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Research article

Does combined dry land strength and aerobic training inhibit performance of young competitive swimmers?

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Abstract
The aim of the current study was twofold: (i) to examine the effects of eight weeks of combined dry land strength and aerobic swimming training for increasing upper and lower body strength, power and swimming performance in young competitive swimmers and, (ii) to assess the effects of a detraining period (strength training cessation) on strength and swimming performance. The participants were divided into two groups: an experimental group (eight boys and four girls) and a control group (six boys and five girls). Apart from normal practice sessions (six training units per week of 1 h and 30 min per day), the experimental group underwent eight weeks (two sessions per week) of strength training. The principal strength exercises were the bench press, the leg extension, and two power exercises such as countermovement jump and medicine ball throwing. Immediately following this strength training program, all the swimmers undertook a 6 week detraining period, maintaining the normal swimming program, without any strength training. Swimming (25 m and 50 m performances, and hydrodynamic drag values), and strength (bench press and leg extension) and power (throwing medicine ball and countermovement jump) performances were tested in three moments: (i) before the experimental period, (ii) after eight weeks of combined strength and swimming training, and (iii) after the six weeks of detraining period. Both experimental and control groups were evaluated. A combined strength and aerobic swimming training allow dry land strength developments in young swimmers. The main data can not clearly state that strength training allowed an enhancement in swimming performance, although a tendency to improve sprint performance due to strength training was noticed. The detraining period showed that, although strength parameters remained stable, swimming performance still improved.

Key words: Children, combined training, detraining, hydrodynamics, cross training.

Introduction

Many sports depends heavily upon muscular strength and aerobic enhancement especially at competition level (Leveritt et al., 2000), being swimming no exception. In fact, combined intervention of strength and aerobic training is a common practice in swimming training, but the scientific evidence is still scarce (Aspenes et al., 2009). Combining strength and aerobic training into a synthesized program has been one of the major tasks for coaches. Several studies showed that combined strength and endurance training regimens seems to inhibit strength and power development when compared with strength training alone (Dudley and Djamil, 1985; Abernethy and Quigley, 1993; Hennessey and Watson, 1994). However, the scientific literature has produced inconclusive results. In fact, some studies showed that concurrent training compromises the development of strength and power but does not effect the development of aerobic conditioning when compared with either form of stand-alone training (Dudley and Djamil, 1985; Hennessey and Watson, 1994), and other studies reported that concurrent training has an inhibitory effect on the development of strength and endurance (Sale et al., 1990; Abernethy and Quigley, 1993).

Recently, Aspenes et al. (2009) examined the effect of 11 weeks training (twice a week) intervention of a combined strength and endurance among young adult competitive swimmers. In this study, the intervention group improved dry land strength, tethered swimming force and 400 m freestyle performance more than the control group. No changes were observed in stroke length, stroke rate, and performance in 50 and 100 m freestyle. Thus, some studies state the combined strength and endurance training interventions negatively influences each other, and other support the existence of benefits from the referred combination when training is applied appropriately. However, of the three studies investigating the effects of dry land strength training on swimming (Tanaka et al., 1993; Trappe and Pearson, 1994; Girold et al., 2007) only one found benefits of a combined strength and swim training group versus a swim-training without strength tasks (Girold et al., 2007). Several studies, including dry land training protocols, reported positive effects on sprint performances in swimming, and generally the gains in sprint performance are consistent: between 1.3 and 4.4% (Costill, 1999; Pichon et al., 1995; Strass, 1988). Strass (1988) showed that a maximal strength program using free weights led to a significant 4.4 and 2.1% increase in performance over 25 and 50 m freestyle, respectively. Nevertheless, other studies (e.g. Tanaka et al., 1993) did not found performance enhancement after a dry land strength training period that include both strength and aerobic training. These authors questioned the specificity of the strength training methods in swimmers and stated that the combined swim and traditional dry land strength training did not improve swimming performance, whereas combined swim and swim-specific in-water strength training increased swimming velocity. These data suggested that specific in-water

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strength training would be more efficient than dry land training in swimmers. Surprisingly, although dry land, resisted and assisted-sprint training methods on sprint performance are both widely documented (e.g. Girold et al., 2007; Strass, 1988; Tanaka et al., 1993), to the best of our knowledge, no study attempted to understand the effects of dry land strength training combined with aerobic training in young competitive swimmers.

In fact, investigations in young competitive swimmers are much reduced in comparison to the one established in adult swimmers mainly due to financial coasts but also to ethical issues (Barbosa et al., 2010). Although measurements in young swimmers must be less expensive, less invasive, less complex and less time consuming, several testing protocols for young swimmers are carried-out by swimmers' coaches, including anthropometric, strength, energetic and hydrodynamic procedures (e.g., Carzola, 1993; Costa et al., 2009a; 2009b; Costill et al., 1992; Silva et al., 2007). Therefore, we believe that the study of the effects of dry land strength training combined with aerobic training in young competitive swimmers could lead to interesting data that could help swimmers' coaches during their preparation.

Swimming performance is a multi-factorial phenomenon depending upon energetics, biomechanics, hydrodynamics, anthropometrics and strength parameters (Barbosa et al., 2009; 2010). Indeed, strength and speed are two major factors determining a swimmer's performance (Tanaka et al., 1993; Trappe and Pearson, 1994). Several studies reported that upper-body muscular strength and power outputs correlated highly with swim velocity over distances ranging from 23 to 400 m (Tanaka and Swensen, 1998). Furthermore, active drag seems to be an important variable to be analyzed in swimming since active drag is significantly dependent on swimming technique (Toussaint et al., 1988; Kjendlie and Stallman, 2008). Hence, considering that swimming technique can be improved due to strength training (Maglischo, 2003), it seems important to analyse the effects of combined strength and aerobic swimming training on active drag in young competitive swimmers.

The detraining period was also studied in the present study since little is known on this subject in swimming. Interruptions in training sessions because of illness, injury, vacancies, post-season break or other factors are normal situations in any kind of sport. A reduction of physical activity level is often reported (e.g., Hortobagyi et al., 1983; Kraemer et al., 2002). However, as stated before, the detraining period and its consequences is not well reported in sports literature, and namely in swimming. Furthermore, a period of overload decrement (strength training cessation) could produce a positive delay transformation to enhanced sports specific performance (Zatsiorsky, 1995).

Therefore, the main purpose of the current study was twofold: (i) to examine the effects of eight weeks of combined dry land strength and aerobic swimming training for increasing upper and lower body strength, power and swimming performance in young competitive swimmers and, (ii) to assess the effects of a detraining period (strength training cessation) on strength and swimming performance.

Methods

Subjects

Twenty-five (14 boys and 11 girls) young competitive swimmers (age: 12.08 ± 0.76 years, body mass: 42.22 ± 7.79 kg, height: 1.51 ± 0.09 m, Tanner Stages 1-2) participated in this study. Since boys and girls demonstrate fairly similar rates of strength gain during preadolescence (Faigenbaum et al., 2002), they were combined in this research. The participants' parents and coaches provided written informed consent to participate in this research, and the procedures were approved by the institutional review board.

