

Research article

Can 8-weeks of training affect active drag in young swimmers?

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Abstract

The aim of this study was to assess the effects of 8-weeks of training on active drag in young swimmers of both genders. Eight girls and twelve boys' belonging to the same swimming team and with regular competitive participation in national and regional events for the previous two seasons participated in this study. Active drag measurements were conducted in two different evaluation moments: at the beginning of the season and after 8 weeks of training (6.0 ± 0.15 training units per week, 21.00 ± 3.23 km per week and 3.50 ± 0.23 km per training unit). The maximal swimming velocity at the distance of 13 m, active drag and drag coefficient were measured on both trials by the method of small perturbations with the help of an additional hydrodynamic body. After 8 weeks of training, mean active drag (drag force and drag coefficient) decreased in girls and boys, although no significant differences were found between the two trials. It seems that 8 weeks of swimming training were not sufficient to allow significant improvements on swimming technique.

Key words: Swimming, children, technique, drag, training effects.

Introduction

Swimming is characterized by the intermittent application of a propulsive force to overcome a velocity-dependent water resistance (i.e., hydrodynamic drag) (Marinho et al., 2009a). Hydrodynamic drag is the force that a swimmer has to overcome in order to maintain his movement through water and is influenced by velocity, shape, size and the frontal surface area (Kjendlie and Stallman, 2008). Theoretical calculations (e.g., Larsen et al., 1981; Massey, 1989), numerical solutions (e.g., Marinho et al., 2009a; 2009b; Silva et al., 2008) and experimental approaches (e.g., Hollander et al., 1986; Rennie et al., 1975; Tairar et al., 1999) have been used to study hydrodynamics in human swimming. Theoretical calculations are based on the application of the fluid mechanics basis and of the Newtonian equations to determine the hydrodynamic forces, whereas numerical simulations consisted of the computational modeling of the water flow around the human body. Concerning experimental approaches, several attempts have been made to apply technology to determine this force (Hollander et al., 1986; Kolmogorov and Duplishcheva, 1992). First trials used measurement techniques determining the resistance of swimmers gliding passively through the water. For example, Dubois-Reymond (1905) measured resistance with a dynamome-

ter, towing people behind a rowing boat, whereas Liljestrand and Strenstrom (1919) towed swimmers by means of a windlass on shore. Amar (1920) and Karpovich (1933) used measurement techniques to determine the drag of swimmers gliding passively through the water. However, it was hypothesized that the movements necessary to create propulsion could induce additional drag (Toussaint et al., 2004). In fact, during swimming, the body is never in a stable prone position, since some propulsive forces are generated. Thus, one of the most important parameters in the swimming hydrodynamics scope is to determine the drag of a body that is actively swimming. This assumption resulted in attempts to determine the drag of a person who is actively swimming. Indeed, passive drag is lower than active drag for the same subject (Kjendlie and Stallman, 2008).

Aiming to achieve this goal, techniques to assess active drag were developed by several research groups in the 70s, based on interpolation techniques (e.g., Clarys and Jiskoot, 1975; di Prampero et al., 1974). These methods involved indirect calculations based upon changes in oxygen consumption, as additional loads were placed on the swimmer. Later on, Hollander et al. (1986) developed the MAD-system (measurement of active drag), relying on the direct measurement of the push-off forces while swimming the front crawl stroke only with arms. In the 90s, Kolmogorov and Duplishcheva (1992) designed another method to determine the active drag: the velocity perturbation method, also known as the method of small perturbations. In this approach, subjects swim a lap twice at maximal effort: (i) free swimming; and (ii) swimming while towing a hydrodynamic body that creates a known additional drag. For both trials, the average velocity is calculated. Under the assumption that in both swims the power output to overcome drag is maximal and constant, drag force can be determined taking into account the difference in swimming velocity. In contrast to the interpolation techniques and the MAD-system, that required heavy and costly experimental procedures, the velocity perturbation method just required the use of the hydrodynamic body device and a chronometer to assess active drag. Additionally, this approach can be applied to measure active drag in all four competitive strokes. Other methods are only applicable to the front crawl (e.g., the MAD-system, Hollander et al., 1986) and the swimmer presents some segmental constraints, since legs are not taken into account as they are held by a pull-buoy. Therefore, the velocity perturbation method seems to represent

