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The effects of dry-land strength training on competitive sprinter swimmers

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ABSTRACT

Background/objective: This study aimed to examine the effects of eight weeks of dry-land strength combined with swimming training on the development of upper and lower body strength, jumping ability, and swimming performance in competitive sprinter swimmers.

Methods: Twenty (14 men and 6 women) university swimmers of national-level (age: 20.55 ± 1.76 years, body mass: 68.86 ± 7.69 kg, height: 1.77 ± 0.06 m, 100 m front crawl: 71.08 ± 6.71s, 50 m front crawl: 31.70 ± 2.45s) were randomly divided into two groups: experimental group (EG: 11) and control group (CG: 9). In addition to the usual in-water training (3–4 sessions per week of ~80 min), the EG performed 8 weeks (one session per week) of strength-training (ST). The ST included bench press, full squat, countermovement jumping, countermovement jumping with free-arm movement, and the medical ball throwing. Stroke length, stroke frequency, stroke index, and swimming velocity were recorded during 50 and 100 m front crawl time-trials. Strength and swimming performance were evaluated before and after 8 weeks of training.

Results: The results showed a significant improvement in sprint performance (50 m: $p < 0.01$, $d = 0.47$; 100 m: $p < 0.05$, $d = 0.42$), stroke frequency (50 m: $p < 0.01$, $d = 0.90$) and stroke index (100 m: $p < 0.01$, $d = 0.29$) in the EG. Despite both groups' increased strength performance, increases in bench press were higher in the EG ($p < 0.001$, $d = 0.75$) than CG ($p = 0.05$, $d = 0.34$).

Conclusions: Complementing in-water training with strength training seems to be relevant to improve upper body strength and to optimize 50 m and 100 m swimming performance, adapting technical patterns used during all-out swimming.

Introduction

A strength training (ST) program seems to improve the rate of force production, contributing to increased performance.[1] Dry-land ST has been reported to positively influence sprint performance in swimming, with improvements ranging between 1.3 and 4.4%.[2–4] However, these gains seemed to be negatively affected when ST is combined with an aerobic stimulus, which is very common in the aquatic sports training.[5–7] There is a lack of studies to determine whether ST positively influences swimming competitive performance.[5,6] Although several studies have reported that muscle strength is highly associated with performance in short and high-intensity efforts, recent studies have pointed out that, specifically in swimming, better performances were also recorded in longer distances for swimmers with a higher level of strength.[8–10]

A program of 11 weeks of training (twice a week) using a combined intervention of strength and aerobic training in competitive swimmers produced significant improvements in dry-land strength, in the propelling force during tethered swimming and in 400 m front crawl performance.[11] However, no changes were found in the 50 and 100 m front crawl performances.[11] Thus, it appears that ST is related to a greater extent with an increase in long-distance swimming performance.[8,10] Nevertheless, other

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studies[8,12] showed that 8 weeks of combined strength and swimming training (twice a week) produced significant increases in strength, power, and swimming performance during short distances in young swimmers. It seems therefore that adding ST to routine swimming training also allowed sprint performance to improve in young swimmers.

To our knowledge, some studies showed significant and positive results when combining strength and swimming training *versus* swimming training alone.[2,5,6,8,13–17] These studies reported positive effects on sprint and middle-distance swimming when using dry-land training programs with intensities ranging from 80 to 90% of 1RM combined with swimming training. Therefore, the authors recommended heavy-load ST programs (3 sets of 5/6 repetitions maximum with a rest interval of 2–5 min) to improve strength and swimming performance in elite swimmers. Under these recommendations, a maximum strength training program (intensities between 90 and 100% + 1 kg 1RM) using free weights resulted in significant increases of 4.4 and 2.1% in 25 and 50 m front crawl performances, respectively.[4] Interestingly, two strength programs of six weeks, one focusing on power (3 × 15-25 s with 60–70% of 1RM) and another on hypertrophy (3x6-8 repetitions with 80–90% of 1RM), combined with the same swimming training, showed improvements in performance.[2] Nevertheless, in the group that performed power training, the improvements were higher (2.21–1.46%) in 50 m front crawl.[2] To achieve strength gains, general swimming load should also be considered at no more than 5000 m per day, reducing the possible effect of neuromuscular fatigue in sprinter swimmers.[6] In opposition, other training programs stated that there were no relationships between improvements in dry-land ST and swimming performance.[10,12,18,19]

A dry-land strength program combined with swimming training in masters (30–39 and 40–49 years) assessing technical and kinematic variables (stroke length: SL, stroke frequency: SF, and stroke index: SI) and 50 m front crawl performance, did not report any improvements.[9] Yet, the authors stated that the swimming performance was more dependent on swim kinematics variables than strength parameters in the 30–39 age group, whereas the improvements in the 40–49 age group were related to the strength program.[9] Moreover, no relationship was found between stroke kinematics and strength gains in both groups.[9] In fact, the swimming technique is essential to swimming performance,[20] and it seems important to analyze the effects of the combination of ST and swimming training on practical technical variables (stroke kinematics).