The participants were divided into two groups, being the experimental group consisted of eight boys and four girls (age: 12.0 ± 0.78 years, body mass: 41.29 ± 8.05 kg, height: 1.51 ± 0.04 m, 100 m short course front crawl performance: 70.34 ± 10.52 s), whereas the control group included six boys and five girls (age: 12.18 ± 0.75 years, body mass 43.40 ± 7.66 kg, height: 1.52 ± 0.06 m, 100 m short course front crawl performance: 72.08 ± 8.61 s). Efforts were made to recruit subjects for making comparable groups. Following the completion of a medical history questionnaire, the team physician examined all the children in order to evaluate musculoskeletal status, document pre-existing orthopaedics injuries, and assess maturity level based on Tanner stages (Faigenbaum et al., 2002). There were no significant differences between groups for age or Tanner ratings, neither in swimming, strength and power performances at the beginning of the protocol when the subjects were divided into two groups ($p > 0.05$). No subject had regularly participated in any form of strength training prior to this experiment. Participants were included if they were under 14 years old and above 10 years of age, free from injury and train regularly for at least 6 times a week. The following exclusion criteria were used: children with a chronic paediatric disease, children with an orthopaedic limitation, and children classified as Tanner Stage 3 at the beginning of the study.

There was no significant difference in anthropometrical variables between pre and post test ($p > 0.05$).

Test procedures

Swimming, strength and power performances were tested in three moments: (i) before the experimental period (T1), (ii) after 8 weeks of combined strength and swimming training (T2), and (iii) after the 6 weeks of detraining period (T3). Both experimental and control groups were evaluated at the same moments. The evaluations were conducted during one week in each evaluation moment. Subjects were acquainted with all test procedures 4 weeks before the measurements were applied (McCurdy et al., 2004).

Swimming performance

After a standard warm-up, all swimmers performed 25 m and 50 m maximal tests in front crawl, with two days interval in-between. All the swimmers performed two maximal trials in 25 m and 50 m, with a 15 min passive recovery period between the two trials and the mean value was used for analysis. The evaluation process was conducted in a 25 m indoor swimming pool, being used in-water starts. The performance time was determined by two trained subjects with a chronometer (Golfinho Sports MC 815, Aveiro, Portugal), and the mean value of both measurements was obtained in each trial. The test-retest reliability, as showed by intra class coefficient correlation (ICC), was 0.94 and 0.91 for 25 m and 50 m swimming performance, respectively.

Hydrodynamic performance

The velocity perturbation method with the help of an additional hydrodynamic body was used to determine active drag in front crawl swimming (Kolmogorov and Duplishcheva, 1992; Kolmogorov et al., 1997). Active drag was calculated from the difference between the swimming velocities with and without towing the perturbation buoy. To ensure similar maximal power output for the two sprints, the swimmers were instructed to perform maximally at both trials. Both trials were conducted in a 25 m indoor swimming pool (Marinho et al., 2010).

Active drag was calculated as indicated in Equation 1 (following Kolmogorov and Duplisheva, 1992):

$$D = \frac{D_b v_b v^2}{v^3 - v_b^3} \quad (1)$$

Where D is the swimmer's active drag at maximal velocity, D_b is the strength of the perturbation buoy and, v_b and v are the swimming velocities with and without the perturbation device, respectively.

The drag of the perturbation buoy was calculated from the manufacturer's calibration of the buoy-drag characteristics and its velocity (Kolmogorov and Duplisheva, 1992). Drag coefficient (C_D) was calculated according to equation 2:

$$C_D = \frac{2D}{\rho S v^2} \quad (2)$$

Where ρ is the density of the water and S is the projected frontal surface area of each swimmer.

Frontal surface area was estimated using Clarys's prediction (Clarys, 1979), according to equation 3:

$$S = \frac{6.93BM + 3.50H - 377.2}{10000} \quad (3)$$

Where BM is the body mass and H is the swimmers' height.

Each swimmer performed two maximal 25 m front crawl swim with an underwater start with and without the perturbation device. Swimming velocity was assessed during 13 m (between 11 m and 24 m from the starting wall). The time spent to cover this distance was measured with a chronometer (Golfinho Sports MC 815, Aveiro, Portugal) by two expert evaluators and the mean value was assessed.

Strength performance

Each subject's six maximum repetitions (6-RM) were determined on the leg extension and bench press. Dynamic strength for upper body was assessed using a free-weight barbell machine. Child size dynamic constant resistance equipment (Heartline Fitness Equipment, Gaithersburg, MD, USA) was used for leg testing. After an initial warm-up of 10 sub maximal repetitions, the 6-RM was determined within 3 to 4 trials and was measured to within 1.5 kg. The maximal weight that could be lifted 6 times with correct form throughout the full range of motion was recorded. Following a 72 h rest period, the strength testing procedures were repeated. The heaviest 6-RM load lifted on each exercise, on either testing day, was recorded as the child's criterion 6-RM score. Test-retest reliabilities, as showed by ICC, ranged from 0.91 to 0.96 for the bench press and leg extension, respectively.

Power performance

The vertical jump height was measured using the countermovement jump (CMJ) test. With a preparatory countermovement, each subject started from an erect standing position and the end of the concentric phase corresponded to a full leg extension: 180º. The protocol required the performance of three jumps, each followed by two minutes of rest. An average of the two best jumps was taken to analysis. The countermovement jump showed an ICC of 0.92. This test was measured on a trigonometric carpet (Ergojump Digitime 1000, Digest Finland).

Ball throwing performance was measured with different weighted balls. After a general warm-up of 10 minutes, which included of throwing with different weighted balls to warm up the shoulders, throwing was tested. Tests were performed on maximal throwing velocity with a 1 kg medicine ball (circumference 0.60 m) and a 3 kg medicine ball (circumference 0.68 m). Before the first evaluation, the participants were familiarized in throwing with different weighted balls in order to avoid a learning effect. Each participant sat on the floor with his or her back against the wall. Each participant held the ball in front of him or her with both hands, resting it against his or her lap. They were instructed to throw the medicine ball as far and fast as possible. Torso and hip rotation was also prohibited. Three approved attempts were made with each ball with one-minute rest between each attempt. The sequence of ball type was randomized for each participant to ensure that fatigue or learning effects did not alter the performance. The maximal velocity with the medicine ball was determined using a Doppler radar gun (Sports Radar 3300, Sports Electronics Inc., Draper, Utah, USA), with ± 0.03 m/s accuracy within a field of 10º from the gun. The radar gun was located 8 m in front of the participant during the throw. Throwing distance with an accuracy of 0.10 m was measured for the medicine ball. Only the best attempts with each ball were used for further analysis. The test-retest reliability (three repeats per condition), as indicated by ICC, varied between 0.90 and 0.92 for throwing velocity and distance for both 1 kg and 3 kg medicine balls.

Training procedure

Swimming training

During the eight weeks of experimental training period all

Table 1. Resistance training program between week 1 and week 8.

