

Relationship of aerobic and anaerobic parameters with 400 m front crawl swimming performance

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ABSTRACT: The aims of the present study were to investigate the relationship of aerobic and anaerobic parameters with 400 m performance, and establish which variable better explains long distance performance in swimming. Twenty-two swimmers (19.1 ± 1.5 years, height 173.9 ± 10.0 cm, body mass 71.2 ± 10.2 kg; $76.6 \pm 5.3\%$ of 400 m world record) underwent a lactate minimum test to determine lactate minimum speed (LMS) (i.e., aerobic capacity index). Moreover, the swimmers performed a 400 m maximal effort to determine mean speed (S400m), peak oxygen uptake ($\dot{V}O_{2PEAK}$) and total anaerobic contribution (C_{ANA}). The C_{ANA} was assumed as the sum of alactic and lactic contributions. Physiological parameters of 400 m were determined using the backward extrapolation technique ($\dot{V}O_{2PEAK}$ and alactic contributions of C_{ANA}) and blood lactate concentration analysis (lactic anaerobic contributions of C_{ANA}). The Pearson correlation test and backward multiple regression analysis were used to verify the possible correlations between the physiological indices (predictor factors) and S400m (independent variable) ($p < 0.05$). Values are presented as mean \pm standard deviation. Significant correlations were observed between S400m (1.4 ± 0.1 m·s⁻¹) and LMS (1.3 ± 0.1 m·s⁻¹; $r = 0.80$), $\dot{V}O_{2PEAK}$ (4.5 ± 3.9 L·min⁻¹; $r = 0.72$) and C_{ANA} (4.7 ± 1.5 L·O₂; $r = 0.44$). The best model constructed using multiple regression analysis demonstrated that LMS and $\dot{V}O_{2PEAK}$ explained 85% of the 400 m performance variance. When backward multiple regression analysis was performed, C_{ANA} lost significance. Thus, the results demonstrated that both aerobic parameters (capacity and power) can be used to predict 400 m swimming performance.

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INTRODUCTION

Swimming performance is highly dependent on technical, morphological and physiological factors [1, 2]. With respect to the physiological factors, the anaerobic threshold and peak oxygen uptake ($\dot{V}O_{2PEAK}$) have often been used to predict long distance performance in swimming [1, 2].

Several methods can be used to determine the anaerobic threshold in incremental exercise, including fixed (i.e., onset blood lactate accumulation) and not fixed lactate concentrations ($[La^-]$) [3]. Independent of the method, correlations between these aerobic variables and long distance performance have been observed [4, 5]. However, the absolute value of the anaerobic threshold obtained during incremental tests can be influenced by nutritional factors (e.g., glycogen content [6]) or subjectivity of analysis (i.e., visual inspection). Thus, the lactate minimum test could be a robust alternative to determine anaerobic threshold, especially since the lactate minimum speed (LMS) does not change after glycogen depletion [7], and can be determined through a mathematical model (reducing subjective

determination). Studies have demonstrated the validity and applicability of the lactate minimum test in swimmers [8], but the relationship between LMS and long distance performance is still unclear.

The determination of oxygen consumption during swimming requires the use of specific apparatus (e.g. a snorkel), which might interfere with the swimming technique, since turns and undulations cannot be performed [9]. Thus, the $\dot{V}O_{2PEAK}$ values might not represent the real oxygen cost observed during a competition and, consequently, the relationship between this variable and long distance performance could be compromised. In this regard, the backward extrapolation technique seems to overcome these limitations, principally because oxygen uptake is determined only after the end of the freestyle swimming exercise (i.e., after 2-3 s of delay) [1, 10]. However, few studies have investigated the relationship between the $\dot{V}O_{2PEAK}$ obtained using this method and long distance performance [11].

Furthermore, Laffite et al. [12] observed a 20% anaerobic pathway contribution during a 400 m maximal effort, demonstrating the

importance of this metabolism even in long distance events. However, the relationship between total anaerobic contribution (C_{ANA}) and long distance performance is still unclear.

