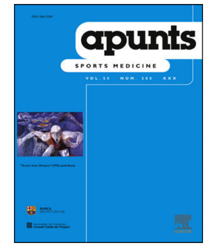
Apunts Sports Med. 2020;**55(206)**:53–61

apunts
SPORTS MEDICINE
www.apunts/org



ORIGINAL ARTICLE

Effects of strength training based on velocity versus traditional training on muscle mass, neuromuscular activation, and indicators of maximal power and strength in girls soccer players

Jairo Alejandro Fernandez Ortega[a,*], **Yennys Gonzalez De los Reyes**[b], **Felipe Ricardo Garavito Peña**[b]

[a] *Laboratory of Exercise Physiology, National Pedagogical University, calle 72, #11-86 Bogotá, Colombia*
[b] *Santo Tomas University Bogotá, Colombia*

Received 14 June 2019; accepted 31 March 2020
Available online 24 May 2020

KEYWORDS
Soccer;
Maximal power;
Females;
Mean propulsive velocity

Abstract This study examines the effects of two strength training (ST) programs, one based on mean propulsive velocity (MPV) and another under the traditional method, the % one-repetition maximum (1RM), on neuromuscular performance and muscle composition in girls who play soccer. Fifty players with an average age of 13.6 ± 1.2 years participated in the study and were randomly assigned into three groups: a maximal execution velocity training group (VG, $n = 15$), a maximal strength group (RMG, $n = 13$), and a control group (CG, $n = 18$). The study was developed for a period of twelve weeks during regular team training to prepare for the season. The VG and RMG groups performed additional strength or muscle power training three times a week, including movements of full squat and pedaling on a cycle ergometer. The two types of training groups and the control group exhibited significant gains. However, the greatest increases were achieved with VG training, with significant increases ($p < 0.000$) in maximal strength, ($p < 0.000$) squat power, ($p < 0.000$) velocity over 30 m, ($p < 0.000$) cycle ergometer power, and ($p < 0.008$) lower limb muscle mass. Statistically significant differences were observed between VG and RMG in countermovement jump (CMJ) ($p < 0.008$) and squat power ($p < 0.01$) tests, between VG and CG in CMJ ($p < 0.01$), squat power ($p < 0.000$), and maximal squat strength ($p < 0.000$), and between RMG and CG in maximal squat strength ($p < 0.000$) only. These findings might indicate that high-velocity ST can be performed simultaneously with regular training to improve the explosive actions of soccer players.

* Corresponding author.
E-mail address: jairofdz@pedagogica.edu.co (J.A. Fernandez Ortega).

https://doi.org/10.1016/j.apunsm.2020.03.002

Introduction

Power, velocity, and agility are fundamental aspects of a soccer player's performance because they are the basis for performing different actions such as high-velocity and short-duration movements (1–7 s), sudden jumps, and changes in direction.[1,2] Mara et al.[3] observed the accelerations and decelerations that occur during an official game involving elite female soccer players (24.3 years of age), reporting that the players performed 423 (±126) accelerations and 430 (±125) decelerations at different velocities per game. The average time of accelerations and decelerations was ± 5 s and ± 4 s, respectively, and the mean and maximum distances traveled per effort were 1–4 m and 2–8 m, respectively, differing between each intensity category ($p < 0.001$, partial $\eta^2 = 0.753–0.908$). It was also identified that high-velocity movements constituted 1–11% of the total distance traveled during a match. The crucial events in soccer are mainly performed at high intensity, including linear sprints, vertical jumps, changes in direction, passes, tackles and many other actions that require increased strength and power generation by the muscles of the lower limbs.[2] An increase in muscle contraction force of the lower limbs allows for better acceleration and velocity, which are the basis for dribbling and other fundamental skills in soccer.[4] In addition, greater power can be produced by increasing the execution velocity of the force, which will be manifested in higher velocity at the moment of execution of a sports gesture.[4]

In this respect, several studies have demonstrated correlations between maximal squat strength and jump height, 10-m sprint, and 30-m sprint performances. For example, Wisloff et al.[5] observed correlations ($r = 0.78$ and 0.94) between the one-repetition maximum (1RM) in squats and in 10-m and 30-m sprint velocities in professional soccer players, and Chelly et al.[6] identified significant correlations between the 1RM in squats and velocity over a distance of 5 m ($r = 0.66$) in young soccer players (17–19 years). Additionally, Peterson et al.[7] identified a positive correlation in school athletes between 1RM in squats and sprint velocity over 36 m ($r = -0.60$) as well as between the maximal strength in the extensor muscles of the leg and velocity over 18 m ($r = 0.82$) and 36 m ($r = 0.85$). Conversely, other studies[8] did not observe correlations between maximal strength and velocity.