	Session															
Exercises (*)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Leg extension (1)	2x8 50%	2x8 50%	3x8 50%	3x8 55%	3x8 60%	3x8 60%	3x6 65%	3x6 65%	3x6 70%	3x6 70%	3x6 75%	3x6 75%	2x6 60%	2x6 55%	2x6 60%	2x6 55%
CMJ	2x5	2x5	2x5	2x5	2x5	3x5	3x5	3x5	3x5	3x5	3x5	3x5	2x5		2x5	
CMJbox	2x5	2x5	2x5	2x5	2x5	3x5	3x5	3x5	3x5	3x5	3x5	3x5	2x5		2x5	
Bench press (2)	2x8 50%	2x8 50%	3x8 50%	3x8 55%	3x8 60%	3x8 60%	3x6 65%	3x6 65%	3x6 70%	3x6 70%	3x6 75%	3x6 75%	2x6 60%	2x6 55%	2x6 60%	2x6 55%
Ball throwing (3)	2x8 1kg	2x8 1kg	2x8 1kg	2x8 1kg	3x8 1kg	3x8 1kg	3x8 1kg	3x8 1kg	3x8 1kg	3x10 1kg	3x10 1kg	3x10 1kg	2x8 1kg		2x8 1kg	

(1): Example: 3x6: 70%: 3 sets of 6 reps with 70 percent of 6RM, (2): Example: 2x8: 50%: 2 sets of 6 reps with 50 percent of 6RM, (3): Example: 2x8: 1kg - 2 sets of 8 reps with a 1 kg medicinal ball . (*) Rest intervals of 2 minutes were permitted between sets and between categories. CMJ: countermovement jump, CMJbox: CMJbox onto a box (30 cm)

the subjects performed 48 swimming training units (six sessions per week). The swimmers performed 188.60 km, corresponding to a mean value of 23.60 ± 1.98 km per week and 3.90 ± 0.33 km per training unit. They performed 20.80 km at intensity corresponding to their critical velocity (2.60 ± 1.00 km per week) and 7.20 km at an intensity corresponding to their aerobic power (1.44 ± 0.54 km per week). The remaining training comprised low aerobic tasks (~ 70% of whole volume), technical (~ 14%) and velocity training (~ 1%).

Strength training

Apart from normal practice sessions (six training units per week of 1 h and 30 min per day), the experimental group underwent eight weeks (two sessions per week: Table 1) of strength training. This program was directly supervised by two specialists in strength training and by the team head coach. The control group performed the same swimming training as the experimental group.

The strength training regimen was performed twice per week during the eight consecutive weeks, with each session lasting approximately 20 minutes. Table 1 provides a detailed description of the training routine. The principal strength exercises were the bench press and the leg extension. Subjects performed 2-3 sets of 6-8 repetitions for each exercise in the range of 50-75% of their predetermined 6-repetition maximum. In addition, two power exercises such as countermovement jump and medicine ball throwing (1 kg) were included in the training program to target explosive strength for the upper and lower body. Rest intervals of two minutes were permitted between all sets and exercises.

Strength detraining

Immediately following this strength training program, all the swimmers undertook a six week detraining period, maintaining the normal swimming program, without any strength training. During this six week detraining period, the subjects performed 33 swimming training units (5.50 ± 0.44 sessions per week). The swimmers performed 135.00 km, corresponding to a mean value of 22.50 ± 5.00 km per week and 4.10 ± 0.38 km per training unit. They performed 15.60 km at intensity corresponding to their critical velocity (3.90 ± 0.93 km per week) and 7.10 km at intensity corresponding to their aerobic power (1.42 ± 0.94 km per week). The remaining training comprised low aerobic tasks, technical and velocity training.

Statistical anlyses

Normality of distribution was checked with Shapiro-Wilk test (SPSS 12.0, Lead Tools, 2003) and a non-normal distribution was found. The values of each variable are presented as mean ± standard deviation.

All differences between groups were calculated by a Mann-Whitney test, and within group differences between pre and post training were assessed by a Wilcoxon matched-pairs signed-ranks test.

The test-retest reliability was calculated according to the procedures of Weir (2005) and measured on 12 participants with five days between the measurements (seven from the strength training group and five from the control group). The level of significance was set at $p \leq 0.05$.

Results

Swimming performance

Figures 1 and 2 present the swimming performance in 25 m and 50 m front crawl, respectively, at the beginning of the protocol (T1), after eight weeks of training (T2) and after six weeks of stopping with strength training (T3) for the experimental and the control group.

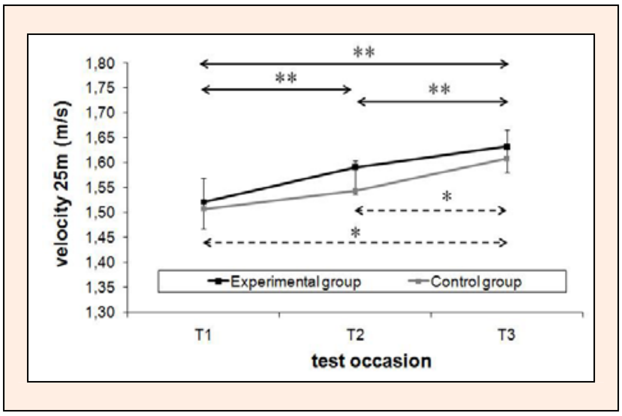

Figure 1. Swimming performance in 25 m front crawl at the beginning of the protocol (T1), after eight weeks of training (T2) and after six weeks of stopping with strength training (T3) for the experimental and the control group. Solid lines and * represent differences between evaluation moments in the experimental group. Non-solid lines and * represent differences between evaluation moments in the control group. * $p < 0.05$, ** $p < 0.01$.

As one can notice, there was a general tendency for swimming performance enhancement in both groups.

Although no differences were verified between the experimental and the control group, the experimental group tended to present more improvements on sprint performance. Regarding the 25 m test, the experimental group increased the performance from T1 to T2 in 4.45% ($p < 0.01$), from T1 to T3 in 6.95% ($p < 0.01$) and from T2 to T3 in 2.50% ($p < 0.01$) whereas the increase in performance was not verified from T1 to T2 ($p>0.05$) in the control group. Regarding the 50 m test, the experimental group increased the performance from T1 to T2 in 1.94% ($p < 0.01$), from T1 to T3 in 4.77% ($p < 0.01$) and from T2 to T3 in 2.83% ($p < 0.01$) whereas the increase in performance in the control group was verified from T1 to T2 (1.88%, $p < 0.05$) but not from T2 to T3 ($p > 0.05$).

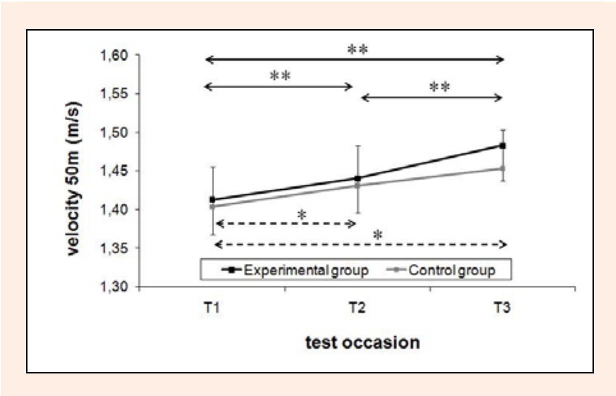

Figure 2. Swimming performance in 50 m front crawl at the beginning of the protocol (T1), after eight weeks of training (T2) and after six weeks of stopping with strength training (T3) for the experimental and the control group. Solid lines and * represent differences between evaluation moments in the experimental group. Non-solid lines and * represent differences between evaluation moments in the control group. * $p < 0.05$. ** $p < 0.01$.

