AVERAGE RESULTANT IMPULSE PER PHASE IN SWIMMING: A TOOL FOR TECHNICAL ANALYSIS

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INTRODUCTION

Performance in competitive swimming relies mainly on maximal energy output and the efficiency of the power transfer process to overcome drag. This last factor can be assessed by the measurement of swimming economy, which is the energy cost associated to a given velocity of displacement. A lower energy cost for submaximal paces and a faster maximum swimming speed are advantages that result from a better swimming economy. The inter-individual variation of energy cost is, usually, large and is thought to depend mainly on technical ability (Toussaint, 1992). Nevertheless, few studies have focused on the relationship between swimming economy and stroke mechanics, and only in front crawl swimming (Chatard et al., 1990).

Averaged impulses resulting from the difference between propulsion and body drag (ARI) can be calculated in each phase of a stroke cycle, providing us with information about the technical proficiency of the swimmer and identifying weak points to correct. This approach has been used for breaststroke (Van Tilborg et al., 1983; Vilas-Boas & Fernandes, 1993), but not, to our knowledge, regarding the other competitive swimming strokes.

The purpose of this study was to investigate the relationship between ARI, calculated from hip point kinematics, swimming economy and competitive performance in front crawl and backstroke.

METHODS

Twelve well-trained male swimmers participated in this study (age: 17.75±1.82 years, height: 178.46±6.07 cm, body mass: 67.63±6.59 kg, and %FAT: 7.63±2.02). Testing protocol consisted on 2 sub maximal 250 meters swims, with progressive intensity, at 75 and 85 % of maximal velocity for that distance, and 1 x 400 meters maximal swim. Oxygen uptake was measured from the expired air collected during 8 seconds after the finish of each swim. Swimmers were free of equipment and were instructed to keep a constant pace in each swim, following a light tracer.

The $\dot{V}O_2$ / swimming speed relationship estimated for each subject was considered to be his swimming economy profile. Swimming economy, expressed in $mlO_2.m^{-1}$, was calculated from each $\dot{V}O_2$ individual regression line at 1.1, 1.2 and 1.3 $m.s^{-1}$ in front crawl and at 1.0, 1.1 and 1.2 $m.s^{-1}$ in backstroke. An exponential regression technique was used to describe the relation between swimming speed and rate of metabolism (Hollander et al., 1990).

The swimmers were filmed underwater (sagital plane) during the 400 swim with a video camera (60 Hz), fixed from the wall, 6 m from the swimmer, perpendicular to the direction of swimming and 30 cm underwater.

Pull kinematic characteristics and hip acceleration were obtained by numerical treatment of data from hand displacement and hip horizontal displacement and evaluated by a video analysing system (Ariel Performance Analysis System). A complete underwater arm stroke, from the entry in the water to the exit of the hand was digitised, always corresponding to the right side of the swimmer. Marks were fixed on the joint axes of the arm, on the hand, at the level of the head of the metacarpal bones, and at the hip (trocantherion). The identification of each of the three phases of the underwater hand path in front crawl, the downsweep (DS), the insweep (IS), and the upsweep/exit (US/E) and in backstroke, the initial downsweep (IDS), the upsweep (US), and the final downsweep (FDS), was made from the underwater hand path. Absolute duration of each phase was also measured.

Due to the instrumental difficulty in assessing total body centre of gravity displacement in swimming, which implies simultaneous filming under and over the water of the execution, the study of the hip joint point kinematics has been considered as an acceptable approach (Costill et al., 1987; Maglischo et al., 1987). In the non-simultaneous strokes, the horizontal velocity of the trunk is less submitted to the inertial forces generated by the body section above the water as it happens, for instance, in breaststroke (Colman & Persyn, 1993), in spite of the fact that the side to side disruptive movements of the lateral alignment that often occur at the level of the hip, in strokes where the arms move alternately, could produce apparent peaks of acceleration.

As suggested by Maglischo et al. (1987), in order to reduce the error in the calculation of the body horizontal velocity by digitising the hip point, we used the céntre of the body at the hip rather than the anatomical mark at the trocantherion.

A digital filter with a cutoff frequency of 10 Hz was used to smooth kinematic data of the hand and arm. In the case of the hip point, a cutoff frequency of 5 Hz was chosen for a better estimation of second derivative curves. To estimate velocity and acceleration curves, the first and second derivative of the displacement of the hip were calculated using a digital differentiation filter integrated in the software package Acqknowledge881, 3.0 (Biopac Systems, Inc.). The resultant impulse was calculated using the mean horizontal acceleration per phase, the phase duration and body mass.

Best performances for the 100, 200, 400 and 1500 m swims were taken from official competitions that took place the month before or after the testing measurements.

Swimmers were splited into two groups according to the results of the swimming economy profile test to investigate for differences in the ARI per phase.

All data are expressed as means ± S.D.. Student's t-test was performed to evaluate the differences in ARI, phase to phase, between the two groups based on swimming economy. Correlations performed were Pearson Product Moment. Statistical significance was accepted at the level: $p < 0.05$.

RESULTS

ARI variation per phase for the whole group is shown in the Figure1. In front crawl, the phase where propulsion surpasses body drag the most seems to be the IS (average 17.70 Ns, ranging from -4.38 Ns to 41.02 Ns) , showing the US/E a large inter-individual variation (ranging from -33.04 Ns to 30.83 Ns). In backstroke, the propulsive force created during the US was broadly superior to body drag (average 16.66 Ns, ranging from -1.92 Ns to 76.64 Ns) and the FDS, the last propulsive phase of the underwater hand path, was again the most variable one (ranging from -53.37 Ns to 30.77 Ns).

