



# In-Season Strength Training in Elite Junior Swimmers: The Role of the Low-Volume, High-Velocity Training on Swimming Performance

by

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*The aim of this study was to analyze the effect of long-term combined strength training (ST) and plyometrics on strength, power and swimming performances in elite junior swimmers during a competitive season. Ten elite junior swimmers (5 women and 5 men) completed the study (age:  $16.6 \pm 0.7$  years; mass:  $62.2 \pm 5.4$  kg; stature:  $1.70 \pm 0.07$  m). The participants trained twice a week during 20 weeks. The ST program consisted of upper- and lower limbs exercises with low loads and low volume, lifting the load at maximal intended velocity. The effect of the training protocol was assessed using the 1RM in the full squat (SQ) and bench press (BP), jump height (CMJ), the maximal number of repetitions completed in the pull-up (PU) exercise and time during 50-m freestyle. Training program resulted in significant improvements in CMJ (12.1%, ES: 0.57), maximal dynamic strength in the SQ (16.4%, ES: 0.46) and BP (12.1%, ES: 0.34) exercises, the maximum number of repetitions completed during the PU test (90.7%, ES: 0.57) and swimming performance (-3.9%, ES: 0.45). There were no significant differences between both genders. The relative changes in swimming performance showed significant relationship with the relative changes in 1RM of SQ for pooled data ( $r=-0.66$ ,  $p<0.05$ ) and the relative changes in the PU exercise in female swimmers ( $r=-0.99$ ,  $p<0.05$ ). Therefore, coaches and strength and conditioning professionals should consider including in-season dry-land ST programs within the training routine in order to obtain further improvements in swimming performance.*

**Key words:** resistance training, swim time, vertical jump, full squat, youth swimmers.

## Introduction

Strength training (ST) is a common practice in most sports aiming to improve competition performance (Amaro et al., 2018; Aspenes and Karlsen, 2012; Crowley et al., 2017; Kitamura et al., 2017). In swimming, particularly in short distances events, performance is highly related to strength and muscular power, being the capacity to apply force in the water environment a crucial factor for success during the competition (Aspenes and Karlsen, 2012; Crowley et al., 2017; West et al., 2011). Specifically, it has been indicated that strength and power characteristics

of lower limbs are predictors of performance during swimming starts in international sprint swimmers (West et al., 2011) and allow to distinguish between swimmers of different performance levels (Jones et al., 2018). In addition, several studies have shown positive associations between upper limbs muscle strength or power and swimming performance (Garrido et al., 2010; Hawley and Williams, 1991; Keiner et al., 2018; Morouco et al., 2011; Shimonagata et al., 2003). For these reasons, swimming coaches traditionally implement dry-land ST programs although consensus on the specific benefits to a swimmer's

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performance is far to be fully clarified in contemporary literature (Amaro et al., 2018; Blazek et al., 2019; Crowley et al., 2017; Gołaś et al., 2018; Tanaka et al., 1993). There are coaches who assume that ST increases drag forces due to an increase in muscle mass and, consequently, negatively affect swimming ability (Newton et al., 2002). Moreover, several myths exist assuming that muscular strength may negatively impact the swimming technique and, therefore, the performance enhancement (Amaro et al., 2018; Newton et al., 2002). However, recent investigations have shown improvements in swimming performance after a dry-land ST program intervention (Amaro et al., 2018; Aspenes and Karlsen, 2012; Crowley et al., 2017; Girolid et al., 2012; Girolid et al., 2007), although the number of investigations conducted with youth elite swimmers is still scarce.

Several ST methods have been described to increase strength and power in swimmers such as plyometric, resistance (RT) or core training (Amaro et al., 2018; Aspenes and Karlsen, 2012; Crowley et al., 2017; Girolid et al., 2007; Tanaka et al., 1993; Weston et al., 2015). The efficiency of this training programs depends on the specificity of the event (Girolid et al., 2007; Stewart and Hopkins, 2000) and the intensity of the training sessions (Girolid et al., 2007; Stewart and Hopkins, 2000). Some studies applying plyometric training resulted in significant increases in the swimming start and turn performance (Bishop et al., 2009; Potdevin et al., 2011), which are important factors in short distances events. However, most studies have used dry-land RT. In general, investigations using this training method have shown significant performance increments (1% - 7%) (Amaro et al., 2018; Aspenes et al., 2009; Aspenes and Karlsen, 2012; Girolid et al., 2012; Girolid et al., 2007; Strass, 1988), although some studies found no changes after the training period (Tanaka et al., 1993; Trappe and Pearson, 1994). Notwithstanding these findings, previous studies present some methodological limitations of conditioning programs and the practical application: 1) in many of these studies ST program involved only upper limb exercises (Girolid et al., 2012; Girolid et al., 2007; Strass, 1988; Tanaka et al., 1993), despite the relevant importance of lower limbs strength in swimming performance (Jones et al., 2018; West et al., 2011); 2) the participants were swimmers at

