2022 · *Retos Nº 46 / Págs. 613-621*

Analysis of vertical jump, rating of perceived exertion, delayed-onset muscle soreness, and muscular peak power in young male Brazilian football players submitted to plyometric and semi-squat training with weights
Análisis del salto vertical, índice de esfuerzo percibido, dolor muscular de aparición tardía y potencia muscular máxima en jóvenes futbolistas brasileños sometidos a entrenamiento pliométrico y entrenamiento de semi sentadillas con pesas

*,**Renato Tavares Fonseca, *Gustavo Casimiro Lopes, *Juliana Brandão Pinto de Castro, ***Luciano Alonso Valente dos Santos, *Bruno Lucas Pinheiro Lima, *Gilson Ramos de Oliveira Filho, *Rodolfo de Alkmim Moreira Nunes, *,**Rodrigo Gomes de Souza Vale

*Universidade do Estado do Rio de Janeiro (Brasil), **Universidade Estácio de Sá (Brasil), ***Universidade Federal do Rio de Janeiro (Brasil)

Abstract. This study analyzed the effects of plyometric and strength training on vertical jump (VJ), rating of perceived exertion (RPE), delayed-onset muscle soreness (DOMS), and absolute (APP) and relative (RPP) muscle peak power in young male football players. Twenty-five participants were randomly divided into semi-squat training group (SSTG), plyometric training group (PTG), and control group (CG). The duration of the intervention was six weeks. VJ was analyzed with a computerized jumping platform. DOMS and RPE with the Borg's Visual Analogue Scale (VAS) and the Adapted Borg Scale (ABS), respectively. The SSTG showed improvements ($p < 0.05$) in countermovement jump (CMJ), squat jump (SJ), APP (3190.67 ± 338.49 W), and RPP (47.75 ± 5.01 W/kg). PTG showed improvements ($p < 0.05$) in SJ. In the intragroup comparations, SSTG, PTG, and CG showed an increase ($p < 0.05$) in RPE and DOMS. Between groups, PTG presented an increase ($p < 0.05$) on RPE and DOMS compared with SSTG and CG. CMJ presented strong correlations between APP and VJ, RPP, and VJ, and APP and RPP. SJ showed a higher positive correlation between all the physical variables. Only SSTG promoted an increase in both types of jumps, with a greater APP and RPP and a lower RPE and DOMS.

Keywords: Drop jump, muscle strength, power training, DOMS, soccer.

Resumen. Este estudio analizó los efectos del entrenamiento pliométrico y de semi sentadillas con pesas sobre el salto vertical (SV), el índice de esfuerzo percibido (IEP), el dolor muscular de aparición tardía (DMAT) y la potencia máxima muscular absoluta (PMMA) y relativa (PMMR) en hombres jóvenes jugadores de futbol. Veinticinco participantes se dividieron aleatoriamente en un grupo de entrenamiento de semi sentadillas con pesas (GESSP), un grupo de entrenamiento pliométrico (GEP) y grupo de control (GC). El SV fue analizado con una plataforma de salto computarizada. DMAT y IEP con la Escala Analógica Visual de Borg (EAVB) y la Escala de Borg Adaptada (EBA), respectivamente. GESSP mostró mejoras ($p < 0,05$) en salto con contramovimiento (SCM), sentadilla con salto (SC), PMMA (3190,67 ± 338,49 W) y PMMR (47,75 ± 5,01 W/kg). GEP mostró mejoras ($p < 0,05$) en SC. En las comparaciones intragrupo, GESSP, GEP y CG mostraron un aumento ($p < 0,05$) en IEP y DMAT. Entre grupos, GEP presentó un aumento ($p < 0,05$) en IEP y DMAT en comparación con GESSP y CG. SCM presentó fuertes correlaciones entre PMMA y SJ, IEP y SV, y PMMA y PMMR. SC mostró una mayor correlación positiva entre todas las variables físicas. Solo GESSP promovió un incremento en ambos tipos de saltos, con mayor PMMA y PMMR y menor IEP y DMAT.

Palabras clave: Salto de caída, fuerza muscular, entrenamiento de potencia, dolor muscular de aparición tardía, fútbol.

Introduction

Knowing about the tactical ability development of young football players is important to designing training programs (Moreira et al., 2021). Football is an intermittent sport with frequent activity changes. This game demands a high number of explosive movements such as accelerations, decelerations, changes of direction as well as jumps, impacts, shots, and tackles (Mohr et al., 2016).

Many sporting actions require a high production of explosive force to be performed, such as the vertical jump (Picón-Martínez et al., 2019). These actions require power and strength of the lower limbs' muscles, capacities considered important for the performance of young players of this modality (Ferley, Scholten & Vukovich, 2018; Flávio, Oliveira & Souza, 2018).

The implementation of neuromuscular training, using strength, plyometric, and speed training strategies, during maturation, is effective in promoting the physical development of young football players (Rumpf, Cronin, Oliver & Hughes, 2013). During a football match,

Fecha recepción: 04-04-22. Fecha de aceptación: 24-07-22
Juliana Brandão Pinto de Castro
julianabrandaoflp@hotmail.com

muscle power and strength are critical physical factors for successful participation. Plyometric activities are widely implemented as a training methodology for enhancing functional sports performance (Bianchi, Coratella, Dello Iacono & Beato, 2019).

Among the most important vertical jumps to assess neuromuscular capacity are the countermovement jump (CMJ), squat jump (SJ), and drop jump (DJ) (Moreno, 2020). Typical plyometric exercises include the CMJ, which is a jump that uses the eccentric and concentric phases of muscle contraction, and the DJ, which is an exercise where an athlete drops from a pre-determined height and attempts to jump immediately upon landing (Makaruk, Czaplicki, Sacewicz & Sadowski, 2014; Maloney, Richards & Fletcher, 2018).

