OXYGEN UPTAKE KINETICS AT MODERATE AND EXTREME SWIMMING INTENSITIES

EXERCISE AND SPORTS MEDICINE CLINIC

ORIGINAL ARTICLE

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ABSTRACT

Introduction: Traditionally, studies regarding oxygen consumption kinetics are conducted at lower intensities, very different from those in which the sports performance occurs. Objective: Knowing that the magnitude of this physiological parameter depends on the intensity in which the effort occurs, it was intended with this study to compare the oxygen consumption kinetics in the 200 m front crawl at two different intensities: moderate and extreme. Methods: Ten male swimmers of international level performed two tests separated by 24h: (i) progressive and intermittent protocol of 7 x 200 m, with 30 seconds intervals and with increments of $0.05 m.s^{-1}$, to determine the anaerobic threshold correspondent step; and, (ii) 200 m at maximal velocity, in both expiratory gases were continuously collected breath-by-breath. Results: Significant differences were obtained between amplitude and time constant determined in the 200 m at extreme and moderate intensities, respectively (38.53 ± 5.30 ml. $kg^{-1}.min^{-1}$ *versus* 26.32 ± 9.73 ml. $kg^{-1}.min^{-}1$ and 13.21 ± 5.86 s versus 18.89 ± 6.53 s ($p \leq 0.05$). No differences were found in time delay (9.47 ± 6.42 s *versus* 12.36 ± 6.62 s, at extreme and moderate intensity, respectively ($p \leq 0.05$). A negative correlation between time delay and time constant at the moderate intensity was reported ($r = -0.74$, $p \leq 0.05$). Conclusions: Both intensities were well described by double-exponential fittings and there were significant differences between them in terms of amplitude and time constant.

Keywords: swimming, VO_2 kinetics, moderate intensity, extreme intensity.

INTRODUCTION

The magnitude and nature of the adjustment of the oxygen consumption (VO_2) at the beginning of any physical exercise strongly depends on the intensity at which the effort is performed[1]. In fact, at moderate intensities, where exercise is performed below the anaerobic threshold, the VO_2 reaches a quick balance state after a single growth phase, which is named fast component[2]. At high intensity though, for example, above the anaerobic threshold, the VO_2 kinetics reveals a new phase – the slow component –, which, when appearing after the fast component, delays the onset of the balance state of VO_2[3]. At severe intensities, where exercise is performed significantly above the anaerobic threshold, the VO_2 and blood lactate values ([La-]) are not able to stabilize, and therefore, the VO_2 kinetics exposes two components (fast and slow), finishing the exercise before it is possible to obtain a balance state[4]. Although it has been described very recently, the extreme intensity domain, being performed at intensity above maximal oxygen consumption (VO_{2max}), reflects the intensity at which the majority of the competitive efforts occur[2]. However, few studies have been conducted in this domain, being almost unexplored in swimming, especially at higher intensities. The aim of the present work is to analyze and compare the VO_2 kinetics at two distinct swimming intensities, in conditions as close as possible to the ones obtained during competition: (i) moderate intensity, analyzing 200 m *crawl* at intensity corresponding to the individual anaerobic threshold – lan_{ind}); and (ii) extreme intensity, evaluating 200 m *crawl* swam at maximum intensity.

METHODS

Sample

10 male swimmers of international level participated in this study. The individual and mean (± sd) values of their main physical characteristics and of competitive swimming practice are presented in table 1. The body weight and fat mass values were determined through bioelectrical impedance (Tanita TBF 305, Tokyo, Japan). All subjects were previously informed about the details of the experimental protocol before the data collection, having offered their written consent for the participation. The protocol was approved by the ethics committee of the local Institution.

Instruments and procedures

All experimental sessions occurred in an indoors 25 m acclimatized swimming pool (27ºC), with relative humidity of 45%. Each subject performed two distinct protocols in the *crawl* style, and an interval of 24 hours between them was respected. A progressive and interval protocol of 7 x 200 m, with 30 seconds of interval with increments of 0.05m.s-1 between each step[5,6]. The velocity of the last step was determined according to the performance hypothetically reached at that time at 400 m crawl, subtracting later to six intensity thresholds; swimming velocity was controlled with a light pacer (TAR 1.1, GBK – electronics, Aveiro, Portugal), placed in the bottom of the pool. This test was used to determine the 200 m which was closer (or coinciding) with the velocity corresponding to the lan_{ind}, 24 hours after that, the 200 m crawl at maximum velocity was performed[7]. In both protocols, the starts were performed from

Table 1. Individual and mean (± dp) values of the main physical characteristics and sports performance of the swimmers.