the recreational, regional, national or collage level (Aspenes et al., 2009; Girolid et al., 2012; Girolid et al., 2007; Tanaka et al., 1993), whereas few studies were conducted with youth elite swimmers. In addition, in most of ST studies in youth swimmers, the ST program involved moderate to high loads (~70 - 100% of 1RM) and repetitions ending at or close to muscle failure (Aspenes et al., 2009; Girolid et al., 2012; Girolid et al., 2007; Strass, 1988; Tanaka et al., 1993). These ST configurations have been shown to induce a high degree of fatigue, which could last up to 24-48 h after the training session (Gonzalez-Badillo et al., 2016; Pareja-Blanco et al., 2018). Fortunately, recent studies have suggested that ST programs with light loads, few repetitions per set and maximal voluntary lifting velocities, either alone or in combination with plyometric exercises could be an appropriate stimulus to induce changes in physical performance (Franco-Marquez et al., 2015; Rodriguez-Rosell et al., 2017). The results of these studies indicate that training programs with these characteristics are equally or even more effective than ST regimens with heavier loads and repetitions to failure in inducing gains in maximal and explosive strength movements (Franco-Marquez et al., 2015; Rodriguez-Rosell et al., 2017). However, studies using this type of ST programs in young elite swimmers have received insufficient attention.

In order to maintain a certain level of maximal and explosive strength, the magnitude and/or the frequency of explosive type strength training should be given careful attention during the competitive season (Newton et al., 2002; Stewart and Hopkins, 2000). To date, however, it has not been clarified how these variables change during the in-season in elite junior swimmers. The purpose of the present investigation therefore was to examine changes in strength, power and swimming performances in a group of elite junior swimmers during a competitive season, which included both ST and plyometric exercises through twenty consecutive weeks. The hypothesis argued in this paper is that junior elite swimmers will be able to improve physical performance, including maximal dynamic strength, jumping, and swimming by including a ST program with light loads, few repetitions per set and maximal voluntary lifting velocities in combination with plyometric exercises with

traditional technical/tactical swim training sessions.

## Methods

### *Participants*

Ten elite junior swimmers (5 women and 5 men) competing in Portuguese Swimming Championships, European Junior Swimming Championships, and World Junior Championships volunteered to participate in this study. Descriptive characteristics of participants are presented in Table 1. All the participants remained in a high swimming center during the investigation. Therefore, the conditions of training, feeding and rest were the same for all swimmers. Before starting the experiment, all swimmers underwent physical examination by a physician, and each was cleared of any medical disorders that might limit their participation in the investigation. The swimmers were not taking exogenous anabolic-androgenic steroids, drugs or other supplements that may affect physical performance or hormonal balance during the study. This was controlled by the medical department and by one of the researchers. Coaches and parents were informed about the different test procedures and training sessions to be performed during the study. Parental/guardian consents for all participants under the age of 18 involved in this investigation were obtained. All subjects were informed about the experimental procedures and potential risks before they provided their written informed consent. The present investigation met the ethical standards of this journal (Harriss et al., 2017) and was approved by the Institutional Review Committee Board of the local Committee for Medical Research Ethics and current Portuguese law and regulations, and carried out according to the Helsinki Declaration.

### *Study design*

This study comprised a 20-week longitudinal project completed over an in-season in elite young swimmers (5 women and 5 men). During this period, participants were involved in Portuguese Swimming Championships, European Junior Swimming Championships, and World Junior Championships. In addition, swimmers performed 5-6 swimming practice sessions per week combined with a ST regimen twice a week (described below). Prior to the initiation of the

current in-season study, the swimmers were familiarized with all testing and training exercises as they completed a pre-season training routine during four consecutive weeks. Consequently, all athletes were in good overall condition and were adequately familiarized with all procedures and exercise techniques. Apart from traditional technical/tactical practice sessions (3-4 hours per day) and competitions, the athletes completed a 20-week ST regimen that included upper and lower body exercises targeting strength and power. Performance was evaluated prior and following the 20-week training intervention using a variety of strength, jumping, and swimming tests.

Because of ethical considerations, it was not possible to include a control group; so all athletes completed the same in-season ST program. Experimental studies in elite athletes, especially in competitive sports such as swimming, are very difficult to put into practice (Kraemer, 2005; Song et al., 2009). These difficulties are compounded by a problem discussed by Kraemer (Kraemer, 2005). In practical terms, to locate a specific control group (i.e., another elite swimming sample with the same training and at the same performance level as the experimental group) and to access testing conditions is not an easy task for coaches or researchers. In addition, it is unethical to apply a training program that aims to improve sports performance to one group of subjects and not to another within the same group of athletes, as the ultimate goal for everyone is to reach their best sports level. Thus, the fact of not having a control group should not detract from the necessity and importance of this type of investigation or of the present case report, especially in swimming.

### *Testing procedures*

An introductory session was used for anthropometric assessments, medical examination, and familiarization with testing protocols. In this session, the participants arrived at the laboratory in a well-rested condition and a fasted state. After being medically screened, and having their body composition measured, the participants performed an exercise session with light loads (~30-40% 1RM) and a low volume (2-3 sets of 4-8 repetitions per set) while researchers emphasized proper technique to ensure they were familiarized with the protocol to be used in each

testing session. The testing sessions were always conducted in the afternoon (16:00-18:00 am) under similar environmental conditions (~22°C-24°C and ~55 %-65 % humidity) for all participants. At least 2 days before test time, the participants were required not to perform fatiguing training sessions. Strong verbal encouragement was provided during all tests to motivate participants for maximal effort.

