The Effects of Wet Suits on Physiological and Biomechanical Indices During Swimming

Ricardo Dantas de Lucas[1], Pedro Balikian[2], Cassiano Merussi Neiva[2], Camila Coelho Greco[1] & Benedito Sérgio Denadai[1]

[1]Human Performance Laboratory, UNESP, Rio Claro, Brasil.
[2]Laboratory of Experimental Physiology and Nutrition, University of Ribeirão Preto, Brasil.

---

de Lucas, R.D., Balikian, P., Neiva, C.M., Greco, C.C., & Denadai, B.S. (2000). The effects of wet suits on physiological and biomechanical indices during swimming. *Journal of Science and Medicine in Sport 3* (1): 1-8.

The objectives of this study were to verify the effects of wet suits (WS) on the performance during 1500m swimming (V1500), on the velocity corresponding to the anaerobic threshold (VAT) and on the drag force (AD) as well as its coefficient (Cx). 19 swimmers randomly completed the following protocols on different days (with and without WS): 1) maximal performance of 1500m swimming; 2) VAT in field test, with fixed concentration of blood lactate (4 mM) and 3) determination of hydrodynamic indices (AD and Cx). The results demonstrated significant differences ($p < 0.05$) in the VAT (1.27±0.09; 1.21±0.06 $m.s^{-1}$), and in the V1500 (1.21±0.08; 1.17±0.08 $m.s^{-1}$), with and without WS, respectively. However the AD, and its Cx did not present significant differences ($p>0.05$) for the respective maximal speeds of swimming. In summary, we can conclude that WS allows swimmers to reach greater speeds in both, long- and short-course swims. This improvement can be related to the decrease of the AD, since with higher speeds (with WS) the subjects presented the same resistance, as they did when compared to speeds without a WS. Moreover, these data suggest that the methodology used in this study to determine the Cx is unable to detect the improvement caused by WS.

Introduction

In triathlon, an endurance sport which combines swimming in open water with cycling and running, it is common for athletes to use a wet suit (WS) in the swimming stage. The main purpose of this is to protect the athlete against cold water, impeding thermal stress. However, in addition to this effect of thermal insulation, it can also increase swimming speed (Parsons & Day, 1986; Cordain & Kopriva, 1991; Lowdon et al., 1992; Trappe et al., 1996), possibly due to an increase in body flotation, with consequent reduction of drag force (Toussaint et al., 1989). Therefore, the energy spent to move through the water can be smaller due to the hydrodynamic position which the swimmer can assume. This can promote better performance that is determined by the swimmer's ability to generate propulsive force, while reducing the resistance imposed on movement (Miller, 1975; Toussaint & Beek, 1992).

Active drag (AD) has been studied for at least three decades (Di Prampero et al., 1974; Schleihauf, 1979; Hollander et al., 1986). However, researchers have had difficulty in quantifying the AD due to the complexity of human movement when swimming, as well as to the fluid (water) with which they are involved. Even so, some methodologies were created to measure or to estimate the AD. Most of these methodologies are too expensive, requiring specific equipment, or three-dimensional analysis of the underwater movements.

Toussaint et al. (1989) studied the effect of a WS on the active drag during swimming in three varying sub-maximal speed swims, through the MAD-system, and found that the resistance provided by the water can be reduced by 14% when competing at typical race speed (1.25 $m.s^{-1}$). The authors attributed this decrease in resistance to the improvement in flotation, which takes the swimmer's body to a better hydrodynamic position, and possibly the WS influences the three components of AD, particularly frictional and form resistance (and in this way, Cx).

Recently Kolmogorov and Duplishcheva (1992) published an interesting methodology of low cost and easy application to measure AD and its coefficient (Cx) and power output during swimming at maximal velocity. This method has been shown to be reliable, and AD measurements have been verified with a maximum potential error of 6%-8% (Kolmogorov and Duplishcheva, 1992). However, this method presents some limitations for the determination of AD and power output due to the fact that these are measured at maximal velocity. On the other hand, Cx is known in fluid mechanics for being a non-dimensional variable and to be one of the largest determinants of AD. The authors proposed that Cx is a representative index of the level of the swimmer's ability, as well as of anthropometric variables. This index varies from 0 to 1; the closer to 0, the better the swimmer's technical ability and/or the smaller the area of body surface in contact with the water (Kolmogorov and Duplishcheva, 1992; Kolmogorov et al., 1997).

