ACTIVE DRAG CHANGES BETWEEN TRAINING SEASONS IN YOUNG SWIMMERS

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The purpose of this study was to verify the changes in the hydrodynamic profile of young swimmers from one training year to the next. Twelve male and eight female swimmers (initial age: 13.87 ± 0.82 and 12.45 ± 0.34 years) were evaluated in front crawl using the velocity perturbation method, for determination of maximal velocity (V_{max}), active drag (D_a), drag coefficient (C_{Da}) and power output. Interval between 1st and 2nd evaluations was 9 months. Female swimmers showed lower C_{Da} at the 2nd evaluation, probably caused by stronger technical improvement. In spite of dramatic increases in body mass, competitive performance, and V_{max}, D_a and C_{Da} remained unchanged and the Froud number for a fixed velocity of 1.5 $m.s^{-1}$ decreased, in both genders. Reduced Froud number, dependent on body height, may have counterbalanced the effect of increased V_{max} and body mass, reducing the wave drag component.

KEY WORDS: front crawl, active drag, velocity perturbation method, wave drag

INTRODUCTION: Active drag (D_a) is the force that a swimmer has to surpass in order to maintain his movement through the water, while relying on his capacity to generate propulsion with his body segments. Contrarily to what happens with passive drag, measured by towing the body in a streamlined and static position, mainly dependent on the physical characteristics of the swimmer (Clarys, 1979), D_a showed a large amplitude of values for swimmers with similar physical characteristics (Kolmogorov & Duplishcheva, 1992), which has been interpreted as a fundamental dependency on technique. Nevertheless, several studies reported an association of D_a with some geometrical determinants of the human body, especially with body maximal cross section area (Huijing et al., 1988; Toussaint et al., 1990). The adimensional drag coefficient (C_{Da}), used to compare drag of different objects at different speeds, relates D_a to the order of magnitude estimate:

$$C_{Da} = D_a / 1/2 \rho V^2 S \qquad (1)$$

The Reynolds number (R_e) expresses the relative importance of inertial over viscous forces in a dimensionless way

$$R_e = V.l / \gamma \qquad (2)$$

V – velocity of the flow interacting with the body
l – caracteristic length of the body
γ - kinematic viscosity (ratio between dynamis viscosity and the density of the fluid)

C_D is a function of R_e and of the geometrical configuration of the body. For large R_e, inertial forces predominate. When $R_e \geq 10^6$, as is the case of the human body moving through the water, skin friction becomes neglectable (Clarys, 1979). It can be concluded, thus, that pressure drag prevails in total drag encountered by a completely submersed swimmer, depending mainly on S and the squared velocity (Vorontsov & Rumyantsev, 2000).
Moving at the surface causes extra drag by generating waves. The relative amount of energy lost by wave generation is expressed by the dimensionless Froud number (F_e):

$$F_e = U / \sqrt{g.l} \qquad (3)$$

U – velocity of the flow interacting with the body
l – caracteristic length of the body
g – acceleration of gravity (9,81 $m.s^{-2}$)

Wave drag experienced when swimming at high velocities near or at the surface can be the largest component of the total drag on the swimmer, since it is considered to relate to the

cubed velocity (Vorontsov & Rumyantsev, 2000). In this context, F_e can be a more appropriate criterium of kinematical conformity than R_e (Lighthill, 1993).
The purpose of this study was to verify the changes in the hydrodynamic profile of young swimmers of both genders, from one training year to the next.

METHODS: 20 national level swimmers participated in this study, 8 females and 12 males. The time interval between evaluations was 9 months. Age and physical characteristics in the 1st evaluation (1st Y) and the 2nd evaluation (2ndY) are indicated in Table 1 (male swimmers) and Table 2 (female swimmers). Estimates of R_e and F_e were done using equations (2) and (3), assuming body height as the characteristic length and the value of $0.86.10^{-6}$ $m^2.s^{-1}$ as the kinematic viscosity of water at 26°C (Toussaint et al., 1990).
The velocity perturbation method (VPM) was used for the measurement of D_a and the related parameters C_D and external power output (Po) (Kolmogorov & Duplisheva, 1992). Swimmers were evaluated in an indoor 25 m pool. Manual timing of a 13 m (11 to 24 m) maximal sprint freestyle swim permitted the calculation of maximal velocity (V_{max}). A second timed maximal 13 m freestyle swim, in rested conditions, towing a hydrodynamic body of known characteristics, allowed us to use the observed difference in velocity for the calculation of the added drag, and then D_a, C_D and Po for each swimmer (Active Drag, V1.06, Magus, 1992-94, 97: http://www.arh.ru/constanta/SwimDrag), assuming equal power output for both trials. The hydrodynamic body was attached to a harness wore by the swimmer with a low friction and non elastic 8.35 m cable.
Competitive performance was assessed considering the swimmer's best time in the 100 m freestyle (BT_{100mF}) at the moment of the VPM evaluations.
Differences between evaluations were computed using the *t* test for paired samples and between genders using the *t* test for independent samples. Significance was set at $p \leq 0.05$.

RESULTS: Main results of this study are showed in Table 1 and 2. During the time elapsed between evaluations, swimmers went through important physical changes, with simultaneous competitive performance progress. VPM evaluation showed also significant increase of V_{max}, but C_D remained unchanged for the whole group. R_e increased for both genders but F_e only increased in male swimmers. $F_e1.5$, however, was significantly reduced in both genders, reflecting changes in height between evaluations (Figure 1).

Table 1 Physical characteristics, hydrodynamic profile and performance at the 100 m freestyle for male swimmers one training year (1st year) to the next (2nd year).