a simple and reliable procedure to assess active drag in young swimmers. In fact, the research in competitive young swimmers is much reduced in comparison to the one established in adult swimmers. This lack of investigation in children is due to financial costs but also to ethical issues (Barbosa et al., 2009a). 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. Nevertheless, several assessments tests are performed by young swimmers' coaches. There are testing batteries suggesting procedures for data collection, their analysis and interpretation for young swimmers, including anthropometric, energetic and hydrodynamic procedures (e.g., Carzola, 1993; Barbosa et al., 2009b; Costill et al., 1992; Costa et al., 2009; Silva et al., 2007). Hydrodynamic variables in young swimmers analyses usually included vertical buoyancy and prone gliding after wall push-off since these protocols are very simple to be applied in large samples (e.g., Barbosa et al., 2009b; Carzola, 1993; Silva et al., 2007). However, 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; Tous-saint et al., 1988). Swimming with lower drag at any given velocity reduces the energy cost of swimming, and the movements do not contribute to excessive or unnecessary drag (Millet and Candau, 2002). Indeed, Termin and Pendergast (2001) reported that lateral body movements or excessive kicking movements may reduce the streamline of the body and thus, increase hydrodynamic drag. Arellano et al. (2006) also hypothesized that elite swimmers might be able to generate a vortex with their hands, which would help the body to better slip through the water, thus lowering active drag. In this sense, 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.

The training process can only be improved if one can also improve the methodology used to evaluate each component of the sport performance (Marinho et al., 2006). Moreover, it is not always clear the effects of training in performance or the required temporal period to allow a training load to positively affect performance. In young swimmers, this training control and evaluation should also be a main concern of coaches. For instance, Wakaysohi et al. (1993), Maclaren and Coulson (1999), and Marinho et al. (2009c) reported significant improvements on the aerobic capacity of young swimmers after 12 weeks of training, and Reis and Alves (2006) verified the same effect after 9 weeks of training. Unfortunately, to the authors' best knowledge, few studies with a longitudinal character were conducted attempting to understand the effects of training on active drag in young competitive swimmers (e.g. Kolmogorov et al., 2000). Hence, the aim of this study was to assess the effects of 8 weeks of swimming training on active drag in young swimmers

of both genders.

Methods

Participants

Eight girls and twelve boys belonging to the same swimming team participated in this study. In Table 1, the mean and standard deviation values of their age, height, body mass and personal record of the 100 m freestyle event in short course are presented. Although there were differences in the 100 m freestyle performance, there were no differences in the anthropometrical parameters between boys and girls. All participants have been trained by the same coach and for the same club for the previous two seasons. Both boys and girls were in Tanner stages 1-2. The participants' parents provided their written informed consent and the procedures were approved by the institutional review board.

Procedures

Active drag measurements were conducted in two different moments: (i) at the beginning of the season; and (ii) after 8 weeks of training. This 8 week period corresponded to the general period of preparation of the first macro cycle of training, comprising the months of October and November. The end of this first macro cycle coincided to the participation in the Age-Group Regional Swimming Championship in December. The main aim of this general period of preparation were to develop aerobic capacity and aerobic power and to improve swimming technique in the four strokes and to enhance starts and turns skills. During this 8 week period the subjects performed 48 training units, corresponding to a mean value of 6.0 ± 0.15 training units per week. The swimmers performed 168 km, corresponding to a mean value of 21.00 ± 3.23 km per week and 3.50 ± 0.23 km per training unit. They performed 20.80 km at an intensity corresponding to their aerobic capacity (2.60 ± 1.02 km per week) and 7.2 km at an intensity corresponding to their aerobic power (1.44 ± 0.28 km per week). The remaining training comprised low aerobic tasks (136.50 km) and velocity training (3.50 km). Technical training was performed during the aerobic tasks, including practicing technical drills in each stroke. Dry-land training consisted of two sessions per week of 20 minutes of overall physical condition. The principal exercises were, respectively, abdominals, push-ups, spinal rector, and stretching routines. Subjects performed 3 sets of 15-20 repetitions for abdominals and spinal erector, and 3-4 sets of 10-12 for push-ups. On completion, all swimmers then performed 3-4 stretching exercises for lower an upper extremities. Rest intervals of 2 minutes were permitted between sets and between categories.

The velocity perturbation method with the help of an additional hydrodynamic body was used to determine active drag in front crawl swimming (Kolmogorov and

Table 1. Mean (\pm SD) of age, height, body mass and personal record of the 100 m freestyle event in short course of the sample.

