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RELATIONSHIPS BETWEEN DRY LAND STRENGTH, POWER VARIABLES AND SHORT SPRINT PERFORMANCE IN YOUNG COMPETITIVE SWIMMERS

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ABSTRACT

The aim of this study was to identify the dry land strength and power tests that can better relate with sprint swimming performance in young competitive swimmers. Twenty-eight (16 boys and 12 girls) young competitive swimmers of national level (12.01 ± 0.56 years-old, Tanner stage 1-2) volunteered to participate in this study. Swimming performance (25 m and 50 m freestyle sprint tests), muscle strength (bench press and leg extension) and muscle power (throwing medicine ball and countermovement jump) performances were tested. Spearman ranking correlation coefficient were computed to verify the association between strength and power variables with sprint swimming performance. Regarding strength tests, the bench press and leg extension exercises were moderate but significantly associated with 25 m and 50 m tests ($-0.69 \leq \rho \leq -0.58$). The sprint tests were only associated with throwing power tests ($-0.74 \leq \rho \leq -0.54$) and not with vertical jump height. The main results suggested that, simple dry land strength and power tests although moderate are significantly associated with sprint swimming performance in young competitive swimmers.

Key words: Children, Swimming, Training and Control, Front Crawl, Testing.

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INTRODUCTION

Measurement of selected parameters related to physical conditioning in youth is common in most physical education and sports programs (Milliken et al., 2008). As with competitive running and cycling, dynamic strength seems to be an important determinant of swimming performance (Tanaka et al., 1993; Tanaka & Swensen, 1998). Unfortunately, sport-specific assessment methods for muscle power output of the arms and legs for swimming are poorly developed compared with other sports (Swaine, 2000). This seems to be even more critical in what concerns to young competitive swimmers. When properly administered, strength tests can be used to assess children's overall condition and specific sport performance (Faigenbaum et al., 2002).

Separate arm and leg strength and power output measurement would be useful in evaluating training programs and understanding the importance of power output for swimming performance. The threats of assessing strength and power output of the upper and lower limbs during swimming arise from the absence of suitable and simple apparatus that can detect the segmental force being produced, although some approaches have been used (e.g., Kjendlie & Stallman, 2008; Marinho et al., 2010; Toussaint & Vervoorn, 1990). Assessments in young swimmers must be less expensive, less invasive, less complex and less time consuming in comparison to the ones carried-out in adult swimmers (Silva et al., 2007; Barbosa et al., 2009; in press). In fact, within the sports context, some common muscular strength tests have been used, such as: (i) the vertical jump height (Marques et al., 2008; Costa et al., 2009a); (ii) the ball throwing range or its velocity (van den Tillaar & Marques, 2010); (iii) the leg extension test (Faigenbaum et al., 1996) or; (iv) the bench press assessment (Faigenbaum et al., 2002). Despite the widespread use and acceptance of muscular strength fitness field tests in youth (Ramsay et al., 1990), little is known about how well these field tests can be good predictors to measures of maximal strength in young competitive swimmers. Strength and speed are two major factors determining a sprint swimmer's performance at training and competition (Miyashita & Kanehisa, 1983; Toussaint & Vervoorn, 1990; Tanaka et al., 1993; Trappe & Pearson, 1994; Girolid et al., 2007). If this were so, it would be beneficial to develop a dry land based training programme that might enhance sprint performance (Tanaka & Swensen, 1998; Girolid et al., 2007). In fact, some studies have reported that muscular strength correlated significantly with swim velocity (Tanaka & Swensen, 1998; Aspenes et al., 2009). Furthermore, several researches have reported that upper-body muscular strength and/or power output correlate highly with swim velocity over short swimming distances ($r \sim 0.87$) (Toussaint & Vervoorn, 1990; Hawley & Williams, 1991). These findings suggest that combined swim and swim-specific and/or resistance training improves performance more than swim or combined swim and traditional resistance training in young competitive swimmers (Kiselev, 1991).

To the best of our knowledge, few studies examined the correlations between strength and power variables of national level young competitive swimmers and sprint swimming performance. Thus, our aim was to identify the dry land strength and power tests that can better associate with sprint swimming performance in young competitive swimmers. It was hypothesised that dry land strength and power parameters, assessed with countermovement jump, ball throwing, leg extension, and bench press, would significantly correlate to sprint performance scores.

