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

Tiago J. Lopes a, b, Henrique P. Neiva a, b, Carlota A. Gonçalves a, Célia Nunes a, c, Daniel A. Marinho a, b, *

a University of Beira Interior, Department of Sport Sciences, Covilhã, Portugal
b Research Center in Sport Sciences, Health Sciences and Human Development, CIDESD, Portugal
c Center of Mathematics and Applications, CMA-UBI, Portugal

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 sprinters.1

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.6,6 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.12,10 Nevertheless, other
studies\textsuperscript{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.\textsuperscript{2,5,6,13–17} 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.\textsuperscript{9} Interestingly, two strength programs of six weeks, one focusing on power (3 × 15–25 s with 60–70% of 1RM) and another on hypertrophy (3×6–8 repetitions with 80–90% of 1RM), combined with the same swimming training, showed improvements in performance.\textsuperscript{2} Nevertheless, in the group that performed power training, the improvements were higher (2.21–1.46%) in 50 m front crawl.\textsuperscript{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.\textsuperscript{6} In opposition, other training programs stated that there were no relationships between improvements in dry-land ST and swimming performance.\textsuperscript{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.\textsuperscript{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.\textsuperscript{2} Moreover, no relationship was found between stroke kinematics and strength gains in both groups.\textsuperscript{2} In fact, the swimming technique is essential to swimming performance,\textsuperscript{22} 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: 1.74 ± 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 ± 163 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.\textsuperscript{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,\textsuperscript{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.\textsuperscript{22,23} 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 SI was estimated through the equation:\textsuperscript{24}

\[
SI = \frac{V}{SF}
\]  

(4)

Where SL is the stroke length (m·cycle$^{-1}$), v is the swimmer’s mean speed (m·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):

\[
SI = SL \times v
\]  

(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.
An 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.\(^\text{25,26}\)

**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 Multi-power (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.\(^\text{27}\) 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) was found. Absolute reliability was determined for each individual from the MPV attained against the heaviest load (kg) lifted in the progressive loading test, as follows: \((100 \cdot \text{load})/(\text{5.961} \cdot \text{MPV}^2)\) for BP and \((-0.80 \cdot \text{MPV}^2\) for SQ, respectively.\(^\text{28}\) 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: \((100 \cdot \text{load})/(\text{8.4326} \cdot \text{MPV}^2)\) for BP and \((-73.501 \cdot \text{MPV} + 117)\) for SQ, respectively.\(^\text{29}\)

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 registered 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.\(^\text{30}\) 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.\(^\text{31,32}\) 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: \(\eta_p^2\) 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 \(\eta_p^2\), 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 \((\eta_p^2 = 0.57)\), in the 100 m time \((\eta_p^2 = 0.48)\), and in the SF in the second 50 m partial \((\eta_p^2 = 0.41)\). Moderate interaction was found in SI in the first 50 m partial \((\eta_p^2 = 0.24)\) and in the SI in the 100 m performance \((\eta_p^2 = 0.23)\). 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 Flies                         | 60%: 0.79 m s⁻¹       |               |                         |
| Triceps + Shoulders                    | 60%: 0.79 m s⁻¹       |               |                         |
| 2nd 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 Flies                         | 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 Flies                         | 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 Flies                         | 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                   |
| Supine                                 | 75%: 0.55 m s⁻¹       |               |                         |
| Pull-up/Elevation                      | 80X. 90 cm            |               |                         |
| Bent Arm Flies                         | 5 kg                  |               |                         |
| Triceps + Shoulders                    | 2 kg                  |               |                         |
| 6th Week (6th Session)                 |                       |               |                         |
| Full Squat                             | 75%: 0.55 m s⁻¹       | 4 × 10        | 3 min                   |
| Supine                                 | 75%: 0.55 m s⁻¹       |               |                         |
| Pull-up/Elevation                      | 80X. 90 cm            |               |                         |
| Bent Arm Flies                         | 5 kg                  |               |                         |
| Triceps + Shoulders                    | 2 kg                  |               |                         |
| 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 Flies                         | 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 Flies                         | 70%: 0.62 m s⁻¹       |               |                         |
| Triceps + Shoulders                    | 70%: 0.62 m s⁻¹       |               |                         |

compared to the CG (1st 50 m SF $n^2 = 0.33$; 100 m SF, $n^2 = 0.28$).
In the 50 m time-trial, the interaction between the group and moment was large in the first 25 m ($n^2 = 0.25$), in the 50 m time-trial ($n^2 = 0.25$) and in the SF in the 50 m partial ($n^2 = 0.26$). 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 ($n^2 = 0.28$). 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 ($n^2 = 0.21$).