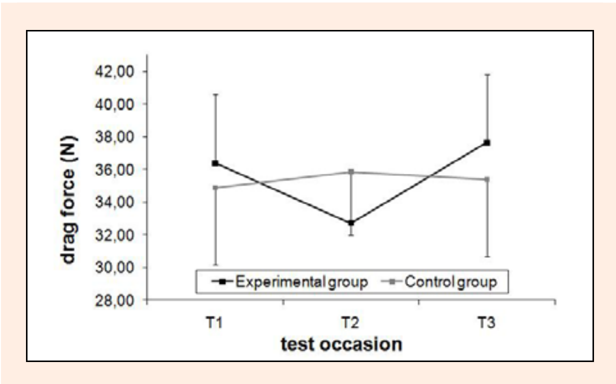

Figure 3. Values of active drag force for the experimental and the control group in the three evaluations moments.

Hydrodynamic performance

Figures 3 and 4 present the values of active drag force and drag coefficient, respectively, for the experimental and the control group obtained in the three evaluations moments. There were no significant differences between groups neither between different evaluation moments within groups for drag force and drag coefficient. Regarding drag force, there was a tendency to a decrease between T1 and T2 and an opposite tendency between T2 and T3 in the experimental group ($p>0.05$), whereas the values of the control group remain almost constant. The drag coefficient values were very similar in the three evaluation moments in both groups.

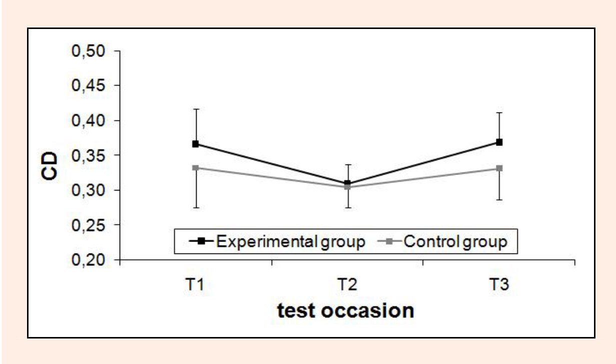

Figure 4. Values of drag coefficient for the experimental and the control group in the three evaluations moments.

Strength performance

Figures 5 and 6 present the values of 6-RM determined on the leg extension and bench press, respectively, for the experimental and the control group in the three evaluations moments.

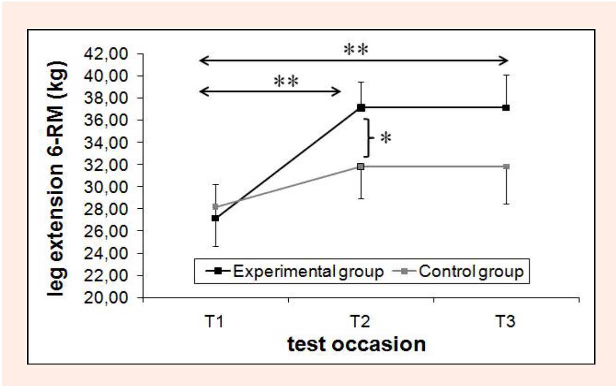

Figure 5. Values of 6-RM determined on the leg extension for the experimental and the control group in the three evaluations moments. Solid lines and * represent differences between evaluation moments in the experimental group. * $p < 0.05$. ** $p < 0.01$.

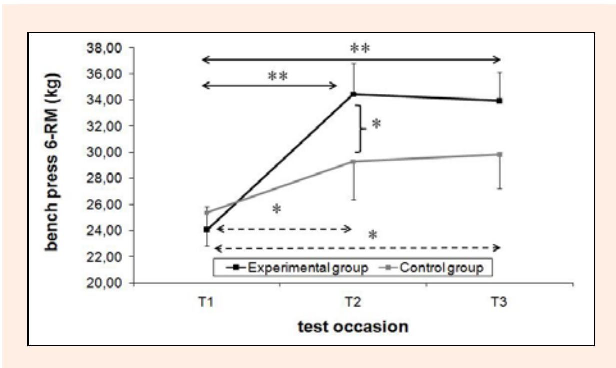

Figure 6. Values of 6-RM determined on the bench press for the experimental and the control group in the three evaluations moments. Solid lines and * represent differences between evaluation moments in the experimental group. Non-solid lines and * represent differences between evaluation moments in the control group. * $p < 0.05$. ** $p < 0.01$.

The leg extension performance significantly increased ($p < 0.01$) between T1 and T2 in the experimental group. Furthermore, after eight weeks of strength training

(T2) the experimental group presented higher values than the control group ($p < 0.05$).

One can observe that performance on bench press increased from T1 to T2 in the experimental ($p < 0.01$) but also in the control group ($p < .05$), although the enhancement in this parameter was more noticeable in the experimental group (~43% vs. ~15% in the control group). Moreover, the experimental group presented higher values of 6-RM bench press comparing with the control group ($p < 0.05$) after the eight weeks of strength training (T2). From T2 to T3 the values remain almost constant in both groups for both leg extension and bench press.

Power performance

Figure 7 presents the values of CMJ performance for the experimental and the control group in the three evaluations moments.

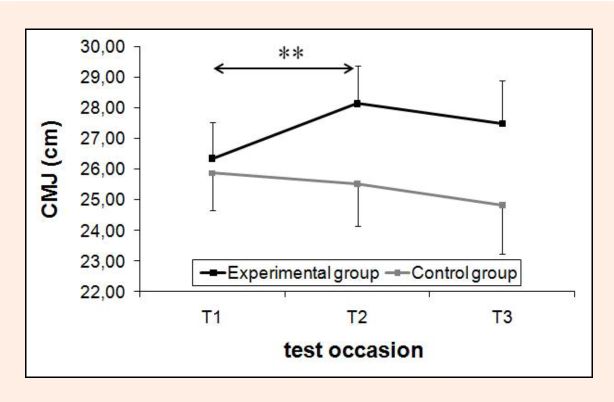

Figure 7. Values of CMJ performance for the experimental and the control group in the three evaluations moments. Solid lines and * represent differences between evaluation moments in the experimental group. ** $p < 0.01$.

Although no differences were verified between groups in any of the evaluation moments, it was possible to observe different responses after the eight weeks of strength training in each group. The CMJ performance significantly increased ($p < 0.01$) between T1 and T2 in the experimental group whereas in the control group the values remained similar.

Figure 8 and 9 present the values of throwing distance performance and Figures 10 and 11 the velocity throwing performance with a 1 kg and a 3 kg medicine ball, respectively, for the experimental and the control group in the three evaluations moments.

Although no differences were verified between groups in any of the evaluation moments, as occurred in the CMJ performance, it was possible to observe different responses after the eight weeks of strength training in each group. The throwing distance significantly increased ($p < 0.05$, 1 kg ball; $p < 0.01$, 3 kg ball) between T1 and T2 in the experimental group whereas in the control group the changes were not significant.

Regarding throwing velocity with 1 kg ball, similar tendency was obtained in both groups: the velocity increased between T1 and T2 and decreased between T2 and T3 ($p < 0.05$). Moreover, no differences were obtained between the two training groups in any of the evaluation moments. Regarding the performance with the 3 kg ball, the tendency for increasing the velocity between T1 and T2 was observed, although no significant differences were presented ($p > 0.05$).