The DJ uses different movement patterns than the CMJ due to shorter contact time and there is a greater contribution of the stretch-shortening cycle (SSC) mechanism for the DJ (Makaruk, Czaplicki, Sacewicz & Sadowski, 2014; Maloney, Richards & Fletcher, 2018). Several studies have examined the effect of plyometric, strength, and neuromuscular training on general and on specific performance in young football players (Hammami, Negra, Aouadi, Shephard & Chelly, 2016; Hoyo et al., 2016; Keiner, Sander, Wirth & Caruso, 2013; Michailidis et al., 2013; Panagoulis et al., 2020; Sáez de Villarreal, Suarez-Arrones, Requena, Haff & Ferrete, 2015; Sander, Keiner, Wirth & Schmidtbleicher, 2013).

Participation in strength training programs seems to induce large gains in strength and moderate improvements in speed and other factors related to football performance (Hammami et al., 2018; Hoyo et al., 2016; Panagoulis et al., 2020; Sander, Keiner, Wirth & Schmidtbleicher, 2013). Strength training is also usually applied to the development of the musculoskeletal system of young football players, including the squat jump (SJ), which uses only the concentric phase of muscle contraction (Panagoulis et al., 2020).

The SJ is one of the exercises most frequently used to develop the quadriceps muscle's concentric strength since it can improve both lower extremity power and specific sports physical performances (Hoyo et al., 2016). Previous investigations have explored the relationships between absolute strength and several predictors, such as relative strength, muscle resistance, and muscle power of athletic performance in male football players (Hammami et al., 2018; Hoyo et al., 2016; Styles, Matthews & Comfort, 2016).

Maximal strength, as measured by the one-repetition maximum (1RM) back squat, was highly correlated with improved sprint performance, change of direction speed, and VJ height in adolescent male football players (Hammami et al., 2018; Hoyo et al., 2016). Thus, improving power is a primary focus of many strength and conditioning programs. There are ways to improve power and speed. One recommendation is to improve both absolute and relative strength through a combination of lower-body resistance training, weightlifting, and plyometric training (Dawes & Lentz, 2012).

The implementation of well-structured methods of training may improve the strength, speed, change of directions, and skill performance of young football players (Hammami et al., 2018; Hoyo et al., 2016; Sáez de Villarreal, Suarez-Arrones, Requena, Haff & Ferrete, 2015). However, high demands of physical effort tend to promote a greater risk of muscle injuries, which are associated with sports that promote accelerations, rapid decelerations, jumps, cuts, spins, or kicks. This can produce a physical performance reduction, as observed in football. Fatigue involves a decrease in the capacity to generate maximal strength or muscular power, which is associated with continuous physical activity, and it results in a reduction in sports performance (Torreblanca-Martínez, Otero-Saborido & González-Jurado, 2017).

Football is an example of a sport in which clubs and academies gather their young players in age-related groups or teams, assuming that they are in equal conditions to participate in the same training and development programs (Peña González, Sarabia & Moya-Ramón, 2022). According to Peña González et al. (2022), there are some negative effects resulting from the football player grouping based on the age of the participants and possible implications in player conditioning and sports development.

Nevertheless, it is not clear yet, that young football players demonstrate the same favorable changes in the age groups chosen in this study, between sixteen and eighteen years old, in some physical performances and physiological responses to strength and plyometric training programs, separately. Therefore, the present study aimed to analyze the effects of plyometric and semi-squat training on VJ, rating of perceived exertion (RPE), delayed-onset muscle soreness (DOMS), and absolute and relative peak power in young male football players. We hypothesized that 6 weeks of plyometric and ST programs would improve the VJ and absolute and relative peak power of the young male football players.

Material & Methods

Participants

This is an experimental study with two different types of intervention applied to two distinct training groups. The volunteers belonged to a second-division football club in Rio de Janeiro, Brazil, and had no experience in any type of strength training programs. The following inclusion criteria were adopted: (a) be male; (b) age between 16 and 18 years old, which corresponds to the final stage of maturation, level 4, classified as the organization level, evaluated in the period between September and October of 2019; (c) have not suffered any serious muscle injury in the last 2 years, according to the club's medical department report; (d) never having participated in any systematic plyometric and muscle ST program before, according to the club´s football department report; (e) not to be competing throughout the study period. The exclusion criteria were: (a) to be considered physically unfit by a medical evaluation; (b) present any type of acute or chronic pathological condition that could be aggravated during the battery of tests or the proposed intervention; (c) using anti-inflammatory or hormone replacement drugs; (d) obtain less than 75% presence in activities during the intervention period. The participants were asked to abstain from any physical conditioning program during this study. None of the subjects were taking any medications or nutritional supplements.

The G*Power 3.1 software estimated the need for a total of 27 football players, divided into 3 groups of 9 participants each. As input, were informed statistical test: ANOVA with repeated measurements and within-between interaction; effect size of 0.25; α of 0.05; power of 0.80; number of groups = 3; number of measurements = 2; correlation coefficient among repeated measures = 0.7.

Ethical procedures

All procedures were conducted according to the Declaration of Helsinki and Resolution 466/12 of the Brazilian National Health Council. This study was approved by the Research Ethics Committee of the Rio de Janeiro State University (process number: 4.626.823). Before participation in the study, the parents of the young football players were informed about the procedures of the study (including risks and benefits) and that the authors were committed to maintaining the confidentiality of the data. The parents signed an informed consent form and the young football players signed an assent form.

Randomization process

The groups were randomly distributed through a simple draw using the random function of the Excel software. The participants were divided according to blinding criteria. The first drawn was allocated in the plyometric training group (PTG), the second in the semi-squat training group (SSTG), and the third in the control group (CG), alternately and consecutively, until all participants were allocated in one of the groups.