The literature is sparse and inconclusive regarding the effects of ST to technical parameters, such as SL and SF, that are two biomechanical key factors for short-distance swimming performance. Thus, the main objective of the present study was to evaluate the effect of eight weeks of combined swimming training with ST on swimming performance (50 and 100 m front crawl) and biomechanical variables (SL, SF and stroke index: SI). As a hypothesis of the study, it was postulated that dry-land ST when combined with swimming training facilitates the improvement of swimmers' performances in addition to changes in the swimming technique.

Methods

Participants

Twenty (14 men and 6 women) university swimmers (age: 20.55 ± 1.76 years, body mass: 68.86 ± 7.69 kg, height: 1.77 ± 0.06 m) participated in the current study. These were randomly allocated into two groups: the control group (CG), which only performed swim training (5 men and 4 women; age: 20.67 ± 2.00 years, body mass: 66.52 ± 9.06 kg, height: 174.33 ± 0.08 m, 100 m front crawl: 71.08 ± 6.71 s, 50 m front crawl: 31.70 ± 2.45 s) and the experimental group (EG), performing strength and swim training (9 men and 2 women; age: 20.45 ± 1.63 years, body mass: 70.76 ± 6.15 kg, height: 1.79 ± 0.05 m, 100 m front crawl: 67.04 ± 8.06 s, 50 m front crawl: 29.95 ± 2.94 s). All the participants were competitive swimmers familiarised with swimming practice and with the experimental assessments used. All procedures were in accordance with the Declaration of Helsinki regarding human research. The University Ethics Board also approved the research design.

Design and procedures

The participants were evaluated in tasks performed in-water (swimming performance) and out of the water (strength). The evaluations were performed in two moments: (i) before the experimental period (M1) and (ii) after the 8 weeks of combined strength and swimming training (M2). Both groups were evaluated in the same moments and the tests were carried out during a week in each moment. While the EG performed water training combined with ST during the 8 weeks, the CG only performed water training. Participants were familiar with all test procedures 7 weeks before the measurements (preparatory phase) and evaluations to be applied.[21] The subjects were instructed in advance to refrain from strenuous exercise during the week of evaluation. Moreover, they kept the same diet and routines 48 h h before any evaluation.

Swimming performance

After warming up for about 1000 m in-water, using usual swimmer's strategies,[22] each participant performed 50 and 100 m front crawl time-trials, with 30 min of recovery between them. These evaluations were carried out in a 25 m indoor pool, with official starts. Times were recorded by two experienced participants with stopwatches (Finis 3 × 100 Stopwatch, Livermore, California) and the mean value of both measures was obtained in each trial. If there was a situation where both timed times were equal to or greater than a 10% difference in time, the swimming test would be repeated the next day. Also, an analysis was performed through the Kinovea program version 0.8.15 to obtain the time of each test performed. The inter-rater reliability, determined by the intraclass correlation coefficient (ICC), presented mean values of 0.995 (95% CI: 0.987–0.998).

During each 50 and 100 m front crawl, biomechanical variables were analyzed to understand the technical changes due to training programs and their influence on swimming performance.[19,23] Thus, the SF was measured with a chrono-frequencimeter in 3 stroke-cycles (Finis 3 × 100 Stopwatch, Livermore, California) and later converted into units of the international system (Hz). The SL was estimated through the equation:[24]

$$SL = \frac{V}{SF} \tag{4}$$

Where SL is the stroke length ($m \cdot cycle^{-1}$), v is the swimmer's mean speed ($m \cdot s^{-1}$), and SF is the stroke frequency (Hz). The swim index (SI) was obtained through the SL and the v, according to equation (5):

$$SI = SL\ X\ v \tag{5}$$

The v and the SF were evaluated during 13 m (between 11 and 24 m from the starting wall), in each 25 m lap of the 50 and 100 m time trials. The evaluation of biomechanical variables was performed using video analysis with Kinovea program version 0.8.15.

Anaerobic critical velocity (ACV) was determined based on the 50 and 100 m performance, considering the slope of the distance-time relationship and plotting the swimming performance over time.[25,26]

Muscle strength, jump and ball throw performance

The full squat (SQ) and bench press (BP) exercises were evaluated by determining the maximal strength for each participant (1RM). After an initial warm-up, each participant was asked to perform a progressive loading test with external loads in a Multipower (Smith Machine, Apiro, Italy). In the SQ, each subject descended in a continuous motion until the top of the thighs reached below the horizontal plane, with knees flexed to a tibiofemoral angle of 35–45° in the sagittal plane, then immediately reversed motion and ascended back to the upright position.[27] In the BP the limit was the deep flexion of the upper limbs with a bar near the center of the chest. In both exercises, the concentric phase was performed at the maximal intended velocity. A linear velocity transducer (T-Force System, Ergotech, Murcia, Spain) was used to register bar velocity. The initial load was set at 20 kg and was progressively increased until the mean propulsive velocity (MPV) values were ~0.60 m s^{-1} for BP and ~0.80 m s^{-1} for SQ, respectively.[27,28] The participants performed 3 repetitions with each load, with 3 min recovery. The estimated 1RM was calculated for each individual from the MPV attained against the heaviest load (kg) lifted in the progressive loading test, as follows: $(100 \cdot \text{load})/(-5.961 \cdot \text{MPV}^2) - (50.71 \cdot \text{MPV}) + 117$ for the SQ,[27] and $(100 \cdot \text{load})/(8.4326 \cdot \text{MPV}^2) - (73.501 \cdot \text{MPV}) + 112.33$ for the BP.[29]