#### ***Anthropometric assessments.***

The participants were dressed in a skin-tight swimsuit and a swimming cap for all measurements. Stature and body mass were measured using a medical stadiometer and scale (Seca 710, Ltd., Hamburg, Germany). Wingspan was measured from the tip of one middle finger to the tip of the other middle finger, with the participants abducting both arms horizontally and perpendicular to the body's upright position. Skinfold thickness at eight sites was measured using standardised Harpenden skinfold callipers. The sites included subscapular, tricep, bicep, iliac crest, supraspinale, abdominal, front thigh and medial calf. Each measurement was taken twice unless the two readings differed by  $\geq 10\%$ , in which case a third measurement was taken. Skinfolds were then averaged to represent skinfold thickness. Measurements were taken by one of two trained researchers, and the same researcher was used for all skinfold measurements on a single subject.

#### ***Progressive loading test in the bench press (BP) and full squat (SQ) exercises.***

These tests were performed: 1) to estimate the strength of the lower and upper limbs; and 2) to estimate the load (kg) that each subject had to use during each training session. Both incremental tests were performed using a Smith machine (Multipower Fitness Line, Peroga, Murcia, Spain). The BP testing protocol has been detailed elsewhere (Gonzalez-Badillo and Sanchez-Medina, 2010; Gonzalez-Badillo et al., 2017). The BP was performed imposing a momentary pause (~1.0 s) at the chest between the eccentric and concentric actions to minimize the contribution of the rebound effect and allow for more reproducible, consistent measurements. Similarly, a detailed description of the SQ testing protocol has been recently provided elsewhere (Sánchez-Medina et al., 2017). Participants started from an upright position, descending in a continuous

motion until the posterior thighs and calves made contact with each other, then immediately reversed motion and ascended back to the starting position. Unlike the eccentric phase, which was performed at a normal, controlled velocity, participants were required to always execute the concentric phase of either the BP or SQ at maximal intended velocity. The individual position for the BP (position on the bench as well as grip widths) and SQ exercise (feet position and placement of the hands on the bar) were measured for each participant so that they could be reproduced in all testing sessions. The initial load was set at 20 kg for all participants in the BP and SQ exercises, and was gradually increased in 10 kg increments. The tests ended for each participant when the attained concentric MPV was lower than  $< 0.6 \text{ m}\cdot\text{s}^{-1}$  in the BP and  $< 0.8 \text{ m}\cdot\text{s}^{-1}$  in the SQ exercise (which corresponds to ~70% 1RM in both exercises (Gonzalez-Badillo and Sanchez-Medina, 2010; Sánchez-Medina et al., 2017)). The  $1\text{RM}_{\text{est}}$  was calculated for each individual from the MPV attained against the heaviest load (kg) lifted in the progressive loading tests, as follows:  $(100 \times \text{load})/(-5.961 \times \text{MPV}^2) - (50.71 \times \text{MPV}) + 117$  for the SQ (Sánchez-Medina et al., 2017), and  $(100 \times \text{load})/(8.4326 \times \text{MPV}^2) - (73.501 \times \text{MPV}) + 112.33$  for the BP exercise (Gonzalez-Badillo and Sanchez-Medina, 2010).

#### ***Vertical jump test.***

A countermovement jump test was performed with the participants standing in an upright position on an infrared timing system (Optojump System; Microgate) with the hand on the hips to avoid arm swings. A fast downward movement was immediately followed by a fast upward vertical movement as high as possible, all in one sequence. After a specific warm-up consisting of 2 sets of 10 squats without external load and 5 CMJs (20 s rest interval), each participant performed three maximal CMJs with their hands on their hips, separated by 1 minute rest intervals. The highest and lowest values were discarded, and the resulting average was kept for analysis. The coefficient of variation (CV) for test-retest reliability was 2.4%, and the intraclass correlation coefficient (ICC) was 0.99 (95% CI: 0.98-1.00).

#### ***Pull-up test (PU).***

The PU testing protocol has been recently described elsewhere (Sanchez-Moreno et al.,

2017). All PU tests were performed on a standard stationary, horizontal bar. During this test, participants were required to complete the maximum number of repetitions until muscular failure. To be counted as a complete PU repetition, it was required that the participants lifted his body from a full-arm extension hanging position until the chin was above the bar. A self-selected width with pronated grip (approximately 150% of the biacromial distance) was used throughout the first testing session and it was recorded allowing to be repeated in the subsequent testing sessions. During each repetition, the subjects were required to perform the eccentric phase in a controlled velocity and maintain a static position for  $\sim 1$  s at the end of this phase before performing the concentric phase at maximal intended velocity upon hearing the command. The test was considered as finished when the participants were not able to raise the chin above the bar or when the subjects paused more than 2 to 3 s in the full-arm extension hanging position. The same warm-up protocol, which consisted of 5 minutes of upper limb joint mobility exercises, and 1 set of 2-5 PU repetitions with no external load, was followed in all testing sessions.