Before the procedures, 2 young football players were removed from the study due to muscle injuries. One of them was in the SSTG and the other was in the CG. Hence, a total of 25 football players were included in the selection of the groups. The groups were thus divided into PTG (n = 9), SSTG (n = 8), and CG (n = 8). Table I presents the characteristics of the groups.

Table 1
Characteristics of the groups (Mean ± standard deviation).

Variables	PTG	SSTG	CG
Age (years)	17.3 ± 0.7	17.4 ± 0.5	17.3 ± 0.5
Height (cm)	175.9 ± 5.8	174.2 ± 5.1	174.6 ± 7.9
Body mass (kg)	65.4 ± 6.3	67.2 ± 8.0	68.3 ± 8.0

PTG = plyometric training group; SSTG = semi-squat training group; CG = control group.

Data collection

The subjects were evaluated in two different types of jumps: CMJ and SJ, with three consecutive jumps during each test, totaling six vertical jumps for each voluntary. The instruction given to the volunteers was as follows: "jump as high as you can" for both tests. At first, the young football players performed the CMJ, followed by the SJ, both with hands fixed on the hips. They performed 3 jumps, with an intWerval of two minutes between each attempt, with an interval of five minutes between the CMJ and SJ test (Markovic, 2007).

The initial knee flexion angle was not specified, but all the subjects performed the CMJ test between 60 e 90° of knee flexion. The athletes were instructed to execute a downward movement followed by a complete extension of the knees to determine the countermovement amplitude to avoid changes in jumping coordination. In the SJ, athletes were required to remain in a static position with a 90° knee flexion angle for 3-second before jumping, without any preparatory movement. The highest jump from the three attempts was used for data analysis. The VJ height, the flight time, as well the absolute and relative power were evaluated. Pre- and post-training measurements were made two days before and one day after the completion of the programs (Markovic, 2007).

The football players performed the tests on a contact platform with a sampling rate of 1,000 Hz (60 × 60 cm; Elite Jump, S2 Sports, São Paulo, Brazil). The validation of the Elite Jump contact was done after using a force platform as the criterion to measure VJ height (Loturco et al., 2017).

Intervention procedures

Regarding the plyometric training, the evaluators received training one week before the beginning of the intervention to minimize the occurrence of errors during the procedures. All sessions of the interventions were done in the morning after all the players have informed that followed all the guidelines in the food recall given by the researchers before the start of the training.

The football players used two benches with a height of 50 cm each. The benches were positioned at 1 meter between each other. Before the start of the intervention, PTG performed 30 minutes of a brief adaptation, with the accomplishment of 1 set of 10 repetitions of DJ. The hands were supported in the pelvic girdle region, during the jumps, which were performed from an upper plane towards the ground. The jumps were performed from a superior plane, over one of the benches directing the body towards the ground, through the initial projection of one of the limbs, to contact both feet at the same time on the ground, for the immediate execution of VJ towards the other bench ahead (DJ). The same procedure was performed from there towards the initial bench, completing one repetition (Fonseca et al., 2017).

The program lasted 6 weeks for each experimental group and was performed twice a week, where the number of repetitions was counted after the round-trip cycle (from the number of foot contacts on the ground) performed at the highest possible speed. The program was designed based on a systematic review, which involved the analysis of the 22 studies with DJ exercises (Markovic, 2007). The plyometric training program is described in Table 2.

Table 2
Plyometric training program with a progressive increase in jumping load and intensity control throughout the training interval.

Week	Days	Sets	Repetitions	Interval	Jumps/repetition	Jumps/day	Jumps/week	Total of jumps
1st	2	3	8	2'	24	48	96	96
2nd	2	3	8	2'	24	48	96	192
3rd	2	4	8	2'	32	64	128	320
4th	2	4	8	2'	32	64	128	448
5th	2	4	10	3'	40	80	160	608
6th	2	4	10	3'	40	80	160	768

' = minutes

Concerning the semi-squat training, the determination of maximum dynamic voluntary muscle strength was performed using the 1 repetition maximum (RM) in the high bar parallel back squat, according to the procedures before the intervention (Chiu et al., 2003).

In the 1st practice session's test, the SSTG performed a general warm-up of five minutes, with the high bar parallel back squat, where the players performed 2 sets of 5 repetitions of underloaded parallel squats (around 50% of body mass). On the 2nd practice session's test, the subjects were tested to determine the maximum load for each player in this group. The maximum load that the volunteer could support with the bar resting on the shoulders, starting from the standing position up to 90° of hips and knee flexion, and immediately after it, to rise this load with the bar on the same position, extending completely the knees without any help, determined the 1RM load for each player. An interval of 3 minutes was performed between the attempts until the highest lifted load was achieved (Chiu et al., 2003).

In the program, the participants completed 1 repetition only when the 2 lower limbs were alternately directed forward during the half-squat, completing 1 roundtrip performed at low speed by the members of the SSTG. The semi-squat training program is presented in Table 3.

Table 3
Semi-squat training program with a progressive increase in the training load after performing the 1RM test.

Week	Days	Sets	Repetitions	Interval	Semi-squats (Repetitions)	Semi-squats (day)	Semi-squats (week)	Load (1RM)	Semi-squats (Total movements)
1st	2	3	8	2'	24	48	96	60%	96
2nd	2	3	8	2'	24	48	96	70%	192
3rd	2	5	6	2'	30	60	120	70%	312
4th	2	5	6	2'	30	60	120	80%	434
5th	2	5	6	3'	30	60	120	80%	554
6th	2	5	6	3'	30	60	120	90%	674

1RM = one-repetition maximum; ' = minutes

The volunteers of the CG performed only low-intensity technical training, such as passing, dribbling, and ball controlling, without performing any physical training involving strength or muscle power training during the study period.