The positive effects of strength training (ST) on jumping and sprinting abilities in adult soccer players have been widely studied. ST has shown to have beneficial effects on the muscular power and motor skill performance of adolescent athletes. However, little information is available in the literature concerning children who play soccer. Most of the studies have been conducted with adolescent and adult soccer players.[9]

Although the importance of ST has a long history in sports training and a number of studies confirm this, the most efficient and appropriate method for its development remains controversial. This is due to the fact that the set of factors comprising the ST load are diverse (e.g., % 1RM, number of sets and repetitions, type and order of exercises, duration of breaks between sets and repetitions, and velocity of execution) and that neuromuscular and structural adaptations will differ according to the way each of them is handled.[10]

In this regard, there is contradiction with the velocity and %1RM at which the movement must be executed.[10–16] Moreover, the adaptation mechanisms that occur at a certain velocity of training and their transfer to other types of movements are unclear. Several studies have indicated that ST at high velocities and low loads (30–60% 1RM)[9–11,17,18] generates better performance results in vertical jump, sprint ability, maximal aerobic speed than does training at low velocities and high loads (70–95% 1RM).[6,19,20]

Therefore, the basis of the problem is associated with the gaps that exist in knowledge about the effects of training velocity[13] and the need for studies that analyze the effects of ST on different physical abilities in children who play soccer. The present study aims to analyze and compare the effects of two types of ST (high velocity-low load vs low velocity-high load) on muscle structure and athletic performance in jumping and velocity of movement in children who play soccer.

Despite the importance of strength and speed in soccer, as far as we know, no study has compared the types of strength training and the changes that these produce in different fitness indicators girls' soccer players

The purpose of this study was to compare the effects of two types of strength training, one based on the VMP and the other in the traditional method with loads of 80% 1RM, on the strength and maximum power of lower limbs, sprint ability, the vertical jump, pedaling power and muscle mass, in a group of girls soccer players.

Methods

Subjects

The population was composed of 50 children who played soccer in Bogota, with an average age of 13.6 ± 1.2 years, height of 1.57 ± 6.6 m, body mass of 46.7. ± 5.3 kg and BMI of 17.6 ± 1.4, who voluntarily agreed to participate in the study. The participants were randomly distributed into three groups: a group that trained at 80% of 1RM (RMG, $n = 16$), a group that trained at maximal execution velocity (VG, $n = 16$), and a control group (CG, $n = 17$). The study is in accordance with the Helsinki ethics protocols, and it was approved by the ethics committee of National Pedagogical University (Colombia). Initially, a meeting was held with the coaches, players, and parents, with the purpose of informing them about the objectives, methodology, benefits, and possible risks of the study. After the meeting, the parents signed informed consent. None of the players who participated had experience in strength training. During the study, three players in RMG and one in VG dropped out of the study because they were excluded from the team, for final sample sizes of $n = 13$ for RMG and $n = 15$ for VG.

Procedures

Days before the evaluations, the participants were carefully familiarized with the procedure and technique of each of the maximal strength and muscular power tests. The assessment of power and maximal strength was performed in three sessions, with an interval of four days between each. Parameters evaluated in the first session were body composition, vertical jump, velocity over 30 m, and pedaling power. Maximal squat strength was evaluated on day 2 and peak power and MPV in squats on day three. Before the tests, the players performed a 10-min warm-up developed at low velocity on a treadmill or stationary cycle ergometer with a workload that could be comfortably maintained with 5 min of specific repetitions of each exercise before training. For full recovery, 10 min of active recovery were allowed between the tests. Because of the effects of circadian rhythms on neuromuscular performance, the tests were always performed at the same time (16:00 h).

The vertical jump was evaluated through the countermovement jump (CMJ). The participants were asked to support their hands on their hips throughout the execution of the movement that started with knee flexion up to 90°, followed by a vertical jump of maximum effort, keeping the knees extended during the flight phase of the jump and ending upright. Each attempt was separated by three minutes of active rest. Five jumps were performed and recorded for subsequent analysis.[21] The heights of the jumps were calculated using an infrared timer system (OptoJump, Microgate®. Germany, 1/1000 s accuracy) that uses the flight time to calculate the following equation: $h = (g \times ft^2)8$, where ''g'' is the acceleration of gravity (9.81 ms^2) and ''ft'' is the flight time.

Sprint velocity was evaluated over a distance of 30 m on a soccer field.[19] Infrared-light photocell systems (model WL34-R240, Sick®, Germany) were used for recording and were located at the starting line and at 30 m. Each participant performed two trials, separated by a recovery interval of three minutes, and the highest velocity between the two values was recorded. The participant started in the high position with the dominant foot on the starting line and the non-dominant foot behind, such that the trunk did not interfere with the infrared signal; the participant then began to sprint. All participants were asked to exert maximum effort in each sprint. Before starting the test, a warm-up was performed that incorporated several 30-m sets with progressively faster acceleration.

The maximal strength of the lower limbs was assessed using the 1RM method by means of the squat test with deep flexion of the legs until exceeding the horizontal of the thigh relative to the floor, then continuing to full extension of the knee. The exercise was performed on a Smith machine, which allows vertical displacement of the bar along a fixed path, with a very low friction force between the bar and the support rails. The Smith machine did not have any type of counterweight mechanism, acting identically to free weights (i.e., isoinertial loading).[22] Prior to the evaluation, a warm-up of three sets of five repetitions was performed with only the weight of the bar, such that the athletes could learn the movement and use of the machine. To determine 1RM, the athletes started with a load of 20 kg; four repetitions were performed, and they were asked to execute them at the maximum possible velocity in order to identify their calculated 1RM. Three minutes of recovery time were allowed, and then progressive increments of 5 kg were performed until the MPV reached less than 0.5 $m\,s^{-1}$; two repetitions were performed. Subsequently, the load was adjusted with smaller increments (1–2 kg), according to each subject, until only one repetition was performed with a mean concentric velocity not higher than 0.20 $m\,s^{-1}$. This was considered to be the 1RM value for that player. Thus, 1RM could be determined with great precision.[6,23] An average of four sets was performed to reach the RM. A linear velocity transducer (*T-FORCE Dynamic Measurement System2*, Ergotech Consulting, S.L., Murcia, Spain) was used to record and control the displacement velocity of the bar.