Vertical jump was evaluated using the countermovement jump (CMJ) and the countermovement jump with free arms (CMJ FA). Each participant started from an erect position and the end of the concentric phase corresponded to a complete leg extension: 180°. Three jumps were recorded for each evaluation and per participant, with 3 min of rest. The mean value and the highest value were considered for further analysis. An optical measuring system consisting of a transmission and reception bar (Optojump Next, microgate, Bolzano, Italy) was used. For the CMJ, ICC values were 0.990 (95% CI: 0.972–0.998) in the CG and 0.966 (95% CI: 0.911–0.990) in the EG, while CMJ FA presented ICC values of 0.977 (95% CI: 0.932–0.994) in the CG and 0.971 (95% CI: 0.924–0.991) in the EG. The CV values in CMJ and CMJ FA were 2.51 and 3.06% in the CG and 3.21 and 2.86% in the EG, respectively.

The ball throwing performance (MBT) was measured by the horizontal distance reached after throwing a 3 kg ball. A general warm-up of 10 min, which included the perfect execution of each throw with different balls (1 kg - circumference of 0.60 m and 3 kg - circumference of 0.68 m), preceded the ball throwing. Each participant 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. All participants were instructed not to rotate over the torso and hip rotation during the execution of the movement was not allowed. Three attempts with the 3 kg medical ball were counted, with a rest period of 1 min between each throw. The distance in meters on each throwing and participant was considered. For the MBT, the ICC presented mean values of 0.977 (95% CI: 0.933–0.994) in the CG and 0.894 (95% CI: 0.720–0.968) in the EG, and CVs of 3.52% in the CG and 4.10% in the EG.

Training procedures

Swimming training

During the eight weeks of experimental training, all participants (CG and EG) performed 27 water training units (swimming) (3.4 sessions per week of ~90 min). The swimmers performed a total of 80.4 km, corresponding to a mean value of 10.05 ± 1.53 km per week and 3.00 ± 0.31 km per training unit. The participants performed 15.40 km at anaerobic critical velocity (7.70 ± 5.94 km per week) and 3.80 km at an intensity corresponding to their aerobic power (1.90 ± 1.70 km per week). The remaining training volumes consisted of low-intensity tasks or low aerobic tasks (≈37% of the total volume), technical training and recovery (≈39%) and speed training (≈4%). Both groups performed the same swimming training.

Strength training

In addition to the usual swimming sessions, the EG performed eight weeks (one session per week) of ST, with 1 h each (Table 1). The entire program was supervised by the team coach, having already experienced the strength procedures used. The main exercises of the ST were BP and SQ, CMJ, CMJ FA and MBT (1 and 3 kg). Also, complementary exercises were performed according to the swimmers' needs,[6] as presented in Table 1. The participants performed 3–5 sets of 6–12 repetitions for each exercise at 60–80% of 1RM. The rest time varied between 3 and 4 min between sets and exercises.

Statistical analysis

Data analysis was performed using Statistical Package for Social Sciences (SPSS), version 22.0, for Microsoft Windows. The level of significance was set at 5%. A descriptive analysis was carried out to describe and summarise the data under analysis, presenting the mean ± standard deviation for each variable. The normality of the data was verified through the Shapiro-Wilk test. Normal distribution was found. Absolute reliability was determined for CG and EG in pre-training by calculating the standard error of measurement (SEM) and CV.[30] The SEM was calculated as the square root of the mean square error from the ANOVA and then expressed as a percentage of their respective mean values through the CV.[31,32] The ICC (95% CI) for each group (CG and EG) in pre-training was determined using the two-way mixed random effects model (absolute agreement type). To compare the mean differences over the two assessment periods between the two groups, the two-way ANOVA was used, with repeated measures in one factor (moment of evaluation), considering the variables under study. Moreover, the effect size was calculated to estimate the variance between moments (partial eta squared: np^2) and Cohen's *d* for subject comparisons. A Cohen's *d* of 0.2 was deemed small, 0.5 medium, and 0.8 large. For np^2, cut-off values were interpreted as 0.01 for small, 0.09 for moderate and 0.25 for large.