Swimmer	Age (years	Height (m)	Weight (kg)	Fat mass (%)	Points len 200m	Years of training (yrs)	%World record 200 m
1	17	1.77	68.1	12.5	1.707.0	8	80.6
2	24	1.82	73.4	9.2	1.376.2	17	88.8
3	24	1.92	81.5	9.1	1.480.3	17	86.1
4	19	1.78	73.7	12.8	1.752.7	8	79.6
5	22	1.84	75.2	9.7	1.511.5	15	85.3
6	21	1.89	74.6	10.1	1.794.7	13	78.6
7	22	1.72	74.2	13.6	1.906.7	13	76.2
8	16	1.87	81.0	11.2	1.734.8	7	79.9
9	21	1.82	72.3	12.3	1.688.6	12	81.0
10	21	1.83	78.4	11.2	1.622.5	15	82.4
Média (± dp)	20.71 (±2.82)	1.82 (± 0.06)	75.24 (± 4.07)	11.17 (± 1.60)	1.657.5 (± 160.7)	12.50 (± 3.71)	81.9 (± 3.9)

the water, and the swimmers were told to perform open laps, always to the same side and without gliding. The VO_2 was measured through continuous expired gas collection breath-by-breath through a portable gas analyzer (K4b[2], Cosmed, Italy), which was connected to the swimmer through a respiratory tube and valve considered suitable for ventilatory gas parameters collection in swimming situations[8]. All that experimental equipment was lifted 2 m above the water surface on a steel cable, which made it possible to follow the swimmer along the pool, minimizing discomfort to the swimmer's movements (figure 1).

In order to minimize the noise resulting from the gas collection breath-by-breath, data were then edited to exclude faulty breathing (e.g. coughing), which do not realistically represent the subjacent kinetics, being only considered the values comprised between the mean ± four standard deviations[9]. Subsequently, the data obtained breath-by-breath were softened through a movable mean of three breaths[10] and recorded in mean periods of five seconds[11], increasing the validity of the estimated parameter. Capillary blood was collected from the earlobe and used to determine the [La$^-$] using a portable analyzer (Lactate Pro analyzer, Arcay, Inc). The collections occurred before each

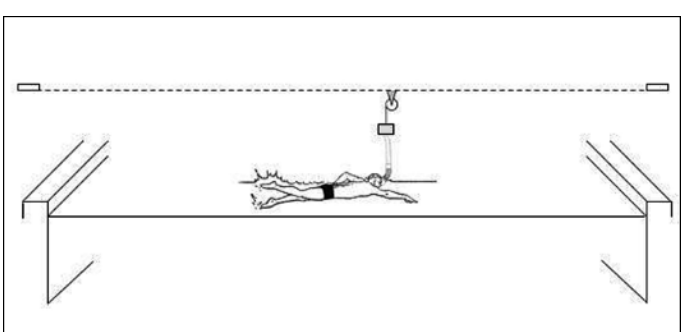

Figure 1. Experimental instrument used for collection of ventilatory gas.

protocol, during the recovery periods (incremental protocol) and at the end of them (at minutes 1, 3, 5 and 7 of recovery). The [La$^-$] enabled the determination of lan_{ind}, in the incremental protocol through the [La$^-$] curve modeling *versus* velocity, assuming it was the interception point of the best adjustment of linear and exponential regressions used for determination of the exact point of the beginning of exponential increase of [La$^-$][12,13]. In all swimmers from the sample, the inflexion point of the [La$^-$] occurred at the 4th step of the incremental protocol. Heart rate values were continuously monitored (at each five seconds) through a monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland).

In order to analyze the VO_2 kinetics, the curves considered (from the 200m corresponding to the lan_{ind} and from 200 m at maximal velocity) were modeled considering a mono-exponential fitting (equation 1):

$$\dot{V}O_2(t) = \dot{V}_b + A*(1 - e^{-(t-D\ /\tau)}) \quad (1)$$

Where t is the time (s), V_b is the VO_2 value at the beginning of the exercise (ml.kg^{-1}.min^{-1}), A is the amplitude of the fast component (ml.kg^{-1}.min^{-1}), TD is time of beginning of the fast component (s) and *t* is the time constant of the fast component (s), i.e., the time needed to reach 63% of the plateau of this phase.

