Frontiers of Ergometry and Hydrodynamics in Aquatic Sports

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ABSTRACT

DAL MONTE A., MIRRI G. and SARDELLA F. Frontiers of Ergometry and Hydrodynamics in Aquatic Sports. *Kinesiology*, Vol. 2, No. 1, pp. 69-74, 1997. The practice of swimming has existed for milleniums, but man has not developed an hydrodynamic form. For this reason many studies have been carried out to improve hydrodynamics of swimmers. These studies have underlined the positive relationship between the bodily surface and the drag and the importance of the position of hands for improving drag values. Another factor able to limit the performance is the energy cost of swimming. Holmer and Astrand (1972) detected in a treadmill test values of oxygen consumption, pulmonary ventilation and heart rate higher than those showed by the same people in a similar test carried out by using a specific ergometer (swimming flume). The differences of the human body's behavior in water leads to hypothesis that the top-level swimmers must undergo specific organic and functional adaptations. Technological progress has opened new horizons in the field of the scientific research applied to aquatic sports. Today, extremely modern instruments are available (Metabolic cart-K4 Cosmed and Respiratory valve-DALAQUA), planned and set up in collaboration with the Institute of Sports Science of CONE, giving the possibility of controlling the evolution of the physiological parameters of a swimmer, during tests carried out in a swimming flume or in a competition site (swimming pool), without considerably interfering with the specific technical action.

Key words: SWIMMING FLUME, HYDRODYNAMICS, TELEMETRY

The practice of swimming has existed for millenniums. Pictorial, sculptural and literary evidence of swimming activity can be found in all ancient civilizations from Egyptians, Assyrians, Phoenicians to pre-Columbian civilizations as well as in ancient Greece and Rome. The most ancient and famous evidence includes the graffiti discovered in a cave of the Libyan desert of Kebir, according to someone dating back to 9.000 years ago, and Egyptian findings formed by the bas-reliefs of Nagoda (5.000 B.C.) and by the seal of waters inspectors (3.000 B.C.), kept in Berlin's Museum. The latter is evidence that already at that time men had developed and were advancing a system in water based on the alternate movement of arms. Even if the origin of swimming is so ancient, man has remained a "terrestrial" animal and has maintained a link with the aquatic enviroment exclusively for leisure or utilitarian purposes without developing, like other mammals (whales, dolphins, seals), a specific genetic structure. It is also to be taken into account that 10.000 years are not so many within the process of life evolution on the earth. For these reasons, since swimming became a competition sport, scientific research has acted for favouring the water approach of these not very "aquatic" living creatures.

The aquatic environment presents particular problems making swimming completely different from other sports. One of the fundamental problems is the resistance offered by water to the advancement of the body (drag). In fact, man, in the course of evolution, has not developed an hydrodynamic form and, consequently, studying the hydrodynamics of swimmers, in particular the drag, is a fundamental element for improving performance. Chaterd and colleagues (1996) have studied the passive drag of 159 swimmers (90 males and 69 females) with respect to the bodily surface at the speed of 1,4ms^{-1} highlighting a positive correlation between the two parameters.

Ergometric swimming flume studies

In the ergometric swimming flume of the Institute of Sports Science of CONI, we have carried out a study on the drag to examine, besides the bodily surface, also different positions of hands and different water speed. This study has confirmed the positive relationship between the bodily surface and the drag and has underlinded the importance of the position of hands for improving drag values, both in absolute terms and with respect to the water speed. Analysing theoretical calculations, a difference between the worst and the best position can be hypothesized. This difference can reach 70 cm at the end of a 400-m competition, assuming that the swimmer executes all strokes, and the start, with "wedge"-shaped hands (worst position) or with one hand near the other (best position). Moreover, the analysis at various speeds of the coefficient for determining the relationship between the passive drag and the bodily surface (different positions) gives us information on the human body immersed in water that has also a variable shape in conditions of high stability. In the current study, the passive drag has also been analysed at 50 cm of depth. The results confirm the common notion of hydrodynamics: underwater the drag is lower, other conditions being equal. Biomechanical studies have been carried out for analyzing the characteristics of the advancement of a swimmer in water. Miyashita and colleagues, already in 1970, highlighted that in crawl swimming ihe athlete advances with constant speed variations according to the cyclic action of arms. In the group studied, the variations ranged from 0,5 to 0,8 m·s^{-1} and in no swimmer was it possible to define a relationship between the movement of arms and that in which the maximum speed is reached.