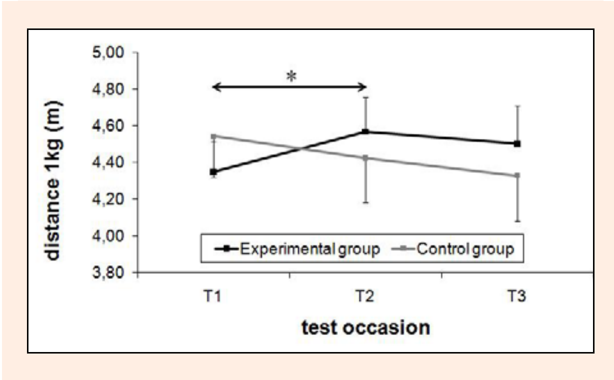

Figure 8. Values of throwing distance performance with a 1 kg medicine ball for the experimental and the control group in the three evaluations moments. Solid lines and * represent differences between evaluation moments in the experimental group. * $p < 0.05$.

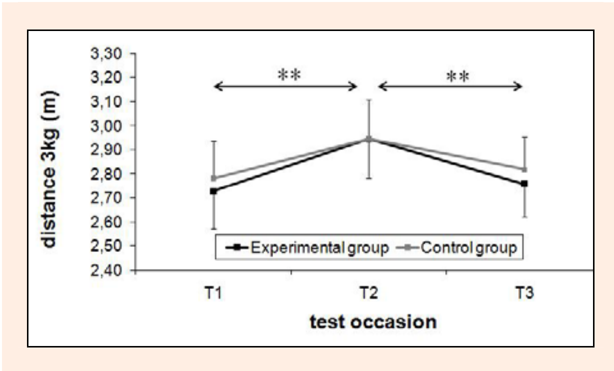

Figure 9. Values of throwing distance performance with a 3 kg medicine ball for the experimental and the control group in the three evaluations moments. Solid lines and * represent differences between evaluation moments in the experimental group. ** $p < 0.01$.

Discussion

This study aimed: (i) to investigate the effects of eight weeks of combined dry land strength and aerobic swimming training for increasing upper and lower body strength, power and swimming performance in young competitive swimmers and, (ii) to assess the effects of a detraining period (strength training cessation) on strength and swimming performance. The present study showed that a combined strength and aerobic swimming training allow dry land strength developments and enhancements of swimming performance. The detraining period showed that, although strength parameters remained stable, swimming performance still improved.

Swimming performance

According to Tanaka and Swensen (1998), traditional dry land strength training or combined swim and strength training does not appear to enhance swimming performance in untrained individuals or competitive swimmers, despite substantially increasing upper body strength. Nevertheless, the present study showed conflicting results. In fact, young competitive swimmers could enhance significantly sprint performance during eight consecutive weeks of high aerobic training volume.

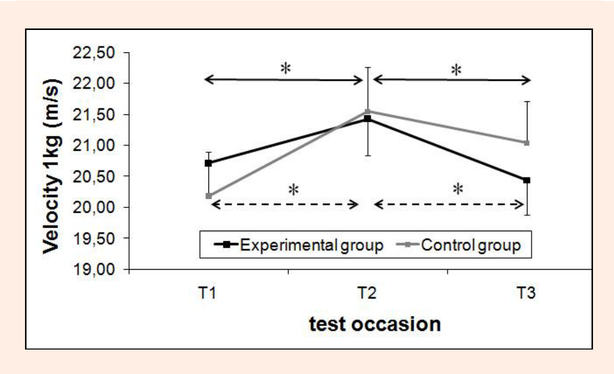

Figure 10. Values of velocity throwing performance with a 1 kg medicine ball for the experimental and the control group in the three evaluations moments. Solid lines and * represent differences between evaluation moments in the experimental group. Non-solid lines and * represent differences between evaluation moments in the control group. * $p < 0.05$. ** $p < 0.01$.

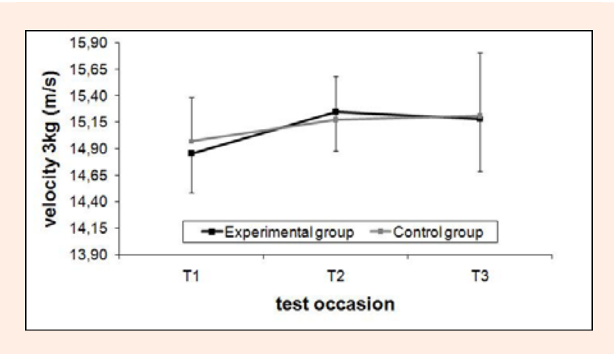

Figure 11. Values of velocity throwing performance with a 3 kg medicine ball for the experimental and the control group in the three evaluations moments.

Early studies that examined the impact of strength training on swim performance used untrained subjects, but many of these experiments did not include a control group or provide information on the type of exercise regimen used as the training stimulus (Costill et al., 1980; Davis, 1955; Nunney, 1960; Tanaka and Swensen, 1998).

Tanaka et al. (1993) studied the effects of combined swim and traditional strength training on swimming performance using competitive collegiate swimmers. Here, although combined training increased upper body strength by approximately 30%, it did not produce faster sprint times compared with swim training only. The authors speculated that the strength gain induced by the strength training regimen was not directly transferred into better performance because swimming is highly technical, being traditional strength training not specific enough to improve swim performance. This hypothesis is supported by data showing that combined swim and swim-specific (or 'in-water') strength training improves performance more than swim or combined swim and traditional strength training in competitive swimmers (Toussaint and Vervoorn, 1990). In this study, swim-specific strength exercises included biokinetic swim bench training, reverse current hydrochannel swimming and in-water devices that the athletes push off from while swimming.

Additionally, Bulgakova et al. (1990) reported that in-water strength training in well conditioned children was more effective than dry land strength training. This fact is partially refuted by the present research. Although no significant differences were found between the two groups on swimming performance, yet, the strength training group increased performance more (25 m: 4.45% T1-T2, $p < 0.01$, 6.95% T1-T3, $p < 0.01$; 50 m: 1.94% T1-T2, $p < 0.01$, 4.77% T1-T3, $p < 0.01$) than the control group (25 m: non-significant improvement T1-T2, 6.44% T1-T3, $p < 0.05$; 50 m: 1.88% T1-T2, $p < 0.05$, 3.16% T1-T3, $p < 0.05$). We agree that swim-specific resistance exercises like reverse current hydrochannel swimming and in-water resistive devices are more specific and also very effective, however the vast majority of strength swimming coaches will not have those equipments available to improve swimming performance.

At these ages, perhaps technical training is more important than strength training (e.g., Barbosa et al., 2010; Kjendlie et al., 2004), which was indicated with prolonged enhancement of swimming performance after six weeks of detraining, although hydrodynamic drag values increased after six weeks of detraining. In fact, according to our data, one can not clearly state that strength training allowed an enhancement in swimming performance in young swimmers, although a tendency to improve performance due to strength training was noticed. The swimmers' competitive level could have influenced the results and the effects of strength training in swimming performance. It could be interesting to study swimmers with more experience in strength training and/or young swimmers with higher performance level (e.g., to only test swimmers who participate in the national championship, swimmers belonging to regional or even national teams). Indeed, although some swimmers of this group presented good swimming performances, some of them did not present such high performance results (e.g., 100 m short course front crawl performance: 71.09 ± 10.32 s). Moreover, in the current study only freestyle swimming was tested. Another interesting concern to be addressed in the future could be testing swimming performance in other techniques rather than freestyle.