The ACV demonstrated significant and large interaction between the two factors ($n^2 = 0.26$). 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 ($n^2 = 0.21$). 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 ($n^2 = 0.61$), although with a larger effect size in the EG. The main effect of the moment factor was significant and large interaction was presented in the BP, in the CMJ, in the MBT ($n^2 = 0.38$), and moderate interaction in the CMJ ($n^2 = 0.24$), 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 $n^2 = 0.39$; CMJ $n^2 = 0.28$; CMJ FA $n^2 = 0.23$; MBT $n^2 = 0.26$).
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 M1-M2 (p-value) | Experimental M1-M2 (p-value) |
| | | Cohen’s d | | | | | | | | |
| Performance of 50 m Front crawl |
| 1st 50 m (s) | 15.19 ± 1.23 | 15.10 ± 1.27 | 0.06** | 0.05** | 0.029 | 0.595 | 0.001** |
| 2nd 50 m (s) | 16.42 ± 1.73 | 16.51 ± 1.39 | 0.11 | 0.045 | 0.112 |
| 50 m (s) | 31.70 ± 2.45 | 31.61 ± 2.59 | 0.04 | 0.265 | 0.119 | 0.019 | 0.043 | 0.006** | 1.335 | 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 (m2 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 = TheEta 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-
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. 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. 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 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. 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.

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. This enhancement of strength performance might be related to the specificity of dry-land ST exercises. Besides, the EG increased body mass by 2 kg and thus could lead to strength increase. 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. Literature pointed out a correlation effect between swimming training and increased strength, which could explain some of the improvements in the CG.

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. 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. One should be aware different factors are contributing to these transfer gains and most authors did not consider sprint and anaerobic performances where different results could be verified. The presented study included specific strength and swimming exercises considered more similar to the actual competition demands. 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.

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.\textsuperscript{35,36,47} 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.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-proﬁt sectors.

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.

Acknowledgments

This work is by national funding through the Portuguese Science and Technology Foundation (FCT), under the project UID04045/2020.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jesf.2020.06.005.

References

1. Marques MC, Zajac A, Pereira A, et al. Strength training and detraining in different populations: case studies. J Hum Kinet. 2013;1:7–14.
2. Amaro NM, Marinho DA, Marques MC, et al. Effects of dry-land strength and conditioning programs in age group swimmers. J Strength Cond Res. 2017;31:2447–2454.
3. Costill DL. Training adaptations for optimal performance. In: Biomechanics and Medicine in Swimming. vol. III. 1999:381–390.
4. Strass D. Effects of maximal strength training on sprint performance of competitive swimmers. In: Ungerechts BE, Wilke K, Reischke K, eds. Swimming Science V. London: Spon Press; 1989:141–150.
5. Garrido N, Marinho DA, Reis VM, et al. Does combined dry land strength and aerobic training inhibit performance of young competitive swimmers? J Sports Sci Med. 2010;9:300–310.
6. Haycraft J, Robertson S. The effects of concurrent aerobic training and maximal strength, power and swim-specific dry-land training methods on swim performance: a review. J Australian Strength Cond. 2015;23:91–99.
7. Tanaka H, Costill DL, Thomas R, et al. Dry-land resistance training for competitive swimming. Med Sci Sports Exerc. 1995;27:666.
8. Barbosa TM, Morais JE, Marques MC, et al. The power output and sprinting performance of young swimmers. J Strength Cond Res. 2015;29:440–450.
9. Espada MC, Costa MJ, Costa AM, et al. Relationship between performance, dry-land power and kinematics in master swimmers. Acta Biomech. 2016;18:145–151.
10. Moroço PG, Marinho DA, Reis VM, et al. Tethered swimming can be a starting point for improvement of swimming performance for swimmers of this 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.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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.

