The effects of intensity on $\dot{V}O_2$ kinetics during incremental free swimming

Kelly de Jesus, Ana Sousa, Karla de Jesus, João Ribeiro, Leandro Machado, Ferran Rodríguez, Kari Keskinen, João Paulo Vilas-Boas, and Ricardo J. Fernandes

Abstract: Swimming and training are carried out with wide variability in distances and intensities. However, oxygen uptake kinetics for the intensities seen in swimming has not been reported. The purpose of this study was to assess and compare the oxygen uptake kinetics throughout low-moderate to severe intensities during incremental swimming exercise. We hypothesized that the oxygen uptake kinetic parameters would be affected by swimming intensity. Twenty male trained swimmers completed an incremental protocol of seven 200-m crawl swims to exhaustion (0.05 m·s$^{-1}$ increments and 30-s intervals). Oxygen uptake was continuously measured by a portable gas analyzer connected to a respiratory snorkel and valve system. Oxygen uptake kinetics was assessed using a double exponential regression model that yielded both fast and slow components of the response of oxygen uptake to exercise. From low-moderate to severe swimming intensities changes occurred for the first and second oxygen uptake amplitudes ($P \leq 0.04$), time constants ($P = 0.01$), and time delays ($P \leq 0.02$). At the heavy and severe intensities, a notable oxygen uptake slow component (>255 mL·min$^{-1}$) occurred in all swimmers. Oxygen uptake kinetics whilst swimming at different intensities offers relevant information regarding cardiorespiratory and metabolic stress that might be useful for appropriate performance diagnosis and training prescription.

Key words: gas exchange, oxygen uptake kinetics, exercise, intensities, front-crawl, modeling.

Résumé : La natation et l’entraînement couvrent une large gamme de distances et d’intensités. Toutefois, la cinétique de consommation d’oxygène pour ces intensités observées en natation n’a pas été reportée. Le but de cette étude était d’évaluer et comparer la cinétique de consommation d’oxygène lors d’intensités de nage de faibles à modérées jusqu’à intenses. Nous faisons l’hypothèse que les paramètres associés seraient affectés par l’intensité d’exercice. Vingt nageurs entraînés ont exécuté un protocole incrémental de sept de 200 m jusqu’à épuisement (incrément de 0.05 m·s$^{-1}$ et intervalle de 30 s), la consommation d’oxygène étant continuellement mesurée par un analyseur de gaz portable relié à un tuba et un système de valves. La cinétique de consommation d’oxygène était évaluée à l’aide d’un modèle de régression à lissage exponentiel double et les paramètres classiques décrivant les composantes lente et rapide. Des changements apparaissent entre les intensités faibles à intenses au niveau des premières et secondes amplitudes de consommation d’oxygène ($P \leq 0.04$), constantes de temps ($P = 0.01$) et délais ($P \leq 0.02$). Dans les domaines d’intensités difficiles et intenses, tous les nageurs montrèrent une remarque composante lente de la cinétique de consommation d’oxygène (>255 mL·min$^{-1}$). La cinétique de consommation d’oxygène en nageant à différentes intensités offre des informations pertinentes quant à l’stress cardiorespiratoire et métabolique qui peuvent être utiles à la planification de l’entraînement (en particulier dans la construction de séries plus appropriées), et par suite à l’amélioration de la performance.

Mots-clés : échanges gazeux, cinétique de consommation d’oxygène, exercice, intensités, crawl, modélisation.

Introduction

Oxygen uptake ($\dot{V}O_2$) kinetics analysis has been proposed as a useful tool for swim training and diagnosis (Fernandes and Vilas-Boas 2012; Reis et al. 2012b), particularly to improve understanding of tolerance to exercise and the effect that traditional parameters of physiological function (i.e., anaerobic and ventilatory thresholds, maximal oxygen uptake ($\dot{V}O_2_{max}$)), and efficiency/economy indicators (Bentley et al. 2007; Hill 2014) have on the $\dot{V}O_2$ response during swimming (Reis et al. 2012a; Rodríguez et al. 2003; Sousa et al. 2011).