To evaluate RPE and DOMS, the researchers were submitted to a training period to correctly apply the anchoring of the Borg's Visual Analogue Scale (VAS) and the Adapted Borg Scale (ABS) (Vieira et al., 2020). The participants were submitted to a program of sensitization to the responses of DOMS and RPE for one week before answering the questionnaires. DOMS and RPE were carried out 48h after the third session of each training, respectively. The VAS has a score ranging from 0 to 10, with the following grading: 0 = absence of pain; 1–2 = minimal pain; 3–5 = moderate pain; 7–8 = severe pain; 9–10 = extreme pain. The RPE has a score from 0 to 10, where: 0 = rest; 1 = extremely light; 2 = very light; 3 = too light; 4 = light; 5 = mild-moderate; 6 = moderate; 7 = moderate-intense; 8 = intense; 9 = very intense; 10 = exhaustive (Vieira et al., 2020).

Statistical Analysis

The data were presented in a descriptive way using mean and standard deviation. Normality and sphericity of data were determined using Shapiro-Wilk and Bartlett tests, respectively. Repeated measures ANOVA was applied to SSTG, PTG, and CG (pre and post-test) for intra- and intergroup comparisons, followed by the adjusted Bonferroni post hoc test to identify possible differences. The Pearson correlation test was used to analyze the associations between the variables of the study. The effect size (*d*) was calculated to analyze the magnitude of the results. It was used for interpretation: < 0.2: weak; 0.2–0.79: moderate; ≥ 0.8: strong (Cohen, 1988). The significance level was set at $p < 0.05$ for all tests. Data were analyzed by the SPSS Statistics 23.

Results

The CMJ comparisons are presented in Table 4. Only SSTG presented significant increases in VJ, APP, and RPP.

The SJ comparisons are presented in Table 5. Both training groups (SSTG and PTG) showed significant increases in VJ, but only SSTG had significant increases in AAP and RPP.

Table 6 shows the intragroup and intergroup comparisons. In intragroup comparison, there was a significant increase in RPE and DOMS in all groups. However, in the intergroup comparison, we found a significant increase in both variables, only in PTG compared with SSTG and CG.

Table 7 present the correlations on the CMJ test. It was found a significant correlation between the APP with VJ and RPP. It was found a higher significant correlation between the RPP with VJ and APP.

Table 7
Correlations between the results on the CMJ test.

		VJ	ET	APP
ET	r	0.375		
	p-value	0.065		
APP	r	0.426*	- 0.123	
	p-value	0.031	0.558	
RPP	r	0.757*	0.371	0.674*
	p-value	< 0.001*	0.068	< 0.001*

VJ = vertical jump; ET = elevation time; APP = absolute muscle peak power; RPP = relative muscle peak power; * $p < 0.05$.

The correlations on the SJ test are presented in table 8. There was a significant correlation between the APP with VJ and RPP. It was found a strong significant correlation between the RPP with VJ and APP.

Table 4
Jump evaluation referring to the concentric and eccentric phases of the muscles involved in the countermovement jump (CMJ) of the study groups (mean ± standard deviation).

Variables	PTG		SSTG		CG	
	pre	post	pre	post	pre	post
VJ (cm)	34.97 ± 2.97	37.62 ± 3.61	34.26 ± 6.27	38.41 ± 4.98*	34.10 ± 5.02	34.33 ± 3.09
ET (ms)	1.07 ± 0.62	0.92 ± 0.51	1.02 ± 0.88	0.53 ± 0.37	1.06 ± 0.43	1.04 ± 0.79
APP (W)	2,927.07 ± 371.43	3,044.19 ± 378.14	2,876.75 ± 303.19	3,190.67 ± 338.49*	2,919.93 ± 325.90	2,900.46 ± 491.65
RPP (W/Kg)	44.78 ± 2.68	46.67 ± 3.77	43.00 ± 3.34	47.75 ± 5.01*	43.50 ± 3.70	43.25 ± 4.56

PTG = plyometric training group; SSTG = semi-squat training group; CG = control group; VJ = vertical jump; cm = centimeters; ET = elevation time; ms = milliseconds; APP = absolute muscle peak power; W = watts; RPP = relative muscle peak power; W/Kg = watts per kilogram; *$p < 0.05$ pre *vs.* post, intragroup comparisons; Effect size (# Strong Effect): VJ/PTG#; APP/STG#; RPP/SSTG#; († Moderate Effect): RPP/PTG†; APP/PTG†; ET/PTG†; VJ/SSTG†. In the intergroups comparison, there were no significant differences (p > 0.05).

Table 5
Jump evaluation referring to the concentric phase of the muscles involved in the squat jump (SJ) of the study groups (mean ± standard deviation).

Variables	PTG		SSTG		CG	
	pre	post	pre	post	pre	post
VJ (cm)	30.98 ± 3.34	34.56 ± 3.89*	31.19 ± 2.70	36.90 ± 5.73*	31.36 ± 3.58	31.92 ± 3.64
ET (ms)	0.71 ± 0.26	0.87 ± 0.54	0.75 ± 0.29	0.53 ± 0.37	0.71 ± 0.17	0.93 ± 0.28
APP (W)	2,890.74 ± 293.17	3,140.66 ± 323.28	2,916.36 ± 402.65	3,190.67 ± 338.49*	2,896.13 ± 322.76	2,929.93 ± 345.59
RPP (W/Kg)	43.22 ± 1.48	47 ± 5.20	42.62 ± 3.54	47.75 ± 5.01*	42.5 ± 3.25	42.25 ± 3.45

PTG = plyometric training group; SSTG = semi squat training group; CG = control group; VJ = vertical jump; cm = centimeters; ET = elevation time; ms = milliseconds; APP = absolute muscle peak power; W = watts; RPP = relative muscle peak power; W/kg = watts per kilogram; *$p < 0.05$ pre *vs.* post; intragroup comparations; Effect Size (# Strong Effect): VJ/PTG#; VJ/SSTG#; RPP/SSTG#) - († Moderate effect): RPP/PTG†; APP/STG†; ET/PTG†. In the intergroup comparisons, there were no significant differences.