Results

Tables 2–4 present swimming and strength performances at the beginning of the protocol (M1) and after the eight weeks of training (M2), in the CG and in the EG. Considering the 100 m, the interaction (group vs. moment) was significant and large in the second 50 m partial ($np^2 = 0.57$), in the 100 m time ($np^2 = 0.48$), and in the SF in the second 50 m partial ($np^2 = 0.41$). Moderate interaction was found in SI in the first 50 m partial ($np^2 = 0.24$) and in the SI in the 100 m performance ($np^2 = 0.23$). By analyzing the comparisons of moments within each group and the profile graphs (Fig. 1 and Table 2), it was verified that the EG increased the performance from M1 to M2 in the five variables described. In opposition, the CG showed a small decrease in performance from M1 to M2. It should be noted that in the SI in the first 50 m partial small changes from M1 to M2 were found. The SF in the first 50 m and in the 100 m presented large significance regarding the group factor, concluding that EG presented a better performance when

Table 1
Dry land strength training program between week 1 and week 8.

	Exercises	Load	Series x Rep.	Recovery between series
1st Week (1st Session)	Full Squat	60%; 0.79 m s^{-1}	3 × 12	3 min
	Countermovement Jump	Nd		
	Supine	60%; 0.79 m s^{-1}		
	Medicinal Ball Throw	2–3 kg		
	Pull-up/Elevation	Nd		
	Bent Arm Flys	60%; 0.79 m s^{-1}		
	Triceps + Shoulders	60%; 0.79 m s^{-1}		
2 nd Week (2nd Session)	Full Squat	70%; 0.62 m s^{-1}	4 × 10	4 min
	Countermovement Jump	Nd		
	Supine	70%; 0.62 m s^{-1}		
	Medicinal Ball Throw	3 kg		
	Pull-up/Elevation	Nd		
	Bent Arm Flys	70%; 0.62 m s^{-1}		
	Triceps + Shoulders	70%; 0.62 m s^{-1}		
3rd Week(3rd Session)	Full Squat	75%; 0.55 m s^{-1}	5 × 8	4 min
	Supine	75%; 0.55 m s^{-1}		
	Pull-up/Elevation	2–3 kg		
	Bent Arm Flys	75%; 0.55 m s^{-1}		
	Triceps + Shoulders	75%; 0.55 m s^{-1}		
4th Week (4th Session)	Full Squat	80%; 0.47 m s^{-1}	5 × 6	3 min
	Supine	80%; 0.47 m s^{-1}		
	Pull-up/Elevation	3 kg		
	Bent Arm Flys	80%; 0.47 m s^{-1}		
	Triceps + Shoulders	80%; 0.47 m s^{-1}		
5th Week (5th Session)	Full Squat	75%; 0.55 m s^{-1}	4 × 10	4 min
	Countermovement Jump	BOX 90 cm		
	Supine	75%; 0.55 m s^{-1}		
	Medicinal Ball Throw	5 kg		
	Pull-up/Elevation	2 kg		
	Bent Arm Flys	75%; 0.55 m s^{-1}		
	Triceps + Shoulders	75%; 0.55 m s^{-1}		
6th Week (6th Session)	Full Squatting	75%; 0.55 m s^{-1}	4 × 10	3 min
	Countermovement Jump	BOX 90 cm		
	Supine	75%; 0.55 m s^{-1}		
	Medicinal Ball Throw	5 kg		
	Pull-up/Elevation	2 kg		
	Bent Arm Flys	75%; 0.55 m s^{-1}		
	Triceps + Shoulders	75%; 0.55 m s^{-1}		
7th Week (7th Session)	Full Squat	80%; 0.47 m s^{-1}	5 × 6	3 min
	Supine	80%; 0.47 m s^{-1}		
	Pull-up/Elevation	3 kg		
	Bent Arm Flys	80%; 0.47 m s^{-1}		
	Triceps + Shoulders	80%; 0.47 m s^{-1}		
8th Week(8th Session)	Full Squat	70%; 0.62 m s^{-1}	4 × 10	4 min
	Supine	70%; 0.62 m s^{-1}		
	Pull-up/Elevation	1/2 kg		
	Bent Arm Flys	70%; 0.62 m s^{-1}		
	Triceps + Shoulders	70%; 0.62 m s^{-1}		

compared to the CG (1st 50 m SF $np^2 = 0.33$; 100 m SF. $np^2 = 0.28$).

In the 50 m time-trial, the interaction between the group and moment was large in the first 25 m ($np^2 = 0.25$), in the 50 m time trial ($np^2 = 0.25$) and in the SF in the 50 m partial ($np^2 = 0.26$). One could observe, through the multiple comparisons and analysis of the profile graphs (Fig. 1 and Table 3), that the EG increased the performance from M1 to M2 in the three described variables. The CG showed a tendency to improve from M1 to M2 but the result is not significant in the same variables. SL in the 50 m showed that there were great changes from M1 to M2 ($np^2 = 0.28$). The second part of the 25 m showed moderate changes concerning the group factor, and it was evidenced that the EG presented a better performance when compared to CG ($np^2 = 0.21$).

The ACV demonstrated significant and large interaction between the two factors ($np^2 = 0.26$). Multiple comparisons and analysis of the profile graph (Fig. 1 and Table 3) suggested that EG slightly increased the performance from M1 to M2, contrasting with the CG that showed a small performance decrease from M1 to M2.