	Age (years old)	Height (m)	Body mass (kg)	100 m personal record (s)
Total (n = 20)	12.20 (.70)	1.51 (.08)	41.76 (8.98)	74.24 (2.98)
Girls (n = 8)	11.63 (.52)	1.52 (.08)	40.50 (8.98)	77.74 (2.76)
Boys (n = 12)	12.58 (.51)	1.51 (.11)	41.79 (6.07)	71.90 (3.12) *

* differences between boys and girls; $p < 0.05$.

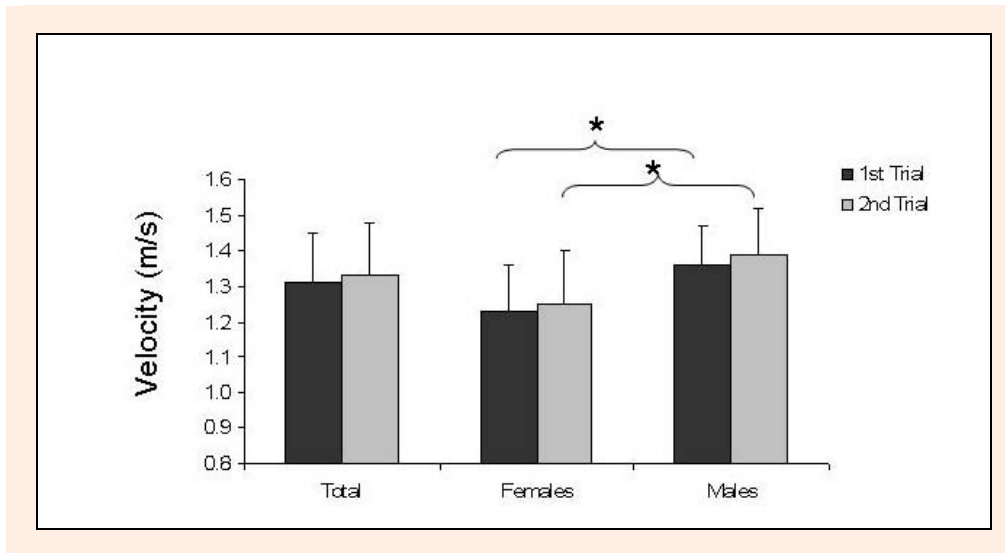


Figure 1. Mean and standard deviation values of swimming velocity for the total sample and for girls and boys in both trials. * $p < 0.05$.

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.

Active drag was calculated as (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 resistance 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 the swimmers.

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. Subjects performed the bouts alone without any other swimmer in the same swim lane to reduce the drafting or pacing effects. 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 an expert evaluator.

Statistical analysis

Normality of distribution was checked by Shapiro-Wilk tests (SPSS 12.0, Lead Tools, 2003). The values of drag, drag coefficient and maximal velocity are presented as mean \pm standard deviation. Comparisons between the first and second trials were conducted using Wilcoxon test. Friedman test was used to analyse differences between girls and boys. The statistical significance was set at $p \leq 0.05$.

Results

In Figures 1, 2, and 3, the values of swimming velocity, drag force and drag coefficient for the total sample and for girls and boys in both trials are presented.

As one can notice, although no significant differences were obtained, swimming velocity increased between the two trials (total: 1.31 ± 0.14 vs. 1.33 ± 0.15 m/s; girls: 1.23 ± 0.13 vs. 1.25 ± 0.15 ; boys: 1.36 ± 0.11 vs. 1.39 ± 0.13 ; $p > 0.05$), corresponding to a 1.53 ± 0.07 % increase for the total sample. Additionally, after 8 weeks of training, mean active drag (drag force and drag coefficient) decreased in girls and boys, although no significant differences were found between the two trials (total: 34.66 ± 16.84 N vs. 32.81 ± 12.60 N, 0.34 ± 0.16 vs. 0.31 ± 0.09 ; girls: 29.18 ± 15.24 N vs. 27.50 ± 10.36 N, 0.35 ± 0.23 vs. 0.30 ± 0.09 ; boys: 38.30 ± 17.49 N vs. 36.35 ± 13.12 N, 0.33 ± 0.11 vs. 0.31 ± 0.09 ; $p > 0.05$). These differences corresponded to a 5.34 ± 0.46 % and 8.82 ± 0.83 % decrease for the total sample, considering the drag force and drag coefficient, respectively.

