV_{20}, MPV_{30}, MPV_{40} and MPV_{50} (▶ **Fig. 2**). The magnitude of the change of movement velocity against the different absolute loads (ES = 1.17–2.28) was substantially greater than those reported by Lopez-Segovia et al. [23] (ES = 0.27–0.72), although such study was longer (16 weeks) than the present study (6 weeks) and the initial strength levels appear to be similar. As mentioned above, the discrepancy with our results could be due to the fact that in this study [23] ST was combined with a large amount of aerobic work. Furthermore, our players were younger than those who took part in the study of Lopez-Segovia et al. [23]. Thus, it is possible that our soccer players were in the so-called critical periods (windows of trainability) for strength development, which may favor the adaptations induced by ST [27]. In fact, several researchers [3, 33] have demonstrated a performance spurt in strength and power development to be peak approximately 0.5–1.0 years after peak height velocity, similar to that shown by the soccer players of the current study. As mentioned above, improvements in strength and consequently in power output are attributed to the rise of hormone levels (testosterone and growth hormones) associated with puberty around PHV [9, 36].
On the other hand, the improvements shown by STG in $1RM_{est}$ compared to CG (25.6%; ES = 1.00) were similar to those observed in previous studies (7–30%) [5, 8, 21, 29] in soccer players with similar duration and frequency of training. However, these studies used a RT with greater load (70–95% 1RM) and repetitions per set to muscular failure or close to it. This type of RT may hamper the effective ball practice during subsequent technical-tactical field training due to onset of localized muscular fatigue [1] and may have a greater potential risk of injury. In light of these findings, it appears that the higher velocities and accelerations associated with lighter training load may compensate for the lighter mass. Therefore, the resistance training of the present study that combines low loads and low volume with a sufficient rest period between sets might be a good alternative to obtain improvements in physical performance producing minimal interference with the specific soccer training.

Relationship between strength, vertical jump and sprint time

When the data from both teams were pooled, significant negative correlations were observed between the individual relative changes in CMJ and the individual relative changes in T_{10} and T_{20} (▶ **Fig. 3a, b**). Similar results have been reported in previous studies performed with young soccer players [13]. These relationships are in agreement with those biomechanical analyses of sprinting that show that short-distance sprint performance is highly dependent on the subject's ability to generate powerful extensions of the knee extensor, hip extensor and plantar flexor muscles [13]. On the other hand, a significant correlation was observed between the individual relative changes in $1RM_{est}$ and the individual relative changes in CMJ ($r = 0.63$; $P < 0.001$) and T_{20} ($r = -0.37$; $P < 0.05$). These relationships suggest that the improvements obtained in CMJ and sprint time were partially due to the increase of lower limb strength. The fact that the correlation between $1RM_{est}$ and CMJ was greater than the correlation between $1RM_{est}$ and T_{20} is probably explained by the principle of training specificity, as greater biomechanical similarities seem to exist between squat and CMJ (i.e., triple extension of hip, knee and ankle joints; force simultaneously applied with both feet; larger ground contact time; etc.) than between squat and sprint.

Training load analysis

The training load (kg) in full squat exercise was established according to the velocity achieved against different loads during

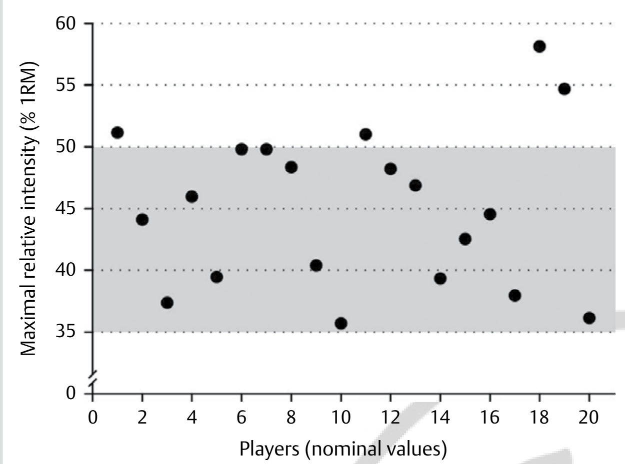

Fig. 4 Maximal relative load achieved in the last 3 training sessions for each player of strength training group. X-axis values represent nominal values.

