VO₂ off transient kinetics in extreme intensity swimming

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Abstract
Inconsistencies about dynamic asymmetry between the on- and off-transient responses in oxygen uptake are found in the literature. Therefore, the purpose of this study was to characterize the oxygen uptake off-transient kinetics during a maximal 200-m front crawl effort, as examining the degree to which the on/off regularity of the oxygen uptake kinetics response was preserved. Eight high level male swimmers performed a 200-m front crawl at maximal speed during which oxygen uptake was directly measured through breath-by-breath oxymetry (averaged every 5 s). This apparatus was connected to the swimmer by a low hydrodynamic resistance respiratory snorkel and valve system. Results: The on- and off-transient phases were symmetrical in shape (mirror image) once they were adequately fitted by a single-exponential regression models, and no slow component for the oxygen uptake response was developed. Mean (± SD) peak oxygen uptake was 69.0 (± 6.3) mL·kg⁻¹·min⁻¹, significantly correlated with time constant of the off-transient period (r = 0.76, p < 0.05) but not with any of the other oxygen off-transient kinetic parameters studied. A direct relationship between time constant of the off-transient period and mean swimming speed of the 200-m (r = 0.77, p < 0.05), and with the amplitude of the fast component of the effort period (r = 0.72, p < 0.05) were observed. The mean amplitude and time constant of the off-transient period values were significantly greater than the respective on-transient. In conclusion, although an asymmetry between the on- and off kinetic parameters was verified, both the 200-m effort and the respectively recovery period were better characterized by a single exponential regression model.

Key words: Swimming, oxygen uptake kinetics, recovery, front crawl.

Introduction
Oxygen uptake (VO₂) kinetics has been analyzed through mathematical modeling of the constant-load exercise onset and offset VO₂ response. This response profile appears to be of an exponential nature, which could indicate first or second order kinetics operations (DiMenna and Jones, 2009). This analysis has shown that VO₂ exponentially increases at the onset of moderate exercise with constant power output (on-fast component), reaches a steady state, and rapidly decreases at the offset of moderate exercise (off-fast component) (Kilding et al., 2006; Ozyener et al., 2001; Paterson and Whipp, 1991; Scheuermann et al., 2001). First-order kinetics mandates on/off symmetry, which means that the change in VO₂ occurring when the contractile activity is ceased must be a mirror image of that which occurred when it was commenced (Rossiter et al., 2005). In the heavy intensity exercise, i.e., at intensities greater than the anaerobic threshold but below the maximal VO₂, an delayed increase (on-slow component) after the on-fast component is presented (Barstow and Molé, 1991; Barstow et al., 1996; Ozyener et al., 2001; Paterson and Whipp, 1991; Scheuermann et al., 2001), but at the offset only an off-fast component is developed (Ozyener et al., 2001; Scheuermann et al., 2001). At the severe exercise intensity, which is significantly above the anaerobic threshold, and neither VO₂ nor blood lactate levels can be stabilized (Poole et al., 1988), the on-transient VO₂ kinetics is reverted to a single-exponential profile (Ozyener et al., 2001), while the off-transient kinetics is retained for a two-component form (Dupond et al., 2010; Ozyener et al., 2001). At the highest intensity - extreme exercise leading to exhaustion before maximal oxygen uptake is attained (DiMenna and Jones, 2009; Hill et al., 2002) -, the VO₂ on-transients response is characterized by the development of an evident fast component, being the slow component phenomenon not developed (Burnley and Jones, 2007; Figueiredo et al., 2011; Whipp, 1994). This area of intensity was recently described (Hill et al., 2002), and, to the best of our knowledge, the VO₂ off-kinetic profile has never been studied at this particular intensity.