Additionally, the VO_2 curves corresponding to the lan_{ind} were also modeled considering two exponential phases (equation 2 – bi-exponential):

$$\dot{V}O_2(t) = \dot{V}_b + A_1*(1 - e^{-(t-D\ _1/\tau_1)}) + A_2*(1 - e^{-(t-D\ _2/\tau_2)}) \quad (2)$$

Where *t* is the time (s), V_b is the VO_2 value at the beginning of the exercise (ml.kg^{-1}.min^{-1}), A_1 and A_2 are the amplitude of the fast and slow components (ml.kg^{-1}.min^{-1}), TD_1 and TD_2 are the times of the beginning of the fast and slow components (s) and t_1 and t_2 are the time constants of the fast and slow components (s), respectively. The linear method of the minimum squares was implemented in the Matlab program for the adjustment of this function to the VO_2 data.

Statistical Analysis

The mean values (± standard deviation) for the descriptive analysis were obtained for all the variables of the study, for the total sample and each subject, and normality of its distribution was verified through the Shapiro-Wilk test. The SPSS program (linear regression, and the T-Test of repeated measures) was used for the inferential statistical analysis, and significance level was established at 0.05. The F-Test was used for comparison of the monoexponential and bi-exponential fitting of the VO_2 curves corresponding to the $lan_{ind.}$ swimming intensity.

RESULTS

The F-Test ($p = 0.91$) presented the homogeneity of the variance of the monoexponential and bi-exponential models used to analyze the 200 m *crawl* performed at the intensity corresponding to the $lan_{ind,}$ which was confirmed by the equality of mean values through the T-Test ($p = 0.97$). Thus, in the present study the VO_2 kinetics at moderate and extreme intensities seem to be well-described by a monoexponential function, not being positive to use a bi-exponential function. Figure 2 presents two illustration curves of the VO_2 kinetics of one swimmer, in the 200 m corresponding to the Ian_{ind}, and in the 200 m performed at maximum intensity.

The mean values (± sd) of A_{Ian}, A_{200}, t_{Ian}, t_{200}, TD_{Ian} and TD_{200}, at moderate and extreme intensities, are presented in table 2.

Statistically significant differences were obtained in two kinetic parameters (amplitude and time constant) between the 200 m performed at the Ian_{ind} and maximal velocity intensities. Additionally, negative correlations were found between TD_{Ian} and t_{Ian} ($R = -0.74$, $p = 0.01$, figure 3). Nonetheless, further significant relations were not found in the remaining studied parameters.

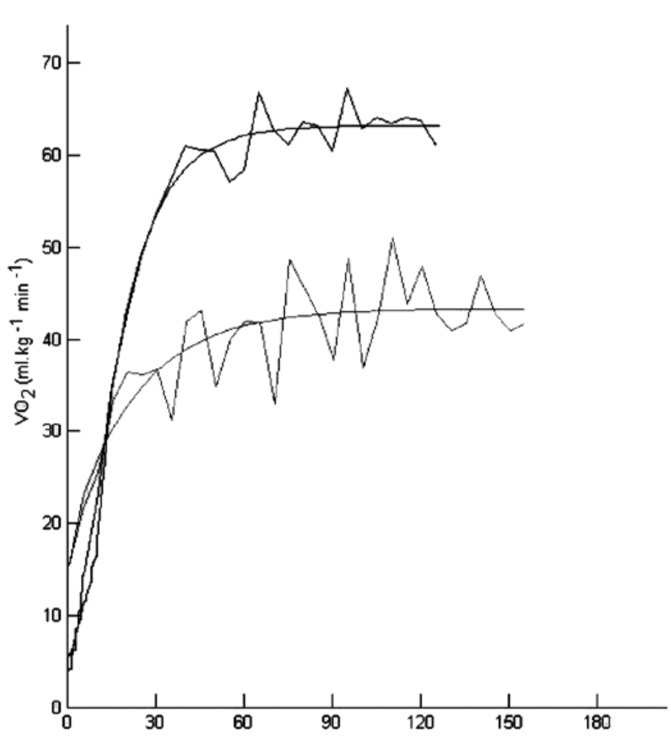

Figure 2. Example of two curve of the oxygen consumption kinetics corresponding to two distinct intensities – to the individual anaerobic threshold (gray color) and to the maximum velocity of 200 m *crawl* (black color).

Table 2. Individual and mean (± sd) values of Alan, A_{200}, tlan, t_{200}, TDlan and TD_{200} corresponding to the threshold where Ianind occurred in the incremental protocol and at 200 m performed at maximum velocity.