Hydrodynamic performance

Active drag seems to be an important variable to be analyzed in swimming since active drag is significantly dependent on swimming technique (Kjendlie and Stallman, 2008; Toussaint et al., 1988). Although no significant changes were obtained in both groups between the three evaluation moments, some interesting trends were observed regarding drag values. The most visible one was the decrease in drag parameters from T1 to T2 and the following increase from T2 to T3 in the experimental group, in contrast with more stable values observed in the control group (figures 3 and 4), suggesting the improvement in swimming technique due to strength training. Strength training could allow the enhancement in coordination profile, thus helping the swimmer to improve his technique (Maglischo, 2003). A more stable prone position in the water, the reduction of lateral body movements, the decrease of excessive kicking movements and the increase of propulsive efficiency seems to be some reported aspects that contribute to reduce body drag that could be linked with the enhancement in coordination profile (Arellano et al., 2006; Millet and Candau, 2002; Termin and Pendergast, 2001). Nevertheless, these findings should be read with caution, since non-differences were observed during the period of testing. Marinho et al. (2010) presented also non-significant changes in drag parameters after eight weeks of swimming training in young competitive swimmers, although a tendency to decrease drag was noticed. Therefore, although active drag, using the velocity perturbation method, can be considered a practical and useful parameter to assess changes in swimming technique due to training process, some caution should be presented to justify changes due to training process. Moreover, this approach requires the calculation of the frontal surface area of the swimmers. The equation to predict the swimmer's frontal surface area was developed based upon few Dutch adult/Olympic swimmers (Clarys, 1979). Hence, some concerns can be addressed whereas this equation can be applied to nowadays swimmers and, especially, if it can be applied to non-adult swimmers. Furthermore, the quality of the Clarys's prediction equation was not very high ($R^2 \sim 0.70$). Therefore, future studies should focus on this issue, attempting to developed better prediction equation to determine the swimmers' frontal surface area (Marinho et al., 2010).

Strength performance

The improvements of dry land strength occurred as expected mainly in the intervention group. Regarding leg extension performance, this improvement was clearly noticed, with the experimental group presenting higher values than the control group after eight weeks of strength training. Moreover, although bench press values increased from T1 to T2 in both experimental and control groups, the intervention group presented higher values of 6-RM bench press comparing with the control group after the eight weeks of strength training. The main explanation for this strength performance enhancement can be related to the specificity of the dry land strength training exercises (Zatsiorsky, 1995). However, Aspenes et al. (2009) reported that the control group also improved land strength significantly (11.8% and 9.3% in whole and female, respectively). The authors suggested that the control group might have been technically familiarized with the method from pre- to post-test, and/or the improvement is a response to the swimming or dry land strength training they have brought out in the intervention period. In addition, whole control group increased weight, which might have been a response to increased muscle mass and thus increased strength (Beunen and Thomis, 2000). On this, our study showed no improvements neither for body mass nor height in both experimental and control groups. This suggested that our strength training program could be effective to produce dry land specific strength gains.

Power performance

Regarding CMJ and throwing distance tests, although no differences were verified between groups, performance increased after the strength training in the experimental group whereas in the control group the values remained similar. Once again, this can be related to the specificity of the dry land strength training exercises (Tanaka and Swensen, 1998; Zatsiorsky, 1995), inducing changes in the experimental group. However, regarding throwing velocity, both groups presented a similar tendency to increase performance between T1 and T2 and to decrease it between T2 and T3, although this trend was more noticed with the 1 kg ball. This tendency to increase performance more with the 1 kg ball was expected in the experimental group, since the swimmers only trained with this medicine ball. These findings of this study are in line with the ones of van den Tillaar and Marques (2009). Nevertheless, not only this increase occurred both in the experimental and control groups, but it also occurred with the 3 kg ball. It can be speculated that other factors such morphological, neuromuscular and hormonal aspects can contribute to influence physical exercise performance in children (e.g., Brownlee et al., 2005; Croix, 2007), and should be deeply study in future studies.

Detraining

To the best of our knowledge, this is the first study that examined the detraining effect on young swimming athletes. Thus, it is difficult to compare the present results with other studies that have investigated strength cessation because they differ markedly in a number of factors, including the sample and the method of measurement. In addition, few studies examined detraining effects in swimming athletes and most of them analyzed physiological parameters variables and not strength or performance variables.

Athletes often experience interruptions in training processes and competition programs (Hortobagyi, 1983; Kraemer et al., 2002), which may result in a reduction or cessation of their normal physical activity levels. Previous studies claimed different results. In fact, Hakkinen and Komi (1985a; 1985b) observed significant decreases in vertical jump height ($p < 0.05$) after 24 weeks of strength training followed by 12 weeks of detraining. Hakkinen et al. (1981) also reported 11.6% and 12.0% decreases in squat-lift and leg extension forces, respectively, after eight weeks of training stoppage. This was coupled with decreased averaged maximal bilateral (5.6%) and unilateral (12.1%) strength. Neufer et al. (1987) observed that college swimmers maintained their muscular strength as measured on a swim bench during four weeks of training cessation, but their swim power, i.e., their ability to apply the force during swimming, declined by 13.6%. This could be due to a longer period of detraining. It seems that with shorter detraining periods of between 2 to 6-7 weeks, performance could be maintained as was showed on the present investigation for intervention group. This assumption tends to be borne out by those of the present investigation. Here, subjects showed no decline in their swimming performance during the detraining period. As expected, specific swimming training have positively influenced sprint swim performance. Kraemer et al. (2002) observed that recreationally trained men can maintain jump performance during short periods of detraining (six weeks). The researchers argued that other factors like jumping technique may be critical for vertical jump performance and may have contributed to the lack of change despite the reduction of performance. Marques and González-Badillo (2006) also showed that team handball players declined jump ability during the detraining period, though not a significant one. In our opinion, this could suggest that game-specific jumping is a better means of positively influencing jump performance in team handball players. The maintenance of athletic performance during the detraining period may also be explained by the continuation of specific team handball practices and competitions and, simultaneously, by the short duration of detraining itself. However, in the same study (Marques and González-Badillo, 2006) could observed that ball throwing velocity was significantly reduced after the detraining period (2.7%, $p < 0.05$), despite coinciding with a competition phase. Several authors have proposed that strength losses are related to neural changes (Connolly et al., 2002) coupled with longer-term atrophic decline (Kraemer et al., 2002). We suggest that such decreases may be due to the incapacity of subjects to stimulate their motor units or to recruit fast twitch fibbers in both explosive skills, reinforcing the hypothesis that strength training absence induces significant neural losses in the muscles involved in throwing ability.

Strenuous physical exercise has been shown to result in short and long-term alterations of the endocrine system (Viru, 1992). According to Mujika et al. (1996), in their constant search for performance enhancement, competitive swimmers train several hours per day, performing large amounts of intense exercise. When this strenuous in-water training is carried out for prolonged periods and with insufficient recovery between training sessions, the swimmer athlete may become overtrained (Kuipers and Keizer, 1988; Lehmann et al. 1993). Furthermore, physiological adaptations following the reduction in exercise training volume, such as increased muscular power, strength, and single muscle fibber size, as well as altered metabolic and contractile properties of single muscle fibbers, have been documented (Widrick et al., 1996). Unfortunately, the time course for these adaptations has not been well described. Here, to the best of our knowledge, only Trinity et al. (2006) examined the time course of changes in maximal mechanical power and swim performance that occur during the taper. The taper has been defined as the period of training during which the negative impact of training is reduced and the positive impact of physical training is increased. In brief, the authors (Trinity et al., 2006) reported that maximal arm power measured using inertial load ergometry increased largely during the first and third weeks after training volume was tapered for peak performance in elite collegiate swimmers (Trinity et al., 2006). It is unclear whether the inconsistency of results between different studies involving different sports is due to methodological differences, different training backgrounds, or to different population characteristics. We suggest that such decreases founded in our study can be due to the incapacity of subjects to stimulate their motor units or to recruit fast twitch fibers in both explosive skills (jump and ball throwing velocity), reinforcing the hypothesis that strength training absence induces significant neural losses in the muscles involved in throwing ability. Furthermore, this ability is not daily stimulated in swimmers.