the initial isoinertial squat loading test, and no adjustments were performed during the training period. Thus, the minimum scheduled load corresponded to ~45% 1RM (~1.20 m·s^{-1}), whereas the maximum scheduled load was ~58% of baseline 1RM (~1.00 m·s^{-1}) (◉ **Table 2**). However, since the average improvement in $1RM_{est}$ in this exercise was 29.51%, it is reasonable to assume that the maximum load used during the RT program was not ~58% 1RM. Specifically, the average load performed in the last 3 sessions represented ~45.74±7.26% of the post-test $1RM_{est}$ (38.05÷83.95×100, where 38.05 is the average absolute load of the last 3 sessions and 83.95 is the average of the post-test $1RM_{est}$ of STG). These results seem to indicate that the relative load (%1RM) of FS exercise remained practically stable during the 6-week strength training and in this period only the absolute load (kg) increased. Thus, most of the players of STG (16 soccer players) trained with a maximum load below or equal to 50% 1RM (◉ **Fig. 4**). Therefore, our results suggest that RT in which the 50% 1RM is not overcome involves a stimulus that is sufficient to obtain relevant improvements on the performance of young soccer players without the need to use heavy loads with repetitions to muscular failure.

Conclusions and Practical Applications

The results of the present study showed that an RT program consisting of weight-lifting with low loads and low volume combined with plyometric and sprint exercises, in addition to the normal soccer training, induced important gains in strength, jumping height and sprint performance compared with only typical soccer training. Thus, several critical implications for coaches may be derived from this investigation to optimize the training process in young soccer players. First, RT with low loads and lifting the load at maximal voluntary velocity involves an intense stimulus within the normal soccer training program that produces greater improvements in tasks critical to soccer performance than those generated by specific soccer practice, without the need for performing repetitions to muscle failure. Finally, since the strength training applied in this study has a short duration and produces low fatigue levels, it can be easily integrated twice a week before the normal technical-tactical field soccer training.