#### *Swimming performance (50m test).*

After warming up for about 1000 m in-water, using usual swimmer's strategies (Neiva et al., 2014), and including short sprint races, the swimmers rested until they gained a total subjective readiness to perform the maximal effort test ( $\sim 5$  min). The test started from the starting block and, on the sound of a whistle, the swimmers began the race. The swimmers were instructed to attain maximal swimming speed as quickly as possible and to maintain it as long as possible. The race time was recorded by means of manual chronometer, from the moment of first whistle, until the swimmer completed the 50-m test signified by touching the wall with one hand. Participants performed two 50m front crawl time-trials, with 10 min of recovery between them. These evaluations were carried out in a 25 m indoor pool ( $\sim 27.5^\circ\text{C}$  of water temperature) (Aspenes et al., 2009; Girolid et al., 2012; Girolid et al., 2007). Similar to previous studies (Trappe and Pearson, 1994; Weston et al., 2015), time was recorded by two experienced participants with a stopwatch (Finis 3x100 Stopwatch, Livermore,

California) and the mean value of both measures was obtained in each trial. The CV was 4.3%, and the intraclass correlation coefficient was 0.96 (95% CI: 0.93-0.99).

#### *Training program*

The ST program consisted of 2 cycles of 9 weeks each with a week of recovery between them. Because strength was expected to increase with training, in this recovery week, an isoinertial progressive loading test in the BP and SQ exercises was performed in order to adjust the load for the subsequent training cycle. The participants trained twice a week, on non-consecutive days (Monday and Thursday). Descriptive characteristics of the ST are presented in Table 2. The ST comprised the following exercises: SQ, squat jump (SJ), CMJ, BP, PU, shoulder press (SP). Exercises were performed in the same order in which they appear in Table 2, and all training sets of an exercise had to be completed before performing the following training exercise. All ST sessions were performed during the afternoon (16:00 - 18:00 h) and they lasted  $\sim 60$ -70 min. The loads used by each swimmer in the SQ and SJ exercises were assigned according to  $1\text{RM}_{\text{est}}$  obtained in the SQ loading test. Thus, relative load of the SQ exercise ranged from 40% to 60%  $1\text{RM}$  during the whole training period, whereas for the SJ exercise the relative load ranged from 15% to 25%  $1\text{RM}$ . Similarly, the loads used by each swimmer in the BP and SP exercises were assigned according to  $1\text{RM}_{\text{est}}$  obtained in the BP loading test. In this case, relative load of the BP exercise ranged from 45% to 65%  $1\text{RM}$  during the whole training period, whereas for the SP exercise the relative load ranged from 20% to 35%  $1\text{RM}$ . Finally, the number of repetitions per set to be performed during each training session for the PU exercise was individually assigned according to the maximal number of repetitions completed in the PU test. Thus, the number of repetitions per set by each participant progressively increased from 50% to 75%. The participants were instructed to perform all exercises at maximal intended velocity. At least 2 trained researchers supervised each workout session and recorded the compliance and individual workout data during each training session. In all sessions, the general warm-up consisted of 5 minutes of jogging and 5 minutes of joint mobility exercises. Then, a

specific warm-up consisting of 2 sets of 8 down to 6 repetitions (2-minute rest intervals) with lower loads at maximal scheduled load in each session was performed before each exercise. Besides the training program described above, the participants performed some abdominal and lower-back strengthening exercises.

#### **Statistical analysis**

Standard statistical methods were used for the calculation of mean values and standard deviations. Correlations are reported using Pearson product-moment correlation coefficients ( $r$ ). Homogeneity of variance across tests was verified using the Levene's test, whereas the normality of distribution of the data was examined with the Shapiro-Wilk test. Independent sample  $t$ -tests were used to examine the differences between the 2 groups (female and male) at pre-test, revealing significant initial group differences in all variables analyzed. Therefore, analysis of covariance (ANCOVA) controlling for pre-test values was then used for comparison between genders. This analysis creates an adjusted mean for post-test values of the female and male groups. When data were pooled, a paired samples  $t$ -test was used to detect differences between pre-test and post-test for each variable. Intra-group effect sizes (ES) were calculated using Hedge's  $g$  (Hedges and Olkin, 1985). Threshold values for assessing magnitudes of standardized effects were 0.20, 0.60, 1.20 and 2.00 for small, moderate, large and very large, respectively (Hopkins et al., 2009). 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-participant standard deviation (Hopkins et al., 2009)]. 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. 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**

Data for all variables analyzed were homogeneous and normally distributed ( $P < 0.05$ ). After the training program, both gender groups showed significant changes ( $P < 0.05 - 0.001$ ) in all variables analyzed, with no significant differences between them (Table 3). The ES ranged from moderate to large in both gender groups, with a slight tendency to greater ES in females than males, except for the 50m swimming test. When data were pooled, statistically significant differences were greater than when data were analyzed by gender, but the standardized differences were lower (ES: 0.34 - 0.57, Table 3). Regarding the analysis of the load-velocity curves in the SQ and BP exercises, our results revealed significant ( $P < 0.05 - 0.001$ ) and relevant increase in MPV against all loads analyzed in both the SQ ( $\Delta$ :10-13.3%; ES: 0.30-0.47) and BP ( $\Delta$ :9.3-26.3%; ES: 0.28-0.39) exercise (Figure 1).