Assessment of maximal lower limb power was achieved by means of two protocols. The first protocol was performed by means of the Wingate test, which consisted of pedaling for 30 s at maximal velocity against a constant resistance equivalent to 5.3% of body weight. The test began without a load, pedaling as fast as possible to achieve the maximal velocity expressed in RPM (revolutions per minute), after which the load was placed.

A Monark 835E cycle ergometer (Monark Exercise, Varberg, Sweden) was used in this study. The saddle was adjusted to the height of the iliac spine, and the athletes were instructed to remain seated throughout the test. The athletes warmed up for five minutes at 40 RPM, with a load of 2% of their body weight. They then sprinted for 5 s at 2-, 3-, and 4-min marks; after 3 min of recovery, the participants performed the test.

The athletes warmed up for three minutes at a pedaling speed of 40 RPM, with a load of 2% of their body weight and performed maximum accelerations in the last 5 s of minutes 1, 2 and 3. After three minutes of recovery, the participants performed the test.

The second protocol was performed by means of the squat test, with deep flexion of the legs. The participants performed two executions at the highest velocity possible with loads of 30%, 40%, 45%, 60%, 70%, and 80% of the 1RM obtained previously, with the purpose of obtaining MPV, maximal velocity, and maximal power values.[18] Throughout the procedure, the athletes were encouraged to perform the execution at maximal velocity, and the best time was recorded. Five minutes of recovery were allowed between sets. To obtain the MPV, maximal velocity, and maximal power, a linear velocity transducer was used (*T-FORCE Dynamic Measurement System2*, Ergotech Consulting, S.L., Murcia, Spain, with a sampling rate of 1000 Hz and an accuracy of 0.0002 m), which automatically calculates the relevant kinematic parameters of each repetition and provides real-time auditory and visual feedback of the velocity.[22]

Body mass was assessed by dual-energy X-ray absorptiometry (DXA) using a General Electric® Lunar Prodigy densitometer and ENCORE® 2009 version 13.0 software. Information was obtained on total body mass, height, fat mass, bone mass, and muscle mass both of the entire body and of the lower limbs. The developmental stage of sexual maturation was determined using secondary sexual characteristics by applying the Tanner scale (Fig. 1). A questionnaire was delivered and explained to the parents, who completed it together with the girls.

Intervention: In addition to daily soccer training, VG and RMG performed ST for a period of 12 weeks, with a frequency of three times a week, performing four sets of squats on the Smith machine and four velocity sets on the cycle ergometer (Monark 835E, Monark Exercise, Varberg, Sweden), with 3-min recovery between sets. Soccer training commenced immediately after this protocol.

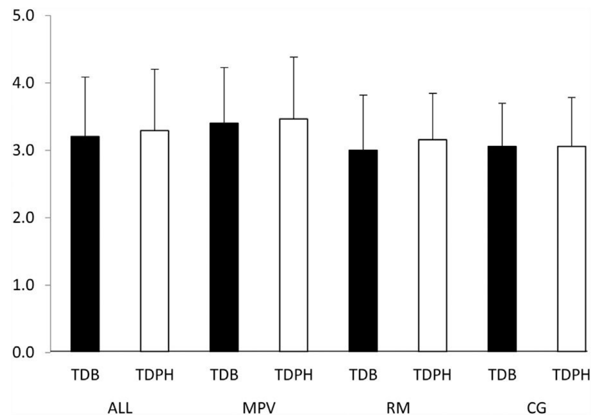


Figure 1 Development stage according to Tanner's puberty scale.

Protocol I. VG performed squat three sets with deep flexion of the legs according to the previously described protocol, with a load equivalent to 65% of 1RM; which moved at a speed of 0.70 m s^{-1} during the concentric phase and 0.50 m s^{-1} during the eccentric phase of each repetition (17).[17] In each set, an indeterminate number of repetitions was performed until a maximum loss of 20% of the concentric MPV was presented.[24] The velocity of each repetition was controlled throughout the training with a linear velocity transducer (*T-FORCE Dynamic Measurement System2,*Ergotech Consulting, S.L., Murcia, Spain).

In cycle ergometer sets, four repetitions were performed at maximal velocity, with 65% of the load applied in the initial assessment until there was a loss of more than 20% of the maximal RPM obtained in the initial evaluation. The RPM was controlled by the panel of the cycle ergometer.

Protocol II. RMG performed three sets of ten repetitions of squats under the same protocol described above, with a load equivalent to 80% of 1RM performed at maximal velocity during the concentric phase (MPV $\pm$ 0.47 m s^{-1}) of each repetition.[17] The velocity of each repetition was controlled throughout the training with a linear velocity transducer (*T-FORCE Dynamic Measurement System2,* Ergotech Consulting, S.L., Murcia, Spain).

In cycle ergometer sets, four repetitions were performed at maximal velocity, with 80% of the load applied in the initial assessment up to an 80% loss in velocity. The RPM was controlled by the panel of the cycle ergometer.

