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MEASURING ENERGY EXPENDITURE IN SWIMMING TO ASSESS GROSS MECHANICAL EFFICIENCY

Carlo Baldari, Laura Guidetti and Marco Meucci

Exercise and Sport Sciences Unit, Department of Health Sciences, University of Rome "Foro Italico", Rome, Italy

When swimming at submaximal speeds the rate of energy expenditure can be estimated from respiratory analysis. Over the past decades many methods for stationary non-aqueous evaluation of respiratory and ventilatory parameters in swimmers has emerged. Recently there have been advances in portable telemetric systems (Cosmed K4 b2, Italy) that can measure these variables from rest to maximal activity while swimming without the need to stop the exercise. Preliminary data show that the last modified snorkel system can be considered as a valid device for collecting expired gas for BxB analysis, comparable to the standard facemask, with the advantage of being suitable for measurements during swimming.

KEY WORDS: Swimming, oximetry, validation, snorkel system.

INTRODUCTION: Efficiency is defined as the work accomplished divided by the energy expended to do that work (Stainsby, Gladden, Barclay & Wilson, 1980). Since it is often more convenient to express these quantities as time-related, the gross efficiency has also been defined as the mechanical power output (Po) with respect to the rate of energy expenditure or power input (Pi) (Miller, 1975). This definition of overall or gross efficiency seems to be simple and straightforward, but in fact the way in which both mechanical power and rate of energy expenditure are defined and measured have been considered with different approaches (Montpetit, Leger, Lavoie & Cazorla, 1981; Toussaint, Knops, de Groot & Hollander, 1990; Barbosa, Keskinen, Fernandes, Colaço, Lima & Vilas-Boas, 2005; Reis, Marinho, Policarpo, Carneiro, Baldari & Silva, 2010). To measure the true gross efficiency it is necessary to quantify the total mechanical power output (Po) and the rate of energy expenditure (power input :Pi). In this presentation we will focus only on the quantification of the Pi.
At submaximal swimming speeds, the power input of the swimmer is reflected by the power equivalence of the oxygen uptake (Toussaint et al., 1990). The rate of energy input (Pi) in Watts can be estimated from the oxygen uptake ($lmin^{-1}$, STPD = standard temperature and pressure in dry air) using the formula (Cavanagh & Kram, 1985):

$$Pi = \frac{(4{,}940\ RER + 16{,}040)\ VO_2}{60} \qquad (1)$$

where RER equals the respiratory exchange ratio.

In this sense, the oxygen consumption (VO_2) and the related cardiorespiratory parameters have traditionally been used to study the energy expenditure of swimming in humans. The existing body of knowledge on the relationships between swimming and respiratory parameters is based on experiments using either Douglas bags or mixing chamber gas analyses (Dal Monte, Sardella, Alippi, Faina & Manetta, 1994; di Prampero, Pendergast, Wilson & Rennie, 1974; Holmer 1972; Lavoie & Montpetit, 1986, Toussaint, Meulemans, de Groot, Hollander, Schreurs & Vervoorn, 1987). More recently, a portable telemetric system (Cosmed K4 b2, Italy) consisting of a facemask, a flow meter, a gas analyzer with a transmitter, and a receiver has been developed for breath by breath gas analysis to evaluate VO_2 at steady state condition and VO_2 kinetics during free movements.

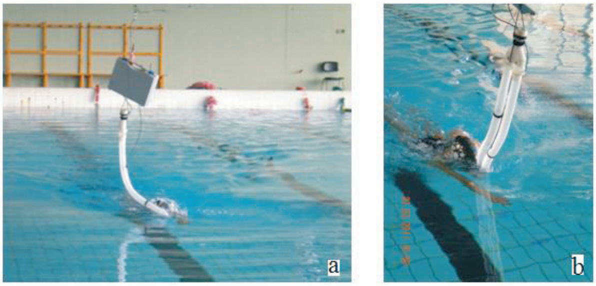

Figure 1: Representation of (a) the use of K4 b2 system in swimming and (b) of the application of modified snorkel and valve devices to swimmers, both in April'2011 in the swimming pool of the Faculty of Sport of the University of Porto (Portugal).