Regarding strength and jump performance, Table 4 shows the values of 1RM determined in the SQ, in the BP, in the CMJ, in the CMJ FA, and the MBT. The interaction was significant and moderate only for the BP ($np^2 = 0.21$). By analyzing the multiple comparisons and the graph of the profile (Fig. 1), it can be observed that in both groups there was a large performance increase from M1 to M2 ($np^2 = 0.61$), although with a larger effect size in the EG. The main effect of the moment factor was significant for the remaining variables, with large interaction in the SQ ($np^2 = 0.26$), in the CMJ FA ($np^2 = 0.26$) and in the MBT ($np^2 = 0.38$), and moderate interaction in the CMJ ($np^2 = 0.24$), thus, presenting significant changes from M1 to M2. In the same way (except for the SQ variable), all the previously mentioned variables were statistically significant considering the group factor. Hence, it can be concluded that EG presents a better performance when compared to the CG. Moreover, significant and large interaction was presented in the BP, in the CMJ, and the MBT, and moderate interaction was verified in the CMJ FA (BP $np^2 = 0.39$; CMJ $np^2 = 0.28$; CMJ FA $np^2 = 0.23$; MBT $np^2 = 0.26$).

Table 2
Comparison throughout the two moments of evaluation between the two groups in the performance of 100 m swimming.

	Control Group			Experimental Group			Moment	Group	Interaction	Multiple Comparisons (Interaction)	
	M1	M2	Effect Size	M1	M2	Effect Size	*p-value*	*p-value*	*p-value*	Control	Experimental
			Cohen's D			*Cohen's d*				M1-M2 (*p-value*)	M1-M2 (*p-value*)
Performance of 100 m Front Crawl											
1st 50 m (s)	33.68 ± 3.50	33.77 ± 3.61	0.03	30.41 ± 1.92	29.85 ± 1.82	0.31	0.309	**0.011***	0.162		
2nd 50 m (s)	37.40 ± 3.37	38.01 ± 3.92	0.18	35.84 ± 4.95	33.67 ± 3.97	0.48	**0.013***	0.125	**0.000****	0.164	**<0.001****
100 m (s)	71.08 ± 6.71	71.78 ± 7.35	0.11	67.04 ± 8.06	64.13 ± 6.46	0.42	**0.023***	0.084	**0.001****	0.301	**<0.001****
1st 50 m SF (Hz)	0.72 ± 0.08	0.71 ± 0.08	0.20	0.81 ± 0.07	0.810 ± 0.08	0.00	0.530	**0.009****	0.575		
2nd 50 m SF (Hz)	0.66 ± 0.08	0.65 ± 0.09	0.20	0.72 ± 0.09	0.759 ± 0.07	0.48	0.197	**0.048***	**0.004****	0.221	**0.002****
SF 100 m (Hz)	0.67 ± 0.07	0.68 ± 0.08	0.19	0.77 ± 0.08	0.784 ± 0.07	0.25	0692	**0.016***	0.061		
1st 50 m SL (m)	2.11 ± 0.20	2.14 ± 0.23	0.15	1.96 ± 0.10	2.02 ± 0.20	0.40	0.178	0.096	0.668		
2nd 50 m SL (m)	2.02 ± 0.19	2.04 ± 0.21	0.11	2.00 ± 0.29	1.99 ± 0.28	0.04	0.616	0.754	0.478		
100 m SL (m)	2.06 ± 0.18	2.09 ± 0.21	0.16	2.00 ± 0.23	2.03 ± 0.27	0.13	0.131	0.560	0.885		
1st 50 m SI ($m^2\ c^{-1}\ s^{-1}$)	3.22 ± 0.54	3.25 ± 0.63	0.05	3.27 ± 0.54	3.48 ± 0.67	0.36	**0.041***	0.607	0.119		
2nd 50 m SI ($m^2\ c^{-1}\ s^{-1}$)	2.72 ± 0.42	2.73 ± 0.44	0.02	2.87 ± 0.69	3.02 ± 0.73	0.22	**0.018***	0.420	**0.028***	0.898	**0.002****
100 m SI ($m^2\ c^{-1}\ s^{-1}$)	2.97 ± 0.46	2.99 ± 0.53	0.04	3.07 ± 0.61	3.25 ± 0.68	0.29	**0.010***	0.498	**0.031***	0.718	**0.001****

First 50 m (s) = first pass at 50–100 m front crawl; Second 50 m (s) = second pass at 50–100 m front crawl; SF = Stroke Frequency; SL = Stroke length; SI = Swim index; First 25 m (s) = first pass at 25–50 m front crawl; Second 25 m (s) = second passage at 25–50 m front crawl. M1 = Moment of evaluation 1; M2 = Moment of evaluation 2. Effect Size = The Eta Squared Partial was used to identify the Effect Size value for each of the factors (Moment and Group) and Interaction. Effect Size = Used Cohen's d to identify the Effect Size value for the Moment 1 and 2 in control group and experimental group. The p-value for multiple comparisons is presented when the interaction is significant in order to interpret the effect of interaction between the factors. *P < 0.05 **p < 0.01.