Protocol III. The CG performed only the daily soccer training, which was the same as that of the VG and RMG.

Every four weeks and according to the results of the training follow up, the load was increased for each participant so that the same training speed determined at the beginning was maintained.

Statistical analysis

Statistical analysis of the results was conducted using SPSS software version 23.00. In the descriptive analysis, measures of central tendency, such as the mean and standard deviation, were determined for each of the variables of the groups. All variables were adjusted to normality criteria using the Shapiro—Wilk test. Levene's test was used to evaluate the homogeneity of the variance among the groups. Subsequently, multiple analysis of variance (MANOVA) was performed (3 groups $\times$ 2 times $\times$ 8 variables), and the values were adjusted by analysis of covariance (ANCOVA) using fat-free lean mass as a covariate for all groups, considering assumptions of linearity, homogeneity, and independence. Differences between the groups before and after training were compared, and Bonferroni adjustment was performed to determine the P value of the comparisons. Statistical power was calculated using values between 0.75—0.80, and $p < 0.05$ was considered statistically significant. Two dropouts were recorded in RMG during the post-test assessment stage. The square eta (η^2) and eta (η) were calculated from the following formula: (η^2) = sum of the squares between groups/total of the sum of squares and this was provided as a measure of the effect size in the ANOVA. A value of 0.2 for a small effect size, 0.5 for a medium one, 0.8 for a large one and 1.3 for a very large one will be taken into account.

Results

Table 1 shows the descriptive characteristics of the different variables evaluated in each of the study groups before and after the twelve weeks of training. The training generated significant positive changes in the three groups. In VG, these changes were between <0.000 and <0.008 in all muscle strength and power tests and also in lower limb lean mass (LLLM). The RMG showed significant changes between <0.000 and <0.007 in the variables PMaxC, SJ, 1RMS, and LLLM, and the CG exhibitedchanges between <0.000 and <0.003 in PMaxC, PMaxRC, CMJ, SJ, PMaxS, and 1RMS.

According to the Tanner scale of physical development, there were no significant differences between the groups in either of the two components (development of breasts or pubic hair), which places all the girls at a similar stage of sexual maturation. Fig. 1 shows the results for each group and the consolidated results.

Regarding intergroup differences in the post-test results, statistically significant differences were observed between the VG and RMG ($p < 0.008$) in CMJ (Fig. 2) and squat power ($p < 0.01$) tests (Fig. 3), between the VG and CG ($p < 0.01$) in CMJ (Fig. 2), squat power ($p < 0.000$) (Fig. 3), and maximal squat strength ($p < 0.000$), and between the RMG and CG in maximal squat strength ($p < 0.000$) only (Fig. 4).

An important element that stands out in this research is the efficiency of the training. Each participant of the VG group on average developed a total training volume of 15,921.3 kg vs. 27,648 kg of the RMG group, indicating 42% less in the total volume training, of equal and achievement and greater increases in the set of variables observed in the study, than the RMG group, which is of the utmost importance in the context of ST.

Discussion

Several studies have shown a clear relationship between absolute and relative strength and performance in sprint velocity and jumping in adult athletes. However, this relationship has not been well studied in younger athletes.[25] According to a literature review of this topic in the

Table 1 Changes in the variables of strength, power, and muscle composition between pre- and post-test after training in each of de groups.

Variables	VG ($n = 15$)			RMG ($n = 13$)			CG ($n = 18$)			Effect sizes
	Pre-test	Post-test	*P* value	Pre-test	Post-test	*P* value	Pre-test	Post-test	*P* value	(η^2)
Weight (kg)	47.1 ± 5.7	42.9 ± 2.6	0.049	48.0 ± 5.5	45.7 ± 5.5		45.6 ± 5.2	42.5 ± 5.9		
Height(cm)	156.7 ± 5.7	156.5 ± 5.3		160.1 ± 7.7	157.4 ± 5.4		155.7 ± 6.5	153.0 ± 5.8		
BMI(kg/m^2)	17.9 ± 1.7	17.3 ± 0.8		17.4 ± 1.6	18.1 ± 1.2		17.4 ± 1.1	17.8 ± 1.5		
FMI(kg/m^2)	4.8 ± 0.9	4.4 ± 0.4		4.8 ± 2.0	4.5 ± 0.7		4.4 ± 0.6	4.6 ± 1.0		
FFMI (kg/m^2)	12.4 ± 1.0	12.4 ± 0.6		12.2 ± 1.1	12.9 ± 0.8	0.049	12.4 ± 1.0	12.8 ± 0.7		0.251
LLMM (Kg)	11.7 ± 1.6	12.3 ± 1.4	0.009	11.9 ± 1.4	12.5 ± 1.1	0.014	11.6 ± 1.4	11.9 ± 1.6		0.328
BMC(g)	781.6 ± 113.7	801.4 ± 101.1	0.0001	808.3 ± 115.7	813.4 ± 85.5		752.8 ± 106.7	766 ± 81.6		
BMD(g)	1.2 ± 0.1	1.2 ± 0.1	0.0001	1.2 ± 0.1	1.2 ± 0.0		1.1 ± 0.2	1.2 ± 0.1		
VMax30 (s)	5.1 ± 0.2	4.9 ± 0.1	0.000	5.1 ± 0.1	5.15 ± 0.2		5.3 ± 0.2	5.2 ± 0.1		0.547
PMaxC (watts)	244.8 ± 58.3	299.1 ± 60.9	0.000	256.5 ± 51.9	299.4 ± 26.0	0.002	250.5 ± 22.2	294.3 ± 12.3	0.000	0.449
VMaxC (RPM)	121.1 ± 16.3	153.2 ± 29.2	0.002	125.9 ± 15.0	132.4 ± 9.4		122.5 ± 9.2	132.8 ± 5.2		
PMaxRC (W/kg)	3.3 ± 0.5	2.6 ± 0.3	0.000	3.4 ± 0.5	3.3 ± 0.6		3.5 ± 0.4	3.1 ± 0.2	0.003	0.448
CMJ(cm)	23.6 ± 2.3	27.1 ± 3.2	0.000	23.8 ± 2.7	24.2 ± 1.8		24.7 ± 1.2	26.5 ± 3.4	0.000	0.351
SJ(cm)	21.5 ± 3.3	24.2 ± 3.3	0.001	19.5 ± 3.1	22.3 ± 2.2	0.002	20.8 ± 3.7	23.2 ± 2.5	0.003	0.179
PMaxS(watts)	200.3 ± 39.5	251.8 ± 45.4	0.000	160.0 ± 14.4	172.1 ± 10.6		156.8 ± 19.3	182.6 ± 18.3	0.000	0.555
ApvS(m/s)	0.9 ± 0.1	1.0 ± 0.2	0.002	0.8 ± 0.0	0.8 ± 0.1		0.8 ± 0.1	0.8 ± 0.1		0.308
1RMS (kg)	31.5 ± 5.1	50.6 ± 9.9	0.000	32.0 ± 5.8	49.2 ± 6.3	0.000	28.2 ± 3.4	37.8 ± 3.7	0.000	0.785