VO₂ assessment has been carried out mainly in well controlled environments, particularly in exercise laboratories, and the number of studies conducted in field is very scarce (Billat et al., 2002; Fernandes et al., 2008). In fact, the VO₂ off-transient kinetics is documented in constant-load exercise performed from the moderate to severe intensities. Nevertheless, studies that aim to model the VO₂ recovery kinetics at extreme intensity exercise were not yet conducted in swimming. In this sense, the purpose of this study is to characterize the VO₂ off-transient kinetics, examining also the on/off symmetry, during a 200-m front crawl maximal effort performed at extreme intensity. It was hypothesized that an on/off symmetry of the VO₂ kinetics response would be preserved, although the post-exercise VO₂ did not match the VO₂ deficit.

Methods
Participants
Eight highly trained male swimmers volunteered to participate in the study. The participants provided informed written consent before data collection, which was approved by the local ethics committee and was performed

Received: 18 April 2011 / Accepted: 20 July 2011 / Published (online): 01 September 2011
according to the declaration of Helsinki. Their mean performance for long course 200-m freestyle was 109.3 ± 2.0 s, corresponding to 90.3 ± 3.2% of the 2009 world record for this event. This sample included a finalist and five participants at the European Championships. Individual and mean (± SD) values for subjects’ main physical and performance characteristics were: age (21.8 ± 2.4 years), height (184.5 ± 6.2 cm), body mass (76.1 ± 6.5 kg), fat mass (10.4 ± 1.7%) and lean body mass (62.4 ± 4.4%).

Data collection
In an indoor 25-m swimming pool, with a water temperature of 27°C, each swimmer performed a 200-m front crawl effort at maximal speed. In water starts and open turns, without underwater gliding, were used. Each swimmer performed a 200-m front crawl maximal effort, according to his best individual 200-m performance and his own experiences, and was encouraged to swim at his best effort; therefore, no visual or acoustic pacing was implemented. VO2 kinetics was measured using a telemetry portable gas analyzer (K4b2, Cosmed, Italy), which was connected to the swimmer by a low hydrodynamic resistance respiratory snorkel and valve system (Keskinen et al., 2003; Rodriguez et al., 2008), and was calibrated before and after each test. Respiratory variables were continuously monitored after the 200-m effort until baseline VO2 values were obtained (after approximately 12 min of recovery the assessment was ended). Swimmers were advised to use continuous rhythmical breathing during swimming, turning and in the recovery period. Expired gas concentrations were measured breath-by-breath and averaged every 5 s for a better temporal resolution (Sousa et al., 2010) in order to reduce inter breath fluctuations (“noise”). Peak oxygen uptake (VO2peak) was considered as the highest value of this sampling interval.

Data analysis
The following equation was used to fit VO2 kinetics on the on-transient period:

\[
\text{VO}_2(t) = \text{VO}_2\text{sys} + \text{A}_\text{sys} \times \left(1 - e^{-(t/T_{\text{D}0})} \right)
\]

where \( t \) is the time, \( \text{VO}_2\text{sys} \) is the oxygen uptake at the start of the exercise (mL·kg⁻¹·min⁻¹), \( \text{A}_\text{sys} \) is the amplitude of the fast component (mL·kg⁻¹·min⁻¹), \( T_{\text{D}0} \) is the time for the onset of the fast component (s) and \( \tau_{\text{D}0} \) stands for the time constant for the fast component, i.e., the time to reach 63% of the plateau of this phase during which physiological adaptations adjust to meet the increased metabolic demand. The cardiodynamic phase was not taken into consideration due to its amplitude insignificant value. The inexistence of a slow component was confirmed by the rigid intervals method, particularly by the difference between the last VO2 measurement of the exercise and the value measured in the final 5 s of the 200-m event (adapted from Fernandes et al., 2003; Koppo and Bouckaert, 2002).