	1st year	2nd year	p	Mean variation (%)
Decimal age (years)	13,87 ± 0,82	15,14 ± 0,82	0,000	--
Height (cm)	164,92 ± 6,34	171,35 ± 6,17	0,000	3,74 ± 2,35
B_m (kg)	52,57 ± 6,55	57,82 ± 5,74	0,000	9,17 ± 5,54
V_{max} ($m.s^{-1}$)	1,59 ± 0,05	1,67 ± 0,06	0,001	4,51 ± 3,55
D_a (N)	57,11 ± 19,13	64,31 ± 12,14	0,178	11,09 ± 26,36
C_{Da}	0,3201 ± 0,100	0,3108 ± 0,066	0,732	-4,17 ± 30,48
P_o (W)	91,23 ± 31,33	107,46 ± 21,16	0,066	15,12 ± 25,21
F_e	0,3960 ± 0,001	0,4072 ± 0,015	0,022	2,67 ± 3,48
F_e1,5	0,3731 ± 0,001	0,3660 ± 0,0015	0,000	-1,94 ± 1,25
R_e	$3,06*10^8 \pm 1,8*10^7$	$3,33*10^8 \pm 1,9*10^7$	0,000	8,06 ± 4,61
BT_{100mF} (s)	64,15 ± 3,31	60,93 ± 2,48	0,003	-5,34 ± 4,94

Table 2 Physical characteristics, hydrodynamic profile and performance at the 100m freestyle for female swimmers from one training year (1st year) to the next (2nd year).

	1st year	2nd year	p	Mean variation (%)
Decimal age (years)	12,45 ± 0,34	13,61 ± 0,34	0,000	--
Height (cm)	160,25 ± 6,53	165,16 ± 6,73	0,003	2,96 ± 1,80
B_m (kg)	47,25 ± 4,86	52,73 ± 4,09	0,002	10,38 ± 5,83
V_{max} ($m.s^{-1}$)	1,46 ± 0,09	1,56 ± 0,11	0,007	6,63 ± 4,30
D_a (N)	38,80 ± 15,75	42,25 ± 10,20	0,610	3,35 ± 42,48
C_{Da}	0,2778 ± 0,117	0,2500 ± 0,0535	0,595	-19,93 ± 52,75
P_o (W)	56,44 ± 23,78	66,34 ± 17,95	0,344	9,91 ± 39,66
F_e	0,4060 ± 0,002	0,4020 ± 0,001	0,795	-0,53 ± 4,92
F_e1.5	0,3785 ± 0,008	0,3728 ± 0,007	0,002	-1,53 ± 0,94
R_e	$3,21.10^8 \pm 3,03.10^7$	$3,37.10^8 \pm 3,33.10^7$	0,041	4,75 ± 5,35
BT_{100mF} (s)	74,10 ± 8,93	65,69 ± 2,40	0,015	-12,59 ± 10,93

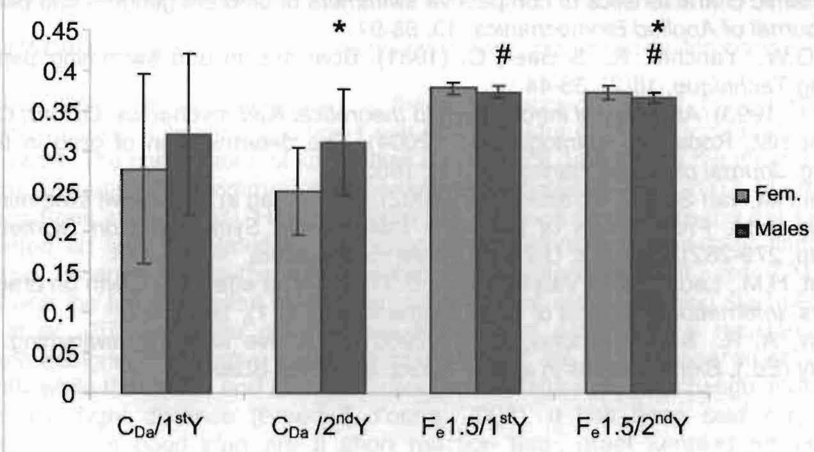

Figure 1 C_{Da} and F_e1.5 of male and female swimmers in 1stY and 2ndY. Significant differences between gender (* $p \leq 0.05$) and training year (# $p \leq 0.01$) are indicated.

DISCUSSION: In spite of questionable assumptions (Toussaint et al, 2004), results from VPM compared well with other studies. Care was taken not to have velocity differences between free and towed swims higher than 10%, as indicated by Kolmogorov & Duplisheva (1992). Contrarily to Kolmogorov et al. (1997) we found lower values of C_{Da} for female swimmers but only in 2ndY, due probably to more pronounced technical improvement during this period, as the female swimmers of this study are younger, and so have less training experience, than male swimmers.

It can be concluded from equation (3) that height *per se* may constitute a hydrodynamical advantage for a competitive swimmer, as was first put by Larsen et al. (1981). Toussaint et al. (1990), in a group of young swimmers evaluated within a time span of 2.5 years, did not find an increase in D_a as would be expected from the physical changes showed by the subjects, due to growth and body strengthening. The authors imputed this fact to a counterbalancing effect of increased height in total drag by reducing the wave component. Notwithstanding the shorter time span of our study, our results seem to confirm this hypothesis. Nevertheless, care must be taken in the interpretation of these results since technical improvement may have also played a role in this development and the assumption of the quadratic dependence of D_a on velocity may have caused its underestimation, since wave drag can account as much as 21% of total D_a for velocities higher than 1.70 $m.s^{-1}$ (Toussaint et al, 2002).

CONCLUSION: The efficiency gain showed by the swimmers from one training year to the next (same D_a for higher velocities) is attributable to a reduced relative wave drag component, as is indicated by the lower F_e for a fixed velocity.

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