Table 3
Comparison throughout the two moments of evaluation between the two groups in the performance of 50 m swimming and anaerobic critical velocity.

	Control Group			Experimental Group			Moment	Group	Interaction	Multiple Comparisons (Interaction)	
	M1	M2	Effect Size	M1	M2	Effect Size	*p-value*	*p-value*	*p-value*	Control	Experimental
			Cohen's d			*Cohen's d*				M1-M2 (*p-value*)	M1-M2 (*p-value*)
Performance of 50 m Front crawl											
1st 25 m (s)	15.19 ± 1.23	15.10 ± 1.27	0.08	14.03 ± 0.92	13.35 ± 0.62	0.91	**0.006****	**0.005****	**0.029***	0.595	**0.001****
2nd 25 m (s)	16.50 ± 1.42	16.51 ± 1.39	0.01	15.61 ± 1.73	14.81 ± 1.16	0.57	0.119	**0.045***	0.112		
50 m (s)	31.70 ± 2.45	31.61 ± 2.59	0.04	29.65 ± 2.94	28.47 ± 2.25	0.47	**0.013***	**0.043***	**0.026***	0.835	**0.001****
50 m SF (Hz)	0.77 ± 0.05	0.786 ± 0.04	0.43	0.82 ± 0.13	0.92 ± 0.10	0.90	**0.003****	**0.030***	**0.025***	0.519	**<0.001****
50 m SL (m)	2.14 ± 0.24	2.12 ± 0.29	0.08	2.04 ± 0.17	1.88 ± 0.17	0.99	**0.020***	0.092	0.072		
50 m SI ($m^2\ c^{-1}\ s^{-1}$)	3.40 ± 0.50	3.39 ± 0.62	0.02	3.48 ± 0.40	3.45 ± 0.63	0.06	0.785	0.776	0.860		
ACV	1.28 ± 0.14	1.27 ± 0.18	0.07	1.37 ± 0.19	1.42 ± 0.17	0.29	0.186	0.133	**0.022***	0.453	**0.010***

First 50 m (s) = first pass at 50–100 m front crawl; Second 50 m (s) = second pass at 50–100 m front crawl; SF=Stroke Frequency; SL=Stroke length; SI=Swim index; First 25 m (s) = first pass at 25–50 m front crawl; Second 25 m (s) = second passage at 25–50 m front crawl. M1 = Moment of evaluation 1; M2 = Moment of evaluation 2. Effect Size = The Eta Squared Partial was used to identify the Effect Size value for each of the factors (Moment and Group) and Interaction. Effect Size = Used Cohen's d to identify the Effect Size value for the Moment 1 and 2 in control group and experimental group. The p-value for multiple comparisons is presented when the interaction is significant in order to interpret the effect of interaction between the factors. *P < 0.05 **p < 0.01.

Discussion

The present study aimed to investigate the effects of eight weeks of ST combined with swimming aerobic training in competitive swimmers. The swimmers that performed dry-land ST showed improvements in the 50 and 100 m front crawl, with different biomechanical adjustments to SF and SI in the 100 m and to SF in the 50 m front crawl, compared to those that only performed in-

Table 4
Comparison throughout the two moments of evaluation between the two groups in the performance of dry-land.

	Control Group			Experimental Group			Moment	Group	Interaction	Multiple Comparisons (Interaction)	
	M1	M2	Effect Size	M1	M2	Effect Size	*p-value*	*p-value*	*p-value*	Control	Experimental
			Cohen's d			*Cohen's d*				M1-M2 (*p-value*)	M1-M2 (*p-value*)
Performance of Dry-land											
SQ (kg)	56.61 ± 17.58	58.46 ± 21.89	0.10	70.30 ± 17.02	79.95 ± 21.47	0.52	**0.022***	0.053	0.107		
BP (kg)	55.40 ± 13.45	60.07 ± 15.89	0.34	74.55 ± 13.86	85.67 ± 17.10	0.75	**<0.001****	**0.004****	**0.044***	**0.049***	**<0.001****
CMJ Med (cm)	27.79 ± 7.17	28.28 ± 8.60	0.07	34.70 ± 5.88	37.05 ± 5.85	0.42	**0.014***	**0.019***	0.090		
CMJ Max (cm)	28.43 ± 7.22	28.84 ± 8.52	0.06	35.56 ± 5.96	37.74 ± 5.83	0.39	**0.027***	**0.017***	0.118		
CMJFA Med (cm)	32.31 ± 6.89	33.22 ± 9.50	0.12	39.89 ± 6.71	41.85 ± 6.90	0.30	**0.027***	**0.025***	0.388		
CMJFA Max (cm)	33.28 ± 7.36	34.18 ± 9.54	0.11	40.86 ± 7.02	42.56 ± 6.87	0.26	**0.022***	**0.031***	0.450		
MBT Med (m)	4.31 ± 0.96	4.42 ± 0.83	0.13	5.06 ± 0.70	5.33 ± 0.78	0.38	**0.001****	**0.034***	0.102		
MBT Max (m)	4.42 ± 0.94	4.49 ± 0.86	0.08	5.21 ± 0.67	5.50 ± 0.80	0.41	**0.004****	**0.023***	0.057		