Moreover, there were no significant differences between boys and girls in both testing trials for the variables analysed, although girls tended to have lower active drag values ($p > 0.05$). Girls presented lower swimming velocities than boys in both moments (first trial: 0.15 ± 0.06 m·s⁻¹ of difference; second trial: 0.13 ± 0.05 m·s⁻¹; $p < 0.05$).

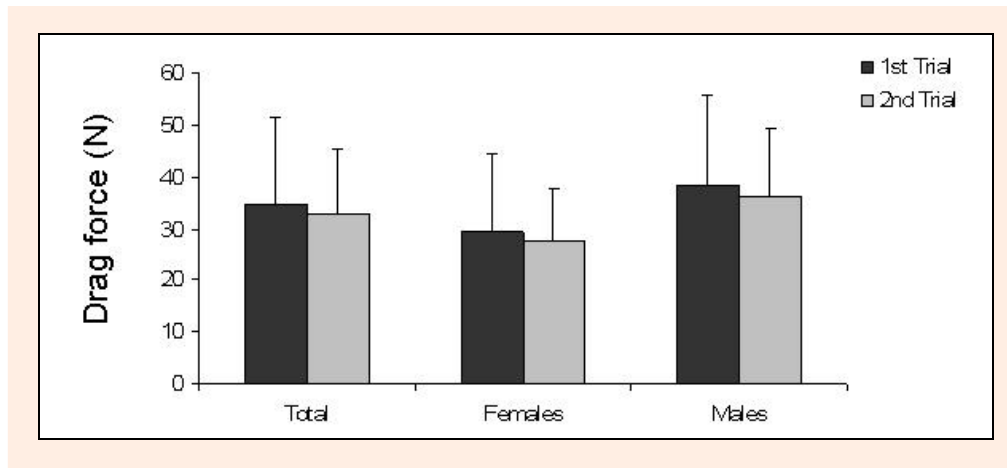


Figure 2. Mean and standard deviation values of drag force for the total sample and for girls and boys in both trials.

Discussion

The purpose of this study was to assess the effects of 8 weeks of training on active drag in young swimmers of both genders. Main data was that no significant differences were found in active drag between the two evaluation moments.

This paper reports only to freestyle. Freestyle is one of the swim strokes with more competitive events and that some coaches present more training routines and drills. However, since it is possible to apply the velocity perturbation method to all competitive strokes, it seems interesting to enlarge this study to all of them and to verify the changes in active drag for butterfly, backstroke and breaststroke after a training period. Although the interesting approach of the velocity perturbation method to determine active drag in swimming, this approach requires the calculation of the frontal surface area of the swimmers. The Clarys's prediction equation (Clarys, 1979) was developed based upon few Dutch adult/Olympic swimmers. Thus, it raises the question whereas this equation can be applied to nowadays swimmers and, especially, if it can be applied to young swimmers. Furthermore, the quality of the Clarys's prediction equation was not very high ($R^2 \approx 0.70$). Therefore, future studies should focus on this issue, attempting to developed better predic-

tion equation to determine the swimmers' frontal surface area. Another important concern of this method is related to the sources of systematic errors, as described by Havriluk (2007), using frequency distributions and meta-analytic procedures. However, one should be aware that the simplicity of the variables used to calculate this parameter remains as one of the main reasons to be usually used in swimming research (e.g. Kjendlie et al., 2004; Kjendlie and Stallman, 2008; Toussaint et al., 1988).

Drag force values of the current study were very similar to values found in other experiments conducted with children, using the velocity perturbation method (e.g. Kjendlie and Stallman, 2008) and the MAD-system (e.g. Toussaint et al., 1990). These values were quite lower than the ones presented by adults, as expected (e.g. Huijing et al., 1988, Toussaint et al., 2004, using the MAD-system; Zamparo et al., 2009, using the method of di Prampero et al., 1974). Regarding drag coefficient, some controversy still remains. Kjendlie and Stallman (2008) found drag coefficient values higher than the ones verified in the current study (0.66 ± 0.14) using a similar sample. Kolmogorov and Duplisheva (1992), using the velocity perturbation method, reported similar values for this variable (drag coefficient: 0.28 ± 0.09). However, Havriluk et al. (2007) stated that drag coefficient values allow determining the effects of performance factors, although this