Data are mean ± SD.

BMI, body mass index; FMI, fat mass index; FFMI, fat-free mass index; LLMM, lower limb muscle mass; BMC, bone mineral content; BMD, bone mineral density; VMax30, maximal velocity over 30 metres; PMaxC, maximum power on the cycloergometre; VMaxC, maximum velocity on the cycloergometre; PMaxRC, relative maximal power on the cycloergometre; CMJ, countermovement jump; SJ, squat jump (without counter movement); PMaxS, maximal power in squats; ApvS, average propulsive velocity in squats; 1RMS, one-repetition maximum-maximal squat strength.

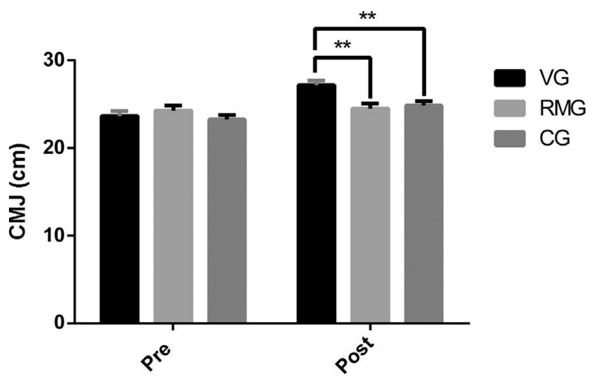


Figure 2 Differences between the VG and RMG in CMJ, pre- and post-test after training in each of de groups.

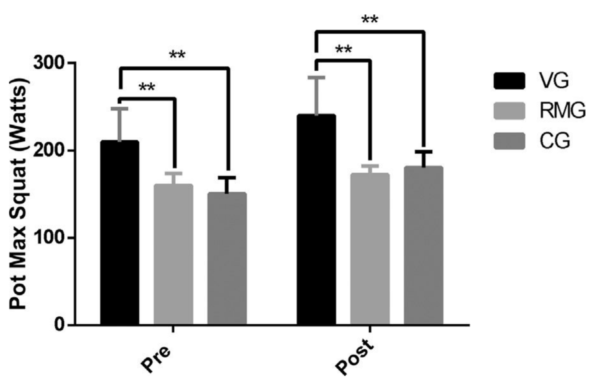


Figure 3 Differences between the VG and RMG in squat power, pre- and post-test after training in each of de groups.

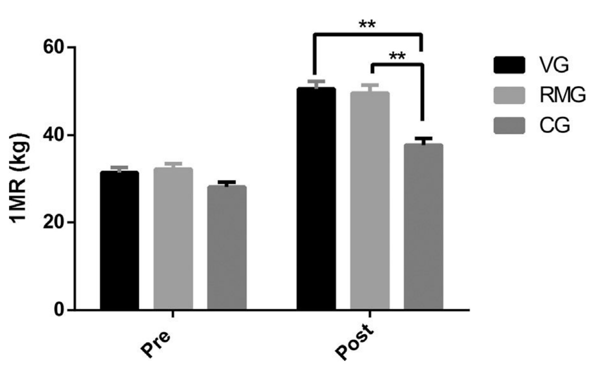


Figure 4 Differences between the VG and RMG in maximal squat strength pre- and post-test after training in each of de groups.

SPORTDiscus, PubMed, EBSCOhost, JSTOR, Ovid, ProQuest, ScienceDirect, Taylor & Francis, and Wiley Online Library databases, this is the first study to analyze the effect of two training programs on improving muscle power in children who play soccer, and it is also the first to include high-intensity sprint training in cycle ergometer sets.