MATERIAL AND METHOD

Subjects

A sample of twenty-eight (16 boys and 12 girls) young competitive swimmers of national level (age: 12.01 ± 0.56 years-old; body mass: 41.23 ± 7.67 kg; height: 1.50 ± 0.67 m) participated in this study. Swimmers were at Tanner Stages 1-2. Since boys and girls demonstrate fairly similar rates of strength gain during preadolescence (Faigenbaum et al., 2002), they were pooled together in this research. No subject had regularly participated in any form of strength training prior to this experiment. The following exclusionary criteria were used: (i) children with a chronic paediatric disease; ii) children with an orthopaedic limitation and; (iii) children classified as Tanner Stage 3 or higher at the beginning of the study.

The participants' parents and coaches provided their written informed consent to participate in this research and the procedures were approved by the institutional review board.

Test procedures

The tests were selected to minimize possible interference with the training and competition schedule. These are tests that can be quickly administered and were previously used in children (Faigenbaum et al., 2002) and even in competitive swimmers (Strass, 1988). Subjects were acquainted with all test procedures four weeks before data collection.

Swimming performance

All the swimmers performed two maximal freestyle trials in both 25 m and 50 m, with a 15 min active recovery period between the two trials.

The tests took place with two days interval, starting with the 25 m test and were always preceded by the same warm-up routine. The data collection was conducted in a 25 m indoor swimming pool. In both tests in-water starts were used and swimmers performed the maximal trial alone in each lane. The time spent to cover the swim distances were determined by two expert evaluators with a chronometer (Golfinho, Sports MC 815, Aveiro, Portugal). For each trial, mean value of both measurements was computed. The test-retest reliability was very high (25 m sprint: ICC = 0.94; 50 m sprint: ICC = 0.91).

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 a standard warm-up of 10 sub maximal repetitions, the 6-RM was determined within 3 to 4 trials and was measured with a 1.5 kg accuracy. The maximal weight that could be lifted 6 times with correct form throughout the full range of motion was recorded (Garrido et al., 2010). 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. The test-retest reliability was very high (bench press: ICC = 0.91; leg extension: ICC = 0.96).

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 of 180°. The protocol required the performance of three jumps on a trigonometric carpet (Ergojump Digitime 1000, Digest Finland), followed by two minutes of rest. An average of the two best jumps was taken to analysis. The test-retest reliability was very high (CMJ: ICC = 0.92).

Ball throwing performance was measured with different weighted balls. Previously it was done a standard warm-up of 10 minutes for shoulder joints, including the throwing of different weighted. Tests consisted on performing the throwing of 1 kg medicine ball (circumference 0.60 m) and a 3 kg medicine ball (circumference 0.68 m) with maximal velocity. 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. The ball was held 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 and/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 10° from the gun. The radar gun was located 8 m in front of the participant during the throw. Regarding the throwing range, an accuracy of 0.10 m was considered. Only the best attempts with each ball were used for further analysis (Garrido et al., 2010). The test-retest reliability was very high (throwing velocity: ICC = 0.90; range: ICC = 0.92 for both 1 kg and 3 kg medicine balls).

Statistics

Normality of distribution was checked with Shapiro-Wilk test and a non-normal distribution was found. The values of each variable are presented as mean \pm 1 standard deviation. The test-retest reliability was calculated according to the procedures of Weir (2005) and measured on 12 swimmers within a five days timeframe between both measurements. Spearman correlation rank coefficients were computed to verify the association between swimming sprint performance (25 m and 50 m sprint tests) and remaining variables. The level of significance was set at $p \leq 0.05$. Data was analyzed using SPSS 12.0 (Lead Tools, 2003).

RESULTS

The mean and standard deviation values of both 25 m and 50 m sprint tests were 16.12 ± 0.67 s and 35.21 ± 1.98 s, respectively.

Table 1 presents the descriptive statistics for all strength and power variables assessed and their correlation coefficients with sprint swimming performance (25 m and 50 m sprint tests).

Table 1. Mean and 1 standard deviation (SD) calculated for strength and power variables and its Spearman rank correlation coefficients with 25 m and 50 m sprint performance.