For the off-transient period, the individual responses were fitted by using both a single (equation 2) and a double exponential (equation 3) regression models for the entire recovery period, in which the exponential term started at the beginning of the off-transient period modeling (TDoff in the equations):

\[
\text{VO}_2(t) = \text{A}_{\text{off}} \times e^{-(t/T_{\text{D}0})} + A_0
\]

\[
\text{VO}_2(t) = A_{\text{1off}} e^{-(t/T_{\text{D}1\text{off}})} + A_{\text{2off}} e^{-(t/T_{\text{D}2\text{off}})} + A_0
\]

where \( t \) is the time, \( A_{\text{off}} \) represents the amplitude for the exponential term and the \( \tau_{\text{D}1\text{off}} \) and \( \tau_{\text{D}2\text{off}} \) are the associated time constant and time delay. A nonlinear least squares method was implemented in MatLab for the adjustment of these functions to VO2 data.

After a visual exploratory inspection of all VO2 curves, and for the sake of numerical stability, it was verified that, due to the extreme exercise intensity in which the 200-m held, all swimmers started the recovery period immediately after the 200-m effort. In this sense and assuming that \( T_{\text{D}0\text{off}} = 0 \), the off-transient period was modeled according to the restructure equations:

\[
\text{VO}_2(t) = A_{\text{1off}} e^{-(t/\tau_{\text{off}})} + A_0
\]

\[
\text{VO}_2(t) = A_{\text{1off}} e^{-(t/\tau_{\text{off}})} + A_{\text{2off}} e^{-(t/T_{\text{D}0\text{off}})} + A_0
\]

Statistical analysis
For the entire sample, mean and SD computations for descriptive analysis were obtained for all variables and for the entire group of subjects, and were checked for distribution normality with the Shapiro-Wilk test. All statistical procedures were conducted with SPSS 10.05. An F-test was used to compare the single and double exponential regression models best fitting. To compare on- and off-transient parameters Paired sample T-tests were used. Simple linear regression and Pearson’s correlation coefficient were computed to indicate the linear relationship between parameters and with swimming time. The level of significance was set at \( p < 0.05 \).

Results
The F-test (0.28) showed the homogeneity of both models variances, confirmed also by the equality of their mean values (\( p=0.98 \)), and therefore, the off-transient response was well described by a single exponential function. In fact, this characterization was not improved by using the double exponential model. In this sense, the on- and off-transient periods are symmetrical in shape (mirror image) once they were adequately fitted by single-exponential functions. An example of the oxygen (O2) uptake on and off kinetics curve is shown in Figure 1.

The mean (± SD) values for swimming speed (200speed), VO2peak, Aoff, TDoff, \( \tau_{\text{off}} \) and Aoff and \( \tau_{\text{off}} \) for the 200-m front crawl effort and recovery period are presented in Table 1. Significant differences were obtained between the on- and off- VO2 kinetic parameters (all for \( p<0.01 \)), and its amplitude was higher in the recovery period. Complementarily to the above referred data, direct relationships were observed between \( \tau_{\text{off}} \) and 200speed (\( r = 0.77, p = 0.02 \)) and TDoff and VO2peak (\( r = 0.76, p = 0.03 \)) and \( \tau_{\text{off}} \) and Aoff (\( r = 0.72, p = 0.04 \)) (see Figure 2). No significant correlations were found between VO2peak and the other VO2 off-transient parameters (\( A_{\text{off}}, r = 0.35, \) for \( p > 0.05 \)). The absences of significant relationships were also observed between \( \tau_{\text{off}} \) and \( \tau_{\text{off}} \) (\( r = 0.19 \)) and Aoff and Aoff (\( r = 0.5 \), all with \( p > 0.05 \).
**Discussion**

The aim of this study was to characterize the VO\textsubscript{2} off-transient kinetics and to examine the on/off symmetry during a self-imposed 200-m swimming at race pace. We tested the hypothesis that the VO\textsubscript{2} kinetics response will manifest a symmetric on/off response, even if the post-exercise VO\textsubscript{2} does not match the \(\text{O}_2\) deficit.