Traditionally, the analysis of $\dot{V}O_2$ kinetics parameters (i.e., amplitude/s, time constant/s and time delay/s) are used to characterize the $\dot{V}O_2$ dynamics in the low-moderate-, heavy-, severe-, and extreme-exercise intensities (Poole and Jones 2012). The low-moderate–exercise intensity includes all power outputs below (and at) the lactate threshold (LT) boundary, with $\dot{V}O_2$ obtaining a steady state (Roberts 2014) and no change (or only a transient increase) in blood lactate (La) concentrations (Burnley and Jones 2007; Carter et al. 2002). The heavy intensity displays power outputs above the LT, starting with a notable slow component ($\dot{V}O_2_{sl}$), leading to a higher $\dot{V}O_2$ amplitude (Pringle et al. 2003) and eliciting a significant La accumulation as a function of time (Burnley and Jones 2007). For the severe intensity, the exercise is significantly higher than LT and neither $\dot{V}O_2$ nor La values can be stabilized (Gaesser...
and Poole 1996), showing a pronounced VO2a and a greater La accumulation time compared with the previous intensity (Burnley and Jones 2007; Pringle et al. 2003).

Over the last 90 years, VO2 kinetics in the above-referred exercise intensities were well documented in exercise in the cycle ergometer and, less frequently, in treadmill running (see e.g., Jones and Burnley 2009), but evaluations carried out in free swimming conditions (i.e., not in swimming flume) are very scarce. Since the pioneer work of Rodríguez et al. (2003), who investigated the VO2 kinetics during the 100- and 400-m front crawl within the extreme intensity response in swimming pool conditions — some recent studies also considered the VO2 — focusing on the heavy or severe intensities (e.g., Fernandes et al. 2008; Pessoa Filho et al. 2012; Sousa et al. 2014b). Despite this, and knowing that the swimming training process encompasses a wide range of exercise intensities, it seems relevant to evaluate and compare the VO2 kinetics during different intensities, particularly including those above the LT but also within the low-moderate–exercise intensity.

The comparison of VO2 kinetics across different exercise intensities is not novel in running and cycling (Carter et al. 2000; Koppo et al. 2004; Pringle et al. 2003), and helped scientists to identify how VO2-related parameters relate to training and performance. For example, Carter et al. (2000) showed that well-trained runners achieved short time-constant values (i.e., a fast stabilization on VO2 values) during incremental exercise, indicating an evident effect of endurance development on initial VO2 adjustments. Thus, findings about the parameters of dynamic VO2 response, such as the amplitude and time constant of the fast component (and the slow phase, when existing) obtained across different exercise intensities could be of great interest for a better definition of the bioenergetical training zones and to a correct exercise-intensity prescription.

As no research comparing the VO2 kinetics with a wide range of swimming intensities has been done, we used a discontinuous incremental protocol to analyze and compare the VO2 kinetics within the low-moderate–, heavy–, and severe-exercise intensities. Based on cycling and running exercise studies conducted at these intensities (e.g., Carter et al. 2002; Koppo et al. 2004), we hypothesized that little or no changes in VO2 kinetics (nor the appearance of a slow component) would be observed in different velocity bouts within the low-moderate intensity, whereas the time constant and time-delay values would show noticeable changes within the heavy and severe intensities. Moreover, it was expected that there would be a notable increase in the fast- and slow-component amplitudes in the most intense intensities, i.e., in the last steps of the incremental protocol, which would be significantly above LT.

Materials and methods

Participants

Twenty well-trained male swimmers (mean ± SD: age, 18.8 ± 3.3 years old; body mass, 72.7 ± 5.8 kg; height, 178.2 ± 6.0 cm; fat mass, 10.6% ± 2.1% (InBody230 Co., Ltd, USA); training age, 10.5 ± 3.6 years; and best 400-m front-crawl performance in 25-m pool, 243 ± 3 s) volunteered to participate in the study. Swimmers trained at least 8 times per week and competed regularly in freestyle events at the national level for at least 5 years prior to the experiments and were familiarized with the testing procedures. The Ethics Committee of Faculty of Sport from the University of Porto approved the research in accordance with the guidelines set forth by the World Medical Association Declaration of Helsinki (2013). All participants (or parent/guardian when subjects were under 18 years old) provided informed consent before data collection.