The main finding of this study is that participants of the VG who performed strength and pedal training at high speed showed better results in all physical performance variables analyzed (lower limb strength, jumping, running) as well as in muscle mass. The results from this study suggest that only 12 weeks of training combined with typical tactical-technical soccer training could provide greater gains in performance than could ST with high loads or typical soccer training.

The VG and RMG demonstrated increases in LLLM. Training with loads of 80% of the maximal strength led to a slightly greater increase in muscle volume than did velocity training (5.7% vs 5.4%). Nonetheless, it is important to note that the VG performed 45% fewer repetitions than the RMG and obtained similar increases in the total muscular volume of the lower limbs. The greater number of repetitions performed by the RMG during the entire training period resulted in different metabolic and neural stresses,[26] which may have a greater impact on the processes of muscular hypertrophy.

The results of this study are even more impressive if we consider that deep squat and bicycle sprint training was only performed for 12 weeks (36 sessions).

Although there is a consensus that ST leads to muscle hypertrophy, controversy remains with regard to which type of training generates a better response.[27] Gains in muscle mass have been reported in several studies in which increases in muscle mass were indicated by measuring the circumference of the upper arm[12] or by bioimpedance.[27–29] Nimphius et al.[30] implemented strength, power, and movement velocity training for 20 weeks in female softball players aged 18.1 years and observed changes in the characteristics of muscle architecture through magnetic resonance, which correlated with the percentage of variation in maximal strength, movement velocity, and jumping. In contrast, another study indicated no significant gains in muscle mass.[6]

Overall, changes produced by ST in preadolescent populations are a topic of debate. Despite observing significant improvements in muscle strength, Ramsay et al.[31] did not identify muscle hypertrophy (as measured by computed tomography) in prepubertal boys. (9–11 years) after a 20-week high-intensity ST program. This would indicate that observed gains in peak power are due to neuromuscular adaptations, such as selective activation of the motor units, enhanced recruitment of motor units, and better synchronization.

Sufficient evidence exists of acute responses of anabolic hormones in men and women, regardless of age. Although any type of resistance exercise appears to stimulate secretion of anabolic hormones, a substantial hormonal response has not been shown, especially for GH, after high-intensity exercises with few repetitions.[32] Goto et al.[33] evaluated GH responses at different exercise levels (50–90% of 1RM). The results indicated that the exercises performed at 50% of 1RM caused marked increases in lactate and GH concentrations in the blood. These results support the observation that the VG achieved a greater increase in muscle mass than the other groups.

Although the three groups showed increases in maximal squat strength after 12 weeks of training at high speed, a maximum loss of speed of 20% resulted in a gain of 60.7% in maximum squat strength, which is significantly higher than the gains obtained by the other two groups (54% for the RMG and 25% for the CG), despite the fact that as indicated previously, the VG had a lower total volume per work session. These results are consistent with the increase in muscle mass of the lower limbs in the VG and RMG.

The gains in maximal strength obtained in the present study are consistent with those reported in the literature.[12] Regardless, the conclusions are not convincing. Some studies reported greater strength gains when training was performed at high velocities,[10–14] whereas others did not observe differences in strength gains between groups training at low or high velocities.[16]

Several studies have compared the effects of training at different velocities (low and high) for strength development but do not reach a consensus about the effect of movement velocity on strength increases associated with ST[10–12] due to the number of variables (weight, sets, repetitions, execution velocity) that interact in the response to training; thus, the results are heterogeneous among studies.[34] It is also likely that this discrepancy is influenced by methodological differences among studies. A plausible explanation of why several studies did not find greater strength gains with high-velocity training may be because repetitions were performed until muscle failure, which leads to a progressive and involuntary decrease in the velocity of the final repetitions[17] thus, the velocity of the final repetitions becomes very similar between high- and low-velocity groups, with a tendency to equal the average training velocity.[13]

It is also important to note that although the three groups showed improvements in all tests, the VG presented the best results in power tests compared to the other two groups. In vertical jump height (CMJ), we observed an increase of 14.8% in the VG vs 1% in the RMG and 6.4% in the CG, and in squat power, we observed an increase of 30.4% in the VG vs 5.1% in the RMG and 14.1% in the CG.

In the tests of sprinting over 30 m, and power on a cycle ergometer, despite not identifying significant differences among the three groups, the VG obtained better results for velocity over 30 m (the VG exhibited an increase of 2.96% vs 0.49% in the RMG and 1.13% in the CG) and in power on the cycle ergometer (the VG exhibited an increase of 22.3% vs 16.32% in the RMG and 15.03% in the CG).

A possible explanation for this result may be that the higher number of repetitions performed by the RMG group at low speed (MPV < 0.40 m/s) could be responsible for a significant reduction in faster fibers.[35] Strength and speed decreased between repetitions of the same set, which is concomitant with an increase in the degradation of purine nucleotides as individuals approach muscle failure, leading to a loss of strength.[24]

These results coincide with those of other studies, such as that of Chelly et al.,[6] who reported similar results with a significant increase in the peak power obtained on a bicycle, in CMJ height, and in the velocity of movement, in a group of young soccer players. Pareja-Blanco et al.[10] also indicated that ST performed at high velocities in a group of men (23 years) lead to improved stimuli that induce neuromuscular adaptations compared to ST with high loads and at low velocity. In a group of soccer players (17 years), Kotzamanidis et al.[19] observed the effects of combined strength and speed training for 13 weeks, with a frequency of three times a week, and reported that combined strength and velocity training results in significant positive effects in strength, velocity, squat jump, and CMJ.