Although the relationship between aerobic and anaerobic fitness indices with swimming performance has previously been observed [5, 11], an understanding of which variable better explains performance is essential for training prescription and evaluation. Therefore, the aims of the present study were to investigate the relationship between aerobic (LMS and $\dot{V}O_{2PEAK}$) and anaerobic (C_{ANA}) parameters with 400 m performance, and establish which variable better explains long distance performance in swimming. In contrast to previous studies, the aerobic variables were determined using methods that take into account nutritional status and swimming technique (i.e., the lactate minimum test and backward extrapolation technique).

MATERIALS AND METHODS

Participants. Twenty-two swimmers (15 men and 7 women) voluntarily participated in this study (19.1 ± 1.5 years, height 173.9 ± 10.0 cm, body mass 71.2 ± 10.2 kg; $76.6 \pm 5.3\%$ of 400 m world record or 538.5 ± 68.8 FINA points). The athletes had at last five years of competitive swimming experience, and all tests were applied during the preparatory period for the season (i.e., 80% of training at lactate threshold or above). All the procedures were approved by the University's Institutional Review Board for Human Subjects (Human Research Ethics Committee) and conducted according to the principles stated in the Declaration of Helsinki. The athletes and their parents, when pertinent, were informed about the experimental procedures and risks, and both provided a written informed consent form authorizing the athletes' participation in the study.

Experimental design

The participants performed two evaluation sessions separated by at least 24 h. On the first day, the swimmers underwent a lactate minimum test to determine LMS (i.e., aerobic capacity index). On the second day, the participants performed a 400 m maximal effort, to determine mean speed (S400m), $\dot{V}O_{2PEAK}$ and anaerobic parameters (i.e., C_{ALA} , C_{LAT} and C_{ANA}).

All evaluations were performed after a 1000 m moderate intensity warm-up in a 25 m swimming pool with a water temperature of $28 \pm 1^\circ\text{C}$. To determine $[\text{La}^-]$ during the lactate minimum test and the 400 m maximal effort, blood samples were taken from the earlobes in 25- μL heparinized capillary tubes and analyzed using a lactate analyzer (YSI 1500 Sport, Yellow Spring Instruments, Ohio, USA). The oxygen uptake values were determined after the 400 m maximal effort using a gas analyzer (VO2000, MedGraphics, USA). The gas analyzer was calibrated prior to each test following the manufacturer's recommendations and the oxygen uptake values were obtained every three breaths. This equipment has been previously used for determining $\dot{V}O_{2PEAK}$ in swimming [13]. All tests were performed in front crawl swimming.

Lactate minimum test

The lactate minimum method [7] was adapted for swimming [4, 8] to determine LMS. This protocol consisted of a primary phase during which hyperlactataemia was induced, and a second incremental phase, when LMS was determined. In the present study, hyperlactataemia was induced through a 200 m maximal effort. Following eight minutes of passive recovery, swimmers performed an incremental test composed of five stages of 200 m. Although the stage increments were applied progressively ($\sim 5\%$ per stage), this was performed subjectively, using as a reference the athlete's swimming performance from a previous training session. Three, five and seven minutes after the initial maximal 200 m effort, and immediately after each of the five stages of the incremental test, blood samples (25 μL) were collected to determine $[\text{La}^-]$. The relationship between the $[\text{La}^-]$ and the respective exercise intensities of the incremental phase was plotted using a second order polynomial adjustment. LMS was assumed as the zero derivative of this relationship [4, 14].

400 m maximal effort, $\dot{V}O_{2PEAK}$ and anaerobic parameters

The swimmers were instructed to perform the 400 m maximal effort in as little time as possible (Timex, model 85103, Brazil) and S400m was determined. Blood samples were collected at rest (10 minutes of passive rest) and three, five and seven minutes after the end of the effort, to determine peak lactate concentration ($[\text{La}^-]_p$). Immediately after the 400 m maximal effort (delay of 1-3 seconds) the participants were connected to the gas analyzer to determine $\dot{V}O_{2PEAK}$ and C_{ALA} . The athletes continued breathing on the gas analyzer for five minutes to determine the excess post-exercise oxygen consumption (EPOC).