SQ = Squat; BP = Bench Press; CMJ = Countermovement Jump; CMJ FA = Countermovement Jump free arms; MBT = Medicinal Ball Throw. M1 = Moment of evaluation 1; M2 = Moment of evaluation 2. Effect Size = The Eta Squared Partial was used to identify the Effect Size value for each of the factors (Moment and Group) and Interaction. Effect Size = Used Cohen's d to identify the Effect Size value for the Moment 1 and 2 in control group and experimental group. The p-value for multiple comparisons is presented when the interaction is significant in order to interpret the effect of interaction between the factors. *P < 0.05 **p < 0.01.

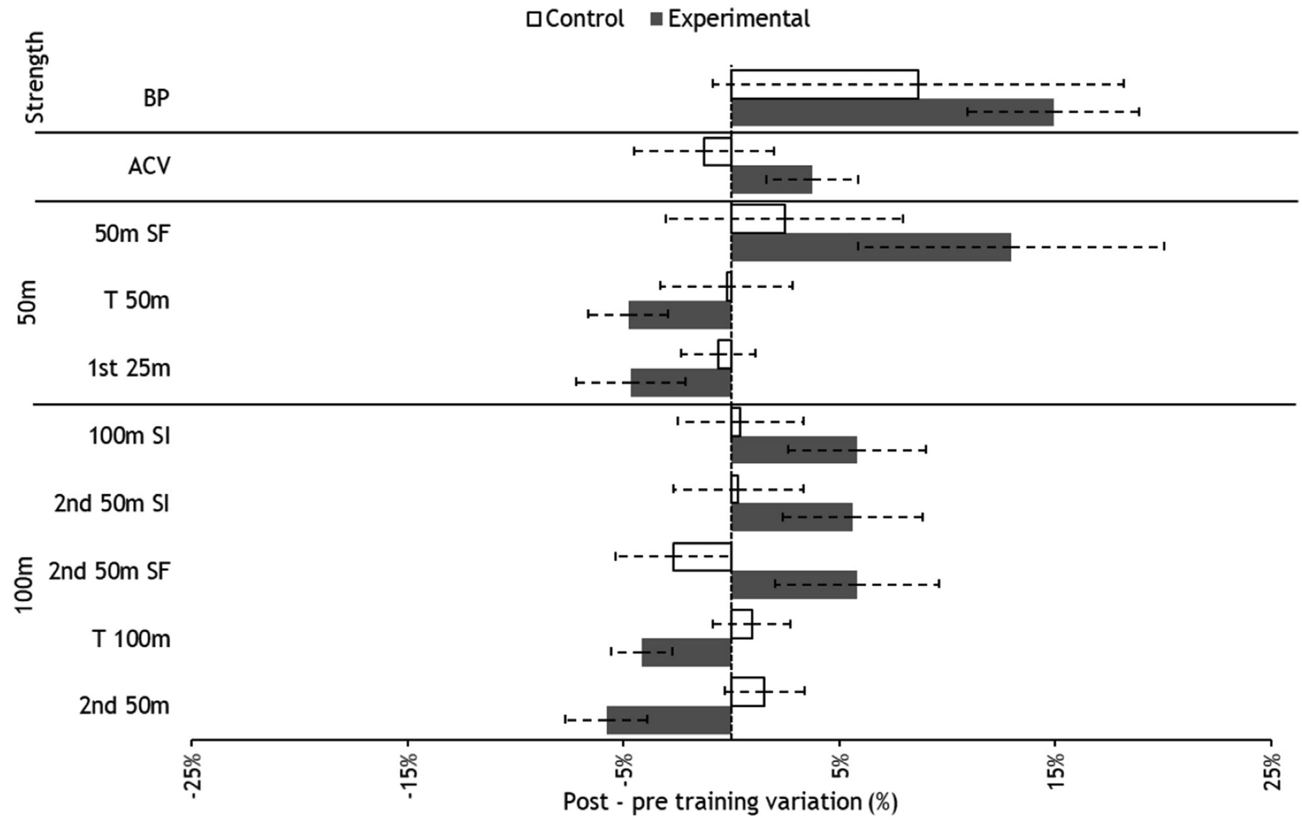

Fig. 1. Percentage variation in variables with significant interaction, for performance, technique and strength. BP = Bench Press; First 50 m (s) = first pass at 50–100 m front crawl; 2nd 50 m = second pass at 50–100 m front crawl; SF=Stroke Frequency; SL=Stroke length; SI=Swim index; 1st 25 m (s) = first pass at 25–50 m front crawl.

water swimming training. Furthermore, it was suggested that dry-land ST improved swimmers' dry-land strength performance, particularly in BP exercise. The present study showed that ST combined with swimming training allowed the development of dry-land strength and improved swimming performance, resulting from some adjustments to the swimming technique.

