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The Relationship between Front Crawl Swimming Performance and Strength Variables in College Swimmers

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Abstract

Swimmers are tested in both dry land and specific swim protocol. The purpose of the present study was to verify the relationships between dry-land exercises and sprint swimming performance. Fifteen male college swimmers (age: 20 ± 1.46; body mass: 67.81 ± 8.04 kg; height: 177.60 ± 6.99 cm) of high-level volunteered to participate. Strength variables (bench press, full-squat, countermovement jump and the medicine ball throwing), swimming performance (50m and 100m front crawl), biomechanical variables (stroke length, stroke frequency, stroke index) were assessed in different days in the beginning of the season. The correlations between swimming test and strength test were quantified using Pearson's bivariate correlation coefficient (r), assuming a significance level of $p<0.05$. Bench press a maximum repetition (1RM) showed correlation with 50m front crawl performance ($p<0.05$). The strength variables were strongly correlated with the biomechanical variables, specifically the stroke length and the stroke index in the 50m ($r = 0.56$ to 0.83) and in 100m front crawl ($r = 0.561$ to 0.718). It is suggested that strength variables are relevant to swimming performance and also influence swimming technique. Thus, strength training should be included to improve swimming performance. Coaches are encouraged to implement strategies enable to increase overall power and strength in sprinter swimmers, considering the abovementioned dry-land exercises.

Keywords: Front-Crawl; Dry-Land; Resistance Training; Sprint; Kinematics

Introduction

Swimming sprint performance seems to be highly influenced by neuromuscular and biomechanical factors, such as muscle power, propulsion efficiency and biomechanical performance [1,2]. This was also evidenced by the relationship recently found between short swimming distances and in-water propelling force and some strength assessments [3]. Researchers extensively used tethered swimming to measure and quantify forces in each stroke and in different swimming techniques. However, due to their specificity and some bias in training monitoring (considering some constraints of the tethered swim, differing from the real swim performance), the results found still not consensual about the influence of strength in swimming and further studies should be developed [1-3].

Recent studies showed that maximum swimming strength is moderately correlated with swimming performance in 200m front crawl (r = 0.61) [4]. There is a greater correlation when shorter distances are considered, since the anaerobic energy pathways predominate over aerobic ones [5]. Another study revealed that the correlation increases to 0.91 when consider the 50m front crawl [6]. These results showed that strength is an important determinant of swimming sprint performances.

Strength and power training is needed to improve performance in high-level swimmers [7]. However, it still critical to find out which dry-land training exercises could optimize swimming performance. It is suggested to perform traditional physical exercises (bench press or/and full-squat exercises) in dry-land strength training. Studies carried-out by Aspenes, et al. [8] and Girold, et al. [9] assumed that training adaptations resulted in improved swimming performance. Neiva, et al. [10] found that the full-squat exercise and countermovement jump (CMJ) were highly correlated with the propelling force applied in the tethered swimming (r = 0.73 and 0.75, for full-squat and CMJ, respectively), but not with the actual swimming performance in competitive swimmers. The ambiguity of the results suggests the need for further studies concerning the transfer between force mechanisms and swimming performance, in order to improve technical and swimming performance [11]. The selection of strategies and training exercises that are more effective and appropriate to practice, enable of inducing positive adaptations to swimming kinematics will be the most important for swimming coaches. Thus, the purpose of the present study was to verify the relationships between strength and power variables (bench press, full-squat, countermovement jump and the medicine ball throwing) and sprint swimming performance (50 and 100m front crawl) in competitive college swimmers. It was expected that stronger swimmers presented higher values of strength and higher swimming performances.