As a WS decreases body density (Cordain & Kopriva, 1991) and consequently exposes a smaller frontal surface area in contact with the water, an improvement of Cx and AD can be expected (Toussaint et al., 1989). However, there were no published data in literature concerning the effect of a WS on the components previously mentioned (AD, Cx and mechanical potency), according to the method described by Kolmogorov and Duplishcheva (1992).

This study presents an opportunity to determine the effect of a WS on the following variables:

1) coefficient of hydrodynamic force (drag coefficient - Cx) and active drag force - AD, in maximal swimming velocity;
2) metabolic index (Anaerobic threshold determined by the blood lactate - VAT);
3) performance in 1500 m swimming (V1500).

Methods and Procedures

Subjects

Nineteen athletes (12 men and 7 women) participated in the study. Eight subjects were triathletes of the Brazilian national rank. Eleven were swimmers who competed regionally. All subjects were participating in regular swimming training programs with average duration of 6±2 $h.wk^{-1}$, corresponding on an average to 18±6 $km.wk^{-1}$ The physical characteristics of the subjects are shown in Table 1. Maximal swim times for 400 m were measured in a 25 m pool. Each swimmer started in the water, without diving. To participate in this study, the subjects gave their prior written consent. The study was also approved by the UNAERP Ethics Committee.

Anthropometry

The body fat content was estimated from the skin thickness, expressed in mm,

Group	Age (yr)	Weight (kg)	Height (cm)	ST (cm)	T400m (sec)
Men	20.7 ± 4.4	70.2 ± 6.8	176.6 ± 5.4	27.6 ± 3.8	305.2 ± 7.8
Women	22.0 ± 3.1	58.4 ± 3.2*	163.4 ± 4.2•	30.1 ± 4.3*	330.8 ± 9.7*

Values are mean±SD
*p<0.05 vs men
ST= skinfold thickness (sum of 3 sites)
T400m - best time of 400m freestyle

Table 1: Physical characteristics and performance of subjects (12 men, 7 women).

representing the sum of three different skin areas (triceps, suprailiac and abdominal for men; thigh, suprailiac and subscapular for women) measured on the right side of the body with Lafayette® Calipers, following the method described by Guedes (1994).

Protocols

Protocols were applied to subjects under two different vestment conditions: 1) Standard swim suit and 2) Neoprene wet suit.

The wet suits were Ironman® (New Zealand), full-body (small size for females and medium size for males), sleeveless, and the same covered the trunk, arms and legs, but not the head of the swimmer. The thickness was 5 mm for the trunk and 3mm for the arms and legs. The dry weights of a WS were 10 kg and 13 kg respectively for small and medium sizes. The wet weight of a WS increased approximately 3 kg for both sizes.

The temperature of the water during the experiments varied from 25°C to 26°C.

The subjects, during a period of 3 weeks, accomplished the following protocols:

1. Determination of AD and Cx

In accordance with the method described by Kolmogorov and Duplishcheva (1992) adapted by Pessoa Filho and Kokubun (1997), the determination of the AD and Cx were made through the comparison of two maximal swimming velocities. This method changes maximal swimming velocity using added drag provided by a hydrodynamic body (HB). The HB consisted of a small cylinder filled with water attached to the bottom of a floating board (Figure 1). The

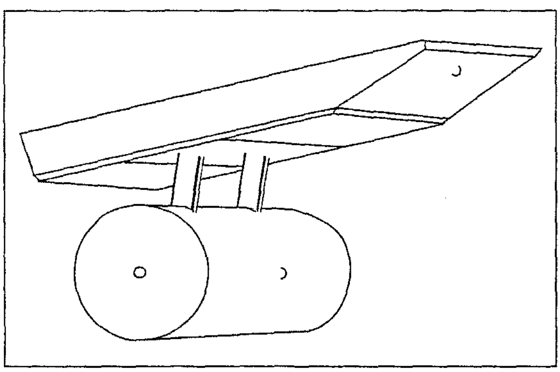

Figure 1: The hydrodynamic body.

hydrodynamic properties of the HB were previously calibrated allowing us to calculate the drag at any velocity, in accordance with Kolmogorov and Duplishcheva (1992) and in our laboratory by Pessoa Filho and Kokubun (1997). Using this method, subjects performed two 30 m trials during which the average velocity was calculated. One trial consisted of free swimming and during the other, the swimmer towed (3.5-4.5 body lengths behind) a HB.