Acknowledgments

This work is by national funding through the Portuguese Science and Technology Foundation (FCT), under the project UID04045/2020.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jesf.2020.06.005.

References

1. Marques MC, Zajac A, Pereira A, et al. Strength training and detraining in different populations: case studies. J Hum Kinet. 2013;1:7–14.
2. Amaro NM, Marinho DA, Marques MC, et al. Effects of dry-land strength and conditioning programs in age group swimmers. J Strength Cond Res. 2017;31:2447–2454.
3. Costill DL. Training adaptations for optimal performance. In: Biomechanics and Medicine in Swimming. vol. III. 1999:381–390.
4. Strass D. Effects of maximal strength training on sprint performance of competitive swimmers. In: Ungerechts BE, Wilke K, Reischke K, eds. Swimming Science V. London: Spon Press; 1989:141–150.
5. Garrido N, Marinho DA, Reis VM, et al. Does combined dry land strength and aerobic training inhibit performance of young competitive swimmers? J Sports Sci Med. 2010;9:300–310.
6. Haycraft J, Robertson S. The effects of concurrent aerobic training and maximal strength, power and swim-specific dry-land training methods on swim performance: a review. J Australian Strength Cond. 2015;23:91–99.
7. Tanaka H, Costill DL, Thomas R, et al. Dry-land resistance training for competitive swimming. Med Sci Sports Exerc. 1995;27:666.
28. Sanchez-Medina L, Perez CE, Gonzalez-Badillo JJ. Importance of the propulsive phase in strength assessment. Int J Sports Med. 2010;31:123–129.
29. Gonzalez-Badillo JJ, Sanchez-Medina L. Movement velocity as a measure of loading intensity in resistance training. Int J Sports Med. 2010;31:347–352.
30. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. J Strength Cond Res. 2005;19:231–240.
31. Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. Sports Med. 1998;26:217–238.
32. Hopkins WG. Measures of reliability in sports medicine and science. Sports Med. 2000;30:1–15.
33. Tanaka H, Swensen T. Impact of resistance training on endurance performance. A new form of cross-training? Sports Med. 1998;28:191–200.
34. Nunney D. Relation of circuit training to swimming. Restor Q. 1960;31:188–198.
35. Toussaint HM, Vervoorn K. Effects of specific high resistance training in the water on competitive swimmers. Int J Sports Med. 1990;11:228–233.
36. Morouço PG, Marinho DA, Anaro NM, et al. Effects of dry-land strength training on swimming performance: a brief review. J Hum Sport Exer. 2012a;7:553–559.
37. Marques MC, van den Tillaar R, Vescovi JD, et al. Changes in strength and power performance in elite senior female professional volleyball players during the in-season: a case study. J Strength Cond Res. 2008;20:563–571.
38. Bencke J, Damsgaard R, Saelens A, et al. Anaerobic power and muscle strength characteristics of 11 years old elite and non-elite boys and girls from gymnastics, team handball, tennis and swimming. Scand J Med Sci Sports. 2002;12:171–178.
39. Zatsiorsky VM. Science and Practice of Strength Training. Champaign: Illinois: Human Kinetics Books; 1995.
40. Beunen G, Thomis M. Muscular strength development in children and adolescents. Pediatr Exerc Sci. 2000;12:174–197.
41. Taber C, Bellon C, Abbott H, et al. Roles of maximal strength and rate of force development in maximising muscular power. Strength Cond J. 2016;38:71–78.
42. Yeater RA, Martin RB, White MK, et al. Tethered swimming forces in the crawl, breast and back strokes and their relationship to competitive performance. J Biomech. 1981;14:527–537.
43. Brownlee KK, Moore AW, Hackney AC. Relationship between circulating cortisol and testosterone: influence of physical exercise. J Sports Sci Med. 2005;4:76–83.
44. Croix M. Advances in paediatric strength assessment: changing our perspective on strength development. J Sports Sci Med. 2007;6:292–304.