Methods

Participants

Fifteen competitive college male swimmers (mean ± SD: age of 20 ± 1.46 years, height 177.60 ± 6.99 cm, body mass: 67.81 ± 8.04 kg, dry-land training experience: 4.02 ± 2.64 years) participated in this study. The participants were informed about the procedures, signed an informed consent and they were free to withdraw at any time without penalty. The present study also adhered to the International Journal of Sports Medicine standards described by Harriss and Atkinson [12]. All subjects included in the sample were familiar with strength training (experienced), participating in regular strength sessions

Test Procedures

The subjects performed maximal 50 and 100m front crawl, in an early stage of the swimming competitive season. The stroke frequency (SF), stroke length (SL), stroke index (SI), time (T) and mean velocity (V) were assessed in those two time-trials. In the same period, dry-land strength was also evaluated by assessing one maximal repetition (1RM) in full-squat exercise (SQ) and bench press (BP), CMJ with no arm movement and with free-arm movement (CMJ FA) and medicine ball throw (MBT). The evaluations were carried out in the same week to analyze the acute correlation between strength variables and time-trials variables. Subjects were familiar with all test procedures 4 weeks prior (preparatory phase) of the measurements and evaluations to be applied [13].

With regard to time-trials, each swimmer performed maximal 50 and 100m front crawl, with official start from a starting block, on the same day, with 40 min of active recovery between distances. Time was recorded by two experienced subjects with a stopwatch (Finis 3x100 Stopwatch) and the mean value of both measures was obtained in each trial. For each 50 and 100m front crawl, the stroke frequency (SF) was measured with a chrono-frequencimeter analyzing 3 stroke's cycles (Finis 3x100 Stopwatch, Livermore, California) and later converted into units of the international system (Hz).The stroke length (SL) was estimated through the equation 1 [14]:

$$SL = \frac{V}{SF} \qquad (1)$$

Where SL represents the stroke length (m·c-1), V is the average swimmer's speed (m·s-1), and SF is the stroke frequency (Hz).

$$SI = SL\ X\ V \qquad (2)$$

Where SI represents the stroke index was obtained through the SL and the velocity in meters per second, according to equation 2.

These biomechanical variables were evaluated during 13m (between 11 m and 24 m from the starting point to the wall), in every 25m of the 50 and 100m trials.

Moreover, anaerobic critical velocity (ACV) variables were evaluated. The ACV was calculated in $m \cdot s^{-1}$ using the determination of the distance-time line for the 50 and 100m. Using the equation of the regression line of $y = ax + b$ [15], where y represents swim distance, x represents time and a = ACV, b is the y-interception value.

Bench press and full-squat exercises were evaluated by accessing the maximum repetition for each subject (1-RM), after an initial warm-up of 10 submaximal repetitions. In order to perform the full-squat and bench press 1-RM evaluation, three repetitions with progressive external loads were performed in a Multipower (Smith Machine, Apiro, Italy). In the full-squat, each subject flexed deeply from the lower limbs until the quadriceps touched the calves. In the bench press, the participant performed a deep flexion of the upper limbs with bar moving down until near the chest. The Multipower bar was connected by a steel cable to a linear position meter (T-Force System, Murcia, Spain). The linear meter had an accuracy of 0.0002m for the calculation of the different variables measured in each repetition (velocity, power, load). Load increments were made until the average propulsive velocity of each subject was lower than $1 m \cdot s^{-1}$ ($0.60 m \cdot s^{-1}$ for bench press and $0.80 m \cdot s^{-1}$ for full-squat). Only the three best repetitions were recorded during the concentric phase. The software (T-Force System, Murcia, Spain) automatically estimated the maximum repetition value (1-RM).

Vertical countermovement jump (CMJ) and also countermovement jump with free arms (CMJ FA) were also evaluated. Each subject started from a erect position and the end of the concentric phase corresponded to a complete leg extension of 180º. Three jumps were recorded for each participant, with pause of two minutes of rest between each jump. For analysis, the average of the three jumps performed was considered. An optical measuring system consisting of a transmission and reception bar (Optojump Next, microgate, Bolzano, Italy) was used. Each transmission bar contains 96 leds (resolution of 1.0416cm) causing continuous communication with the receiver bar. The system detects all interrupts in communication between buses and calculates their duration. Measuring flight and contact times during the execution of a series of jumps with an accuracy of 1/1000 of a second.