The $\dot{V}O_{2PEAK}$ was established using the values obtained every three breaths of the first 30 s of recovery using the backward extrapolation technique [13, 15]. Mathematical adjustments were performed for the eventual delay between the end of the effort and the first breath inside the mask. Oxygen uptake values were log-transformed and linearly adjusted as a function of time. $\dot{V}O_{2PEAK}$ was assumed as the y-intercept of the linear regression [13, 15]. Similar analyses were used by Jürimäe et al. [13] to determine $\dot{V}O_{2PEAK}$ in swimmers using the same maximal effort.

To determine the C_{ALA} , the oxygen uptake values obtained every three breaths during five minutes of recovery were adjusted as a function of the time using a bi-exponential model (Equation 1). This adjustment allowed the determination of the EPOC fast component (i.e., the product of the amplitude and tau [16]), which was assumed as C_{ALA} (Equation 2). The C_{LAT} was determined through accumulated $[\text{La}^-]$ (i.e., the difference between $[\text{La}^-]_p$ and $[\text{La}^-]$ at rest), considering a metabolic equivalent of $3 \text{ mL} \cdot \text{O}_2 \cdot \text{L}^{-1} \cdot \text{kg}^{-1}$ for each 1 mM of blood lactate concentration increase [17, 18]. C_{ANA} was assumed as the sum of the C_{ALA} and C_{LAT} . These procedures were similar to those performed in other studies [19, 20].

$$\dot{V}O_{2(t)} = \dot{V}O_{2BAS} + A_1[e^{-(t-\delta)/T1}] + A_2[e^{-(t-\delta)/T2}] \quad (\text{Eq. 1})$$

$$C_{ALA} = A_1 \cdot T^{-1} \quad (\text{Eq. 2})$$

Where: $\dot{V}O_{2(t)}$ is the oxygen uptake at time t in recovery time, $\dot{V}O_{2BAS}$ is the oxygen uptake at baseline, A is the amplitude, δ is the time delay, T is the time constant (tau) and $_1$ and $_2$ denote fast and slow components, respectively. In equation 2 (Eq. 2), C_{ALA} is the alactic anaerobic contribution.

Statistical analyses

The Shapiro-Wilk test was used to confirm the normality of data, which allowed the use of parametric tests and the presentation of results as the mean (standard deviation) and 95% confidence interval (95%CI) for each variable. The relationship between the physiological parameters (LMS, $\dot{V}O_{2PEAK}$ and C_{ANA}) and the S400m were verified using Pearson's correlation test. After verifying the relationships, a backward multiple regression was performed to detect the variable that had the greatest influence (i.e., predictor factor) on performance (i.e., dependent variable). Only the variables that presented a correlation with 400 m performance were included in the model, and the variance inflation factor (VIF) was used to identify possible collinear effects between predictor factors. All statistical tests were performed using Statistical Package for the Social Sciences, version 17.0 (SPSS Inc, Chicago, Illinois), and in all cases the significance level was set at 5% ($p < 0.05$).

RESULTS

Swimmers completed the 400 m performance in 278.9 ± 17.6 s (95%CI = 271.1–286.7 s). The r^2 of determination coefficient of bi-exponential adjustment of EPOC was 0.96 ± 0.04 (95%CI = 0.94–0.97), with amplitude and Tau correspondent to 3.0 ± 1.3 L \cdot min⁻¹ (95%CI = 2.4–3.6 L \cdot min⁻¹) and 0.9 ± 0.3 s (95%CI = 0.7–1.0 s), respectively. Blood lactate concentration at rest was 1.1 ± 0.5 mM (95%CI = 0.8–1.3 mM) and $[La^-]_p$ was 8.6 ± 3.2 mM (95%CI = 7.1–10.0 mM) (i.e., lactate accumulation: 7.9 ± 2.9 mM (95%CI = 6.6–9.2 mM)).