Testing

The participants were instructed to avoid high-intensity training in the previous 24 h, and to abstain from food, caffeine, alcohol, nicotine, and other drugs in the 3 h before testing. The experiments took place between 0800 to 1200 hours in a 25-m indoor swimming pool (1.90 m deep) with constant environmental conditions (temperature – water: 27.3 ± 0.1°C; air: 28.5 ± 0.2°C; relative humidity – 55.2% ± 0.4%). After a 20-min low-moderate–intensity warm-up, swimmers performed a discontinuous incremental front-crawl swimming test for VO2max assessment, consisting of seven 200-m swims with 0.05 m·s−1 increments and 30-s resting intervals between steps to voluntary exhaustion (Fernandes et al. 2011; Figueiredo et al. 2013). In-water starts and open turns without underwater gliding were used. The predefined speed of the last step was established according to each swimmer’s personal best time at 400-m front crawl at the time of the experiments. Then, 0.05 m·s−1 was successively subtracted, allowing the determination of the mean target speed for each step of the incremental protocol (for a detailed description of the protocol see Fernandes et al. 2012). To help maintaining the predefined individual speed, a visual pacer with flashing lights (GBK-Pacer; GBK-electronics, Aveiro, Portugal) was placed on the bottom of the pool. Manual timing was performed using a digital chronometer (Seiko, Japan).

Data collection

During the incremental protocol, respiratory gas exchange was assessed using a portable telemetric gas analyzer (Cosmed K4 b2, Cosmed, Italy) suspended over the water by a 25-m steel cable at 2-m height. This equipment was connected to the swimmer by a respiratory snorkel and valve system, specifically developed for aquatic exercise (Aquatrainer; Cosmed) (Baldari et al. 2013). The gas analyzers were calibrated before each test with gases of known concentration (16% O2, 5% CO2) and the turbine volume transducer was calibrated using a 3-L syringe according to the manufacturer’s instructions. Ambient pressure and temperature were measured by sensors built in the portable unit, and the relative humidity was manually inputted before each test. During the end of each 200-m step, the expired air temperature detected at the turbine was measured with an infrared thermometer (Kramer Med Inc., Italy). Heart rate (HR) was recorded at rest and every 5 s of the protocol using a Vantage NV (Polar electro Oy, Kempele, Finland) that telemetrically emitted the data to the K4 b2 portable unit.

Blood samples were collected from the ear lobe at the resting period, immediately after the end of each step, and at the 3rd and 5th minutes of the recovery period for La analysis (Lactate Pro; Arkay Inc., Kyoto, Japan).

Data processing and modeling

Prior to analysis, the collected breath-by-breath VO2 data were edited to exclude occasional errant breaths caused by swallowing, coughing, signal interruptions, and so forth, and to improve parameter estimation (Koga et al. 2005). First, values deviating more than 4 SDs of the predicted regression value were considered as aberrant breaths and eliminated. Second, raw data were smoothed, using a 3-breath moving average at 5-s intervals, using the time-averaging function of the Cosmed analysis software. VO2 data were analyzed for each of the 7 steps of the incremental protocol and were categorized as low-moderate–, heavy–, and severe-exercise intensities (Burnley and Jones 2007; Poole and Jones 2012) according to the intensities corresponding to LT and VO2max. First, a La-velocity curve modeling procedure was used to assess the anaerobic threshold (identified as LT) as the intersection point of the best fit of a combined linear and exponential pair of regressions (Fernandes et al. 2011; Figueiredo et al. 2013). Second, conventional physiological criteria were used to identify VO2max namely, the occurrence of a plateau in VO2 (≤2.1 mL·kg−1·min−1) despite an increase in swimming speed, high levels of maximal La (Lamax) (≥8 mmol·L−1), elevated respiratory exchange ratio (≥1.0), and elevated HR (>90% (220 – age)) (Poole et al. 2008). Then, taking
LT and VO\textsubscript{2max} as metabolic intensity indicators, the 1st to 4th steps were categorized as low-moderate-intensity, as they were under (1st to 3rd) and at (4th step) the LT boundary (i.e., \(-35 \text{ mL kg}^{-1} \text{min}^{-1}\)). The 5th and 6th step were considered to be heavy intensity, as they corresponded to an intensity above the LT and below the maximal oxygen uptake corresponding to the VO\textsubscript{2max} (Fernandes and Vilas-Bôas 2012) (i.e., between 45 and 55 mL kg\(^{-1}\) min\(^{-1}\)), and the 7th step was considered as severe exercise, as it coincided with the step in which VO\textsubscript{2max} was attained (i.e., \(-60 \text{ mL kg}^{-1} \text{min}^{-1}\)).