Swimmer	A_{Ian} (ml.-kg^{-1}.min^{-1})	A_{200} (ml.-kg^{-1}.min^{-1})	t_{Ian} (s)	t_{200} (s)	TD_{Ian} (s)	TD_{200} (s)
#1	38.52	44.83	23.60	18.16	4.90	19.51
#2	31.05	32.03	19.17	22.32	9.99	15.00
#3	22.86	32.54	23.75	8.82	9.51	2.36
#4	26.73	33.57	8.85	9.33	4.99	9.99
#5	37.32	36.81	20.63	14.56	7.90	9.00
#6	18.57	45.18	23.49	22.41	17.37	4.32
#7	28.92	45.63	12.93	7.05	9.99	5.15
#8	34.52	40.72	7.79	11.01	25.0	4.98
#9	31.45	36.02	9.91	7.39	20.0	19.59
#10	22.94	36.97	20.24	11.14	13.99	4.81
Mean (± sd)	26.32 (± 9.73)	38.43 (± 5.30)*	18.89 (± 6.53)	13.21 (± 5.86)*	12.36 (± 6.62)	9.47 (± 6.42)

A_{Ian}, A_{200} = amplitude of the 200 m at the intensity corresponding to Ian_{ind} and maximum velocity, respectively; TD_{Ian}, TD_{200} = time delay of the 200 m at intensity corresponding to Ian_{ind} and maximum velocity, respectively; t_{Ian}, t_{200} = time constant of the 200 m at intensity corresponding to Ian_{ind} and maximum velocity, respectively.
* Significantly different from the respective kinetic parameter corresponding to the intensity individual anaerobic threshold.

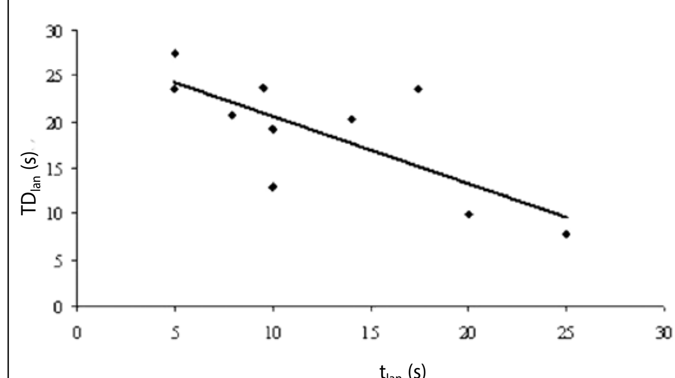

Figure 3. Ratio obtained between time of the beginning of the fast component to the intensity corresponding to the individual anaerobic threshold (TD_{Ian}) and the time constant of the fast component to the intensity corresponding to the individual anaerobic threshold (t_{Ian}) ($y = 26.62 – 0.75x$, $n = 10$, $r = -0.74$, $p \leq 0.05$).

DISCUSSION

The aim of the present study was to assess and compare the VO_2 kinetics in 200 m *crawl* performed at two distinct swimming intensities: moderate (corresponding to the Ian_{ind}) and extreme (at maximal intensity). Since these two intensities are considered very important in the swimming training, as they are used for the development of the aerobic and anaerobic capacities, respectively, it seems crucial to provide better understanding on the VO_2 kinetic parameters. The literature has highlighted the study of low and moderate effort intensities, while studies concerning higher intensities are scarcer, which are representative of the swimming rhythm used during competition. Moreover, the existing studies occurred at unspecific and/or laboratory evaluation conditions (e.g. cycling ergometer and treadmills), compromising hence the validity and applicability of their results. Concerning swimming, only Rodríguez *et al.*[14], Rodríguez *et al.*[15] and Sousa *et al.*[7] carried out studies at high intensities and at conditions as close as possible to the real swimming conditions, and there are no comparative studies between intensity domains.

Exercise intensity below the Ian_{ind} is characterized by the presence of three distinct phases: cardiodynamic, fast and the VO_2 stabilization which occurs three minutes after the beginning of the exercise[16]. The intensity immediately above the Ian_{ind} presents an additional phase (slow component), which delays the onset in the VO_2 stabilization, appearing approximately 10 minutes after the beginning of the effort[2]. However, being the upper boundary of the moderate intensity and, consecutively, the lower one in the high intensity domain, the lan_{ind} is an intensity little studied concerning the VO_2 kinetics. However, Ozyener *et al.*[9] refer that moderate intensities are well-described by monoexponential fittings, instead of the high intensities (high and sever intensity domains) which are better characterized by bi-exponential fittings.