The mechanisms by which training velocity influences strength adaptations were not investigated in this study, but other authors have indicated that such mechanisms may include changes in the type of muscle fiber,[36] the expression of Types IIX to IIA myosin heavy chains,[15] or a greater ability to selectively recruit fast-twitch motor units. Fast-velocity training leads to higher rates of discharge in motor units and to an increase in the frequency of stimulation[37]; these improved responses may even be due to neuromuscular adaptations in response to the specificity of the tests used in training. These phenomena might be the basis of the greater response to training.

Studies with young soccer players have commonly used high-load repetitions (70–95% 1RM) to improve strength and power.[6,20,38] However, ST with high loads can induce excessive fatigue, which does not allow players to have effective ball practice immediately after this type of training. Moreover, training with high loads is not transferable to sprint velocity performance because the nervous system cannot learn and control the levels of strength or muscle mass acquired in very fast movements

The recent review by Silva et al.,[39] in which 22 studies on ST in soccer players of different ages(mostly older than 20 years) were considered, indicates that strength/power training independent of the players' normal training led to increases, ranging from 11% to 52%,in the 1RM of well-trained players during the squat exercise.

They also noted that the average increase of 24.4% of 1RM in squats leads to an increase in the CMJ and SJ of approximately 6.8% and that increases of 23–26% in the 1RM resulted in average improvements of 1.9% in 40-m running speed, which indicates that the large increases in 1RM cannot be translated into superior improvements in sprint performance in high level players.

This series of movements has important practical implications for explosive sports such as soccer. A meta-analysis of 38 studies conducted by Harries et al.[40] aimed to determine the effectiveness of endurance training programs on muscle power and athletic performance in adolescent athletes. The results indicated that ST improves jumping performance and sprint velocity.

The findings of the present study suggest that when no maximum losses of 20% of the MPV are allowed in each series, the applied force and speed will be greater in each repetition, leading to an increase in the average speed of the training[35] and resulting in neuromuscular adaptations necessary for sports that involve power actions such as soccer.

Perspective

This study is one of the first to examine the effects of two ST programs, one based on VMP and the other at 80% of 1RM, on the neuromuscular performance and muscle composition of girls who play soccer. The findings contribute to consolidate the evidence observed by several authors in relation to the positive effects of the speed of execution in a ST program,[22,35] which distorts the hypothesis that intensity is determined solely by the magnitude of% 1RM. The results indicate, on the contrary, that the execution speed is a fundamental component of the ST intensity.

In conclusion, the results of the present study suggest that strength training performed at high speed ($0.70\,m\,s^{-1}$) compared to one performed at low speed ($0.47\,m\,s^{-1}$) is more efficient and produces excellent stimuli that would lead to induce better neuromuscular adaptations. They also seem to indicate that high loads and many repetitions are not required to significantly improve maximum strength and, more importantly, sports performance. High-speed training generated more effective gains than low-speed training, at maximum squat strength, CMJ, short-distance sprint and muscle mass.

Financing

This study was funded with resources from the National Pedagogic University of Colombia (Universidad Pedagógica Nacional de Colombia) and Saint Thomas University of Colombia (Universidad Santo Tomas de Colombia).

Conflicts of interest

The manuscript was prepared and reviewed with the participation of all of the authors, who declare that there are no conflict of interests that jeopardize the validity of the results presented.