Variables	Mean \pm 1 SD	Correlation coefficients (ρ) with	
		25 m sprint	50 m sprint
6-RM leg extension (kg)	27.60 \pm 2.06	-0.692***	-0.622**
6-RM bench press (kg)	24.64 \pm 1.43	-0.575**	-0.586**
CMJ (m)	0.26 \pm 0.07	-0.149	-0.204
1 kg throwing range (m)	4.43 \pm 0.15	-0.661***	-0.641**
1 kg throwing velocity (m/s)	20.48 \pm 0.49	-0.558**	-0.542**
3 kg throwing range (m)	2.75 \pm 0.09	-0.744***	-0.726***
3 kg throwing velocity (m/s)	15.00 \pm 0.26	-0.727***	-0.730***

*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$

It was found significant associations between the 25 m and 50 m sprint performances and several strength and power variables. Regarding strength tests, the bench press and the leg extension exercises were moderate but significantly associated with both 25 m and 50 m sprint tests. The highest value was observed between the 25 m sprint test and the leg extension ($\rho = -0.692$).

The sprint tests were related with a moderate level with throwing power tests but not with vertical jump height. In fact, amongst all strength variables, throwing range ($\rho \sim -0.72$) and velocity ($\rho = -0.74$) with the 3 kg ball presented moderate but significant correlation values.

DISCUSSION

The purpose of the present study was to examine the factors causally related to the swimming sprint performance of young competitive swimmers. Main data found moderate but significant associations between 25 m and 50 m sprint tests and several strength and power variables.

Many of the muscular fitness tests used in youth testing batteries grew out of validation studies that demonstrated the association between selected specific sport fitness tests and muscular strength measured in different populations of adults (Marques et al., 2008; Costa et al., 2009a). Thus, transferring data from adults researches to children ones should be done cautiously (Barbosa et al., 2009; in press). According to several authors (Silva et al., 2007; Costa et al., 2009b) swimming performance is significantly associated to the isometric strength or to the arm power on dry land exercises. Other studies reported that swimming velocity is more correlated to the specific strength and muscle power produced in aquatic environment, being more specific test-types (Tanaka et al., 1993). Most of these studies considered the relationships between the swimming velocity and the strength or muscle power on dry land or water conditions without any comprehensive knowledge about the relationships between these different parameters (Tanaka & Swensen, 1998). On this, Girolid et al. (2006) observed that muscle strength was a good predictor of 100 m swimming performance. Strength of elbow flexors and extensors were

significantly correlated with 100 m performance measured in isometric and concentric conditions. These data are in agreement with previous studies published by Miyashita and Kanshisa (1979), as well as, Hawley and Williams (1991). Both studies showed positive, strong and significant relationships between the power of the upper limbs and the 100 m swimming performance. Several investigations have used isokinetic and isometric tests as strength indexes. Problems with the use of isometric tests are that it only represents the strength at the specific angle measured. Furthermore, in competitive swimming not much of the movements are isometric ones. As consequence, the neuromuscular activation is quite different during isotonic tests in comparison to isometric and isokinetic ones (Marques et al., 2008). Therefore it is not suitable to test isometric strength in relationship with a high velocity movement like short swimming distances, since swimming is a dynamic locomotion technique. To our best knowledge, no study has examined the associations between swimming performance and dynamic strength of the upper and lower extremities in young competitive swimmers. The bench press and leg extension exercises were chosen because interventionist activates on overall the same muscle groups when swimming (Cronin et al., 2007). Thus, using multi-joint exercises tests should be advantageous when exploring for associations with a dynamic movement such as swimming. Birrer (1986) pointed out the importance of the triceps in the pushing phase for all swim strokes. In the present study, bench press was also moderate but significantly related ($\rho \sim -0.58$; $p < 0.01$) with specific swimming performance (for both 25 m and 50m sprint tests).