To analyze pulmonary VO\textsubscript{2} kinetics, weight-related (relative) VO\textsubscript{2} data (mL kg\(^{-1}\) min\(^{-1}\)) were first modeled using a mono-exponential function:

\begin{equation}
\text{VO}_2(t) = \text{VO}_{2b} + \text{A}_s \left(1 - e^{-t/\text{TD}_s}\right) + \text{A}_p \left(1 - e^{-t/\text{TD}_p}\right)
\end{equation}

where \(\text{VO}_2(t)\) represents the relative VO\textsubscript{2} at a given time (t); \(\text{VO}_{2b}\) is the baseline, pre-exercise VO\textsubscript{2} (i.e., averaged for the 20 s before the start of the 200 m step); and \(\text{A}_s, \text{TD}_s,\) and \(\tau_s\) are the amplitude, time delay, and time constant, respectively, of the primary component; and \(\text{A}_p, \text{TD}_p,\) and \(\tau_p\) are the corresponding parameters of the slow component.

The VO\textsubscript{2} response data were fitted to mono-and bi-exponential functions using a routine based on nonlinear least-square regression technique (lsqcurvefit) implemented in MATLAB R2010b (Mathworks, USA). The parameters of the model were estimated from the derived function. Additionally, the goodness-of-fit was judged by visual inspection of the residual plot (Fig. 1).

### Statistical analysis

Data are reported as mean values ± SD. The normality of distribution was checked with the Shapiro-Wilk’s test. Before statistical analysis of the VO\textsubscript{2} kinetics parameters, the 2 nonlinear regression fits (i.e., mono- and bi-exponential) were compared for each step of the incremental swimming protocol using an F-test approximation. To compare the 3 swimming intensities, a repeated-measures ANOVA was performed after checking for sphericity (Mauchly’s test), and as this assumption was not violated, no further adjustments of the VO\textsubscript{2} values were required. Pairwise multiple post hoc comparisons were conducted with Bonferroni’s correction. The level of significance was set at \(P < 0.05\) (2-tailed).

### Results

The F-test output showed homogeneity of variance when using the 2 nonlinear functions for low-moderate-swimming intensity (\(P = 0.87\)), but differences were found for the heavy and severe intensities (\(P = 0.03\)); this led us to analyze the VO\textsubscript{2} kinetics using the double bi-exponential function for all 7-step exercise loads, as displayed in Fig. 1 for a representative subject.

Table 1 shows the VO\textsubscript{2} parameters estimated using the bi-exponential regression model, as well as HR and La, for each step of the incremental swimming protocol.

No significant differences were found among the estimated values for VO\textsubscript{2} amplitude, TD, and \(\tau\) in the first 4 exercise loads corresponding to the low-moderate intensity (\(P \geq 0.33\)). Conversely, all VO\textsubscript{2} kinetics parameters in the later steps (5th, 6th, and 7th), corresponding to the heavy- and severe-swimming intensities, differed for VO\textsubscript{2b} \((F_{3,15} = 2.65, P = 0.02)\) and the rest of parameters of the primary and slow components: \(\text{A}_s (F_{3,17} = 6.23, P = 0.01)\), \(\text{A}_p (F_{3,15} = 6.61, P = 0.02)\), TD\(_p\) \((F_{3,15} = 3.54, P = 0.04)\), TD\(_s\) \((F_{3,15} = 5.13, P = 0.02)\), \(\tau_p (F_{3,15} = 5.22, P = 0.01)\), and \(\tau_s (F_{3,15} = 3.25, P = 0.01)\). Thus, a faster VO\textsubscript{2} kinetics pattern became evident at the 5th and later steps with the appearance of an increased VO\textsubscript{2max} superimposed on the faster primary response VO\textsubscript{2p} (\(\Delta\text{VO}_2 > 250 \text{ mL min}^{-1}\)) (Table 1, Fig. 1). As expected, HR and La values progressively increased and were significantly higher while swimming at heavy \((F_{2,18} = 4.21, P = 0.02)\) and severe intensities \((F_{2,18} = 6.69, P = 0.03)\) compared with the low-moderate-intensity loads.

### Discussion

This study investigated the on-transient VO\textsubscript{2} kinetics during an incremental swimming test from rest to maximal exercise eliciting VO\textsubscript{2max} across the low-moderate to severe intensities in competitive swimmers. The main findings were (i) the VO\textsubscript{2} kinetics pattern remained stable within the range of intensities corresponding to the low-moderate intensity (up to the LT boundary), reaching a steady state; and (ii) conversely, across the heavy- and severe-exercise intensities (above LT) faster VO\textsubscript{2} kinetics shorter time-constant and time-delay values) and greater VO\textsubscript{2} gains in the primary component were noted, with the appearance of a noticeable slow component at \(-130 \text{ s} (\Delta\text{VO}_2 > 250 \text{ mL min}^{-1})\). As a central interpretation of these findings, one could argue that the changes observed in the VO\textsubscript{2} kinetics parameters in the 6th and 7th steps of the incremental protocol might have been caused by the prior heavy exercise (i.e., 5th step) (Burnley et al. 2011; Jones et al. 2006), and not by the previous moderate steps (i.e., between the 1st and 4th steps) (Caritá et al. 2015; Sousa et al. 2014a).