An understanding of the VO\textsubscript{2} kinetics is considered an important parameter to improve sports training methodology and increase performance in sport (Billat et al., 2001). Furthermore, it was recently suggested that the determinants of exercise tolerance and the limitations to sports performance can be better understood through an appreciation of the physiological significance of the fast and slow components of the dynamic VO\textsubscript{2} response to exercise (Burnley and Jones, 2007). For a long time, studies regarding O\textsubscript{2} uptake assessment in swimming were conducted with either Douglas bags (di Prampero et al., 1974; Lavoie and Montpetit, 1986) or mixing chamber gas analyzers (Dal Monte et al., 1994; Demarie et al., 2001). It was only recently that the development of a swimming snorkel suitable for breath-by-breath analysis (Keskinen et al., 2003; Rodríguez et al., 2008) allowed assessing VO\textsubscript{2} dynamics in swimming pool conditions through direct oxymetry (Fernandes et al., 2003; Rodríguez et al., 2003). Nevertheless, in the O\textsubscript{2} uptake kinetics related literature, studies that aimed to characterize it in human non-constant load extreme intensity exercises are very scarce. Moreover, among these studies, only Rodríguez and Mader (2003), Rodriguez et al. (2003), and Silva et al. (2006) implemented a swimming effort at intensities similar to our protocol.

Considering the total sample, VO\textsubscript{2peak} ranged from 60.2 to 81.8 ml·kg\(^{-1}\)·min\(^{-1}\), which is in accordance with recently reported data obtained in trained male competitive swimmers performing during swimming in pool conditions (Fernandes et al., 2008; Figueiredo et al., 2011; Reis et al., 2010; Rodríguez and Mader, 2003; Rodriguez et al., 2003; Silva et al., 2006).

![Figure 1. Example of an oxygen consumption to time curve, being the time of the onset of the fast component (TD\textsubscript{on}), the time constant of the fast component (\(\tau\text{on}\)) and the amplitude of the fast component (A\textsubscript{on}) in the on-transient and off-transient (A\textsubscript{off}, \(\tau\text{off}\)) periods identified.](image)

### Table 1. Individual, mean (± SD) values, coefficient of variation and confidence interval for mean for 200\textsubscript{speed}, VO\textsubscript{2peak}, A\textsubscript{on}, TD\textsubscript{on} and \(\tau\text{on}\), A\textsubscript{off} and \(\tau\text{off}\) in the 200-m maximal effort and recovery period.