Correlation analysis revealed that relative changes in PU performance were significantly correlated with relative changes in the 50m swimming test for females ( $r = -0.99$ ), whereas when data were pooled, a significant negative correlation was observed between individual relative changes in the 50m swimming test and the relative changes in 1RM in the SQ exercise ( $r = -0.66$ , Table 4). In addition, high but not significant correlation coefficients were observed between the relative changes in the 50m swimming test and the relative changes in the CMJ and 1RM, as well as the velocity attained against 20 and 30 kg in the SQ exercise for both gender groups. The relative changes in 1RM and the velocity attained against 20 and 30 kg during the BP exercise did not show significant relationship with the relative changes in the 50m swimming test in any female, male or pooled group (Table 4).

## **Discussion**

The primary aim of the current study was to examine changes in strength and swimming performances in a group of elite junior swimmers during an in-season.

**Table 1***Swimmers physical characteristics.*

	Age (years)	Weight (kg)	Height (m)	Wingspan (m)	FM (%)
<b>Female (n = 5)</b>	16.8 ± 0.8	61.1 ± 4.0	1.68 ± 0.04	1.72 ± 0.05	13.7 ± 1.5
<b>Male (n = 5)</b>	16.4 ± 0.5	63.3 ± 6.8	1.72 ± 0.08	1.80 ± 0.12	7.3 ± 0.4
<b>Pooled (n = 10)</b>	16.6 ± 0.7	62.2 ± 5.4	1.70 ± 0.07	1.76 ± 0.10	10.5 ± 3.6

*Data are mean ± SD; FM: Fat mass.*

**Table 2***Characteristics of the strength training program.*

CYCLE 1										
Exercise	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8	Wk 9	Wk 10
SQ (%1RM: S×R)	40: 3x6	40: 3x8	45: 3x6	45: 3x8	50: 3x4	50: 3x6	55: 3x4	55: 4x4	55: 4x4	
SJ (%1RM: S×R)	15: 3x3	15: 3x3	15: 3x4	15: 3x4	25: 3x3	25: 3x3	25: 3x4	25: 3x4	25: 3x4	
CMJ (S×R)	3x4	3x4	3x5	3x5	3x4	3x4	3x5	3x5	3x4	<b>Control Test</b>
BP (%1RM: S×R)	45: 3x8	45: 3x10	50: 3x8	50: 3x10	55: 3x6	55: 3x8	60: 3x6	60: 4x6	60: 4x6	
PU (S×%MR)	3x50%	3x50%	4x50%	3x60%	4x60%	4x60%	3x75%	3x75%	3x75%	
SP (%1RM: S×R)	20: 3x8	20: 3x10	25: 3x8	25: 3x10	30: 3x6	30: 3x8	35: 3x6	35: 4x6	35: 4x6	
CYCLE 2										
Exercise	Wk 11	Wk 12	Wk 13	Wk 14	Wk 15	Wk 16	Wk 17	Wk 18	Wk 19	Wk 20
SQ (%1RM: S×R)	45: 3x6	45: 3x8	50: 3x6	50: 3x8	55: 3x4	55: 3x6	60: 3x4	60: 4x4	60: 4x4	
SJ (%1RM: S×R)	15: 3x3	15: 3x3	15: 3x4	15: 3x4	25: 3x3	25: 3x3	25: 3x4	25: 3x4	25: 3x4	
CMJ (S×R)	3x4	3x4	3x5	3x5	3x4	3x4	3x5	3x5	3x5	<b>Post Test</b>
BP (%1RM: S×R)	50: 3x8	50: 3x10	55: 3x8	55: 3x10	60: 3x6	60: 3x8	65: 3x6	65: 4x6	65: 4x6	
PU (S×%MR)	3x50%	3x50%	4x50%	3x60%	4x60%	4x60%	3x75%	3x75%	3x75%	
SP (%1RM: S×R)	25: 3x8	25: 3x10	25: 3x10	30: 3x8	30: 3x8	30: 3x8	35: 3x6	35: 4x6	35: 4x6	

*SQ: Full back squat; SJ: Squat jump; CMJ: Countermovement jump; BP: Bench press; PU: Pull-ups; SP: Shoulder press; %1RM: Percentage of one-repetition maximum; S×R: Sets × repetitions; %MR: Percentage of maximum number of repetitions completed during the pull-ups test.*

**Table 3**  
*Changes in selected neuromuscular performance variables from pre- to post-training for female, male and pooled groups.*