Limitations and future studies

The current data should be interpreted within the context of the study and its sample of young swimming athletes. The primary limitation of this research is the reduce numbers of subjects. However, there are inherent difficulties in randomizing some individuals to both experimental and control group when attempting to investigate resistance training effects with young talent swimming athletes. Moreover, we expect that a resistance training program intervention superior to eight weeks would promote better results. Thereby suggesting further studies comparing the effects of combined resistance and aerobic training should be conducted. Furthermore, the overall resistance volume can be a factor that has to be considered, especially in performance low intensity resistance regimens. For practitioners, the investigation may be useful in suggesting ways to optimize training whilst avoiding detraining effects. Future studies should also look further into the mechanisms of the improvements of strength training and should try to find methods to impose the increased swimming force on improved swimming biomechanics.

Conclusion

The main results suggested that a combined strength and aerobic swimming training allow dry land strength developments in young swimmers. The main data can not clearly state that strength training allowed an enhancement in swimming performance, although a tendency to improve sprint performance due to strength training was noticed.

The detraining period showed that, although strength parameters remained stable, swimming performance still improved.

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References

Abernethy, P. and Quigley, B. (1993) Concurrent strength and endurance training of the elbow extensors. *Journal of Strength and Conditioning Research* **7(7),** 234-240.

Arellano, R., Terres-Nicol, J.M. and Redondo, J.M. (2006) Fundamental hydrodynamics of swimming propulsion. In: *Biomechanics and Medicine in Swimming X.* Eds: Vilas-Boas, J.P., Alves, F. and Marques, A. *Portuguese Journal of Sport Sciences* **6,** 15-20.

Aspenes, S., Kjendlie, P.L., Hoff, J. and Helgerud, J. (2009) Combined strength and endurance training in competitive swimmers. *Journal of Sports Science and Medicine* **8,** 357-365.

Barbosa, T.M., Marinho, D.A., Costa, M., Coelho, J., Cruz, A., Marques, M.C. and Silva, A.J. (2009) Path-flow analysis model for anthropometric, hydrodynamic and biomechanical variables in age-group swimmers. *Journal of Sports Science and Medicine* **8(Suppl. 11),** 183.

Barbosa, T.M., Costa, M.J., Marinho, D.A., Coelho, J., Moreira, M. and Silva, A.J. (2010) Modelling the links between age-group swimming performance, energetic and biomechanic profiles. *Pediatric Exercise Science*, in press.

Beunen, G. and Thomis, M. (2000) Muscular strength development in children and adolescents. *Pediatric Exercise Science* **12,** 174-197.

Brownlee, K.K., Moore, A.W. and Hackney, A.C. (2005) Relationship between circulating cortisol and testosterone: influence of physical exercise. *Journal of Sports Science and Medicine* **4(1),** 76-83.

Bulgakova, N.Z., Vorontsov, A.R. and Fomichenko, T.G. (1990) Improving the technical preparedness of young swimmers by using strength training. *Soviet Sports Review* **25(2),** 102-104.

Carzola, G. (1993) *Tests Spécifiques d'évaluation du Nager*. Editions Vigot, Paris.

Clarys, J.P. (1979) Human morphology and hydrodynamics. In: *Swimming III*. Eds: Terauds, J. and Bedingfield, E.W. University Park Press, Baltimore. 3-41.

Connolly, D.A., Reed, B.V. and McHugh, M.P. (2002) The repeated bout effect: does evidence for a crossover effect exist? *Journal of Sports Science and Medicine* **1(3),** 80-86.

Costa, A.M., Silva, A.J., Garrido, N.D., Louro, H., Marinho, D.A., Marques, M.C. and Breitenfeld, L. (2009b) Angiotensin-converting enzyme affects skeletal muscle strength in elite athletes. *Journal of Sports Science and Medicine* **8,** 410-418.

Costa, A.M., Silva, A.J., Louro, H., Reis, V.M., Garrido, N.D., Marques, M.C. and Marinho, D.A. (2009a) Can the curriculum be used to estimate critical velocity in young competitive swimmers? *Journal of Sports Science and Medicine* **8,** 17-23.

Costill, D., Maglischo, E. and Richardson, A. (1992) *Swimming. Handbook of Sports Medicine and Science*. Blackwell Scientific Publications, Oxford.

Costill, D., Sharp, R. and Troup, J. (1980) Muscle strength: contributions to sprint swimming. *Swim World* **21,** 29-34.

Costill, D.L. (1999) Training adaptations for optimal performance. In: *Biomechanics and Medicine in Swimming VIII*. Eds: Keskinen, K.L., Komi, P.V. and Hollander, A.P. University of Jyvaskyla, Jyvaskyla. 381-390.

Croix, M. (2007) Advances in paediatric strength assessment: changing our perspective on strength development. *Journal of Sports Science and Medicine* **6(3),** 292-304.

Davis, J.F. (1955) The effect of weight training on speed in swimming. *Physical Educator* **12,** 28-29.

Dudley, G. and Djamil, R. (1985) Incompatibility of endurance and strength training modes of exercise. *Journal of Applied Physiology* **59,** 1446-1451.

Faigenbaum, A.D., Milliken, L.A., Loud, R.L., Burak, B.T., Doherty, C.L. and Westcott, W.L. (2002) Comparison of 1 and 2 days per week of strength training in children. *Research Quarterly for Exercise and Sport* **73(4),** 416-24.

Girold, S., Maurin, D., Dugue, B., Chatard, J.C. and Millet, G. (2007) Effects of dry-land vs. resisted- and assisted-sprint exercises on swimming sprint performances. *Journal of Strength and Conditioning Research* **21,** 599-605.

Hakkinen, K. and Komi, P.V. (1985a) Changes in electrical and mechanical behavior of leg extensor muscles during heavy resistance strength training. *Scandinavian Journal of Sports Science* **7(2),** 55-64.

Hakkinen, K. and Komi, P.V. (1985b) Effect of explosive type strength training on electromyographic and force production characteristics of leg extensor muscles during concentric and various stretch-shortening cycle exercises. *Scandinavian Journal of Sports Science* **7(2),** 65-76.

Hakkinen, K., Komi, P.V. and Tesch, P.A. (1981) Effect of combined concentric and excentric strength training and detraining on force-time, muscle fiber and metabolic characteristics of leg extensor muscles. *Scandinavian Journal of Sports Science* **3(2),** 50-58.

Hennessey, L.C. and Watson, W.C. (1994) The interference effects of training for strength and endurance simultaneously. *Journal of Strength and Conditioning Research* **8(1),** 12-19.

Hortobagyi, T., Hounard, J.A., Stevenson, J.R., Fraser, D.D., Johns, R.A. and Israel. R.G. (1983) The effects of detraining on power athletes. *Acta Physiologic Scandinavian* **25,** 929-935.