Twelve of the nineteen subjects accomplished this protocol in a 50 m pool. Between each trial the subjects rested for 30 min. Randomly, the HB was added in one of two trials. The time to cover 30 m (between the 15th and 45th m) was registered using a hand operated stopwatch.

Active drag and Cx were calculated using the assumption of equal power output in both trials. Therefore, through the following equation, the Cx was calculated:

$$C\chi = \frac{Fb.v^2}{\frac{1}{2}\, p.S.\,(v_1^3 - v_2^3)} \qquad (1)$$

where Fb is the drag added through HB, p is the density of the water, S characterizes the surface area (m^2) of the swimmer (S was found using body volume [m^3] to the power) and v_1 and v_2 are the velocities without and with the addition of HB, respectively.

The following equation determined the values of AD during maximal velocity:

$$A_D = \frac{Fb \bullet v_2 \bullet v_1^2}{v_1^3 - v_2^3} \qquad (2)$$

2. Determination of VAT

The anaerobic threshold (VAT) was determined in a field test (25 m pool), in accordance with the protocol proposed by Mader et al. (1976) : 3 x 200 m with intensities of 85%, 90% and 95% of the maximal effort for the distance (previously determined during the training sessions) and passive recovery of 15 minutes between the bouts. After the trials, 25 µl of arterialized blood was collected from the subject's ear lobe in the 1st, 3rd and 5th minutes for the determination of blood lactate concentration (YSI 2300 STAT). Thus, through linear interpolation, the velocity corresponding to a 4mM lactate concentration was determined.

3. Determination of V1500

The subjects were asked to swim 1500 m, in a 25 m pool, at maximal velocity. Through the final time achieved, the mean velocity of the 1500 m was calculated.

Statistical analysis: Two-way (gender by clothing) ANOVA was used to evaluate all data. When responses were similar between gender, the data were combined for comparison between different clothing conditions (with and without a WS). The comparison of conditions with and without the use of a WS was made using a Student's paired t-test. In the test, the data are represented as the mean ± standard deviation and the significance level was set at $p \leq 0.05$.

Results

Swim times were significantly ($p<0.05$) reduced in 1500 m swim trial when the subjects were wearing the WS (1231.5±81.7s) than when wearing traditional swim suit (1278.7±87.1s), granting an improvement of 3.7%. The results presented in Table 2 demonstrated significant differences ($p<0.05$) in the VAT (1.27±0.09;

	Without Wetsuit			With Wetsuit		
	V_{AT} ($m.s^{-1}$)	V_{1500} ($m.s^{-1}$)	$\%V_{AT}$	V_{AT} ($m.s^{-1}$)	V_{1500} ($m.s^{-1}$)	$\%V_{AT}$
Female (N=7)	1.20± 0.04	1.14 ± 0.08	95.8 ± 2.8	1.25 ± 0.05*	1.18± 0.05*	94.6 ± 2.1
Male (N=12)	1.23± 0.08	1.19 ± 0.04	96.4 ± 3.4	1.29 ± 0.06*	1.25± 0.04*	96.3 ± 2.9
Overall (N=19)	1.21± 0.06	1.17 ± 0.08	96.1 ± 4.3	1.27 ± 0.09*	1.21± 0.08*	95.4 ± 2.1

*p<0.05 in relation to without a WS

Table 2: Mean values and standard deviations of the velocity corresponding to the anaerobic threshold (V_{AT}), the performance in 1500m (V_{1500}) and the percentile of the velocity in 1500m in relation to the velocity corresponding to anaerobic threshold (V_{AT} - V_{1500}/V_{AT} X 100), with and without the use of a wet suit (N=19).