Female group (n = 5)						
Variable	Pre	Post	$\Delta$ (CI: 90%)	ES (CI: 90%)	Percent changes of better/trivial/worse effect	
CMJ (cm)	26.4 ± 2.6	30.2 ± 2.9 *	14.1 (4.6 to 24.5)	1.04 (0.35 to 1.72)	97/2/1	Very Likely
1RM_SQ (kg)	46.4 ± 7.4	53.6 ± 6.0 **	16.1 (8.1 to 24.7)	0.75 (0.39 to 1.10)	98/1/0	Very Likely
1RM_BP (kg)	35.8 ± 5.0	41.0 ± 5.7 **	14.6 (7.7 to 21.9)	0.74 (0.40 to 1.08)	99/1/0	Very Likely
Pull-up (Rep)	2.5 ± 1.9	6.0 ± 4.2 *	156.4 (103.5 to 222.9)	0.85 (0.64 to 1.05)	99/1/0	Very Likely
50m (s)	30.71 ± 1.93	29.73 ± 1.90 *	-3.2 (-4.8 to -1.6)	0.41 (0.20 to 0.62)	95/5/0	Very Likely
Male group (n = 5)						
Variable	Pre	Post	$\Delta$ (CI: 90%)	ES (CI: 90%)	Percent changes of better/trivial/worse effect	
CMJ (cm)	35.4 ± 3.8	38.9 ± 3.9 ***	10.1 (8.9 to 11.2)	0.72 (0.64 to 0.80)	100/0/0	Almost certain
1RM_SQ (kg)	74.0 ± 16.7	86.6 ± 21.0 *	16.8 (8.2 to 26.1)	0.53 (0.27 to 0.79)	97/3/0	Very Likely
1RM_BP (kg)	60.2 ± 8.1	66.0 ± 8.3 *	9.7 (3.4 to 16.4)	0.56 (0.20 to 0.91)	95/4/1	Very Likely
Pull-up (Rep)	10.4 ± 4.4	14.8 ± 3.7 **	50.6 (12.0 to 102.4)	0.70 (0.19 to 1.20)	95/4/1	Very Likely
50m (s)	27.56 ± 1.57	26.30 ± 1.12 **	-4.5 (-6.5 to -2.5)	0.67 (0.37 to 0.97)	99/1/0	Very Likely
Pooled group (n = 10)						
Variable	Pre	Post	$\Delta$ (CI: 90%)	ES (CI: 90%)	Percent changes of better/trivial/worse effect	
CMJ (cm)	30.9 ± 5.6	34.5 ± 5.6 ***	12.1 (8.0 to 16.3)	0.57 (0.39 to 0.76)	100/0/0	Almost certain
1RM_SQ (kg)	60.2 ± 19.0	70.1 ± 22.7 ***	16.4 (11.6 to 21.5)	0.46 (0.33 to 0.58)	100/0/0	Almost certain
1RM_BP (kg)	48.0 ± 14.3	53.5 ± 14.8 ***	12.1 (8.0 to 16.3)	0.34 (0.23 to 0.45)	100/0/0	Almost certain
Pull-up (Rep)	6.9 ± 5.3	10.9 ± 5.9 ***	90.7 (51.1 to 140.8)	0.57 (0.36 to 0.77)	99/1/0	Very Likely
50m (s)	29.13 ± 2.35	28.01 ± 2.33 ***	-3.9 (-5.0 to -2.7)	0.45 (0.32 to 0.58)	100/0/0	Almost certain

*Data are mean ± SD; Pre: Initial evaluation; Post: Final evaluation;  $\Delta$ : Percentage of change; ES: Intra-group effect size; CI: Confidence Interval; CMJ: Countermovement jump; 1RM: Estimated one-repetition maximum; SQ: Full back squat; BP: Bench press.*

*Statistically significant differences respect to Pre: \*  $P < 0.05$ , \*\*  $P < 0.01$ , \*\*\*  $P < 0.001$ .*

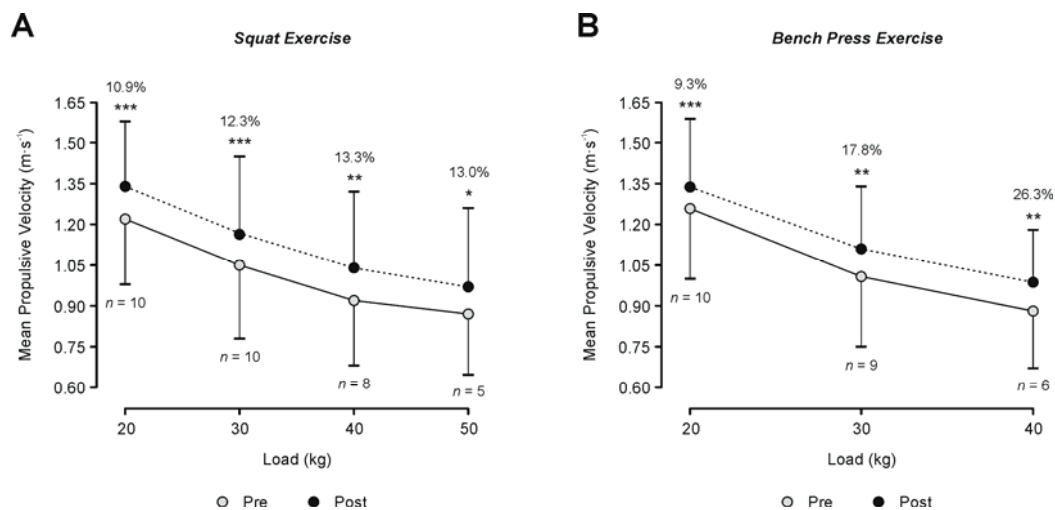
*Note: The positive ES indicate a positive effect, whereas the negative ES indicate a negative effect.*