TABLE 1. Mean, standard deviation (SD), 95% confidence interval (95%CI) and correlation coefficient (r) with significance level (p value) between physiological indices and performance (n = 22).

	Variables		Correlation	
	Mean \pm SD	95%CI	r	p-value
LMS (m \cdot s ⁻¹)	1.3 \pm 0.1	1.3 – 1.4	0.80	0.01
$\dot{V}O_{2PEAK}$ (L \cdot min ⁻¹)	4.5 \pm 1.3	3.9 – 5.0	0.72	0.01
C_{ANA} (L \cdot O ₂)	4.7 \pm 1.5	4.1 – 5.4	0.44	0.03
S400m (m \cdot s ⁻¹)	1.4 \pm 0.1	1.4 – 1.5	----	----

Note: LMS: lactate minimum speed; $\dot{V}O_{2PEAK}$: peak oxygen uptake; C_{ANA} : total anaerobic contribution; S400m: mean speed during 400 m swimming performance; ----; not applicable.

The aerobic indices, anaerobic contribution, and performance are described in Table 1. Significant correlations were found between the physiological indices (LMS, $\dot{V}O_{2PEAK}$ and C_{ANA}) and S400m ($p < 0.04$) (Table 1). All variables correlated with performance were included in the backward multiple regression model ($F = 16.0$; $p = 0.001$) (i.e., Model 1). However, the VIF demonstrated a collinear effect and the C_{ANA} lost significance for explaining performance variance. Thus, the second model (i.e., Model 2) was constructed with only aerobic parameters ($F = 25.2$; $p = 0.001$), which were able to explain 85% of performance variance. No evidence of a collinear effect was observed in the second model. The characteristics of the two backward multiple regression models are described in Table 2.

TABLE 2. Multiple regression models constructed from the significantly correlated variables (predictor factors) and performance (dependent variable).

Model	r^2	Variables included	β	p-value	VIF
1	0.85	LMS	0.57	0.01	1.85
		$\dot{V}O_{2PEAK}$	0.41	0.04	2.45
		C_{ANA}	-0.05	0.75	1.54
2	0.85	LMS	0.58	0.01	1.55
		$\dot{V}O_{2PEAK}$	0.37	0.02	1.55

Note: r^2 : determination coefficient; β : slope; p value: significance level; VIF: variance inflation factor.

DISCUSSION

The aims of the present study were to investigate the relationship between aerobic and anaerobic parameters with 400 m front crawl performance and establish which variable better explains long distance performance in swimming. The main findings of the present study were that LMS, $\dot{V}O_{2PEAK}$ and C_{ANA} were correlated with performance. However, after backward multiple regression analysis, the aerobic indices alone explained 85% of performance variance.

Although LMS is a valid tool for assessing aerobic capacity [8], its utilization is still limited in swimming, since other aerobic capacity indices are more commonly utilized [3, 5, 21]. The present study verified that LMS has a high association with velocity in 400 m performance ($r = 0.80$; $p < 0.05$). This finding agrees with Mez-zaroba and Machado [4], who observed a strong correlations between LMS and S400m ($r = 0.91$; $p < 0.05$) in young swimmers. These results demonstrate the importance of aerobic capacity in long distance swimming performance and confirm that LMS can be used as a predictor of 400 m performance without nutritional influences [7]. Moreover, LMS is a more robust tool for assessing aerobic capacity, mainly due to the absence of influence from nutritional factors such as glycogen content [7], increasing its usefulness during training routines. Thus, the results of the present study provide new evidence of the aerobic validity of LMS.

The analysis of $\dot{V}O_{2PEAK}$ was performed using the backward extrapolation technique. This technique has proven validity [22] and can be used to determine aerobic power [13] and energetic cost during swimming [12]. Agreeing with the results of the present study, Costill *et al.* [11] verified significant correlations between $\dot{V}O_{2PEAK}$ (measured through backward extrapolation) and 400 m performance. Moreover, the $\dot{V}O_{2PEAK}$ measured using the backward extrapolation technique after a 400 m maximal effort presented similar values to those observed in the incremental test [12], facilitating the determination of aerobic power during the swimming training routine. In addition, the backward extrapolation technique takes into account the swimming strategy, turns, and undulations during performance, which increases the robustness of measurements [1, 13, 15]. Thus, the results of the present study demonstrated the possible use of $\dot{V}O_{2PEAK}$, measured through the backward extrapolation technique, to assess aerobic power and predict 400 m performance in swimming.