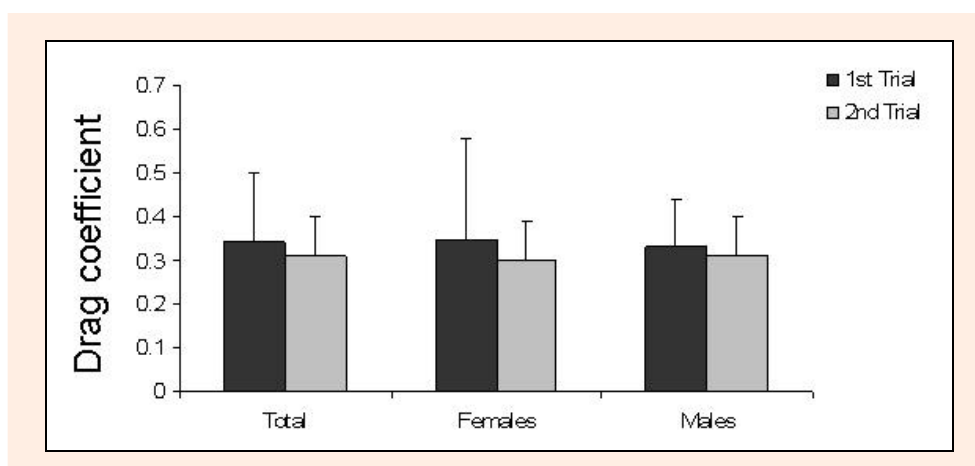


Figure 3. Mean and standard deviation values of drag coefficient for the total sample and for girls and boys in both trials.

finding was only reported for passive drag assessments. Thus, additional research is required regarding this issue in order to clarify it.

It seems that 8 weeks of swimming training (48 training units, 3.50 ± 0.23 km per training unit) were not enough to allow significant improvements on swimming technique. Moreover, there was a non-significant increase in swimming performance (total: 1.31 ± 0.14 vs 1.33 ± 0.15 m·s⁻¹, girls: 1.23 ± 0.13 vs. 1.25 ± 0.15 m·s⁻¹; boys: 1.36 ± 0.11 vs. 1.39 ± 0.13 m·s⁻¹; $p > 0.05$) and also non-significant differences in the subjects' anthropometrical profile between the two evaluation moments (height: 1.51 ± 0.08 vs. 1.52 ± 0.09 m; body mass: 41.76 ± 8.98 vs. 41.58 ± 7.67 kg). These findings are important since velocity, height and body mass could influence hydrodynamic drag (Equations 1, 2 and 3).

Non-significant differences were obtained in drag force and drag coefficient after 8 weeks of training, although a slightly decrease were obtained in these variables. These results can be due to several reasons: (i) the heterogeneity of the sample, since it comprised swimmers of different skill level of the same club; (ii) the small period of training and; (iii) other factors that can influence technique. Indeed, it seems interesting to analyse this changes in drag parameters associated to other technical variables. In the future, it could be of much importance to analyze hydrodynamic drag using the velocity perturbation method, measuring stroke rate, stroke length and stroke index as well. These biomechanical parameters are often used on a regular basis by coaches to analyse swimming technique and can give new insights about training progress (Craig and Pendergast, 1979; Costill et al., 1985). Moreover, it could be interesting to include also the analysis of intra cyclic variations of velocity, since this variable plays an important role in swimming economy and, thus in swimming technique (Barbosa et al., 2008; Seifert et al., 2008).

As shown by Kolmogorov et al. (2000), different physiological training sets can lead to different changes in hydrodynamic characteristics of swimming technique. Kolmogorov et al. (2000) have shown that in swimmers at the age of 14-16 years a large amount of swimming exercises in the training categories of aerobic power (metabolism at the level of maximal oxygen up-take), anaerobic capacity (metabolism at the level of lactate tolerance) and anaerobic power (metabolism at the level of peak lactate production) increases hydrodynamic characteristics of swimming technique. However, these parameters were decreased in the categories of aerobic metabolism (minimum aerobic metabolism and anaerobic threshold). These considerations could advertise coaches to the effects of training in swimming technique. Nevertheless, the findings of Kolmogorov et al. (2000) should be read with careful, since they were obtained after a period of training of 2.5 years, varying the total volume of training from 75-100 km (beginning of the project) to 150-180 km per month (end of the project), values significantly higher than the ones performed by the swimmers of the current study. On the other hand, in the current study, the major part of the training comprised aerobic tasks, representing the anaerobic training a very small component during the

8-weeks of preparation. These swimmers were young swimmers of 11-13 years old and the research was performed during the first general period of preparation, where anaerobic training loads usually represent a small part of the training process. Indeed, Latt et al. (2009) demonstrated that the development of sport-specific technical skills is the most important part during the early years of swimming training in young swimmers. Therefore, it is preferable to underline the findings of Havriluk (2006) who demonstrated that a relatively short duration of carefully targeted instruction could make a meaningful improvement in technique and performance in young competitive swimmers. A one-week of intervention, including three classrooms and five poolside instructional sessions with technique feedback and specific visual and kinaesthetic cues, allowed decreasing active drag coefficient and to increase swimming velocity. Hence, one can recommend that specific training sets concerning technique correction and improvement in young swimmers might be a main aim during training planning in swimming.