**Table 4**  
*Relationship between relative changes in 50m freestyle time and relative changes of the different performance variables for female, male and pooled groups.*

Group	CMJ	1RM_SQ	VMP <sub>20</sub> _SQ	VMP <sub>30</sub> _SQ	1RM_BP	VMP <sub>20</sub> _BP	VMP <sub>30</sub> _BP	PU
Female (n = 5)	-0.86	-0.67	-0.64	-0.55	-0.21	0.14	0.18	-0.99 **
Male (n = 5)	-0.83	-0.71	-0.68	-0.67	0.36	0.49	0.57	-0.58
Pooled (n = 10)	-0.53	-0.66 *	-0.54	-0.44	0.22	0.48	0.39	-0.25

CMJ: Countermovement jump; 1RM: Estimated one-repetition maximum; SQ: Full back squat; VMP<sub>20</sub>: Mean propulsive velocity attained against 20kg during the progressive load test in full back squat and bench press; VMP<sub>30</sub>: Mean propulsive velocity attained against 30kg during the progressive load test in full back squat and bench press; BP: Bench press; PU: Pull-ups.  
 Statistically significant relationship: \* P < 0.05.



**Figure 1**

*Load-velocity curve in (A) the full squat and (B) the bench press exercises obtained before and after a 16-week training period intervention. Values are mean ± SD. Significant difference within 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 loading test in the full squat and bench press exercises, respectively.*

Our results showed that improvements in lower- and upper-limbs strength, as well as jumping and swimming performance are possible during a long competitive cycle by using a combination of strength exercises with low volume, low loads, low frequency and high velocity regimen. Consequently, coaches and strength and conditioning professionals should consider including in-season dry-land ST programs within the training routine in order to obtain further improvements in swimming performance. These ST programs should involve exercises for both the lower and upper limbs for an integral improvement, both of the performance on swimming and non-swimming factor involved during competition.

#### *Strength and jump performance*

The results of current study showed that swimmers improved significantly in maximal dynamic strength (estimated 1RM) and velocity attained against different absolute loads during the SQ and BP exercises (Table 3 and Figure 1). In addition, the training program resulted in significant increases in vertical jump height and the maximum number of repetitions completed during the PU test. These results were attained after a 6 weeks preparatory ST cycle, so that all the swimmers were at good overall strength condition before starting the ST program. For maximal strength and jump values, both male (SQ: 16.8%; BP: 9.7%; CMJ: 10.1%) and female (SQ: 16.1%; BP: 14.6%; CMJ: 14.1%) swimmers responded similarly, although it seems that the female group showed slightly greater improvements in upper body strength and CMJ (Table 3). This fact was somewhat predictable, since the female athletes were significantly less strong compared to male swimmers in trunk and upper extremities, so that this group had greater potential for maximal and explosive strength improvements.

Previous studies in swimmers have also shown similar or even less strength improvements in both upper and lower limb muscles (Aspenes et al., 2009; Crowley et al., 2017; Girold et al., 2012; Girold et al., 2007; Strass, 1988), as well as in CMJ height (Breed and Young, 2003; Song et al., 2009), after ST programs with similar intervention durations, with no significant differences between gender (Girold et al., 2012; Girold et al., 2007). In most studies, ST involved

heavy loads and repetitions ending in or near to muscle failure in each training set (Breed and Young, 2003; Girold et al., 2012; Girold et al., 2007; Strass, 1988; Tanaka et al., 1993), whereas results of the present study were obtained using a in-season ST program characterized by use of low to moderate loads and few repetitions per set. Thus, our findings appear to be in contrast with previous studies and reviews indicating that an increase in muscle strength only occurs at training loads above 70% 1RM (Aspenes and Karlsen, 2012; Behringer et al., 2010), and suggest that elite junior swimmers could increase muscle strength and jump performance using low-volume, low-load and low-frequency ST program (provided that the load is lifted at maximal voluntary velocity) during in-season.

#### *50 m swimming performance*

As the strength and CMJ performance, the training program resulted in significant improvements in swimming performance over 50 m freestyle. Although no significant changes were observed between both genders, the female group showed slightly greater enhancement in swimming performance than the male swimmers. Considering that swimming performance has been reported to be dependent on the force and power produced by the swimmers (Loturco et al., 2016; Perez-Olea et al., 2018; Shimonagata et al., 2003), these greater gains in female athletes could be partially due to the higher increments in strength and jump test results (Table 3).