The medicine ball throwing (MBT) was measured by the horizontal distance between the subject's hip position and where the 3kg medicine ball hit the floor after launching. A general warm-up of 10 min were performed, consisting in the perfect execution of each throw with different balls (1kg-circumference of 0.60m and 3kg-circumference of 0.68m). Each subject sat on the floor with his back against a rectilinear structure (wall). Each individual held the ball in front of him with both hands (close to the chest) in order to achieve the greatest amplitude, speed and distance as possible. All participants were instructed to prohibit rotation of the torso and hip during the execution of the movement. Three attempts with the 3kg medical ball were recorded, with a rest period of one minute between each throw. The distance in meters on each pitch and subject was counted and the maximum value of the three entries was recorded.

Statistical Analysis

The normality of the data was verified using the Shapiro-Wilk test and presented as mean ± standard deviation. The strength of the correlations between the variables obtained on the dry-land strength exercises, and the power exercises and swim performances were quantified through the correlation coefficients of Person (r). The limit used to qualitatively evaluate the correlations was based on Hopkins [16], using the following criteria: <0.1, very small; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9 too large,> 0.9, perfect. The level of statistical significance for all analyzes was set at 5%.

Results

The descriptive data of all parameters for the dry-land strength and swim performance exercises are presented in table 1.

50m front crawl	
Stroke frequency (Hz)	46.34 ± 6.66
Stroke length (m)	2.19 ± 0.27
Stroke index (m^2 c^{-1} s^{-1})	3.68 ± 0.54
Mean velocity (m s^{-1})	1.68 ± 0.14
100m front crawl	
Stroke frequency (Hz)	43.67 ± 5.50
Stroke length (m)	2.08 ± 0.22
Stroke index (m^2 c^{-1} s^{-1})	3.15 ± 0.56
Mean velocity (m s^{-1})	1.50 ± 0.16
Strength variables	
Full-Squat (kg)	59.40 ± 21.16
Bench press (kg)	68.40 ± 22.16
Counter movement jump (cm)	31.30 ± 7.07
Counter movement jump with free arms (cm)	36.42 ± 8.72
Medicine ball throwing (m)	4.63 ± 0.88

Table 1: Mean and standard deviation for swimming test and strength test variables.

Table 2 shows the correlation between the dry-land strength variables, the swimming performance and kinematic variables analyzed in the two time-trials. The SL and the SI were the variables with higher correlation with the velocity and strength variables. When considering the 50m time trial, SL was significantly correlated with the SQ (p <0.01), the CMJ (p <0.05) and the CMJ FA (p <0.05). Additionally, SI was significantly correlated with the SQ (p <0.01), the CMJ (p <0.01) and the CMJ FA (p <0.01). For the 100m performance, the SL and the SI showed a correlation with SQ (p <0.01) and with MBT (p <0.05). It was evidenced a correlation between SI and BP (p <0.05) and between CMJ FA and SL (p <0.05) when considering the 100m performance. Significant correlations were found between the parameters of 50m swimming velocity and BP (p <0.01).

Table 3 shows the correlation between all the parameters for the dry-land strength exercises with the anaerobic critical velocity. There was only a strong correlation between BP and anaerobic critical velocity (p <0.05).

	50m				100m			
	SF	SL	SI	V	SF	SL	SI	V
SQ	-0.238	**0.655****	**0.827****	-0.422	-0.283	**0.718****	**0.644****	-0.326
BP	0.159	0.153	0.413	**-0.574***	0.120	0.466	**0.639***	0.463
CMJ	-0.275	**0.582***	**0.686****	0.281	-0.179	0.480	0.436	-0.204
MBT	0.023	0.277	0.462	-0.389	-0.063	**0.561***	**0.638***	-0.463
CMJ FA	-0.278	**0.569***	**0.664****	-0.315	-0.192	**0.533***	0.491	-0.238

** p < 0.05, ** p < 0.01.*

Table 2: The Pearson correlation coefficient between the values of swimming test and strength test variables.

SF: stroke frequency; SL: stroke length; SI: stroke índex; V: mean velocity; SQ: full-squat; BP: bench press; CMJ: countermovement jump; MBT: medicine ball throwing; CMJ FA: countermovement jump free arms.