Table 6
Intragroup and intergroups comparisons of RPE and DOMS. Values in mean and standard deviation.

Variables	PTG		SSTG		CG	
	pre	post	pre	post	pre	post
RPE	0.33 ± 0.50	7.00 ± 0.71*#	0.37 ± 0.52	3.75 ± 0.89*	0.88 ± 0.60	3.88 ± 0.64*
DOMS	0.44 ± 0.53	5.89 ± 0.93*#	0.38 ± 0.52	3.88 ± 0.64*	0.50 ± 0.53	3.50 ± 0.87*

PTG = plyometric training group; SSTG = semi-squat training group; CG = control group; RPE = rating of perceived exertion; DOMS = delayed-onset muscle soreness. *$p < 0.05$, pre vs. post; #$p < 0.05$, comparations intergroups: (RPE) = PTG × SSTG #; (RPE) = PTG × CG#; (DOMS) = PTG × SSTG#; (DOMS) = PTG × CG#.

Table 8
Correlations between the results on the SJ test.

		VJ	ET	APP
ET	r	0.234		
	p-value	0.261		
APP	r	0.414*	0.169	
	p-value	0.030*	0.420	
RPP	r	0.740*	0.137	0.608*
	p-value	< 0.001*	0.515	0.001*

VJ = vertical jump; ET = elevation time; APP = absolute muscle peak power; RPP = relative muscle peak power $*p < 0.05$.

Discussion

This study compared the effects of a plyometric and a semi-squat training program on VJ, RPE, and DOMS correlated with the absolute and relative muscle peak power in young male football players. It was observed better results on VJ after the semi-squat training program compared with the plyometric training. Only in SSTG occurred a significant increase in CMJ. In another study about the changes in explosive strength performance in sub-20 Brazilian football players, with an intervention period similar to our study (i.e., after 8 weeks of training), it was possible to also observe an increase in CMJ (Hespanhol, Maria, Silva Neto, Arruda & Prates, 2006).

In the current study, the SSTG produced a similar increase in CMJ after 6 weeks of training. The higher increase in CMJ in our study compared with the results of Hespanhol et al. (2006), may have been produced by the half-squat movements, performed by the SSTG, which is like the biomechanical movement of the CMJ.

In this study, the SSTG showed an increase in the APP and the RPP, which seems to demonstrate a greater efficiency of the semi-squat training on muscle peak power. In another study about the velocity-based training of lower limbs to improve absolute and relative power outputs in the concentric phase of half-squat in football players, the training protocol increased RPP and APP, too, after 2 training sessions per week for 10 weeks (Ramírez, Núñez, Lancho, Poblador & Lancho, 2015). These results corroborate with the increase of the post-test values, founded on the RPP and the APP in SSTG in the current study, even with a shorter training time.

Some studies have reported significant decreases in VJ ability on CMJ height after inducing fatigue in the lower limbs by requesting the subjects to sequentially extend/flex their knees in some programs of training (Rodacki, Fowler & Bennett, 2002; Smilios, 1998). In the present study, the higher number of jumps in the PTG compared to the SSTG program may have contributed to not having a significant increase in CMJ among PTG volunteers, probably due to the greater RPE observed through the ABS scale and the DOMS collected through the VAS.

In this study, it could be observed a significant increase in RPE and DOMS in the members of the PTG when compared with the SSTG and the CG. In another study about the effects of lower body muscular fatigue on VJ, it was identified that muscle fatigue typically occurs after high-intensity exercise or prolonged bouts of physical activity (Cooper, Dabbs, Judith & Nicole, 2020). In our study, the CG showed an increase in RPE and DOMS, although the football players did not perform any plyometric or semi-squat training. This increase may have happened because, despite the members of the CG performed a lower intensity technical training, they did all the sessions during the same period of six weeks, as PTG and SSTG.

Probably, the lower result in VJ observed in the PTG in the CMJ test, compared with the SJ test, might have been influenced by fatigue due to the great increase in the result of the RPE and DOMS found in PTG, probably due to the greater landing impact force produced by the DJ, which also occurred in another study that used this same type of jump to verify the effects of aquatic (APT) and land plyometric training (LPT). The group that performed the LPT presented a higher subjective perception of DOMS compared with the APT group (Fonseca et al., 2017).

The results in this study could probably explain one of the main reasons that the plyometric training did not produce the expected effect on the CMJ, due to the performance of the PTG has been done through DJ on the land surface, where some studies showed that this method is one of the causes of exercise-induced muscle damage (EIMD) in the knee extensors, on eccentric contractions (Gribble & Hertel, 2004; Jakeman, Byrne & Eston, 2010; Macaluso, Isaacs, Di Felice & Myburgh, 2014).

Fatigue can be defined as a decline in tension capacity or force output after repeated muscle contractions (Gribble & Hertel, 2004). This may result in negative effects on an individual's overall performance. The VJ height is one of the most sensitive markers of fatigue to monitor elite athletes (Nakamura et al., 2015; Oliver, Lloyd & Whitney, 2015).

For instance, the CMJ height has shown to be progressively reduced over a 7-week training block in youth rugby players, who were considered "overloaded" by their concomitant participation in college and representative teams (Oliver, Lloyd & Whitney, 2015). In the present study, although the CMJ height, after 6 weeks, did not show a reduction in PTG, there was not a significant increase between pre and post-test.