References

1. Impellizzeri FM, Rampinini E, Castagna C, Bishop D, Ferrari Bravo D, Tibaudi A, et al. Validity of a repeated-sprint test for football. Int J Sports Med. 2008;29:899–905.
2. Stolen T, Chamari K, Castagna C, Wisloff U. Physiology of soccer: an update. Sports Med (Auckland, NZ). 2005;35:501–36.
3. Mara JK, Thompson KG, Pumpa KL, Morgan S. The acceleration and deceleration profiles of elite female soccer players during competitive matches. J Sci Med Sport/Sports Med Aust. 2017;20:867–72.
4. Penailillo L, Espildora F, Jannas-Vela S, Mujika I, Zbinden-Foncea H. Muscle strength and speed performance in youth soccer players. J Hum Kinet. 2016;50:203–10.
5. Wisloff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. Br J Sports Med. 2004;38:285–8.
6. 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;23:2241–9.
7. Peterson MD, Alvar BA, Rhea MR. The contribution of maximal force production to explosive movement among young collegiate athletes. J Strength Cond Res. 2006;20:867–73.
8. Harris NK, Cronin JB, Hopkins WG, Hansen KT. Squat jump training at maximal power loads vs. heavy loads: effect on sprint ability. J Strength Cond Res. 2008;22:1742–9.
9. 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. 2015;29:1329–38.
10. 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;35:916–24.
11. Ingebrigtsen J, Holtermann A, Roeleveld K. Effects of load and contraction velocity during three-week biceps curls training on isometric and isokinetic performance. J Strength Cond Res. 2009;23:1670–6.
12. Munn J, Herbert RD, Hancock MJ, Gandevia SC. Resistance training for strength: effect of number of sets and contraction speed. Med Sci Sports Exerc. 2005;37:1622–6.
13. Cronin J, McNair PJ, Marshall RN. Velocity specificity, combination training and sport specific tasks. J Sci Med Sport/Sports Med Aust. 2001;4:168–78.
14. Oliveira AS, Corvino RB, Caputo F, Aagaard P, Denadai BS. Effects of fast-velocity eccentric resistance training on early and late rate of force development. Eur J Sport Sci. 2016;16:199–205.
15. Oliveira FB, Oliveira AS, Rizatto GF, Denadai BS. Resistance training for explosive and maximal strength: effects on early and late rate of force development. J Sports Sci Med. 2013;12:402–8.
16. De Oliveira FB, Rizatto GF, Denadai BS. Are early and late rate of force development differently influenced by fast-velocity resistance training? Clin Physiol Funct Imaging. 2013;33:282–7.
17. Gonzalez-Badillo JJ, Rodriguez-Rosell D, Sanchez-Medina L, Gorostiaga EM, Pareja-Blanco F. Maximal intended velocity training induces greater gains in bench press performance than deliberately slower half-velocity training. Eur J Sport Sci. 2014;14:772–81.
18. Izquierdo M, Hakkinen K, Gonzalez-Badillo JJ, Ibanez J, Gorostiaga EM. Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. Eur J Appl Physiol. 2002;87:264–71.
19. 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;19:369–75.
20. 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;24:936–41.
21. Jimenez-Reyes P, Pareja-Blanco F, Balsalobre-Fernandez C, Cuadrado-Penafiel V, Ortega-Becerra MA, Gonzalez-Badillo JJ. Jump-Squat performance and its relationship with relative training intensity in high-level athletes. Int J Sports Physiol Perform. 2015;10:1036–40.
22. Sanchez-Medina L, Gonzalez-Badillo JJ, Perez CE, Pallares JG. Velocity- and power-load relationships of the bench pull vs. bench press exercises. Int J Sports Med. 2014;35:209–16.
23. Sanchez-Medina L, Perez CE, Gonzalez-Badillo JJ. Importance of the propulsive phase in strength assessment. Int J Sports Med. 2010;31:123–9.
24. Sanchez-Medina L, Gonzalez-Badillo J. Velocity loss as an indicator of neuromuscular fatigue during resistance training. Med Sci Sport Exerc. 2011;43:1725–34.
25. 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;28:173–7.
26. Goto K, Nagasawa M, Yanagisawa O, Kizuka T, Ishii N, Takamatsu K. Muscular adaptations to combinations of high- and low-intensity resistance exercises. J Strength Cond Res. 2004;18:730–7.
27. Schoenfeld BJ. Is there a minimum intensity threshold for resistance training-induced hypertrophic adaptations? Sports Med (Auckland, NZ). 2013;43:1279–88.
28. Giessing J, Eichmann B, Steele J, Fisher J. A comparison of low volume 'high-intensity-training' and high volume traditional resistance training methods on muscular performance, body composition, and subjective assessments of training. Biol Sport. 2016;33:241–9.
29. Giebetasing J, Fisher J, Steele J, Rothe F, Raubold K, Eichmann B. The effects of low-volume resistance training with and without advanced techniques in trained subjects. J Sports Med Phys Fitness. 2016;56:249–58.
30. Nimphius S, McGuigan MR, Newton RU. Changes in muscle architecture and performance during a competitive season in female softball players. J Strength Cond Res. 2012;26:2655–66, http://dx.doi.org/10.1519/JSC.0b013e318269f81e.

31. Ramsay JA, Blimkie CJ, Smith K, Garner S, MacDougall JD, Sale DG. Strength training effects in prepubescent boys. Med Sci Sports Exerc. 1990;22:605–14.
32. Kraemer WJ, Ratamess NA. Hormonal responses and adaptations to resistance exercise and training. Sports Med (Auckland, NZ). 2005;35:339–61.
33. Goto K, Sato K, Takamatsu K. A single set of low intensity resistance exercise immediately following high intensity resistance exercise stimulates growth hormone secretion in men. J Sports Med Phys Fitness. 2003;43:243–9.
34. Gentil P, Arruda A, Souza D, Giessing J, Paoli A, Fisher J, et al. Is there any practical application of meta-analytical results in strength training? Front Physiol. 2017;8:1–4.
35. Pareja-Blanco F, Rodriguez-Rosell D, Sanchez-Medina L, Sanchis-Moysi J, Dorado C, Mora-Custodio R, et al. Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. Scand J Med Sci Sports. 2017;27:724–35.
36. Paddon-Jones D, Leveritt M, Lonergan A, Abernethy P. Adaptation to chronic eccentric exercise in humans: the influence of contraction velocity. Eur J Appl Physiol. 2001;85:466–71.
37. Van Cutsem M, Duchateau J, Hainaut K. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. J Physiol. 1998;513:295–305.
38. Wong PL, Chamari K, Wisloff U. Effects of 12-week on-field combined strength and power training on physical performance among U-14 young soccer players. J Strength Cond Res. 2010;24:644–52.
39. Silva JR, Nassis GP, Rebelo A. Strength training in soccer with a specific focus on highly trained players. Sports Med – open. 2015;1:2–27.
40. 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/Sports Med Aust. 2012;15:532–40.