	Without Wetsuit			With Wetsuit		
Subjects	Vmax ($m.s^{-1}$)	A_D (N)	Cx	Vmax ($m.s^{-1}$)	A_D (N)	Cx
Female						
1- Swimmer	1.49	37.24	0.220	1.57	48.95	0.259
2- Triathlete	1.37	32.52	0.236	1.47	42.00	0.237
3- Swimmer	1.35	26.27	0.208	1.42	33.25	0.231
4- Triathlete	1.27	37.38	0.355	1.35	59.49	0.481
5- Triathlete	1.12	36.16	0.370	1.22	29.95	0.245
X±SD	1.32±0.13	33.91±4.70	0.278±0.07	1.40±0.13*	42.72±11.97	0.291±0.10
Male						
1- Swimmer	1.64	60.45	0.270	1.75	72.28	0.275
2- Swimmer	1.59	74.80	0.330	1.64	86.009	0.356
3- Triathlete	1.52	48.30	0.265	1.57	44.12	0.217
4- Triathlete	1.50	74.6	0.432	1.56	60.16	0.317
5- Triathlete	1.45	66.96	0.372	1.53	65.80	0.340
6- Triathlete	1.44	49.09	0.298	1.49	38.60	0.212
7- Triathlete	1.41	45.62	0.257	1.51	67.79	0.349
X±SD	1.51±0.08	59.89±12.43	0.318±0.06	1.58±0.09*	62.12±16.35	0.295±0.06
Overall (N=12)	1.43±0.14	49.02±16.47	0.301±0.07	1.50±0.12*	54.24±17.25	0.293±0.07

*p<0.05 in relation to without a WS

Table 3: Mean values and standard deviations of the maximal velocity (Vmax) drag force (A_D) in Vmax, and the coefficient of drag force (Cx) obtained in accordance with the methodology proposed by Kolmogorov and Duplischeva (1992) with and without a wetsuit.

1.21±0.06 $m.s^{-1}$) and in the V1500 (1.21±0.08; 1.17±0.08 $m.s^{-1}$) with and without WS, respectively. The subjects swam the 1500m in the same percentage of the VAT in both conditions (95.4±2.1%; 96.1±4.3%) with and without a WS, respectively. No difference in effect when wearing a WS was observed between males and females (Table 2).

The speed corresponding to the 30m trial was also significantly different with the use of a WS (1.50±0.12 versus 1.43±0.14 $m.s^{-1}$). However, the use of a WS did not significantly modify ($p>0.05$) the Cx. It should be noted that the results were quite different among the subjects, with 41.6% of the sample presenting a decreased Cx, while the remaining (58.3%) presented an increase. The AD did not present a significant difference (54.24±17.25 versus 49.02±16.47 N) among the two vestment conditions and varied in the same order that the Cx did among the subjects, which is demonstrated in Table 3. No difference in effect when wearing a WS was observed between males and females (Table 3).

Discussion

Recent studies have shown the several determinants of performance of the triathlon (O'Toole and Douglas, 1995; Margaritis, 1996). In the swimming stage, it is interesting to analyze the effect of a WS that is usually used for protection against cold water. Parsons and Day (1986) studied the effects of a WS on the performance of triathletes. The authors concluded that with the use of a WS, athletes were able to swim 7% faster. Cordain and Kopriva (1991) observed the influence of body composition on swimming performance, with and without the use of a WS. The use of a WS characterized a 3.5% gain in 1500 m performance, and 4.9% gain when swimming 400 m. The authors concluded that individuals with a lower percentile of body fat (%BF) gained greater benefit from the use of a WS than individuals with higher %BF, probably due to the flotation effect. Trappe et al. (1995) studied three different models of WS, as to the surface area of body being covered (full, long and short suit). These authors found a reduction in oxygen uptake, as well as in minute ventilation, when the subjects used a WS in four sub-maximal speed swims (varying from 29% to 65% VO_2 max). However, the notable outcome of this study is that this improves in proportion to the area of body surface covered by a WS. These authors attribute the better efficiency of long suits (full and long) to the decrease of drag force due to greater flotation, as well as smaller friction resistance.

The improvement of V1500 obtained in our study (3.7%) are in compliance with Cordain and Kopriva (1991) (3.5%). However, the increase was smaller than found by Parsons and Day (1986) (7.2%) and Lowdon et al. (1992) (10%). This difference can be explained, at least, as a function of the performance level of the subjects, who participated in the previously mentioned studies. In the Parsons and Day (1986) and Lowdon et al. (1992) studies, the subjects (triathletes) had a mean velocity of 0.77 $m.s^{-1}$ and 0.90 $m.s^{-1}$ for a 1500 m swim respectively, while in the present study, the subjects (swimmers and triathletes) presented a greater velocity for a 1500 m (1.17 $m.s^{-1}$). As demonstrated by Chatard et al. (1995), the greater the performance level, the lower the expected effect of a WS on the performance.