Throwing ability require high levels of reactive neuromuscular control, proprioception and coordination (Marques et al., 2008). Our data showed a moderate but significant association between throwing ability (i.e. range and velocity with both medicinal balls) and swimming sprint tests. Indeed, throwing ability could explain swimming times between 25 and 49 % rounded up. According to Heiderscheit et al. (1996), there seems to be a positive relationship between the effects of isokinetic training with plyometric training using overhead medicine ball throws on shoulder strength and functional performance (i.e., softball throw). As expected, the isokinetic group improved in isokinetic strength. On the other hand, the plyometric group increased softball throw range by 1.4 m, which was nearly five times greater than the isokinetic group, although the change did not reach statistical significance. However, it is difficult to compare our data with data from remaining studies that have investigated the relationships between swimming performance and explosive strength in competitive swimmers (e.g., Hawley & Williams, 1998). Papers differ markedly in a number of factors related to the method design.

Dry land resistance training is intended to improve the strength and power production of the muscles specific to swimming performance (Cronin et al., 2007). Keskinen et al. (2007) evaluated explosive strength of leg extensor muscles using the counter movement vertical jump. The authors observed positive correlations between the 5 set of 200 m swim velocity in short and long-pool swims with the vertical jumping height in the CMJ ($r = 0.55$; $p = 0.039$). Similar association was also reported by Strzala and Tyka (2009) between the front crawl velocity at the 100 m and the 25 m distances with the CMJ anaerobic power ($0.75 \leq r \leq 0.76$). These results suggest that CMJ height can be a good predictor parameter explaining swimming velocity. In addition, Cronin et al. (2007) tried to determine if leg power during a squat jump, countermovement jump would be significantly correlated with tumble turn ability. All these independent variables were significantly related to initial turn velocity, but the correlations could only be described as low to moderate. It is possible that exercises like CMJ lacked specificity or

other factors like swimming technique has greater importance in these ages. Thus, the vertical jump performance in young swimmers would be highly reliant on skill, besides strength itself (Costa et al., 2009a). Since power is a factor in many athletic skills, it is clearly useful for researchers to study these relationships, especially when dealing with elite young athletes.

Watanabe and Takai (2005) tried to analyze the factors that contribute to swimming performance and to determine the extent to which these factors change with respect to age group swimmers' development. Their results suggest that muscle strength does not contribute strongly to the swimming performance in subjects who are less than 14-years-old. Contrarily, they concluded that muscle strength was an important explanatory factor of swimming performance in 50 m in both genders over 15-years-old. Another factor that could possibly contribute to the different outcomes between previous investigations with respect to the associations between swimming performance is the training and subjects background.

On overall, most strength and power variables presented moderate but significant associations with both swim sprint tests. Since non-specific strength and power tests were used (e.g., dry-land tests) it seems obvious that the identifications of higher levels of association between variables could be quite difficult. It might be speculated that when specific in-water tests are applied higher correlation values can be obtained. Specific in-water tests might be the most suitable for adult/elite swimmers. However, assessments in young swimmers must be less expensive, less invasive, less complex and less time consuming in comparison to the ones carried-out in adult swimmers (Silva et al., 2007; Barbosa et al., 2009; in press). In this sense, it seems that dry-land strength and power tests as the ones selected for this research are suitable for training control and evaluation of young competitive swimmers.

CONCLUSION

Most swimming coaches do not have scientific equipment available to determine the optimal dry land parameters related to swim performance on regular basis. Even so, main data suggested that simple dry land strength and power tests are moderate significantly related with sprint swimming performance in young competitive swimmers.

PRACTICAL APPLICATIONS

An assessment protocol requires reliability and easy application, especially when young competitive swimmers are evaluated.

This study investigated the dry land strength and muscle power tests that can better associate with sprint swimming performance in young competitive swimmers.

The freestyle sprint tests (25 m and 50m) were only moderate related with throwing power tests and not with vertical jump height.

Strength tests (bench press and leg extension) were moderate but significantly associated with 25 m and 50 m tests.

It seems that simple dry land strength tests are suitable for young swimmer's assessment.