In another study, significant correlations were found between lower-body strength and performance, especially the relative muscle strength of football players (Andersen, Lockie & Dawes, 2018). The present study found strong correlations between absolute and relative muscle peak power with VJ in the SSTG. Other scientific studies (Fonseca et al., 2021; Turner & Stewart, 2014) also reported significant correlations between maximal strength and an increase in VJ performance in male football athletes. Based on the results of these investigations, it appears that improving absolute muscle strength might bring more benefits if it also enhances the relative muscle strength in this population.

Another important methodological factor when testing CMJ performance is the depth of the countermovement (Pérez-Castilla, Jímenez-Reyes, Haff & García-Ramos, 2021). Although the common practice is to allow participants to self-select the countermovement depth (i.e., self-preferred CMJ), some studies have revealed that the countermovement depth may affect several CMJ performance variables (Domire & Challis, 2007; Gheller et al., 2015; Kirby et al., 2011; Mandic, Jakovljevic & Jaric, 2015; Salles, Baltzopoulos & Rittweger, 2011). Lower values of force and power have been observed using large countermovement depths (i.e., larger CMJ) compared to short countermovement depths (i.e., shorter CMJ) (Gheller et al., 2015; Kirby et al., 2011; Mandic et al., 2015; McBride, Kirby, Haines & Skinner, 2010; Salles et al., 2011).

In the present study, it was used DJ plyometric training, with a height of 50 cm, which requires the execution of a greater countermovement depth. The results showed lower values of absolute and relative power in PTG. In addition, a lower VJ after the CMJ test when compared with the SSTG that used the semi-squats movements, did not perform a greater countermovement depth, and showed greater values of absolute and relative power with significative higher VJ in CMJ and SJ.

Study limitations

New studies must be conducted with different training protocols and including biochemical responses of muscle injury markers to verify other correlations with RPE and DOMS. In our study, we collected blood samples with this intention, however, due to the coronavirus pandemic, it was not possible to access the analyses.

Furthermore, new studies should be conducted with other types of plyometric and strength training, besides the concurrent drills involving the simultaneous application of strength and power to observe the effects on vertical impulsion and fatigue and muscle pain responses in young football players.

Conclusions

The semi-squat training produced an increase in VJ, through the CMJ and SJ, while the plyometric training promoted a significant elevation only in SJ. The semi-squat training promoted a greater APP and RPP and lower RPE and DOMS in the young football players. In both types of jumps, positive correlations were found between APP and VJ, RPP and VJ, as between APP and RPP. The results obtained by the SSTG in CMJ and SJ were an interesting training alternative to develop a greater APP and RPP among young football players, too. Different methods of plyometric training must be tested, with a lower impact on the land to obtain higher results on VJ with lower responses of RPE and DOMS to prevent injuries among young football players.

References

Andersen, E., Lockie, R. G., & Dawes, J. J. (2018). Relationship of absolute and relative lower-body strength to predictors of athletic performance in collegiate women soccer players. *Sports*, *6*, 106. https://doi.org/10.3390/sports6040106

Bianchi, M., Coratella, G., Dello Iacono, A., & Beato, M. (2019). Comparative effects of single vs. double weekly plyometric training sessions on jump, sprint and change of directions abilities of elite youth football players. *Journal of Sports Medicine and Physical Fitness*, *59*, 910–915. https://doi.org/10.23736/S0022-4707.18.08804-7

Chiu, L. Z., Fry, A. C., Weiss, L. W., Schilling, B. K., Brown, L. E., & Smith, S. L. (2003). Postactivation potentiation response in athletic and recreationally trained individuals. *Journal of Strength Conditional Research*, *17*, 671–677. https://doi.org/10.1519/1533-4287017

Cohen J. (1988) *Statistical power analysis for the behavioral sciences*. 2. ed. Hillsdale, NJ: Lawrence Erbaum.

Cooper, C. N., Dabbs, N. C., Judith, D., & Nicole, M. S. (2020). Effects of lower-body muscular fatigue on vertical jump and balance performance. *Biology of Sport*, *34*, 2903–2910. https://doi.org/10.1519/JSC.0000000000002882

Dawes, J., & Lentz, D. (2012). Methods of developing power to improve acceleration for the non-track athlete. *Strength Conditional Journal, 34*, 44–51. https://doi.org/10.1519/SSC.0b013e31827529e6

Domire, Z. J., & Challis, J. H. (2007). The influence of squat depth on maximal vertical jump performance. *Journal of Sports Sciences*, *25*(2), 193–200. https://doi.org/10.1080/02640410600630647

Ferley, D. D., Scholten, S., & Vukovich, M. D. (2020). Combined sprint interval, plyometric, and strength training in adolescent soccer players: effects on measures of speed, strength, power, change of direction, and anaerobic capacity. *Strength Conditional Journal*, *34*, 957–968. https://doi.org/10.1519/JSC.0000000000003476

Flávio, J. M., Oliveira, D. C. X., & Souza, E. G. (2018). Effect of plyometric training on speed performance and height of vertical and horizontal heels for young football players. *Revista Brasileira de Futsal e Futebol*, *10*, 673–680.