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References

1 *Apriantono T, Nunome H, Ikegami Y, Sano S.* The effect of muscle fatigue on instep kicking kinetics and kinematics in association football. J Sports Sci 2006; 24: 951–960
2 *Behringer M, Vom Heede A, Matthews M, Mester J.* Effects of strength training on motor performance skills in children and adolescents: a meta-analysis. Pediatr Exerc Sci 2011; 23: 186–206
3 *Beunen G, Malina RM.* Growth and physical performance relative to the timing of the adolescent spurt. Exerc Sport Sci Rev 1988; 16: 503–540
4 *Comfort P, Stewart A, Bloom L, Clarkson B.* Relationships between strength, sprint, and jump performance in well-trained youth soccer players. J Strength Cond Res 2014; 28: 173–177
5 *Chelly MS, Fathloun M, Cherif N, Ben Amar M, Tabka Z, 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 2009; 23: 2241–2249
6 *Christou M, Smilios I, Sotiropoulos K, Volaklis K, Pilianidis T, Tokmakidis SP.* Effects of resistance training on the physical capacities of adolescent soccer players. J Strength Cond Res 2006; 20: 783–791
7 *Faude O, Koch T, Meyer T.* Straight sprinting is the most frequent action in goal situations in professional football. J Sports Sci 2012; 30: 625–631
8 *Faude O, Roth R, Di Giovine D, Zahner L, Donath L.* Combined strength and power training in high-level amateur football during the competitive season: a randomised-controlled trial. J Sports Sci 2013; 31: 1460–1467
9 *Forbes H, Bullers A, Lovell A, McNaughton LR, Polman RC, Siegler JC.* Relative torque profiles of elite male youth footballers: effects of age and pubertal development. Int J Sports Med 2009; 30: 592–597
10 *Ford P, De Ste Croix M, Lloyd R, Meyers R, Moosavi M, Oliver J, Till K, Williams C.* The long-term athlete development model: physiological evidence and application. J Sports Sci 2011; 29: 389–402
11 *Gonzalez-Badillo JJ, Pareja-Blanco F, Rodriguez-Rosell D, Abad-Herencia JL, Del Ojo-Lopez JJ, Sanchez-Medina L.* Effects of velocity-based resistance training on young soccer players of different ages. J Strength Cond Res 2014
12 *Gonzalez-Badillo JJ, Sanchez-Medina L.* Movement velocity as a measure of loading intensity in resistance training. Int J Sports Med 2010; 31: 347–352
13 *Gorostiaga EM, Izquierdo M, Ruesta M, Iribarren J, Gonzalez-Badillo JJ, Ibanez J.* Strength training effects on physical performance and serum hormones in young soccer players. Eur J Appl Physiol 2004; 91: 698–707
14 *Harries SK, Lubans DR, Callister R.* Resistance training to improve power and sports performance in adolescent athletes: a systematic review and meta-analysis. J Sci Med Sport 2012; 15: 532–540
15 *Harriss DJ, Atkinson G.* Ethical standards in sport and exercise science research: 2014 update. Int J Sports Med 2013; 34: 1025–1028
16 *Hedges LV, Olkin IO.* Statistical methods for meta-analysis. Orlando, FL: Academic Press, 1985
17 *Helgerud J, Rodas G, Kemi OJ, Hoff J.* Strength and endurance in elite football players. Int J Sports Med 2011; 32: 677–682
18 *Hoff J, Helgerud J.* Endurance and strength training for soccer players: physiological considerations. Sports Med 2004; 34: 165–180
19 *Hopkins WG, Marshall SW, Batterham AM, Hanin J.* Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 2009; 41: 3–13
20 *Izquierdo M, Ibanez J, Gonzalez-Badillo JJ, Hakkinen K, Ratamess NA, Kraemer WJ, French DN, Eslava J, Altadill A, Asiain X, Gorostiaga EM.* Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength, and muscle power gains. J Appl Physiol 2006; 100: 1647–1656
21 *Kotzamanidis C, Chatzopoulos D, Michailidis C, Papaiakovou G, Patikas D.* The effect of a combined high-intensity strength and speed training program on the running and jumping ability of soccer players. J Strength Cond Res 2005; 19: 369–375
22 *Lander JE, Hundley JR, Simonton RL.* The effectiveness of weight-belts during multiple repetitions of the squat exercise. Med Sci Sports Exerc 1992; 24: 603–609
23 *Lopez-Segovia M, Palao Andres JM, Gonzalez-Badillo JJ.* Effect of 4 months of training on aerobic power, strength, and acceleration in two under-19 soccer teams. J Strength Cond Res 2010; 24: 2705–2714