<table>
<thead>
<tr>
<th>Swimmer</th>
<th>200\textsubscript{speed} (m·s(^{-1}))</th>
<th>VO\textsubscript{2peak} (mL·kg(^{-1})·min(^{-1}))</th>
<th>A\textsubscript{on} (mL·kg(^{-1})·min(^{-1}))</th>
<th>TD\textsubscript{on} (s)</th>
<th>(\tau\text{on}) (s)</th>
<th>A\textsubscript{off} (mL·kg(^{-1})·min(^{-1}))</th>
<th>(\tau\text{off}) (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1.40</td>
<td>68.4</td>
<td>49.6</td>
<td>10.00</td>
<td>6.21</td>
<td>54.4</td>
<td>62.22</td>
</tr>
<tr>
<td>#2</td>
<td>1.36</td>
<td>60.2</td>
<td>38.6</td>
<td>4.99</td>
<td>12.04</td>
<td>41.2</td>
<td>49.38</td>
</tr>
<tr>
<td>#3</td>
<td>1.44</td>
<td>67.4</td>
<td>44.9</td>
<td>3.98</td>
<td>13.28</td>
<td>41.5</td>
<td>55.14</td>
</tr>
<tr>
<td>#4</td>
<td>1.42</td>
<td>70.7</td>
<td>44.5</td>
<td>4.99</td>
<td>9.31</td>
<td>54.8</td>
<td>73.13</td>
</tr>
<tr>
<td>#5</td>
<td>1.49</td>
<td>81.8</td>
<td>52.0</td>
<td>5.00</td>
<td>12.43</td>
<td>50.1</td>
<td>94.04</td>
</tr>
<tr>
<td>#6</td>
<td>1.42</td>
<td>70.1</td>
<td>45.4</td>
<td>4.99</td>
<td>11.56</td>
<td>49.3</td>
<td>84.36</td>
</tr>
<tr>
<td>#7</td>
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<td>63.7</td>
<td>46.9</td>
<td>4.99</td>
<td>9.17</td>
<td>42.2</td>
<td>73.90</td>
</tr>
<tr>
<td>#8</td>
<td>1.47</td>
<td>69.0</td>
<td>50.2</td>
<td>4.99</td>
<td>13.41</td>
<td>62.3</td>
<td>86.23</td>
</tr>
<tr>
<td>Mean (±SD)</td>
<td>1.42 (.04)</td>
<td>69.0 (6.3)</td>
<td>46.5 (4.2)</td>
<td>5.49 (1.85)</td>
<td>10.92 (2.49)</td>
<td>49.5 (7.56)</td>
<td>72.30(15.75)</td>
</tr>
<tr>
<td>CV mean</td>
<td>2.81%</td>
<td>9.13%</td>
<td>9.05%</td>
<td>33.69%</td>
<td>22.84%</td>
<td>15.27%</td>
<td>21.78%</td>
</tr>
<tr>
<td>CI mean</td>
<td>1.39-1.46</td>
<td>63.7-74.3</td>
<td>43.0-50.0</td>
<td>3.93-7.04</td>
<td>8.84-13.01</td>
<td>43.2-55.8</td>
<td>59.13-85.46</td>
</tr>
</tbody>
</table>

200\textsubscript{speed} = mean swimming speed of the 200-m; VO\textsubscript{2peak} = peak oxygen uptake; A\textsubscript{on} = amplitude of the fast component in the 200-m maximal effort; TD\textsubscript{on} = time of the onset of the fast component in the 200-m maximal effort; \(\tau\text{on}\) = time constant of the fast component in the 200-m maximal effort; A\textsubscript{off} = amplitude of the fast component in the 200-m recovery period; \(\tau\text{off}\) = time constant of the fast component in the 200-m recovery period; CV = coefficient of variation; CI = confidence interval.
Symmetry between the on- and off-transient phases: Since symmetry is an essential quality of VO$_2$ kinetic dynamics viewed as a first-order reaction kinetics (Ros- siter et al., 2005), it was a focus of interest in the present study. The on/off symmetry of the fast components has been observed for the moderate intensity exercise domain performed in cycle ergometer (Paterson and Whipp, 1991; Ozyener et al., 2001; Scheuermann et al., 2001) and treadmill running (Kilding et al., 2006). For the heavy intensity exercise, an asymmetry in the VO$_2$ dynamics has been reported, describing an on-fast component and an off-fast and off-slow components at cycle ergometer (Ozyener et al., 2001) and knee extensor exercise (Ros- siter et al., 2002). This asymmetry was also reported for severe exercise intensity, namely in indoor running (Du- pond et al., 2010) and cycle ergometer (Ozyener et al., 2001). In contrast, in the present study the on- and off-transient phases were symmetrical, once they were adequately fitted by a single exponential function, compared to the double exponential one, and no slow component for the VO$_2$ response was developed (see Figure 1). Nonetheless the above referred studies, the symmetry observed in the present study can be explained by the implementation of a non-constant load, and to the greater exercise intensity. As expected, we observed only an on-fast component, since the non-constant load at freely-chosen maxi- mal race pace induced an exponential rise in VO$_2$ kinetics that enable the development of a VO$_2$ slow component; this fact was previously mentioned but only for ergometer exercise (Burnley and Jones, 2007; Whipp, 1994).