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REFERENCES

1. ASPENES S, KJENDLIE PL, HOFF J, & HELGERUD, J. Combined strength and endurance training in competitive swimmers. *Journal of Sports Science and Medicine*. 2009; 8:357-365. [[Full text](#)] [[Back to text](#)]
2. BARBOSA TM, COSTA MJ, MARINHO DA, COELHO J, MOREIRA M, & SILVA AJ. Modelling the links between age-group swimming performance, energetic and biomechanic profiles. *Pediatric Exercise Science*, 2010; in press. [[Back to text](#)]
3. BARBOSA TM, MARINHO DA, COSTA M, COELHO J, CRUZ A, MARQUES MC, & SILVA AJ. Path-flow analysis model for anthropometric, hydrodynamic and biomechanical variables in age-group swimmers. *Journal of Sports Science and Medicine*. 2009; 8(Suppl. 11), 183. [[Abstract](#)] [[Back to text](#)]
4. BIRRER P. The shoulder, EMG and the swimming stroke. *Journal of Swimming Research*. 1986; 12:20-23. [[Back to text](#)]
5. COSTA AM, SILVA AJ, GARRIDO ND, LOURO H, MARINHO DA, MARQUES MC, & BREITENFELD L. Angiotensin-converting enzyme affects skeletal muscle strength in elite athletes. *Journal of Sports Science and Medicine*. 2009a; 8:410-418. [[Full text](#)] [[Back to text](#)]
6. COSTA AM, SILVA AJ, LOURO H, REIS VM, GARRIDO ND, MARQUES MC, & MARINHO DA. Can the curriculum be used to estimate critical velocity in young competitive swimmers? *Journal of Sports Science and Medicine*. 2009b; 8:17-23. [[Full text](#)] [[Back to text](#)]
7. CRONIN J, JONES J, & FROST D. The relationship between dry-land power measures and tumble turn velocity in elite swimmers. *Journal of Swimming Research*. 2007; 17:17-23. [[Back to text](#)]
8. FAIGENBAUM A, KRAEMER W, CAHILL B, CHANDLER J, DZIADOS J, ELFRINK L, FORMAN E, GAUDIOSE M, MICHELI LJ, NITKA M, & ROBERTS S. Youth resistance training: position paper and literature review. *Journal of Strength and Conditioning Research*. 1996; 18:62-75. [[Full text](#)] [[Back to text](#)]
9. FAIGENBAUM AD, MILLIKEN LA, LOUD RL, BURAK BT, DOHERTY CL, & WESTCOTT WL. Comparison of 1 and 2 days per week of strength training in children. *Research Quarterly for Exercise and Sport*. 2002; 73:416-24. [[Abstract](#)] [[Back to text](#)]
10. GARRIDO N, MARINHO DA, REIS VM, VAN DEN TILLAAR R, COSTA AM, SILVA AJ, MARQUES MC. Does combined dry land strength and aerobic training inhibit performance of young competitive swimmers? *Journal of Sports Science and Medicine*, 2010; in press. [[Back to text](#)]
11. GIROLD S, CALMELS P, MAURIN D, MILHAU N, & CHATARD JC. Assisted and resisted sprint training in swimming. *Journal of Strength and Conditioning Research*. 2006; 20:547-554. [[Full text](#)] [[Back to text](#)]
12. GIROLD S, MAURIN D, DUGUE B, CHATARD JC, & MILLET G. Effects of dry-land vs. resisted- and assisted-sprint exercises on swimming sprint performances. *Journal of Strength and Conditioning Research*. 2007; 21:599-605. [[Abstract](#)] [[Back to text](#)]