24 *Los Arcos A*, *Yanci J*, *Mendiguchia J*, *Salinero JJ*, *Brughelli M*, *Castagna C*. Short-term training effects of vertically and horizontally oriented exercises on neuromuscular performance in professional soccer players. Int J Sports Physiol Perform 2014; 9: 480–488
25 *Maio Alves JM*, *Rebelo AN*, *Abrantes C*, *Sampaio J*. Short-term effects of complex and contrast training in soccer players' vertical jump, sprint, and agility abilities. J Strength Cond Res 2010; 24: 936–941
26 *Meylan C*, *Malatesta D*. Effects of in-season plyometric training within soccer practice on explosive actions of young players. J Strength Cond Res 2009; 23: 2605–2613
27 *Meylan CM*, *Cronin JB*, *Oliver JL*, *Hopkins WG*, *Contreras B*. The effect of maturation on adaptations to strength training and detraining in 11-15-year-olds. Scand J Med Sci Sports 2014; 24: e156–e164
28 *Mohamad NI*, *Cronin JB*, *Nosaka KK*. Difference in kinematics and kinetics between high- and low-velocity resistance loading equated by volume: implications for hypertrophy training. J Strength Cond Res 2012; 26: 269–275
29 *Moore EW*, *Hickey MS*, *Reiser RF*. Comparison of two twelve week off-season combined training programs on entry level collegiate soccer players' performance. J Strength Cond Res 2005; 19: 791–798
30 *Moore SA*, *McKay HA*, *Macdonald H*, *Nettlefold L*, *Baxter-Jones AD*, *Cameron N*, *Brasher PM*. Enhancing a somatic maturity prediction model. Med Sci Sports Exerc 2014
31 *Pareja-Blanco F*, *Rodriguez-Rosell D*, *Sanchez-Medina L*, *Gorostiaga EM*, *Gonzalez-Badillo JJ*. Effect of movement velocity during resistance training on neuromuscular performance. Int J Sports Med 2014; 35: 916–924
32 *Perez-Gomez J*, *Olmedillas H*, *Delgado-Guerra S*, *Ara I*, *Vicente-Rodriguez G*, *Ortiz RA*, *Chavarren J*, *Calbet JA*. Effects of weight lifting training combined with plyometric exercises on physical fitness, body composition, and knee extension velocity during kicking in football. Appl Physiol Nutr Metab 2008; 33: 501–510
33 *Philippaerts RM*, *Vaeyens R*, *Janssens M*, *Van Renterghem B*, *Matthys D*, *Craen R*, *Bourgois J*, *Vrijens J*, *Beunen G*, *Malina RM*. The relationship between peak height velocity and physical performance in youth soccer players. J Sports Sci 2006; 24: 221–230
34 *Ronnestad BR*, *Hansen EA*, *Raastad T*. High volume of endurance training impairs adaptations to 12 weeks of strength training in well-trained endurance athletes. Eur J Appl Physiol 2012; 112: 1457–1466
35 *Ronnestad BR*, *Kvamme NH*, *Sunde A*, *Raastad T*. Short-term effects of strength and plyometric training on sprint and jump performance in professional soccer players. J Strength Cond Res 2008; 22: 773–780
36 *Rumpf MC*, *Cronin JB*, *Pinder SD*, *Oliver J*, *Hughes M*. Effect of different training methods on running sprint times in male youth. Pediatr Exerc Sci 2012; 24: 170–186
37 *Sánchez-Medina L*, *García -Pallarés J*, *Pérez CE*, *Fernandes J*, *Gonzalez Badillo JJ*. Estimation of relative load from mean velocity in the full squat exercise. In: Cable NT, George K.ed. Book of Abstracts of the 16th Annual Congress of the European College of Sports Science. Liverpool, UK: Liverpool John Moores University, 2011; 669
38 *Sanchez-Medina L*, *Gonzalez-Badillo JJ*. Velocity loss as an indicator of neuromuscular fatigue during resistance training. Med Sci Sports Exerc 2011; 43: 1725–1734
39 *Sanchez-Medina L*, *Perez CE*, *Gonzalez-Badillo JJ*. Importance of the propulsive phase in strength assessment. Int J Sports Med 2010; 31: 123–129
40 *Sherar LB*, *Mirwald RL*, *Baxter-Jones AD*, *Thomis M*. Prediction of adult height using maturity-based cumulative height velocity curves. J Pediatr 2005; 147: 508–514
41 *Silva JR*, *Magalhaes J*, *Ascensao A*, *Seabra AF*, *Rebelo AN*. Training status and match activity of professional soccer players throughout a season. J Strength Cond Res 2013; 27: 20–30
42 *Stolen T*, *Chamari K*, *Castagna C*, *Wisloff U*. Physiology of soccer: an update. Sports Med 2005; 35: 501–536
43 *Wisloff U*, *Helgerud J*, *Hoff J*. Strength and endurance of elite soccer players. Med Sci Sports Exerc 1998; 30: 462–467