Although the validity of the use of the 4 mM blood lactate concentration as a measure VAT has been questioned (Stegmann et al., 1981; Tegtbur et al., 1993), recent studies have demonstrated that it presents a great validity as an index of endurance performance in competitive swimmers (Wakayoshi et al. 1993a) and of detecting the adaptations to aerobic training for six months in the swimming (Wakayoshi et al. 1993b). Moreover, until this moment, there were no data which had shown that a fixed blood lactate concentration might represent a different physiological stress with and without a WS. The same seems to be appropriate for the objective of present study.

It is important to note that the subjects presented higher VAT values while wearing a WS, supporting the idea of improvement in the economy of energy cost, which are in agreement with the results of Trappe et al. (1996), since the subjects were able to swim faster (with a WS), at the same intensity (VAT). The percentage of the V1500 in relation to VAT (VAT - V1500/VAT x 100), with and without WS, did not present significant difference. Therefore, it can be proposed that the improvement in performance with the use of a WS happened in function of the improvement of VAT.

In relation to the hydrodynamic indices, more specifically the AD, Miller (1975) and Toussaint and Beek (1992) proposed that the AD is formed by three components: frictional resistance, form resistance and wave resistance. Concisely, a frictional resistance is related to the roughness of the surface area in contact with the fluid. The form resistance is originated from the form and the area of the object that is in contact with the fluid and is determined by Cx and finally wave resistance, that is originated from the deformation of the interface water/air, in front of the object in movement. It is the sum of these three resistance figures that is given by AD. Toussaint et al. (1989) showed a reduction of the AD caused by the use of WS and proposed that one of the great determinants of this improvement is the decrease of Cx.

In our study, the use of a WS determined different influences on Cx. While 41.6% of the subjects presented improvement, i.e., a decrease in Cx, the others (58.3%) displayed an increase with the use of a WS. As all subjects presented improvement in performance trials of 30m, it is not possible to attribute the improvement of performance in function to the decrease of Cx. However, as the mean value of the AD with a WS was not statistically different without the use of a WS, it is possible to consider that in these conditions a decrease of AD has existed, since this variable is proportional to the square of swimming velocity. Thus, other factors may exist, not determined in this study but which are modified with the use of a WS and can present implications.

Our hypothesis, for the lack of improvement of Cx with a WS is that the methodology used in our study did not possess enough sensitivity to detect the flotation effect and the decrease of the resistance that a WS provides. Although such methodology proves to be advantageous due to low cost and easy application while possibly not deteriorating the natural pattern stroke (opposite to MAD - system), it also presents some problems which should be pointed out. The methodology proposed by Kolmogorov & Duplishcheva (1992) assumes that a swimmer generates a power output which is the same in both trials (with and without HB) which does not necessarily take place, and can interfere with results of hydrodynamic measures for being based on the comparison between two trials.

Under the conditions of this study, it can be concluded that the use of a WS improves performance in both short (30 m) and long (1500 m) swimming distances. The effects of a WS on Cx complied with the methodology proposed by Kolmogorov and Duplishcheva (1992) showed quite heterogeneous responses among the subjects studied. The improvement of performance could be not attributed to the isolated modification of this index, although a reduction of AD may have occurred since the velocity in 30m was greater with a WS for the same value of AD. Finally, it should be considered that the fact of Cx and AD were measured at maximal swimming speed in a short distance (30m), while the physiological tests (VAT and 1500-m pace) were realized at greater distances, which could explain the absence of similarity in the changes which occurred in the physiological and biomechanical indices, found in the present study.

References

Chatard, J.C., Senegas, X., Selles, M., Dreanot, P., & Geyssant, A. (1995) Wetsuit effect: a comparison between competitive swimmers and triathletes. **Medicine Science and Sports Exercise 27: 580-6.**

Cordain, L., & Kopriva, R. (1991). Wetsuits, body density and swimming performance. **British Journal of Sports Medicine 25:** 31-3.