Swimmers were suggested to improve sprint performance after eight consecutive weeks of swimming training and ST.[15] Accordingly, in the present study, increased strength was evident in the upper body and improved 50 and 100 m performances were found. Nevertheless, our results are in contrast with other studies that have shown that dry-land ST combined with swimming training does not improve swimming performance in competitive swimmers.[15,17,33] The higher training experience from the participants on those studies could explain these different results. This way, we can suggest that ST could be particularly useful to enhance strength, swimming performance, and swimming technique[25,27] in lower level swimmers and/or with less ST training experience.

Studies showed that perhaps ST at these ages might also be important to technical improvement.[11,37] In fact, the current results revealed an increased SF after the ST program, in swimming performance. Moreover, swimming efficiency showed by SI also revealed an important enhancement in the second part of the 100 m front crawl performance. As reported previously, swimmers adjust technical patterns according to their preparedness so that efficiency can be optimized.[3,8]

The adaptation in kinematics observed in the current study could be due to strength improvements. Some changes were noticed in the CG, but higher enhancements were found in SQ and BP in the EG. It should be noted that, although no interaction was found, SQ performance in the EG was shown to be 10% higher than the CG after eight weeks of ST. These gains agreed with previous analyses revealing similar improvements after eight weeks of ST.[29,38] This enhancement of strength performance might be related to the specificity of dry-land ST exercises.[39] Besides, the EG increased body mass by 2 kg and thus could lead to strength increase.[40,41] However, a small improvement in BP was also noted in the CG. These results could be because swimming training also contributes to improving strength performance, whereas ST combined with swimming training could lead to greater improvement.[5,9,15] Literature pointed out a correlation effect between swimming training and increased strength, which could explain some of the improvements in the CG.[14,42]

Many of the studies that examined the impact of ST on swimming performance did not include a control group or did not provide any information on the type of ST methodology used to find possible improvements and differences between groups.[33,34] Other authors pointed out to the lack of specificity of the ST used, resulting in small transfer between dry-land strength gains and the propulsive force in swimming, contributing to lack of performance improvement.[7] One should be aware different factors are contributing to these transfer gains[35] and most authors did not consider sprint and anaerobic performances where different results could be verified.[8,14,25] The presented study included specific strength and swimming exercises considered more similar to the actual competition demands.[13,36] The applied training program increased the swimmer's strength, especially at the upper body (14.91%), and also increased sprint performance (50 m: 3.97%, 100 m: 4.34%). These results are in agreement with previous evidence reporting that ST in swimmers is more effective than in-water training alone.[5,16]

In the current study, strength performance was assessed by using the CMJ, CMJ FA, and MBT and although no significance was found in the interaction between Group vs Momentum in any of the analyzed variables, there seems to exist a tendency towards higher gains in the EG, with larger effect size values. Once again one could highlight the importance of specific adaptation related to ballistic movements during the ST.[33,43,44] All results presented and discussed help to realize that several factors can influence the improvement of swimming performance for swimmers of this level. It is also important to realize that ST can be a starting point for improving swimming performance, by increasing strength and contributing to technique changes. These changes could be to long-term training effects, optimizing SF and SL, and resulting in higher efficiency during maximal velocity swimming. The changes in technique obtained in the current study could be due to the combination of ST and in-water training. Therefore, coaches should be aware of the importance of ST combined with in-water training. This could influence the swimmer's motor skills, increasing the ability to produce strength in water.

The main limitation of the present study is the reduced number, the level, and the gender of the subjects. Although the participants were competitive swimmers, they only competed at the university level. Moreover, men and women were evaluated together in the current experimental design. It should be interesting to analyze the effects of ST and swimming performance after a detraining period. A period of decreasing overload (or cessation of ST) could produce different changes in performance. Also, different swimming techniques should be studied and deeper physiologic analyses could be implemented.

Conclusions

ST combined with swimming training allowed the improvement of both strength and swimming performance in university swimmers, highlighting the importance of concurrent training in swimming, even when the ST is performed once a week. Moreover, this remark is also important regarding the beneficial effects showed on biomechanics and stroke efficiency. The applicability of ST to swimmers should be considered according to proper water-training planning. The current study showed that ST increased specific strength and could be used to maximize swimmer performance, by adapting swimming technical patterns enhancing swimming economy. The current training approach is simple and can provide long-term applicability allowing improvements in swimming technique, performance, and strength.

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CRediT authorship contribution statement

Tiago J. Lopes: Conceptualization, Methodology, Investigation, Data curation, Writing - original draft. **Henrique P. Neiva:** Conceptualization, Methodology, Formal analysis, Writing - review & editing. **Carlota A. Gonçalves:** Investigation, Data curation, Writing - original draft. **Célia Nunes:** Data curation, Writing - review & editing. **Daniel A. Marinho:** Conceptualization, Validation, Writing - review & editing, Visualization, Supervision, Project administration.

Declaration of competing interest

None declared.

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Appendix A. Supplementary data

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