The vast majority of studies in the field have been performed using cycle ergometry and provided important insights concerning the time-course of the VO\textsubscript{2} responses across a wide range of intensities (e.g., Poole and Jones (2012) for a review). Nonetheless, differences in the response across different exercise modalities (Jones and Burnley 2005) and exercise intensity (Carter et al. 2002; Özyener et al. 2001; Rossiter 2011) do exist. Our results, on the 1 hand, show that the basic features of the VO\textsubscript{2} kinetics response to low-moderate, heavy, and severe intensities in swimming are similar to other modes of exercise, confirming the concept that VO\textsubscript{2} kinetics is modulated by the same fundamental mechanisms. On the other hand, though, differences arise as this is the first study to provide detailed analysis of the VO\textsubscript{2} dynamics using a single incremental exercise protocol across a very wide range of intensities in specific swimming conditions. Currently, incremental exercise to the limit of tolerance remains by far the most widely used test to understand the integrated functioning of the cardiopulmonary and neuromuscular systems (Rossiter 2011). Using this
Table 1. Oxygen uptake estimated parameters from the bi-exponential regression model in each step of the incremental swimming protocol.

<table>
<thead>
<tr>
<th>Step no.</th>
<th>Low-moderate domain</th>
<th>Heavy domain</th>
<th>Severe domain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>VO₂max (mL·kg⁻¹·min⁻¹)</td>
<td>8±1¹⁵⁻⁷</td>
<td>9±1⁵⁻⁷</td>
<td>9±1⁵⁻⁷</td>
</tr>
<tr>
<td>Aₚ (mL·kg⁻¹·min⁻¹)</td>
<td>20±1⁵⁻⁷</td>
<td>21±8⁻⁷</td>
<td>23±₂⁶⁻⁷</td>
</tr>
<tr>
<td>Aₛ (mL·kg⁻¹·min⁻¹)</td>
<td>1±1⁵⁻⁷</td>
<td>1±1⁵⁻⁷</td>
<td>1±1⁵⁻⁷</td>
</tr>
<tr>
<td>TDₚ (s)</td>
<td>15±1⁵⁻⁷</td>
<td>15±1⁵⁻⁷</td>
<td>16±2²₇⁻⁷</td>
</tr>
<tr>
<td>TDₛ (s)</td>
<td>150±4⁸⁻⁷</td>
<td>151±4³⁻⁷</td>
<td>150±2⁷⁻⁷</td>
</tr>
<tr>
<td>τₚ (s)</td>
<td>15±1⁵⁻⁷</td>
<td>15±1⁵⁻⁷</td>
<td>16±2²₇⁻⁷</td>
</tr>
<tr>
<td>τₛ (s)</td>
<td>181²⁻²²⁸⁻⁷</td>
<td>1822⁻²²⁴⁻⁷</td>
<td>181±3³⁻⁷</td>
</tr>
<tr>
<td>VO₂peak (mL·kg⁻¹·min⁻¹)</td>
<td>34±²³⁻⁷</td>
<td>36±²³⁻⁷</td>
<td>37±²³⁻⁷</td>
</tr>
<tr>
<td>Heart rate (beats·min⁻¹)</td>
<td>131±³⁻⁷</td>
<td>147±³⁻⁷</td>
<td>154±³⁻⁷</td>
</tr>
<tr>
<td>Laₘₐₓ (mmol·min⁻¹)</td>
<td>1.3±1⁵⁻⁷</td>
<td>1.4±²⁻⁷</td>
<td>1.8±0.⁹⁻⁷</td>
</tr>
<tr>
<td>Time length (s)</td>
<td>177±⁵⁻³</td>
<td>170±⁵⁻³</td>
<td>162±³</td>
</tr>
</tbody>
</table>

Note: Data are means ± SD. Superscripts represent values significantly different from noted steps (e.g., ⁷⁻⁷, different from step no. 5 to 7; ⁵⁻⁷, different from nos. 5, 6, and 7) (ANOVA, Sidak’s post hoc test, P < 0.05). Heart rate and blood lactate concentrations are also shown. Aₚ and Aₛ, amplitude of the primary and slow components, respectively; HR, heart rate; Laₘₐₓ, blood lactate concentration and time length of each of the steps; τₚ and τₛ, time constants amplitude of the primary and slow component, respectively; TDₚ and TDₛ, time delay of the primary and slow components, respectively; VO₂base, baseline oxygen uptake; VO₂peak, peak oxygen uptake.