During the 8-weeks of training of our sample the anaerobic tasks only represented 2 % of the overall training volume. Maglischo (2003) suggested that lactate tolerance and lactate production training should be used sparingly. However, one should be aware that anaerobic training tasks could enhance the swimmers' hydrodynamic profile (Kolmogorov et al., 2000). Furthermore, Erlandson et al. (2008) stated that to be successful at the international level of swimming competition, intensive training must begin before puberty. Hence, it seems very interesting to keep developing this study during the training season, analysing the effects of different training loads on hydrodynamic drag. For instance, the changes on hydrodynamic drag after the specific preparation period, in which training tasks became more similar to swimming events demands, i.e., more anaerobic tasks, can represent an interesting development on this field. Associated to this concern, the effects of the tapering period on hydrodynamic performance can also represent an important issue to be addressed in the future (e.g., Mujika and Padilla, 2000; Mujika, 2009).

Furthermore, there were no differences between boys and girls concerning active drag. A possible explanation may be related to the similar values of body mass and height in boys and girls found in this study. However, girls tended to have lower drag values than boys, which can be related to the lower velocities achieved by the first ones. Once again, more research is needed with a larger sample to understand the differences between swimmers of both genders. For instance, one can speculate if the differences in active drag between boys and girls can reveal differences between the swimmer's underwater motions (Deschodt and Rouard, 1999). Moreover, both boys and girls swimmers presented the same tendency in active drag decrease between the two evaluation moments. These data supported the findings of Boussaidi et al. (2003), reporting the same global response to exercise in boys and girls, although Boussaidi et al. (2003) only studied metabolic adaptations.

Conclusion

In the present research, 8 weeks of swimming training were not sufficient to allow significant improvements on swimming technique. In competitive swimming, training distance is usually given priority in relation to technique instruction. However, considering the data of this study, it seems that specific training sets and drills concerning technique correction and improvement in young swimmers might represent a main aim during training planning and perhaps training time allocation should be reconsidered.