Fonseca, R. T., Castro, J. B. P., Santos, A. O. B., Lopes, G. C, Nunes, R. A. M., & Vale, R. G. S. (2021). Effects of plyometric training on vertical jump in soccer players between 15 and 18 years old: a systematic review. *Retos*, *39*, 981–987. https://doi.org/10.47197/retos.v0i39.82254

Fonseca, R. T., Nunes, R. A. M., Castro, J. B. P., Lima, V. P., Silva, S. G, Dantas, E. H. M., & Vale, R. G. S. (2017). The effect of aquatic and land plyometric training on the vertical jump and delayed onset muscle soreness in Brazilian soccer players. *Human Movement*, *18*, 63–70. https://doi.org/10.1515/humo-2017-0041

Gheller, R. G., Dal Pupo, J., Ache-Dias, J., Detanico, D., Padulo, J., & Santos, S. G. (2015). Effect of different knee starting angles on intersegmental coordination and performance in vertical jumps. *Human Movement Science*, *42*, 71–80. https://doi.org/10.1016/j.humov.2015.04.010

Gribble, P. A., & Hertel, J. (2004). Effect of lower-extremity muscle fatigue on postural control. *Archives of Physical Medicine and Rehabilitation*, *85*, 589–592. https://doi.org/10.1016/j.apmr.2003.06.031

Hammami, M., Negra, Y., Aouadi, R., Shephard, R. J., & Chelly, M. S. (2016). Effects of an in-season plyometric training program on repeated change of direction and sprint performance in the junior soccer player. *Strength Conditional Journal*, *30*, 3312–3320. https://doi.org/10.1519/JSC.0000000000001470

Hammami, M., Negra, Y., Billaut, F., Hermassi, S., Shephard, R. J., & Chelly, M. S. (2018). Effects of lower-limb strength training on agility, repeated sprinting with changes of direction, leg peak power, and neuromuscular adaptations of soccer players. *Journal of Strength and Conditioning Research*, *32*, 37–47. https://doi.org/10.1519/JSC.0000000000001813

Hespanhol, J. E., Maria, T. S., Silva Neto, L. G., Arruda, M., & Prates, J. (2006). Mudanças no desempenho da força explosiva após oito semanas de preparação com futebolistas da categoria sub-20. *Movimento & Percepção*, *6*, 82–94.

Hoyo, M., Gonzalo-Skok, O., Sañudo, B., Carrascal, C., Plaza-Armas, J. R, Camacho-Candil, F., & Otero-Esquina, C. (2016). Comparative effects of in-season full-back squat, resisted sprint training, and plyometric training on explosive performance in U-19 elite soccer players. *Journal of Strength and Conditioning Research*, *30*, 368–377. https://doi.org/10.1519/JSC.0000000000001094

Jakeman, J. R., Byrne, C., & Eston, R. G. (2010). Lower limb compression garment improves recovery from exercise-induced muscle damage in young, active females. *European Journal of Applied Physiology*, *109*, 1137–1144. https://doi.org/10.1007/s00421-010-1464-0

Keiner, M., Sander, A., Wirth, K., Caruso, O., Immesberger, P., & Zawieja, M. (2013). Strength performance in youth: trainability of adolescents and children in the back and front squats. *Journal of Strength and Conditioning Research*, *27*, 357–362. https://doi.org/10.1519/JSC.0b013e3182576fbf

Kirby, T. J., McBride, J. M., Haines, T. L., & Dayne, A. M. (2011). Relative net vertical impulse determines jumping performance. *Journal of Applied Biomechanics*, *27*, 207–214. https://doi.org/10.1123/jab.27.3.207

Loturco, I., Pereira, L. A., Kobal, R., Kitamura, K., Abad, C. C. C., Marques, G., Gerriero, A., Moraes, J. E., & Nakamura, F. Y. (2017). Validity and usability of a new system for measuring and monitoring variations in vertical jump performance. *Journal of Strength and Conditioning Research*, *31*, 2579–2585. https://doi.org/10.1519/JSC.0000000000002086

Macaluso, F., Isaacs, A. W., Di Felice, V., & Myburgh, K. H. (2014). Acute change of titin at mid-sarcomere remains despite 8 wk of plyometric training. *Journal of Applied Physiology*, *116*, 1512–1519. https://doi.org/10.1152/japplphysiol.00420.2013

Makaruk, H., Czaplicki, A., Sacewicz, T., & Sadowski, J. (2014). The effects of single versus repeated plyometrics on landing biomechanics and jumping performance in men. *Biology of Sport*, 31, 9–14. https://doi.org/10.5604/20831862.1083273

Maloney, S. J., Richards, J., & Fletcher, I. M. (2018). A comparison of bilateral and unilateral drop jumping tasks in the assessment of vertical stiffness. *Journal of Applied Biomechanics*, *34*, 199–204. https://doi.org/10.1123/jab.2017-0094

Mandic, R., Jakovljevic, S., & Jaric, S. (2015). Effects of countermovement depth on kinematic and kinetic patterns of maximum vertical jumps. *Journal of Electromyography and Kinesiology*, 25, 265–275. https://doi.org/10.1016/j.jelekin.2014.11.001

Manske, R., & Reiman, M. (2013). Functional performance testing for power and return to sports. *Sports Health*, *5*, 244–250. https://doi.org/10.1177/1941738113479925

Markovic, G. (2007). Does plyometric training improve vertical jump height? A meta-analytical review. *British Journal of Sports Medicine*, *41*, 349–355. https://doi.org/10.1136/bjsm.035113

McBride, J. M., Kirby, T. J., Haines, T. L., & Skinner, J. (2010). Relationship between relative net vertical impulse and jump height in jump squats performed to various squat depths and with various loads. *International Journal of Sports Physiology and Performance*, *5*, 484–496. https://doi.org/10.1123/ijspp.5.4.484

Michailidis, Y., Fatouros, I. G, Primpa, E, Michailidis, C., Avloniti, A., & Chatzinikolaou, A., … Kambas, A. (2013). Plyometrics' trainability in preadolescent soccer athletes. *Journal of Strength and Conditioning Research*, *27*, 38–49. https://doi.org/10.1519/JSC.0b013e3182541ec6