The graphs in Figure 2 show typical ARI per phase variation in three subjects. In front crawl, large negative values in the DS, as can be seen in subject "b", happen when the hand moves forwards in this phase of the path and not down and outwards, increasing, this way, total body profile drag. Large negative values in the US, in this same stroke, occurring in subject "c", is probably caused by poor mechanics in the performance of the movement (disadvantageous hand pitch and lack of acceleration of the hand to until is out of the water), associated with poor streamlining during the glide of the hand of the opposite side. In backstroke, the large negative value of ARI appearing in the FDS in subject "c" was associated with the hand pronation in the beginning of its downwards displacement and a path directed inwards, finishing below the thigh.

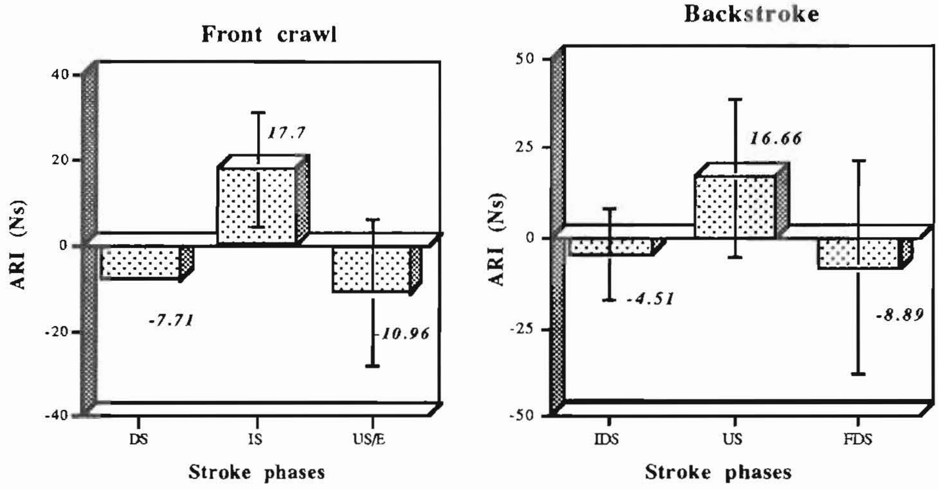

Figure 1 ARI variation per phase of the armstroke in front crawl and backstroke.

In front crawl, best time in the 100m race was positively correlated with ARI in the DS (0.586, $p<0.05$). ARI values occurring during the US, on the contrary, showed negative correlations with best time for the 100m (-0.708, $p<0.01$), 200m (-0.763, $p<0.01$), and 400m (-0.598, $p<0.05$). In backstroke, ARI in the FDS differed significantly ($p<0.05$) in the two swimming economy groups and correlated well (-0.634, $p=0.025$) with best time in the 100 race.

CONCLUSION

In front crawl, the deleterious effect of higher values of ARI in the DS may be explained by a too early pressure on the water in the armstroke or poor synchronisation. In this stroke, the ARI values in the IS seem to be a good predictor of performance. In backstroke, in spite of being in the US that maximal positive values of ARI occurred, it was the value obtained in FDS that emerged as a discriminant factor between individuals with different levels of swimming economy, showing also significant correlation with competitive performance.
Perhaps the most useful application of ARI per phase measurements in swimming lies on the possibility of conducting a quantitative diagnosis of individual performance which should always, evidently, be accompanied by the careful observation of the recorded images in order to connect velocity, acceleration and ARI curves with movement characteristics in a causal relationship.

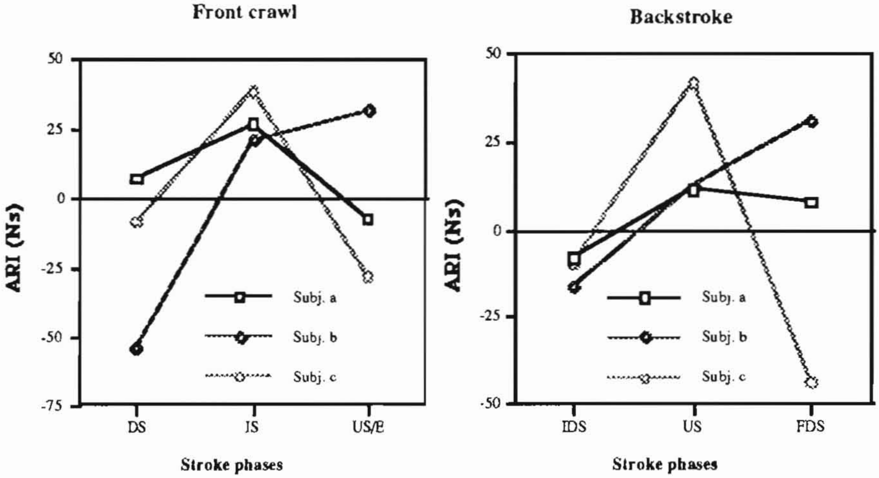

Figure 2 Illustrative contrasting cases of ARI variation along the underwater armstroke in front crawl and backstroke.

Success in elite swimming competitive performance may be determined primarily by technique rather than strength or general and specific endurance, on the supposition that organic adaptations are equally stressed to a level that is very near the individual limits. The measurement of the ARI per phase can be a diagnostic tool helping the optimisation of the movement co-ordination, the body position and stroke mechanics of an individual swimmer during technique training.

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