Published by NRC Research Press
et al. 2013; Sousa et al. 2014 with those reported in swimming (Pessoa Filho et al. 2012; Reis et al. 2012). In fact, it has been suggested that exercising while land-based sports such as cycling and running (Aspenes and Karlsen 2012) would be due to the faster occurrence of the appearance of an evident slow component within the heavy and severe exercises, all these studies suggest that at higher intensities, the well-known 7 × 200-m incremental protocol is suitable to compare previous data for well-trained subjects exercising on the treadmill (Carter et al. 2000; Millet et al. 2003). Moreover, the mean values observed in our study for the moderate, heavy, and severe intensities were lower than those reported for running and cycling (Carter et al. 2002; Cleuziou et al. 2004; Pringle et al. 2003), but were similar with those reported in swimming (Pessoa Filho et al. 2012; Reis et al. 2013; Sousa et al. 2014). This can be due to the fact that swimming is performed in a horizontal position, influencing the cardiorespiratory and metabolic demands compared with other land-based sports such as cycling and running (Aspenes and Karlsen 2012). In fact, it has been suggested that exercising while in a horizontal position induces a lower sympathetic stimulation, VO2 and HR values (Pluto et al. 1988). Finally, we observed shorter time-constant values at the heavy and severe intensities compared with the low-moderate–exercise intensity. These findings corroborate previous data for well-trained subjects exercising on the cycle ergometer (Cleuziou et al. 2004; Köppo et al. 2004) and on the treadmill (Carter et al. 2000; Millet et al. 2003). Previous work also suggested that this progressive decrease of the time-constant is related to the recruitment of different muscle fiber types responsible for force production (Köppo et al. 2004). Despite the appearance of an evident slow component within the heavy and severe exercises, all these studies suggest that at higher intensities swimmers would benefit more from a longer duration of each set of exercise during intermittent aerobic training work. This would be due to the faster occurrence of the VO2 fast component (lower time delay) and its stabilization (lower time constant). At lower intensities (within the low-moderate exercise), and in contrast to that traditionally suggested, the duration of the training series repetitions should be longer than 400–m, as the swimmers attain the VO2 steady-state within 2 to 3 min of exercise.

Study limitations

We must acknowledge that a single incremental test was performed, which, together with the relative short duration of exercise compared with the longer exercise bouts usually investigated (6–7 min), could have led to a comparatively lower resolution and some uncertainty in parameter estimation. We need to emphasize that a discontinuous exercise protocol with 30-s rest periods between steps was performed. This implies that after the first step, an effect of previous exercise needs to be taken into consideration, and making comparisons with square-wave exercises is questionable. Therefore, when comparing different studies we have to take into consideration if they used an individual square-wave intensity or progressive-intensities protocols. Finally, it is also important to mention that step tests with set velocity increments do not increase by a set power increment due to nonlinear velocity-power relationships. Future experiments should be carried out trying to better characterize the underlying mechanism regarding the VO2 dynamic behavior in different groups of swimmers and exercise conditions, as obvious differences on VO2 kinetics parameters between groups were found when using different exercise types. Also exploring the extreme exercise intensity, i.e., above VO2max intensity, would be of particular interest.

Conclusions

The present findings showed that the fast and slow VO2 components changed from low to severe swimming intensities (i.e., progressively greater VO2 amplitudes and faster time constants) and that the well-known 7 × 200-m incremental protocol is suitable to assess these differences. Within the bouts performed at low-moderate intensity, swimmers showed great stability in all VO2 kinetics parameters, whereas at the heavy and severe intensities, faster VO2 kinetics and a pronounced VO2 slow component occurred. Since swimmers typically train in a wide range of intensities, understanding the subtle VO2 kinetics modifications that take place across different training zones might have important implications for optimizing training intensities prescription.

Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgements


References


Fernandes, R.J., and Vilas-Boas, J.P. 2012. Time to exhaustion at the VO2max