Kjendlie, P.L. and Stallman, R. (2008) Drag characteristics of competitive swimming children and Adults. *Journal of Applied Biomechanics* **24,** 35-42.

Kjendlie, P.L., Ingjer, F., Stallman, R. and Stray-Gundersen, J. (2004) Factors affecting swimming economy in children and adults. *European Journal of Applied Physiology* **93,** 65-74.

Kolmogorov, S.V. and Duplisheva, A. (1992) Active drag, useful mechanical power output and hydrodynamic force coefficient in different swimming strokes at maximal velocity. *Journal of Biomechanics* **25,** 311-318.

Kolmogorov, S.V., Rumyantseva, O., Gordon, B. and Cappaert, J. (1997) Hydrodynamic characteristics of competitive swimmers of different genders and performance levels. *Journal of Applied Biomechanics* **13,** 88-97.

Kraemer, W.J., Koziris, L., Ratamess, N.A., Hakkinen, K., Triplett-Mcbride, N.T., Fry, A.C., Gordon, S.E., Volek, J.S., French, D.N., Rubin, M.R., Gómez, A.L., Sharman, M.J., Michael, L.J., Izquierdo, M., Newton, R.U. and Fleck, S.J. (2002) Detraining produces minimal changes in physical performance and hormonal variables in recreationally strength-trained men. *Journal of Strength and Conditioning Research* **16(3),** 373-382.

Kuipers H. and Keizer, H.A. (1988) Overtraining in elite athletes. Review and directions for the future. *Sports Medicine* **6,** 79-92.

Lehmann M., Foster C. and Keul, J. (1993) Overtraining in endurance athletes: a brief review. *Medicine and Science in Sports and Exercise* **25,** 854-862.

Leveritt, M., Abernethy, P., Barry, B.K. and Logan, P.A. (2000) Concurrent strength and endurance training. A review. *Sports Medicine* **28(6),** 413-427.

Maglischo, E.W. (2003) *Swimming fastest. The essential reference on technique, training, and program design*. Human Kinetics Publishers. Champaign, Illinois.

Marinho, D.A., Barbosa, T.M., Costa, M.J., Figueiredo, C., Reis, V.M., Silva, A.J. and Marques, M.C. (2010) Can 8-weeks of training affect active drag in young swimmers? *Journal of Sports Science and Medicine* **9(1),** 71-78.

Marques, M.C. and González-Badillo, J.J. (2006) In-season resistance training and detraining in professional team handball players. *Journal of Strength and Conditioning Research* **20(3),** 563-571.

McCurdy, K., Langford, G.A., Cline, A.L., Doscher, M. and Hoff, R. (2004) The reliability of 1- and 3RM tests of unilateral strength in trained and untrained men and women. *Journal of Sports Science and Medicine* **3(3),** 190-196.

Millet, G.P. and Candau, R. (2002) Facteurs mécaniques du coût énergétique dans trois locomotions humaines. *Science et Sports* **17(4),** 166-176. (In French: English abstract).

Mujika, I., Chatard, J.C., Padilla, S., Guezennec, C.Y. and Geyssant, A. (1996) Hormonal responses to training and its tapering off in competitive swimmers: relationships with performance. *European Journal of Applied Physiology* **74,** 361-366.

Neufer, P.D., Costill, D.L., Fielding, R.A., Flynn, M.G. and Kirwan, J.P. (1987) Effect of reduced training on muscular strength and endurance in competitive swimmers. *Medicine and Science in Sports and Exercise* **19(5),** 486-490.

Nunney, D.K. (1960) Relation of circuit training to swimming. *Research Quarterly* **31(2),** 188-198.

Pichon, F., Chatard, J.C., Martin, A. and Cometti, G. (1995) Electrical stimulation and swimming performance. *Medicine and Science in Sports and Exercise* **27,** 1671-1676.

Sale, D.G., MacDougall, J.D., Jacobs, I. and Garner, S. (1990) Interaction between concurrent strength and endurance training. *Journal of Applied Physiology* **68,** 260-270.

Silva, A.J., Costa, A.M., Oliveira, P.M., Reis, V.M., Saavedra, J., Perl, J., Rouboa, A. and Marinho, D.A. (2007) The use of neural network technology to model swimming performance. *Journal of Sports Science and Medicine* **6,** 117-125.

Strass, D. (1988) Effects of maximal strength training on sprint performance of competitive swimmers. In: *Swimming Science V*. Eds: Ungerechts, B.E., Wilke, K. and Reischle, K. Spon Press, London. 149-156.

Tanaka, H. and Swensen, T. (1998) Impact of resistance training on endurance performance. A new form of cross-training? *Sports Medicine* **28(6),** 191-200.

Tanaka, H., Costill, D.L., Thomas, R., Fink, W.J. and Widrick, J.J. (1993) Dry-land resistance training for competitive swimming. *Medicine and Science in Sports and Exercise* **25,** 952-959.

Termin, B. and Pendergast, D.R. (2001) Training using the stroke frequency-velocity relationship to combine biomechanical and metabolic paradigms. *Journal of Swimming Research* **14,** 9-17.

Toussaint, H.M. and Vervoorn, K. (1990) Effects of specific high resistance training in the water on competitive swimmers. *International Journal of Sports Medicine* **11(3),** 228-233.

Toussaint, H.M., de Groot, G., Savelberg, H.H.,Vervoom, K, Hollamier, A.P. and van Ingen Schnau, G.J. (1988) Active drag related to velocity in male and female swimmers. *Journal of Biomechanics* **21,** 435-438.

Trappe, S. and Pearson D.R. (1994) Effects of weight assisted dry-land strength training on swimming performance. *Journal of Strength and Conditioning Research* **8,** 209-213.

Trinity, J. D., Pahnke, M.D., Reese, E. C. and Coyle, E. F. (2006) Maximal mechanical power during a taper in elite swimmers. *Medicine and Science in Sports and Exercise* **38(9),** 1643–1649.

van den Tillaar, R. and Marques, M.C (2009) Effect of two different throwing training programs with same workload on throwing performance with soccer ball. *International Journal of Sport Physiology and Performance* **4,** 747-484.

Viru, A. (1992) Plasma hormones and physical exercise. *International Journal of Sports Medicine* **13,** 201-209.

Weir, J.P. (2005) Quantifying test-retest reliability using the interclass correlation coefficient and the SEM. *Journal of Strength and Conditioning Research* **19,** 231-240.

Widrick, J.J., Trappe, S.W. Blaser, C. A., Costill, D.L. and Fitts. H. (1996) Isometric force and maximal shortening velocity of single muscle fibers from elite master runners. *American Journal of Physiology* **27,** 666-675.

Zatsiorsky, V.M. (1995) *Science and Practice of Strength Training*. Human Kinetics Books. Champaign, Illinois.

Key points

- This study investigated the effect of dry land strength training on sprint performance in young competitive swimmers.
- A combined strength and aerobic swimming training allow dry land strength developments in young swimmers.
- The main data can not clearly state that strength training allowed an enhancement in swimming performance, although a tendency to improve sprint performance due to strength training was noticed.
- The detraining period showed that, although strength parameters remained stable, swimming performance still improved.

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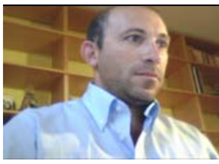

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