However, the correlations between $\dot{V}O_{2PEAK}$ and performance were smaller than those observed for LMS (i.e., aerobic capacity). Moderate correlations between $\dot{V}O_{2PEAK}$ and 400 m performance have been observed previously [1, 13]. Together, these results demonstrate that even in long distance performances, the peripheral factors, which are related to anaerobic threshold (i.e., aerobic capacity and LMS), are more important than the central factors, which are related to aerobic power (e.g., $\dot{V}O_{2PEAK}$) [23, 24]. Moreover, although $\dot{V}O_{2PEAK}$ values have been shown to be sensitive to training applied in young swimmers [1], this parameter presented no change in high-level swimmers after 4 weeks of altitude training (live-high train-high), even with increased haemoglobin mass [25]. Thus, $\dot{V}O_{2PEAK}$ appears to be a parameter which is not strongly correlated with performance or sensitive to training in high-level swimmers.

C_{ANA} , assumed as an anaerobic index, seems to present maximal values in exhaustive efforts [20] and was well correlated with maximal accumulated oxygen deficit [16]. The correlation between the anaerobic energy cost (i.e., C_{ANA}) and 400 m performance indicates the importance of this energetic pathway for swimmers even in long distance events. Laffite *et al.* [12] reported that the contribution of the anaerobic metabolism in a 400 m effort was 20%, which explains the minor association between C_{ANA} and the aerobic indices (e.g. LMS and $\dot{V}O_{2PEAK}$). Moreover, the method used to determine C_{ANA} in the present study seems to be more specific for assessing this anaerobic parameter, mainly because it takes into account the swimming technique (i.e., without a snorkel). Additionally, the C_{ALA} was determined through EPOC analysis, which presents similar values to mathematical methods in swimming [26].

The multiple regression analysis highlighted that the aerobic indices are the main factors that explain 400 m performance. When the model was adjusted, the C_{ANA} lost significance in the model. This result probably occurred because the observed correlation between $\dot{V}O_{2PEAK}$ and C_{ANA} ($r = 0.68$) caused a collinear effect (Model 1). This correlation can be explained by the previously observed relationship between $\dot{V}O_{2PEAK}$ and the time constant evidenced in EPOC [27], which is used in the calculation of C_{ALA} (i.e., majority component of C_{ANA} , 64%). On the other hand, although the LMS seems to be more determinant than $\dot{V}O_{2PEAK}$, together these aerobic indices explained 85% of the 400 m performance variance.

In contrast to previous studies, the aerobic variables were determined using methods that take into account the nutritional status and swimming technique (i.e., lactate minimum test and backward extrapolation technique). Moreover, the use of EPOC to determine the alactic contribution is a method that takes into account individual physiology and presents similar values compared to those calculated by general mathematical models [26]. Thus, the present study demonstrated that the physiological indices determined by the lactate minimum test (i.e., LMI) and backward extrapolation ($\dot{V}O_{2PEAK}$ and C_{ANA}) present significant correlations with 400 m front crawl performance, increasing the applicability during training routines.

CONCLUSIONS

From the results of the present study, we concluded that LMS, $\dot{V}O_{2PEAK}$ and C_{ANA} are related to 400 m swimming performance. However, the best model of backward multiple regression analysis (i.e., the largest coefficient of determination values accompanied by the lowest number of physiological indices) demonstrated that LMS and $\dot{V}O_{2PEAK}$ together explained 85% of swimming performance variance. Moreover, C_{ANA} lost significance in the multiple regression, probably due to the collinear effect induced by the strong correlation observed between this anaerobic parameter and $\dot{V}O_{2PEAK}$.

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