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References

- Amar, J. (1920) *The human motor*. G. Routledge & Sons, Ltd, London.
- Arellano, R., Terres-Nicol, J.M. and Redondo, J.M. (2006) Fundamental hydrodynamics of swimming propulsion. *Portuguese Journal of Sport Sciences* **6**, 15–20.
- Barbosa, T.M., Keskinen, K.L., Fernandes, R.J. and Vilas-Boas, J.P. (2008) The influence of stroke mechanics into energy cost of elite swimmers. *European Journal of Applied Physiology* **103**, 139–149.
- Barbosa, T.M., Costa, M.J., Marinho, D.A., Coelho, J., Moreira, M. and Silva, A.J. (2009a) Modelling the links between age-group swimming performance, energetic and biomechanical profiles. *Pediatric Exercise Science*, in press.
- Barbosa, T.M., Marinho, D.A., Costa, M., Coelho, J., Cruz, A., Marques, M.C. and Silva, A.J. (2009b) Path-flow analysis model for anthropometric, hydrodynamic and biomechanical variables in age-group swimmers. *Journal of Sports Science and Medicine* **8**(Suppl. 11), 183.
- Boussaidi, L., Petibois, L., Melin, A.M. and Cazorla, G. (2003) Adaptations métaboliques à l'entraînement en début de saison de natation. Différences en fonction du sexe. *Science et Sports* **18**(1), 16–19. (In French: English abstract).
- 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. Baltimore: University Park Press. 3–41.
- Clarys, J.P. and Jiskoot, J. (1975) Total resistance of selected body positions in the front crawl. In: *Swimming II*. Eds: Clarys, J.P. and Lewillie, L. Baltimore: University Park Press. 110–117.
- Costa, A.M., Silva, A.J., Louro, H., Reis, V.M., Garrido, N.D., Marques, M.C. and Marinho, D.A. (2009) Can the curriculum be used to estimate critical velocity in young competitive swimmers? *Journal of Sports Science and Medicine* **8**, 17–23.
- Costill, D., Kowaleski, J., Porter, D., Fielding, R. and King, D. (1985) Energy expenditure during front crawl swimming: predicting success in middle-distance events. *International Journal of Sports Medicine* **6**, 266–270.
- Costill, D., Maglischo, E. and Richardson, A. (1992) *Swimming. Handbook of Sports Medicine and Science*. Blackwell Scientific Publications, Oxford.
- Craig, A.B. and Pendergast, D. (1979) Relationships of stroke rate, distance per stroke and velocity in competitive swimming. *Medicine and Science in Sports and Exercise* **11**, 278–283.
- Deschodt, V.J. and Rouard, A.H. (1999) Influence du sexe sur les paramètres cinématiques de nage chez les crawlleurs de haut niveau. *Science et Sport* **14**, 39–44. (In French: English abstract).
- Di Prampero, P.E., Pendergast, D.R., Wilson, D.W. and Rennie, D.W. (1974) Energetics of swimming in man. *Journal of Applied Physiology* **37**, 1–5.
- Dubois-Reymond, R. (1905) Zum physiologie des schwimmens. *Archive für Anatomie und Physiologie (Abteilung Physiologie)* **29**, 252–279.
- Erlanson, M.C., Sherar, L.B., Mirwald, R.L., Maffulli, N. and Baxter-Jones, A.D. (2008) Growth and maturation of adolescent female gymnasts, swimmers, and tennis players. *Medicine and Science in Sports and Exercise* **40**(1), 34–42.
- Havrulik, R. (2006) Magnitude of the effect of an instructional intervention on swimming technique and performance. *Portuguese Journal of Sport Sciences* **6**(Suppl. 2), 218–220.
- Havrulik, R. (2007) Variability in measurement of swimming forces: a meta-analysis of passive and active drag. *Research Quarterly for Exercise and Sports* **78**, 32–39.
- Hollander, A.P., de Groot, G., van Ingen Schenau, G.J., Toussaint, H.M., de Best, H., Peeters, W., Meulemans, A. and Schreurs, A.W. (1986) Measurement of active drag forces during swimming. *Journal of Sports Sciences* **4**, 21–30.
- Huijting, P., Toussaint, H., Mackay, R., Vervoon, K., Clarys, J. and Hollander, P. (1988) Active drag related to body dimensions. In: *Swimming Science V*. Eds: Ungerechts, B., Wilke, K. and Reichle, K. Champaign, Illinois: Human Kinetics Books. 31–37.
- Karpovich, P.V. (1933) Water resistance in swimming. *Research Quarterly* **4**, 21–28.
- 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., Rummyantseva, 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.
- Kolmogorov, S., Lyapin, S., Rummyantseva, O. and Vilas-Boas, J.P. (2000) Technology for decreasing active drag at the maximal swimming velocity. In: *Proceedings of XVIII International Symposium on Biomechanics in Sports – Applied Program: Application of Biomechanical Study in Swimming*. Eds: Sanders, R. and Hong, Y. Hong Kong: The Chinese University Press. 39–47.
- 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.
- Kjendlie, P.L. and Stallman, R. (2008) Drag characteristics of competitive swimming children and Adults. *Journal of Applied Biomechanics* **24**, 35–42.
- Larsen, O.W., Yancher, R.P. and Baer, C.L. (1981) Boat design and swimming performance. *Swimming Technique* **18**(2), 38–44.