On/off kinetic parameters: Although an on/off symmetry in the VO$_2$ kinetic response was observed in this extreme intensity exercise lasting 2.7 min on average, differences between the VO$_2$ on- and off-transient kinetic parameters were observed. In fact, greater A$_{off}$ and $\tau_{off}$ values are reported. This last parameter is a major focus of interest in the VO$_2$ kinetic related literature, once it is a determinant factor in VO$_2$ dynamics. A longer $\tau_{off}$ value, as observed in this study, concur with previous data ob- tained in the heavy exercise domain (Cleuziou et al., 2004; Yano et al., 2007); however, other studies reported the opposite behavior for the same exercise intensity (Engelen et al., 1996; Ozyener et al., 2001; Scheuermann et al., 2001), as well as for the moderate domain (Paterson and Whipp, 1991). At the severe exercise intensity, Billat et al. (2002) and Ozyener et al. (2001) reported no differences in $\tau$ regarding on and off fast periods. In addition, the obtained $\tau_{off}$ mean value was greater than the results reported in the literature for both moderate (Cleuziou et al., 2004; Kilding et al., 2006; Rossiter et al., 2002; Takayoshi et al., 2003), heavy (Rossiter et al., 2002) and severe intensities (Perrey et al., 2002).

However, as suggest, when we compared our data with studies using a double exponential fitting approach, $\tau_{off}$ was shorter comparing to $\tau_{off}$ of the slow component during heavy (Cleuziou et al., 2004) and severe intensity exercise (Dupond et al., 2010). As previously stated, the present study reported a symmetry on the on/off VO$_2$ kinetic response; however differences between the on- and off- VO$_2$ kinetic related parameters were found.

In fact, VO$_2$ kinetics is influenced by endurance training, being reported a faster VO$_2$ on-kinetics in trained subjects involved both in cross-sectional and longitudinal studies (Casaburi et al., 1987; Koppo et al., 2004; Murias et al., 2010; Phillips et al., 1995). Indeed, training seems to change the muscle fiber-type characteristics, mitochondri- drial density, oxidative enzyme activity, oxygen availabil- ity, capillarity density and muscle perfusion (Koppo et al., 2004), existing evident differences between trained and untrained subjects. Although this study did not have the intention to investigate this phenomenon, the mean swimming speed was very high since the onset of the effort, which may induced a faster increase in ATP re- quirements, and a fast lactate accumulation, once a pattern of type I/I muscle fiber contribution seems to be estab- lished without delay (Cunningham et al., 2000). These
facts (and being the off-set fast component explained by the
restore of $O_2$ in blood and in muscle, a significant
lactate removal, and by the resynthesis of ATP and PCr)
may induce discernible slower responses during the recov-
ery period. Hence, the oxygen debt must be larger
than the oxygen deficit, i.e., the post-exercise VO$_2$ quanti-
tatively did not match the $O_2$ deficit (Yano et al., 2007).
In fact, since different pacing strategies were adopted during
the maximal 200-m, different VO$_2$ on kinetics may oc-
curred, which influenced the VO$_2$ response in the recov-
ery period. This is a limitation of the current study com-
paring to constant pace researches.

Regarding the VO$_2$ amplitude, the greater observed $A_{off}$ mean value (comparing to $A_{on}$) is not in accordance
with the results reported for moderate and heavy intensi-
ties (Cleuziou et al., 2004), and for the severe intensity
exercise (Perrey et al., 2002), that showed no significant
differences between the $A_{on}$ and $A_{off}$ mean values. In our
study, the greater values of $A_{off}$ may be a result of the
extreme exercise intensity in which our study was con-
ducted, different modeling procedures that were used, as
also mode of exercise performed. At this exercise inten-
sity, in which highest work rates are observed, the VO$_2$
mean value is high even until the end of the effort. Once
the $A_{off}$ represents the difference between the VO$_2$ at
the end of the exercise and the steady state VO$_2$, the greater
$A_{off}$ mean value seems justified.