Mohr, M., Draganidis, D., Chatzinikolaou, A., Barbero-Alvarez, J. C., Castagna, C., & Douroudos, I. (2016). Muscle damage, inflammatory, immune and performance responses to three football games in 1 week in competitive male players. *European Journal Applied Physiology*, *116*, 179–193. https://doi.org/10.1007/s00421-015-3245-2

Moreira, P. E. D., Sousa, R. B., Morales, J. C. P., Greco, P. J., Arroyo, M. P. M., & Praça, G. M. (2021). Tactical behaviour of soccer players from different playing positions throughout a season. *Retos*, *39*, 1–6. https://doi.org/10.47197/retos.v0i39.75970

Moreno, S. M. (2020). Counter-movement jump height as a means to monitor neuromuscular fatigue. Systematic Review. *Retos*, *37*, 820–826. https://doi.org/10.47197/retos.v37i37.73302

Nakamura, F. Y., Pereira, L. A., Rabelo, F. N., Ramirez-Campillo, R., & Loturco, I. (2015). Faster futsal players perceive higher training loads and present greater decreases in sprinting speed during the preseason. *Journal of Strength and Conditioning Research*, *30*, 1553–1562. https://doi.org/10.1519/JSC.0000000000001257

Oliver, J. L., Lloyd, R. S., & Whitney, A. (2015). Monitoring of in-season neuromuscular and perceptual fatigue in youth rugby players. *European Journal of Sport Science*, *15*, 514–522. https://doi.org/10.1080/17461391.2015.1063700

Panagoulis, C., Chatzinikolaou, A., Avloniti, A., Leontsini, D., Deli, C. K., Draganidis, D., … Fatouros, I. G. (2020). In-season integrative neuromuscular strength training improves performance of early-adolescent soccer athletes. *Journal of Strength and Conditioning Research*, *34*, 516–526. https://doi.org/10.1519/JSC.0000000000002938

Peña González, I., Sarabia, J. M., & Moya-Ramón, M. (2022). Young soccer players aggrupation for conditioning trainings according to players' maturation and physical performance: A practical example. *Retos*, *23*(43), 98–106. https://doi.org/10.47197/retos.v43i0.88580

Pérez-Castilla, A., Jímenez-Reyes, P., Haff, G. G., & García-Ramos, A. (2021). Assessment of the loaded squat jump and countermovement jump exercises with a linear velocity transducer: which velocity variable provides the highest reliability? *Sports Biomechanics*, *20*(2), 247–260. https://doi.org/10.1080/14763141.2018.1540651

Picón-Martínez, M., Chulvi-Medrano, I., Cortell-Tormo, J. M., & Cardozo, L. A. (2019). Post-activation potentiation in vertical jump: a review. *Retos*, *36*, 44–51. https://doi.org/10.47197/retos.v36i36.66814

Ramírez, J. M., Núñez, V. M., Lancho, C., Poblador, M. S., & Lancho, J. L. (2015). Velocity-based training of lower limb to improve absolute and relative power outputs in concentric phase of half-squat in soccer players. *Journal of Strength and Conditioning Research*, *29*, 3084–3088. https://doi.org/10.1519/JSC.0000000000000407

Rodacki, A. L., Fowler, N. E., & Bennett, S. J. (2002). Vertical jump coordination: fatigue effects. *Medicine and Science in Sports and Exercise*, *34*, 105–116. https://doi.org/10.1097/00005768-200201000-00017

Rumpf, M. C., Cronin, J. B., Oliver, J. L., & Hughes, M. G. (2013). Vertical and leg stiffness and stretch-shortening cycle changes across maturation during maximal sprint running. *Human Movement Science*, *32*, 668–676. https://doi.org/10.1016/j.humov.2013.01.006

Sáez de Villarreal, E., Suarez-Arrones, L., Requena, B., Haff, G. G., & Ferrete, C. (2015). Effects of plyometric and sprint training on physical and technical skill performance in adolescent soccer players. *Journal of Strength and Conditioning Research*, *29*, 1894–1903. https://doi.org/10.1519/JSC.0000000000000838

Salles, A. S., Baltzopoulos, V., & Rittweger, J. (2011). Differential effects of countermovement magnitude and volitional effort on vertical jumping. *European Journal of Applied Physiology*, *111*, 441–448. https://doi.org/10.1007/s00421-010-1665-6

Sander, A., Keiner, M., Wirth, K., & Schmidtbleicher, D. (2013). Influence of a 2-year strength training programme on power performance in elite youth soccer players. *European Journal of Sport Science*, *13*, 45–51. https://doi.org/10.1080/17461391.2012.742572

Smilios, I. (1998). Effects of varying levels of muscular fatigue on vertical jump performance. *Journal of Strength and Conditioning Research*, *12*, 204–208.

Styles, W. J., Matthews, M. J., & Comfort, P. (2016). Effects of strength training on squat and sprint performance in soccer players. *Journal of Strength and Conditioning Research*, 30, 1534–1539. https://doi.org/10.1519/JSC.0000000000001243

Torreblanca-Martínez, V., Otero-Saborido, F. M., & González-Jurado, J. A. (2017). Effects of muscle fatigue induced by countermovement jumps on efficacy parameters of instep ball kicking in soccer. *Journal of Applied of Biomechanics*, *33*, 105–11. https://doi.org/10.1123/jab.2016-0040

Turner, N. A., & Stewart, P. F. (2014). Strength and conditioning for soccer players. *Strength and Conditional Journal*, *36*, 1–13. https://doi.org/10.1519/SSC.0000000000000054

Vieira, A. A. Q., Costa, F. N., Frigeri, V. F. N., Camargo, L. B., Martins, G. C., & Fileni, C. H. P., … Almeida, K. S. (2020). Perception of pain and effort in lower members of soccer players after physical-technical training. *Centro de Pesquisas Avançadas em Qualidade de Vida*, *12*(1), 1–7.