ACV	
SQ	0,239
BP	**0,586***
CMJ	0,172
CMJ FA	0,232
MBT	0,469

** $p < 0.05$*

Table 3: The Pearson correlation coefficient between the values of swimming test and anaerobic critical velocity (ACV). ACV: anaerobic critical velocity; SQ: full-squat; BP: bench press; CMJ: countermovement jump; MBT: medicine ball throwing; CMJ FA: countermovement jump free arms

Discussion

The present study aimed to analyze the relationships between dry-land strength and sprint performance in competitive college swimmers. Our results showed that there were relationships between biomechanical and strength variables when performing short distances in front crawl. In addition, there was a strong correlation between BP and swimming performance in the 50m crawl. It is biased to state that there is a tendency for the decrease in robustness in correlation when the distances are higher, as reported previously [4,5,17].

The development of swimming performance over the years can be explained by a better training control and evaluation of the swimmers, leading to a more efficient training process [18]. Thus, with improved performance in elite swimmers, it is evidenced that planning should be performed towards the intended goals.

It is likely that the ability to rapidly develop strength (ie, the impulse) in water strongly influence swimmers (over short distances) [19,20]. In longer swimming distances, it seems that other factors related to aerobic resistance and efficiency may weaken the relationship between strength and swimming performance [21]. Thus, we chose to investigate sprinters and to focus on the type of exercise to be applied in dry-land strength training.

The ability to release strength requires high levels of neuromuscular reactive control, proprioception and coordination [22]. Upper body strength enhancement exercises can result in increased strength, resulting in technical and kinematic performance in swimming [23]. Our study evidenced a clear relationship between isokinetic strength exercises and swimming test variables, specifically kinematic variables. Garrido, et al. [24] and Heiderscheit, et al. [25] showed a moderate but significant association between the throwing ability and the swimming sprints. However, due to the variability of the processes and results, it is difficult to compare our data with data from the remaining studies that investigated the relationships between swimming performance and explosive strength in competitive swimmers [24].

Some studies have shown that dry-land resistance training and explosive strength training aims to improve the strength and energy production of specific muscles (leg extensor muscles using countermovement) for swimming performance [26,27] and there is a decrease in muscle strength with increasing age compared with cardiovascular endurance [12]. Strzala and Tyka [28] evaluated the correlation between the front crawl velocity at distances of 100 m and 25 m with the anaerobic CMJ power ($0.75 \leq r \leq 0.76$). These authors suggested that the CMJ height may be a good predictor parameter explaining the speed of swimming. Thus, the vertical jump performance in young swimmers would be highly reliant on skill, besides strength itself [29]. Since power is a factor in many athletic abilities, it is clearly helpful for researchers to study these relationships. It is also important to investigate the type of group performing the correlation tests between exercise and water performance [30].

From the mechanical point of view, swimmers were expected to be able to apply greater amounts of force against water and therefore to produce higher propulsive forces, resulting in a better speed performance [31]. Biomechanical ability in swimming is of essential importance in metabolic economy [32]. Moreover, it was suggested that when the distance is reduced, the force applied increases [26]. It has also been predicted that swimming technique can be improved by strength training and exercises reported by the authors [33].

Sadowski, et al. [34] emphasized that the ability to perform movements with high speed is represented by muscle power. Specifically in swimming, several studies have reported an association between the explosive strength of the leg extensor muscles and swimming performance [28]. Our results seemed to support previous findings in competitive swimmers, evidencing that a great level of strength and power is required for successful swimming performance [35]. Previous studies verified significant relationships between the strength of the lower limbs (evaluated in the full-squat exercise) and the performance variables in swimming [15]. In the present study we found positive relationships with SL and SI, suggesting increased swimming efficiency during all-out 50 and 100m front crawl. The same happened when analyzing CMJ. Despite not being significant, the correlation coefficients tended to show also a positive influence in swimming velocity and suggesting that lower limbs strength influence sprint performance. It is therefore conceivable that swimmers with higher levels of power of the lower limbs in dry-land strength training also have a greater ability to hold their body in a more horizontal position in the water and, consequently, achieve a higher swimming speed [36].