- Latt, E., Jurimae, J., Haljaste, K., Cicchella, A., Purge, P. and Jurimae, T. (2009) Physical development and swimming performance during biological maturation in young female swimmers. *Collegium Antropologicum* **33**(1), 117–122.
- Liljestrand, G. and Strenstrom, N. (1919) Studien uber die physiologie des schwimmens. *Skandinavisches Archiv für Physiologie* **39**, 1–63.
- Maclaren, D.P. and Coulson, M. (1999) Critical swim speed can be used to determine changes in training status. In: *Biomechanics and Medicine in Swimming VIII*. Eds: Keskinen, K.L., Komi, P.V. and Hollander, A.P. Jyväskylä: Grummerus Printing. 227–232.
- Maglischo, E.W. (2003) *Swimming fastest. The essential reference on technique, training, and program design*. Human Kinetics Publishers. Champaign, Illinois.
- Marinho, D., Vilas-Boas, J.P., Keskinen, K., Rodríguez, F., Soares, S., Carmo, C., Vilar, S. and Fernandes, R. (2006) Behaviour of the kinematic parameters during a time to exhaustion test at VO₂max in elite swimmers. *Journal of Human Movement Studies* **51**, 1–10.
- Marinho, D.A., Reis, V.M., Alves, F.B., Vilas-Boas, J.P., Machado, L., Silva, A.J. and Roubao, A.I. (2009a) The hydrodynamic drag during gliding in swimming. *Journal of Applied Biomechanics* **25**(3), 253–257.
- Marinho, D.A., Roubao, A.I., Alves, F.B., Vilas-Boas, J.P., Machado, L., Reis, V.M. and Silva, A.J. (2009b) Hydrodynamic analysis of different thumb positions in swimming. *Journal of Sports Science and Medicine* **8**(1), 58–66.
- Marinho, D.A., Silva, A.J., Reis, V.M., Costa, A.M., Brito, J.P., Ferraz, R. and Marques, M.C. (2009c) Changes in critical velocity and critical stroke rate during a 12 week swimming training period: a case study. *Journal of Human Sports and Exercise* **4**(1), 48–56.
- Massey, B.S. (1989) *Mechanics of Fluids*. Chapman & Hall, London.
- 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. and Padilla, S. (2000) Detraining: loss of training-induced physiological and performance adaptations. Part I: short term insufficient training stimulus. *Sports Medicine* **30**(2), 79-87.
- Mujika, I. (2009) *Tapering and peaking for optimal performance*. Human Kinetics Publishers. Champaign, Illinois.
- Reis, J. and Alves, F. (2006) Training induced changes in critical velocity and v4 in age group swimmers. *Portuguese Journal of Sport Sciences* **6**(Suppl. 2), 311-313.
- Rennie, D.W., Pendergast, D.R. and di Prampero, P.E. (1975) Energetics of swimming man. In: *Swimming II*. Eds: Clarys, J.P. and Lewillie, L. Baltimore: University Park Press. 97-104.
- Seifert, L., Toussaint, H.B., Schnitzler, C., Alberty, M., Chavallard, F., Lemaitre, F., Vantorre, J. and Chollet, D. (2008). Effect of velocity increase on arm coordination, active drag and intra-cyclic velocity variations in front crawl. In: *The Book of Proceedings of the 1st International Scientific Conference of Aquatic Space Activities*. Eds: Nomura, T. and Ungerechts, B.D. Tsukuba: University of Tsukuba. 254-259.
- 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.
- Silva, A.J., Rouboa, A., Moreira, A., Reis, V., Alves, F., Vilas-Boas, J.P. and Marinho, D. (2008) Analysis of drafting effects in swimming using computational fluid dynamics. *Journal of Sports Science and Medicine* **7**(1), 60-66.
- Taiar, R., Sagnes, P., Henry, C., Dufour, A.B. and Rouard, A.H. (1999) Hydrodynamics optimization in butterfly swimming: position, drag coefficient and performance. *Journal of Biomechanics* **32**, 803-810.
- 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., 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.
- Toussaint, H.M., de Looze, M., van Rossem, B., Leijdekkers, M. and Dignum, H. (1990) The effect of growth on drag in young swimmers. *International Journal of Sports Biomechanics* **6**, 18-28.
- Toussaint, H.M., Roos, P.E. and Kolmogorov, S. (2004) The determination of drag in front crawl swimming. *Journal of Biomechanics* **37**, 1655-1663.
- Wakayoshi, K., Yoshida, T., Ykuta, Y., Mutoh, Y. and Miyashita, M. (1993) Adaptations to six months of aerobic swim training. Changes in velocity, stroke rate, stroke length and blood lactate. *International Journal of Sports Medicine* **14**(7), 368-372.
- Zamparo, P., Gatta, G., Pendergast, D., Capelli, C. (2009) Active and passive drag: the role of trunk incline. *European Journal of Applied Physiology* **106**(2), 195-205.

Key points

- The velocity perturbation method seems to be a good, simple and reliable approach to assess active drag in young swimmers.
- Eight weeks of swimming training were not sufficient to allow significant improvements on swimming hydrodynamics.
- There were no differences between boys and girls concerning active drag. A possible explanation may be related to the similar values of body mass and height in boys and girls found in this study.
- Specific training sets concerning technique correction and improvement in young swimmers might be a main aim during training planning.

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