In the studies carried out in our ergometric flume, the crawl swimming has been decomposed, analysing the propulsive force of arms and legs. The first results showed that using legs in addition to arms implies a force slightly lower than that of strokes and kicks considered separately. This underlines that solutions for advancing implemented by men in water are hydro-dynamically inconvenient. In fact, it seems that using only arms implies higher efficiency, as shown by the behaviour of endurance swimmers who use their legs only for balancing. In using only arms the maximum propulsion is not reached. Thus, higher performances could be reached by trying to improve the lower part of the body: this has been artificially implemented by applying a higher pushing surface to the legs (flippers or single-flipper). Another factor conditioning the drag is floating; in fact, other conditions being equal, those that float more, have a lower surface friction to water. From this point of view, women are advantaged, having a body structure richer in fat which is distributed especially in lower limbs, and this favours movement in water. This advantage expresses itself in the lower energy cost of swimming in women than in men, differently from what happens in sports such as running and cycling, where this factor is not important.

Evaluating the energy cost as an element capable for conditioning performance shows the importance, also in this sport, of surveying and analysing physiological parameters, in parallel with biomechanical studies, for improving competition results. The aquatic environment imposes particular organic and functional stimuli and adaptations fundamentally due to the following facts: a) The athlete works horizontally and carries out the propulsive action mainly (70%) it not completely (endurance swimmers) by using arms: and b) Water exerts a certain pressure (hydrostatic) on the body higher than atmospheric pressure. This implies that pulmonary ventilation, whose rhythm, in all strokes except for back-stroke, is characterized by an inspiration which must be forced and completed in a very short time and and expiration which, takes place underwater, must be also performed against resistance (normally it is passive). So the energy cost for the swimmer is higher.

Concerning the behaniour of other physiological parameters, Holmer and Asinind (1972) surveyed in elite swimmers who underwent to a maximal test on treadmill, values of oxygen consumption (VO_2), pulmonary ventilation (VE) and heart rate (HR), higher than those registered by the same people in a similar test carried out by using a specific ergometer (flume).

It seems that the lowest values obtained in water are due to the fact that the muscular mass used in water is lower than that used in running. In fact, in the flume, legs, causing the consumption of 70% of VO_2max are surely less stimulated than on treadmill; moreover, in water the excursions of joints are lower and the consequent reduction of the muscle's stretching-shortening cycle is another reason for the lowest values of VO_2. Apparently, another factor is that in the push phase (stroke) water is an unstable contact point and, consequently, the athlete is not able to exert all the mechanical power he/she has. Moreover, according to Holmer (1972), the horizontal position of the swimmer reduces the blood flow and consequently the oxygen to the muscles of lower limbs while in running the hydrostatic pressure acts as a factor favouring the "fall" of the blood towards legs. However, it may be what international literature unanimously affirms that the swimmer, in a maximal competition, doesn't use all his/ger maximum oxygen consumption but only percentages of it. This situation is also confirmed by the data of one of our studies carried out on 10 national-level swimmers who underwent two incremental load tests up to exhaustion, one in the treadmill and the other in an ergometric flume. This study (Table 1) confirms the same evolution of physiological parameters described by Holmer and Astrand (1972) but shows a discrepancy between the difference in the values of VO_2max which doesn't reach statistical significance, and the significant difference between the maximal values of pulmonary ventilation (VE), breath frequency (BF) and heart rate (HR), which were undoubtedly higher in the treadmill test. This discrepancy is not easy to interpret. In fact, accepting what has been affirmed by Holmer and Astrand, according to whom the diminution of HR in water necessarily implies a reduction in the cardiac output (the authors have not evidenced difference in stroke volume), then an increase in the peripheral oxygen extraction must necessarily be hypothesized. It is also possible to hypothesize that the cardiac output is not modified by virtue of an increased stroke volume which is due, according to what was affirmed by McArdle and colleagues (1976), to the fact that the horizontal position apparently favours the venous blood return.

Table 1. Comparison of results from a physiological assessment of 10 athletes tested on treadmill and flume. Vaues are meens ± ? (SE or SD ?).

	$\dot{V}O_{2max}$ ($l \cdot min^{-1}$)	HR_{max} ($b \cdot min^{-1}$)	BF_{max} ($1 \cdot min^{-1}$)	$\dot{V}E_{max}$ ($1 \cdot min^{-1}$)	La_{max} (mM))
Treadmill (T)	4.410 ±0.317	197 ±7	60 ±6	132 ±8	8.10 ±0.97
Swimming pool (s)	4.110 ±0.287	170 ±10	47 ±5	108 ±7	6.00 ±1.00
P	>0.30	<0.02	<0.005	<0.02	>0.04
%[T−S]/[T]	−7%	−14%	−21%	−18%	−26%

Moreover, the latter is apparently favoured by the action of "pressing" (hydrostatic pressure) exerted by water on body structures. It seems that the reduction of pulmonary ventilation, completely determined by the diminution of BF due to the peculiarity of the rhythm of respiration in water, is compatible with the lower reduction of VO_2max by virtue of a better ventilation/perfusion ratio obtained in horizontal position. In any case, the differences of the human body's behaviour in water makes us hypothesize that the top-level swimmer must undergo specific organic and functional adaptations. It seems that these adaptations mainly involve arms which, as it was said before, even if responsible for 30% of the VO_2max, exert 70% of the propulsive push. This had already been discovered in two homozygotic sisters, one of whom had undergone specific swimming training, in the early 70's by Holmer and Astrand who detected: a) oxygen consumption almost identical after a maximal test on treadmill; b) an oxygen consumption slightly higher in the swimmer after a maximal test in the flume only using legs; and c) an energy consumption higher by 49% in the swimmer after a maximal test in the flume only using arms (Figure 1). Also, the progressive reduction of the energy cost of swimming as the competition level rises (Di Prampero 1985) documents that specific adaptations take place.