Hausswirth Bicard & Le Chevalier (1997) demonstrated the validity of this instrument for VO_2 measurements from rest to maximum exercise levels. Then, it was developed a snorkel and valve device in order to assess the response to exercise of swimmers in real conditions (Figure 1) (pool or flume) (Barbosa et al., 2005, Rodriguez & Mader, 2003). Considering the metabolic assessment in swimming, it is important the choice of both the adequate equipment and protocol. The energy expenditure can be assessed by VO_2 during steady state condition for swimming speed within the aerobic range of intensities (Holmer, 1972; Pendergast, di Prampero, Craig, Wilson & Rennie, 1977; Toussaint et al., 1990). However, regarding the swimming athletes, it is important to privilege choice of the evaluation protocols with velocities similar to race velocity (Silva, Reis, Marinho, Carneiro, Novaes & Aidar, 2006). Therefore, where the anaerobic energy contribution had to be considered in calculating the overall energy expenditure (Etot), the total energy expenditure is calculated using the VO_2 and the net blood lactate values (Barbosa et al., 2005, Fernandes, Billat, Cruz, Colaço, Cardoso & Vilas-Boas, 2006). The energy equivalent of 1 mmol.l-1 blood lactate increase (difference between the highest value measured at the end of the stage and the rest value) is assumed to be 3 ml O_2·kg-1 (di Prampero, 1981).The equipment used to evaluate the VO_2 has been developed and "adapted to water" condition. In this sense the telemetric system K4b2 (Cosmed) may be used to assess VO_2 in swimming by using the snorkel system. The last developed snorkel system allow the assessment of VO_2 during the different swimming techniques.
Differently from previous systems the new snorkel present two larger (35 mm of diameter) flexible (but not stretchable) tubes of canalization, equipped with two Hans-Rudolf valves (36.5 mm of diameter, one in inspiration and one in expiration) of large diameter in order to reduce flux resistances. The two valves are positioned at the beginning of the tube to prevent mixtures between expiratory and ambient air. Therefore, we conducted a preliminary study aimed to validate the new snorkel system in both controlled laboratory and swimming pool conditions for breath-by-breath (BxB) gas analysis (K4 b2, Cosmed, Rome, Italy).

METHODS: The new two valves snorkel system (2v) had been tested cycling, compared to a standard mask (SM), and swimming, compared to an experimental four valves condition (4v: two at the beginning and two at the apex of the tubes), at three different exercise intensities (low, moderate and high). Nine healthy subjects and seven swimmers performed three bouts of exercise in random order, the first group cycling on a cycle ergometer (Monark 928E Testing Ergometer) and the second one swimming in a 25m swimming pool. Ventilatory and respiratory gas parameters were analyzed using the telemetric system K4b2, with subjects breathing with two and four valves, and the standard mask. Agreement between different conditions was evaluated by Passing–Bablok regression analysis (Keskinen, Rodrıguez &, Keskinen 2003).

RESULTS AND DISCUSSION: Preliminary results showed that the VO_2 values measured with 2v were highly correlated with those obtained using both the SM (R^2=0.96) and the 4v (R^2=0.98). Accordingly, linear regression equations were developed to further improve the accuracy of the measures (Figure 2).

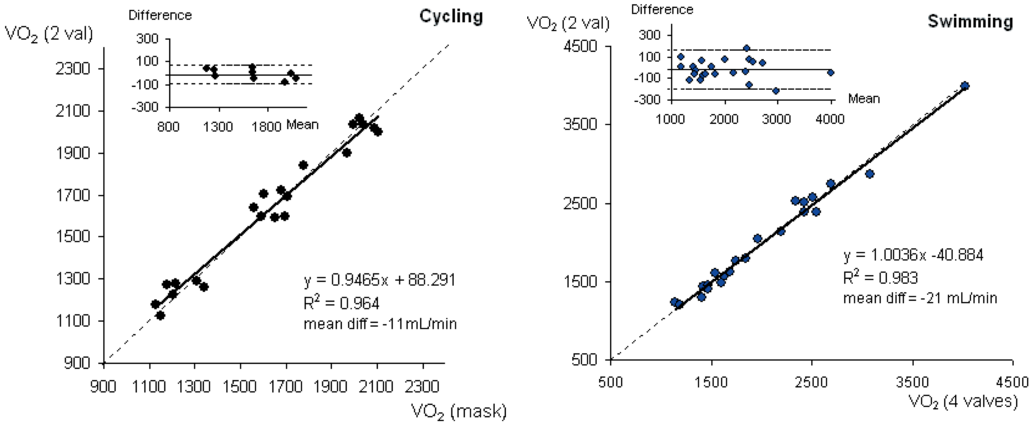

Figure 2: Linear regression representation of VO_2 values at three different intensities (low, moderate and high) comparing the two valves new snorkel system with a standard mask (on the left) and four valves (on the right).

In conclusion we can affirm that the new snorkel system independently by the usage of 2 and 4 valves, can be considered as a valid device for the BxB gas analysis in swimming being comparable to the standard facemask.

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