The percentage change relative to swimming performance over 50 m presented in the current study (3.2 - 4.5%, Table 3) were generally greater compared to those shown (1.2 - 3.6%) in previous studies (Aspenes et al., 2009; Girold et al., 2012; Girold et al., 2007; Sharp et al., 1982; Strass, 1988) using dry-land ST. These differences could be due, at least, to two methodological factors related to the ST program. First, most studies (Girold et al., 2012; Girold et al., 2007; Strass, 1988; Tanaka et al., 1993) mainly used exercises of upper limb, whereas our ST program comprised upper (BP, PU and SP) and lower (SQ, SJ and CMJ) limb exercises. It has been indicated that implementation of ST with these lower limb exercises could be necessary to induce further improvements in neuromuscular qualities that can be transferred to more powerful and efficient swim starts and turns (Jones et al., 2018),

inducing therefore an increase in swimming performance. Second, several studies have shown that ST training programs involving training exercises with low loads, low volume and maximal lifting velocities induce greater physical adaptations on high-velocity actions, such as CMJ, compared to ST programs with heavy loads and high volume (Mora-Custodio et al., 2016; Pareja-Blanco et al., 2017). Therefore, it is likely that a ST with these characteristics represents a more efficient training method, as it induces similar or greater improvements in short-distance swimming performance but with a lower degree of fatigue in each training session compared to heavily loaded ST.

*Relationship between 50-m swimming performance, strength and vertical jump*

Several studies exist analyzing the relationship between swimming performance and muscle strength (Garrido et al., 2010; Hawley and Williams, 1991; Loturco et al., 2016; Morouco et al., 2011; Perez-Olea et al., 2018; Sharp et al., 1982; West et al., 2011) in different swimming distances and populations. However, to the best of our knowledge, no study has examined the associations between relative change in short-distance swimming performance and relative changes in dynamic strength of the upper and lower extremities in competitive elite junior swimmers. In the present study, only the relative changes in 1RM of the SQ exercise when data were pooled ( $r = -0.66$ ,  $p < 0.05$ ) and the relative changes in the PU exercise for females ( $r = -0.99$ ,  $p < 0.05$ ) showed a significant relationship with relative changes in swimming performance (Table 4). In addition, the relative changes in CMJ, 1RM in SQ and MPV<sub>20</sub> and MPV<sub>30</sub> in SQ resulted in a moderate to high correlation coefficient with the relative changes in swimming performance in females, males and pooled groups (Table 4). However, the small number of participants in each group may have reduced the possibility of reaching significance in these relationships.

Both the BP and PU exercises involve mostly the musculature of the upper body. Therefore, it was expected that muscle strength evaluated through these tests could be related with swimming performance. Indeed, some studies have found moderate but significant relationships between 1RM in BP exercise and 15 to 50 m swimming performance in young

competitive swimmers (Garrido et al., 2010) and water polo players (Keiner et al., 2018). However, according with our results, other studies indicated that the strength performance in the BP exercise showed a poor relationship with swimming performance (Crowe et al., 1999; Morouco et al., 2011). Thus, these inconsistent results suggest that the role of maximal strength during the BP exercise in swimming performance remains uncertain. Unlike the 1RM in the BP exercise, there exists a certain consensus regarding the association between 1RM in the PU or lat pull down exercises and swimming performance (Crowe et al., 1999; Martens et al., 2015; Morouco et al., 2011; Perez-Olea et al., 2018). Thus, the correlation observed in the present study confirms the importance of implementing ST programs to improve performance of the *latissimus dorsi* muscle, which is the main muscle activated during the swimming stroke (Martens et al., 2015).

On the other hand, our results revealed high relationships between the relative changes in CMJ and the relative changes in swimming performance for both female ( $r = 0.86$ ) and male ( $r = 0.83$ ) swimmers. Similar to our results, a recent study (Garcia-Ramos et al., 2016) showed that the relative changes in the squat jump height was inversely correlated with the relative changes in the start time at 5 m ( $r = -0.47$ ), 10 m ( $r = -0.73$ ), and 15 m ( $r = -0.62$ ) in elite male swimmers from the Spanish Junior National Team. In addition, other studies have observed significant relationships between CMJ height and short-distance swimming performance (Breed and Young, 2003; Garcia-Ramos et al., 2016; West et al., 2011). These results appear to indicate that the explosive strength of the lower limbs could be determinant for the performance in “non-swimming elements” such as the start or the flip turn, which have been closely related to sprint swimming performance (Tor et al., 2015; West et al., 2011). This correlation could be due to both the vertical jump and swim starts, that include complex actions involving powerful extensions of the ankle, knee, hip, elbow and shoulder joints (Breed and Young, 2003; Garcia-Ramos et al., 2016), even though the movements are made in different planes (vertical vs. predominantly horizontal). Therefore, the correlations obtained between the relative changes in CMJ and 50-m swim time confirm the importance of apply force

quickly in the lower limbs to optimize swimming performance.

### Practical applications

The results of the present study highlighted the fact that with a ST of low-to-moderate load and performing few repetitions per set with maximal execution velocities it was possible to significantly improve different physical performance variables in elite Junior Swimmers. In this way, our data suggested that coaches and strength and conditioning professionals should implement before swimming training, two weekly ST sessions, focused on exercises with light-loads, low volume, and maximal execution velocities, in order to improve swimming performance.

Obviously, some limitations of this study should be mentioned, such as: The sample size, the lack of studies in swimming with similar characteristics that enable the comparison of results. Despite these limitations, the importance of performing a ST program based on low-to-moderate loads, low volume, and maximal execution velocities in elite junior swimmers was evidenced. In addition, dry-land weight training does not seem to be the only way to overload functional muscles, and even though good results can be obtained, the use of a sport-specific program may also be of importance. Therefore, further investigations are required to determine this aspect more precisely.

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