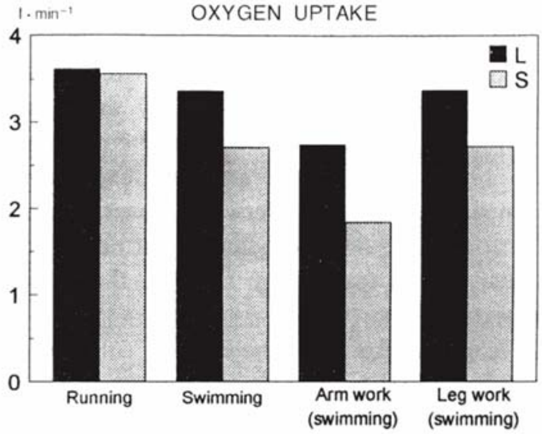

Figure 1. Oxygen uptake during various types of maximal exercise. Two female identical twins: L swimming trained, S no swimming trained, I Holmer et P.O. Astrand, 1972.

Telemetric measurements

There are many other questions concerning man's stimuli and physiological potentialities in water. Fortunately, technological progress has opened new horizons in the field of the scientific research applied to aquatic sports. Today extremely modern instruments are available (RESPIRATORY VALVE-DALAQUA), planned and set up in collaboration with the Institute of Sports Science of CONI, giving the possibility of controlling the evolution of the physiological parameters of a swimmer, during tests carried out in a swimming flume or in a competition site (swimming-pool), without considerably interfering with the specific technical action. It is a nozzle with a double valve inspiration and expiration system, characterized by an extremely light weight (365g), by a very low dead space (15ml), by a very low hydrodynamic resistance and by a low aerodynamic resistance (internal) offered during the respiratory phase (Figure 2). The instrument, provided with a system for draining fluids with air recirculation, is attached to another very recent instrument (METABOLIC CART-K4 COSMED) planned and set up in collaboration with the Institute of Sports Science of CONI. It is a telemetric miniaturized metabolic cart which, adequately modified for being used in tests carried out in water, allows to analyze, contiuously and in real time, the expired gases (VO_2, VCO_2), pulmonary ventilation, heart rate, as well as the derived indices among which is the respiratory quotient.

This technological evolution has enabled the researchers to make a step forward to the knowledge of the model of performance in competitive swimming. On this matter, we quote the results of two studies carried out by the Institute of Sport Science with the co-operation of other foreign Research Institutes. The first of these studies (Billat, Faina and others 1996) in which 9 top level swimmers were tested, stressed an inverse correlation ($r=-0.171$) between the maximum oxygen consumption, detected through an incremental test, and the exhaustion time (time limit) at the minimum intensity of activity capable of inducing the maximum oxygen consumption. Such speed is the one actually used by elite athletes during training, in which the goal is to reach and stand the VO_2max. The second study (Faina, Billat and other 1996, submitted for publication), in which 8 top level swimmers (VO_2max 56.4±16 ml·kg·min) confirmed these data and stressed, on the contrary, a positive correlation ($r=0.81$, $p<0.05$) between the time limit at the VO_2max and the accumulated oxygen deficit. These data suggest that, during an effort at VO_2max the resistance seems to be heavily influenced by the capacity of anaerobic mechanisms. Therefore, this parameter cannot be ignored when the specific adjustments of an athlete are evaluated.

This is the present state of the art. However, sport science always searches for new frontiers and further possibilities are already perceived. One of them is the improvement of hydrodynamic studies, by means of a particularized analysis (colorimetric) of water flows, similarly to what happens for the aerodynamic studies carried out in the wind-tunnel. Another possibility is linked to an application in water of NMR (miniaturized and watertight), which apparently enables surveys of muscular physiology during the carrying out of the specific technical action. Other possibilities are the development of a) telemetry, with lighter, less bulky and easier to fit apparatus for the athletes and with a wider range of transmission; b) miniaturized metabilic cart with storing of data in the transmission unit in real time in order to allow physiological assessment on field when telemetric transmission in disturbed; and c) instrumentation, that allows biochemical and bloodless assessments on field of hematological parameters (lactate, pH, PO_2, PCO_2, HCO_3); These inovations will help in answering questions which are still open and will offer new bases for scientific knowledge, indispensable factor for improving human performance in all swimming specialities.

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