Di Prampero, P.E., Pendergast, D., Wilson, D.W., & Rennie, D.W. (1974). Energetics of swimming in man. **Journal of Applied Physiology 37:** 1-5.

Guedes, D.P. (1994). **Composição corporal: Princípios, técnicas e aplicações.** Londrina, APEF.

Hollander, A.P., De Groot, G., Van Ingen Shbenau, G.J., Toussaint, H.M., De Best, H., Peeters, W., Meulemans, A., & Screurs, A.M. (1986). Measurement of active drag during crawl arm stroke swimming. **Journal of Sports Sciences 4:** 21-30.

Kolmogorov, S.V., & Duplishcheva, O.A. (1992). Active drag, useful mechanical power output and hydrodynamic force coefficient in different swimming strokes at maximal velocity. **Journal of Biomechanics 25:** 311-18.

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

Lowdon, B.J., McKenzie, D., & Ridge, B.R. (1992). Effects of clothing and water temperature on swim performance. **Australian Journal of Science and Medicine in Sports 24:** 33-38.

Mader, A., Heck, H., & Hollmann, W. (1976). Evaluation of lactic acid anaerobic energy contribution by determination of post-exercise lactic concentration of ear capillary blood in middle-distance runners and swimmers. In **The International Congress of Physical Activity Sciences**, pp. 187-199. Quebec, Canada.

Margaritis, I. (1996). Features limitants de la performance en triathlon. **Canadian Journal of Applied Physiology 21:** 1-15.

Miller, D.I. (1975). Biomechanics of swimming. In Wilmore, J.H. & Keogh, J.F. (Eds.). **Exercise and Sport Sciences Reviews,** New York: Academic Press 3: 219-48.

O'Toole, M.L., & Douglas, P.S. (1995). Applied physiological of triathlon. **Sports Medicine 19:** 251-67.

Parsons, L., & Day, S.J. (1986). Do wetsuits affect swimming speed? **British Journal of Sports Medicine 20:** 128-31.

Pessoa Filho, D.M., & Kokubun, E. (1997). Proficiência mecânica e desempenho de nado: Uma análise a partir da determinação do arrasto no meio liquido. In: **Congresso Brasileiro de Biomecânica,** p.63-7 Campinas, Brasil.

Schleihalf, E. (1979). A Hydrodynamic analysis of swimming propulsion. In: Terauds, J. & Bedingfield, E.W. (Eds) **Swimming III,** Baltimore: University Park Press, pp.70-109.

Stegmann, H., Kindermann, W., & Schnabel, A. (1981). Lactate kinetics and individual anaerobic threshold. **International Journal Sports Medicine 2:** 160-5.

Tegtbur, U., Busse, M.W., & Braumann, K.M. (1993). Estimation of an individual equilibrium between lactate production and catabolism during exercise. **Medicine and Science in Sports and Exercise 25:** 620-7.

Toussaint, H.M., & Beek, P.J. (1992). Biomechanics of competitive front crawl swimming. **Sports Medicine 13:** 8-24.

Toussaint, H.M., Bruinic, L., Coster, R., De Looze, M., Rossem, B.V., Veenen, R.V., & Groot, G. (1989). Effect of a triathlon wetsuit on drag during swimming. **Medicine Science and Sports Exercise 21:** 325-28.

Trappe, T.A., Starling, R.D., Jozsi, A.C., Goodpaster, B.H., Trappe, S.W., Nomura, T., Obara, S., & Costill, D.L. (1995). Thermal responses to swimming in three water temperatures: influence of a wetsuit. **Medicine Science and Sports Exercise 27:** 1014-21.

Trappe, T.A., Pease, D.L., Trappe, S.W., Troup, J.P., & Burke, E.R. (1996). Physiological responses to swimming while wearing a wetsuit. **International Journal of Sports Medicine 17:** 111-4.

Wakayoshi, K., Yoshida, T., Udo, M., Harada T., & Morritani T. (1993a). Does critical swimming velocity represent exercise intensity at maximal lactate steady-state? **European Journal Applied Physiology and Occupational Physiology 66:** 90-95.

Wakayoshi, K., Yoshida, T., Ikuta, Y., Mutoh, Y., & Miyashita, M. (1993b). Adaptations to six months of aerobic swim training. Changes in velocity, stroke rate, stroke length and blood lactate. **International Journal of Sports Medicine 14:** 368-72.