In the present study, and considering the F-Test values, it was verified that the intensity corresponding to the lan_{ind}, the VO_2 kinetics will be possibly described considering the existence of a single phase (fast component) and, consequently, the use of a bi-exponential fitting becomes unnecessary. Although no study has been carried out at this specific intensity, other ones conducted at the moderate intensity domain presented monoexponential fitting in the VO_2 kinetics[17-21]. Concerning extreme intensity, monoexponential fittings were previously defined as being more positive for this intensity domain[7].

Concerning the kinetic parameters, we verified that they are significantly different between the two exercise intensities studied, especially regarding amplitude and time constant. Thus, higher values of these two parameters were obtained in the 200 m *crawl* performed at maximal velocity, contrary to the time delay whose mean values were higher at the intensity corresponding to the lan_{ind}. The amplitude values corroborate the ones presented in the literature, either for the moderate [3,17,19,21] or for the extreme domain[7], where only the later was carried out with swimming. The tendency for higher values of amplitude in the extreme domain supports the literature carried out in cycle ergometer[18,19,21] and in domains of high intensity[22]. These differences are due to the higher values of VO_2 reached in the extreme domain (higher oxygen demand), since as the effort intensity increases, the amplitude gain is higher. This fact is well-explained in figure 2, where the higher VO_2 values reached at the end of the exercise can be observed.

Despite this, higher VO_2 values are also observed at the beginning of the moderate effort, comparatively to the effort performed at extreme intensity. Such fact is due to the previous performance of the 200 m *crawl* steps included in the protocol used (cf. instrument and procedures section) and that, despite being performed at low intensity, induced an increase in the VO_2 baseline values at the beginning of the following step. However, studies conducted refer that only previous exercise of high intensity conditions and influences the following efforts, namely slow component VO_2[23,24] kinetics. Thus, it seems that the existence of low intensity plateaus preceding the effort corresponding to the lan_{ind} did not influence the respective VO_2 kinetics to lan_{ind}. Significant differences went to the time constant, being higher at the intensity corresponding to the lan_{ind}, clashing hence with some studies which refer the constancy of this parameter along the different intensities[17,19,21]. However, it should be mentioned that the later ones were performed in cycle ergometer and comparing moderate to high intensity and/or severe domains.

In spite of this information, the values of the time constant observed for the 200 m *crawl* performed at maximal velocity are lower than the ones reported in the literature[14,15], especially for the 100 and 400 m distances, but similar to the ones by Sousa *et al.*[7] for the same distance. Regarding the intensity corresponding to the lan_{ind}, the values presented corroborate the ones reported in the literature for efforts performed in cycle ergometer[17-21]. In the present study, the fact the time constant is not similar between the two intensities seems to be due to the extreme intensity at which the 200 m *crawl* were performed. Therefore, and since the value of the time constant describes the adaptation profile of the cardiovascular and muscular systems at the intensity of the performed effort[25], the sudden and exponential need of VO_2 to higher intensities (figure 2) will be able to explain the lower values of this parameter.

The time delay was the only kinetic parameter where significant differences have not been verified between the two studied intensities, corroborating the studies which compare the moderate and high exercise domains[17] and moderate and severe domains[19]. However, Pringle *et al.*[21] showed that this parameter ranges between the moderate, high and severe domains. Although the mean values found in our study are lower than the ones found in the literature for the moderate domain[17,19,21], the values corresponding to the extreme domain agree with the only study conducted in the swimming environment for the 200 m distance[7]. In the moderate domain, the differences found may be due to the fact the studies mentioned have been conducted in different sports modalities.

The negative correlation observed between the delay and time constant in the 200 m *crawl* performed at lan_{ind} intensities has not been previously reported in the literature; nevertheless, in the present sample the swimmers, whose fast component of VO_2 started earlier (shorter time delay), were those who also needed more time (longer time constant) until they reached stabilization in the VO_2 consumption. Thus, the sports performance level of our sample (high level) as well as its specialty (sprinters) seem to be two factors which explain the correlations reported here.

CONCLUSION

Both were well described by mono exponential fittings and significant differences have been verified between them concerning amplitude and time constant. Thus, higher values of these two kinetic parameters have been obtained in 200 m *crawl* performed at maximum velocity, contrary to the timed delay whose mean was higher at the intensity corresponding to the lan_{ind}. Additionally, negative correlations have been obtained between TD_{lan} and t_{lan}.

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