13. HAWLEY JA & WILLIAMS MM. Relationship between upper body anaerobic power and freestyle swimming performance. *International Journal of Sports Medicine*. 1991; 12:1-5. [[Abstract](#)] [[Back to text](#)]
14. HEIDERSCHEIT BC, MCLEAN KP, & DAVIES GJ. The effects of isokinetic vs. plyometric training on the shoulder internal rotators. *Journal of Orthopaedic and Sports Physical Therapy*. 1996; 23:125-33. [[Full text](#)] [[Back to text](#)]
15. KESKINEN OP, KESKINEN KL, & MERO AA. Effect of pool length on blood lactate, heart rate, and velocity in swimming. *International Journal of Sports Medicine*. 2007; 28:407-413. [[Abstract](#)] [[Back to text](#)]
16. KISELEV AP. The use of specific resistance in highly qualified swimmers' strength training. *Soviet Sports Review*. 1991; 26:131-132. [[Back to text](#)]
17. KJENDLIE PL & STALLMAN R. Drag characteristics of competitive swimming children and Adults. *Journal of Applied Biomechanics*. 2008; 24:35-42. [[Abstract](#)] [[Back to text](#)]
18. MARINHO DA, BARBOSA TM, COSTA MJ, FIGUEIREDO C, REIS VM, SILVA AJ, & MARQUES MC. Can 8-weeks of training affect active drag in young swimmers? *Journal of Sports Science and Medicine*. 2010; 9:71-78. [[Full text](#)] [[Back to text](#)]
19. MARQUES MC, VAN DEN TILLAAR R, VESCOVI JD, & GONZÁLEZ BADILLO JJ. Changes in strength and power performance in elite senior female professional volleyball players during the in-season: a case study. *Journal of Strength and Conditioning Research*. 2008; 20:563-571. [[Abstract](#)] [[Back to text](#)]
20. MILLIKEN LA, FAIGENBAUM AD, LOUD RL, & WESTCOTT W. Correlates of upper and lower body muscular strength in children. *Journal of Strength and Conditioning Research*. 2008; 22:1339-1346. [[Abstract](#)] [[Back to text](#)]
21. MIYASHITA M & KANSHISA H. Effects of isokinetic, isotonic and swim training on swimming performance. In: *Biomechanics and Medicine in Swimming*. Eds: Hollander, P., Huijing, P. and de Groot, G. Human Kinetics, Champaign. 329-334. 1983. [[Back to text](#)]
22. MIYASHITA M & KANSHISA H. Dynamic peak torque related to age, sex and performance. *Research Quarterly*. 1979; 50:249-255. [[Abstract](#)] [[Back to text](#)]
23. RAMSAY J, BLIMKIE CJ, SMITH K, GARNER S, MACDOUGALL J, & SALE D. Strength training effects in prepubescent boys. *Medicine and Science in Sports and Exercise*. 1990; 22:605-614. [[Abstract](#)] [[Back to text](#)]
24. SILVA AJ, COSTA AM, OLIVEIRA PM, REIS VM, SAAVEDRA J, PERL J, ROUBOA A, & MARINHO DA. The use of neural network technology to model swimming performance. *Journal of Sports Science and Medicine*. 2007; 6:117-125. [[Full text](#)] [[Back to text](#)]
25. STRASS D. 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. 1988. [[Back to text](#)]
26. STRZALA M & TYKA A. Physical endurance, somatic indices and swimming technique parameters as determinants of front crawl swimming speed at short distances in young swimmers. *Medicina Sportiva*. 2009; 13:99-107. [[Full text](#)] [[Back to text](#)]
27. SWAINE IL. Arm and leg power output in swimmers during simulated swimming. *Medicine and Science in Sports and Exercise*. 2000; 32:1288-1292. [[Abstract](#)] [[Back to text](#)]

28. TANAKA H & SWENSEN T. Impact of resistance training on endurance performance. A new form of cross-training? *Sports Medicine*. 1998; 28:191-200. [[Abstract](#)] [[Back to text](#)]
29. TANAKA H, COSTILL DL, THOMAS R, FINK WJ, & WIDRICK JJ. Dry-land resistance training for competitive swimming. *Medicine and Science in Sports and Exercise*. 1993; 25:952-959. [[Abstract](#)] [[Back to text](#)]
30. TOUSSAINT HM & VERVOORN K. Effects of specific high resistance training in the water on competitive swimmers. *International Journal of Sports Medicine*. 1990; 11:228-33. [[Full text](#)] [[Back to text](#)]
31. TRAPPE S & PEARSON DR. Effects of weight assisted dry-land strength training on swimming performance. *Journal of Strength and Conditioning Research*. 1994; 8:209-213. [[Abstract](#)] [[Back to text](#)]
32. VAN DEN TILLAAR R & MARQUES MC. Effect of two different throwing training programs with same workload on throwing performance with soccer ball. *International Journal of Sport Physiology and Performance*. 2009; 4:474-484. [[Abstract](#)] [[Back to text](#)]
33. WATANABE M & TAKAI S. Age-related change of the factors affecting swimming performance in junior swimmers. *Japanese Journal of Physical Fitness and Sports Medicine*. 2005; 54:353-361. [[Abstract](#)] [[Back to text](#)]