The relationships between swimming technical variables and strength exercises appear to be high, suggesting that technical improvements can be achieved by applying higher levels of power. However, only BP was highly correlated with swimming velocity (50m performance). It should be noted that under dynamic conditions, maximum force ratings are performed at very low speeds, which may limit what is presented by sprint swimmers when performing specific swimming performance [14]. Several studies have suggested that training with high or maximum loads results in improvements in the application of force with low velocity, while low load training methods cause higher increases for high velocities [37,38]. However, unlike our results, they point to an increase in velocity or tendency to improvement when maximum loads are applied. It is reasonable to assume that these kinematic factors affect the relationships between fast movements and the amount of force applied in the maximum strength tests [26]. Additionally, Loturco, et al. [39] indicated that the bench press failed to explain any mechanical measure in tethered swimming, limiting the role of the upper limbs in generating power to boost swimmers during the tests applied. This fact may be due to the applied test being the tethered swimming, which may make it illusive what the real performance of a competitive swimmer. Other studies showed that the ability to exert force in the upper limbs were of great preponderance for a higher mean swimming velocity, especially in short distances [3,40].

The explanation for the strong relationship effect found on short distances can be explained by the metabolic and physiological factors that determined the performance in these distances. The intensity of maximum oxygen consumption and fatigue threshold is explained by the authors Papoti, et al. [2] and Monod and Scherrer [41], which show large correlations with the performance of 200m (r = 0.89 and 0.63, respectively). In addition, the mechanical similarity between the high movement velocities of short distances and the power strength could help to explain those relationships.

The peak power output can be maximized up to 70% of 1RM [42,23] and these moderate strength applied at high submaximal velocities were considered to be very similar to those normally encountered by aquatic athletes when performing sprint or competition swimming [43,44]. It is important to mention the importance of further studies on the objective of analyzing the effect of the exercises applied on sprinter swimmers on the condition of analyzing the level of performance with the application of these test batteries.

Despite not being main aim of this study, our results showed linear relationships between anaerobic critical velocity and 50m and 100m velocities. These results suggested that anaerobic critical velocity may be an important parameter for monitoring and prescribing anaerobic training in young swimmers, confirming [15] statement that anaerobic critical velocity is an advantageous process in understanding swimmers 'slope. Moreover, the relationship between strength variables and ACV demonstrated the importance of power and strength to high intensity swimming training.

In summary, our data suggest that strength exercises were correlated with swimming performance and will be an excellent tool for improving the performance of the 50 and 100m frontal crawl in long-term sports performance. Some limitations should be presented. The reduced sample size and including only male swimmers can be considered a limitation. It would be interesting to analyze the same procedure in women. The level of the swimmers could be considered another limitation in the study. Moreover, these relationships should be analyzed with more swimming distances and techniques (not only the 50m and 100m front crawl) in the future.

Conclusion

The results showed that there was a correlation between strength test and swimming test (BP for the V in 50m frontal crawl) and these could be used to improve swimming performance. BP being the most predictive exercise. Thus, the resulting strength of the upper body had a greater preponderance for sprint performance. In addition, other strength test variables (SQ, CMJ, CMJ FA and MBT) also showed correlation with technical aspects in swimming performance, showing significant values for SL and SI. SF was the only technical variable in the study that did not present correlation values with no technical and performance aspects in swimming. In short, although BP is the only variable that predicts yield, there are other variables related to technical changes. In a way, it is correct to affirm that the strength manifested in dry-land can influence technical parameters, and may have implications for the yield. Further studies should be performed to understand these yield implications. Although our data present important information to coaches, it is noteworthy that only one study analyzed specific correlations between strength tests and swimming sprint performance (50m and 100m). Further studies are needed to verify relationships between other upper and lower limb strength exercises, such as rowing, shoulder, legs exercises and swimming performance. Finally, swimming performance was shown to be intertwined on strength training, quantifying the dynamic parameters of swimmers, allowing researchers to understand the relationship between dry-land strength exercises and swimming sprint performance. Therefore, it seems interesting to monitoring specific adaptations after swimming training periods that include strength training (especially with exercises that revealed a strong correlation with swimming technique and swimming performance: full-squat, bench, vertical jumps and plyometric exercises). The results presented encourage coaches to use strength and power drills to improve swimming performance.

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