Once the TD$_{off}$ was assumed to be zero, in result of
the sudden and instantaneous diminishing of VO$_2$, com-
parisons with previously reported data obtained for the
moderate (Cleuziou et al., 2004) and heavy intensities
domains (Billat et al., 2002) are difficult to establish.
However, Takayoshi et al. (2003) reported low TD$_{off}$
mean values (1, 2 s) for the moderate exercise intensity
domain. Moreover, and contrasting the results of the pre-
sent study, Perrey et al. (2002) found no differences be-
tween the TD$_{on}$ and TD$_{off}$ mean values at severe intensity.

Conclusion
No slow component for the VO$_2$ off-kinetics was devel-
oped in the all-out 200-m swims, and the on and off-
transient phases were symmetrical once they were ade-
quately fitted by a single-exponential function. However,

$A_{off}$ and $\tau_{off}$ mean values were greater comparing to the
respective on-transients parameters. The VO$_2$peak and
200peak mean values positively correlated with $\tau_{off}$, as this
with $A_{off}$ not being observed any more correlations be-
tween any of the studied on/off-transient kinetic parame-
ters. Accepting that the overall understanding of the VO$_2$
kineis implies the address of other research areas, future
experiments are welcome to understand the underlying
mechanism regarding this VO$_2$ dynamic behavior.

Acknowledgments
This study was supported by grant: PTDC/DES/101224/2008 (FCOMP-
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**Key points**

- The VO2 slow component was not observed in the recovery period of swimming extreme efforts;
- The on and off transient periods were better fitted by a single exponential function, and so, these effort and recovery periods of swimming extreme efforts are symmetrical;
- The rate of VO2 decline during the recovery period may be due to not only the magnitude of oxygen debt but also the VO2peak obtained during the effort period.

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**Degree**
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**Research interests**
Physiology applied to swimming, swimming training.

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<thead>
<tr>
<th><strong>Pedro FIGUEIREDO</strong></th>
<th><strong>Swimming biophysical characterization specially centered on the availability and use of energy.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Employment</strong></td>
<td>FCT research assistant. Sport Sciences PhD student. Collaborator of the Centre of Research, Education, Innovation and Intervention in Sport.</td>
</tr>
<tr>
<td><strong>Degree</strong></td>
<td>Graduation on Sport Sciences.</td>
</tr>
<tr>
<td><strong>Research interests</strong></td>
<td>Biomechanics and physiology applied to swimming, triathlon training.</td>
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</thead>
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<tr>
<td><strong>Employment</strong></td>
<td>Executive Director at Finnish Society of Sport Sciences. Professor, Researcher, Lecturer at University of Jyväskylä.</td>
</tr>
<tr>
<td><strong>Degree</strong></td>
<td>PhD</td>
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<td><strong>Research interests</strong></td>
<td>Physiological evaluation applied to swimming.</td>
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<tr>
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</tr>
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<tr>
<td><strong>Employment</strong></td>
<td>Medical Doctor at the Department of Health and Applied Sciences of the University of Barcelona.</td>
</tr>
<tr>
<td><strong>Degree</strong></td>
<td>PhD, MD</td>
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<tr>
<td><strong>Research interests</strong></td>
<td>Physiological evaluation applied to swimming.</td>
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<tr>
<td><strong>Employment</strong></td>
<td>Auxiliary Professor at the Porto University. Member of Centre of Research, Education, Innovation and Intervention in Sport.</td>
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<td><strong>Degree</strong></td>
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</tr>
<tr>
<td><strong>Research interests</strong></td>
<td>Mathematical approach applied to swimming.</td>
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<tr>
<td><strong>Employment</strong></td>
<td>Full Professor, Head of the Biomechanics Lab at the Porto University. Member of the Scientific Committee of Centre of Research, Education, Innovation and Intervention in Sport.</td>
</tr>
<tr>
<td><strong>Degree</strong></td>
<td>PhD on Sport Sciences.</td>
</tr>
<tr>
<td><strong>Research interests</strong></td>
<td>Biomechanics, exercise physiology applied to swimming.</td>
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