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ORIGINAL ARTICLE

$\dot{V}O_2$ kinetics and energy contribution in simulated maximal performance during short and middle distance-trials in swimming

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Abstract

Purpose This study aims to analyze swimmers' oxygen uptake kinetics ($\dot{V}O_2$K) and bioenergetic profiles in 50, 100, and 200 m simulated swimming events and determine which physiological variables relate with performance.

Methods Twenty-eight well-trained swimmers completed an incremental test for maximal oxygen uptake (Peak-$\dot{V}O_2$) and maximal aerobic velocity (MAV) assessment. Maximal trials (MT) of 50, 100, and 200-m in front crawl swimming were performed for $\dot{V}O_2$K and bioenergetic profile. $\dot{V}O_2$K parameters were calculated through monoexponential modeling and by a new growth rate method. The recovery phase was used along with the blood lactate concentration for bioenergetics profiling.

Results Peak-$\dot{V}O_2$ (57.47 ± 5.7 ml kg^{-1} min^{-1} for male and 53.53 ± 4.21 ml kg^{-1} min^{-1} for female) did not differ from $\dot{V}O_{2\,peak}$ attained at the 200-MT for female and at the 100 and 200-MT for male. From the 50-MT to 100-MT and to the 200-MT the $\dot{V}O_2$K presented slower time constants (8.6 ± 2.3 s, 11.5 ± 2.4 s and 16.7 ± 5.5 s, respectively), the aerobic contribution increased (~ 34%, 54% and 71%, respectively) and the anaerobic decreased (~ 66%, 46% and 29%, respectively), presenting a cross-over in the 100-MT. Both energy systems, MAV, Peak-$\dot{V}O_2$, and $\dot{V}O_2$ peak of the MT's were correlated with swimming performance.

Discussion The aerobic energy contribution is an important factor for performance in 50, 100, and 200-m, regardless of the time taken to adjust the absolute oxidative response, when considering the effect on a mixed-group regarding sex. $\dot{V}O_2$K speeding could be explained by a faster initial pacing strategy used in the shorter distances, that contributed for a more rapid increase of the oxidative contribution to the energy turnover.

Keywords Oxygen uptake kinetics · Maximal trials · Swimming · Energy system contribution · Rate of adjustment of $\dot{V}O_2$

Abbreviations

%	Percentage
%MAV	Percentage velocity to the MAV
%Peak-$\dot{V}O_2$	Percentage to the Peak-$\dot{V}O_2$
τ	Time constant
[La$^-$]	Blood lactate concentration
Δ[La$^-$]	Difference between rest and maximal [La$^-$]
$\Delta\dot{V}O_2/t$	$\dot{V}O_2$ Growth rate
A	Amplitude
Aer	Aerobic
AnaAlac	Anaerobic alactic
AnaLac	Anaerobic lactic
ANOVA	Analysis of variance
b	Heart beats
HR	Heart rate
ISD	Individual snorkel delay
K4b^2	Portable breath-by-breath gas analyzer
kg	Kilogram

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L	Litter
LO_2	Litters of Oxygen
m	Meter
MAV	Maximal aerobic velocity
min	Minute
ml	Milliliter
mmol	Millimole
MRT	Mean response time
MT	Maximal trials
O_2	Oxygen
$O_{2\mathrm{InitialDef}}$	Oxygen deficit at the onset of exercise
off-K	Oxygen uptake off kinetics
p	Probability value
PB	Personal best
PB50	Personal best of the swimmers in the 50 m freestyle event
PB100	Personal best of the swimmers in the 100 m freestyle event
PB200	Personal best of the swimmers in the 200 m freestyle event
Peak-$\dot{V}O_2$	Maximal oxygen uptake at the incremental test
r	Pearson correlation coefficient
RPE	Rate of perceived exertion
s	Second
SPSS	Statistical Package for the Social Sciences
t	Time
TD	Time delay
µl	Microliter
v	Velocity
$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_{2(t)}$	$\dot{V}O_2$ at a given time
$\dot{V}O_{2\mathrm{base}}$	$\dot{V}O_2$ at rest
$\dot{V}O_2$K	Oxygen uptake kinetics
$\dot{V}O_{2\mathrm{peak}}$	$\dot{V}O_2$ Maximal rise in the maximal trials
$\dot{V}O_{2\mathrm{peak}100}$	$\dot{V}O_2$ Maximal rise in the 100 m maximal trial test
$\dot{V}O_{2\mathrm{peak}200}$	$\dot{V}O_2$ Maximal rise in the 200 m maximal trial test
$\dot{V}O_{2\mathrm{peak}50}$	$\dot{V}O_2$ Maximal rise in the 50 m maximal trial test

Introduction

The evaluation of oxygen uptake kinetics ($\dot{V}O_2$K) is a determinant of human performance and its measure allows a greater understanding of the oxidative and non-oxidative energy system contributions at exercise onset (Jones and Burnley 2009). According to Hughson (2009), the study of $\dot{V}O_2$K is based on the description of the dynamic response of oxygen consumption by muscle cells, which is generated throughout the onset of exercise and involves a complex coordination between neuromuscular, cardiovascular, and respiratory systems. Several studies in cycling, running, rowing, and swimming exercises have associated faster $\dot{V}O_2$K with improved fitness status and, consequently, to better sports performance (Burnley and Jones 2007; Ingham et al. 2007; Jones and Burnley 2009; Koppo et al. 2004; Reis et al. 2012a).

In swimming, the environment can influence the typical response of $\dot{V}O_2$, due to the external conditions that generate different scenarios at metabolic and biomechanical levels (Sousa et al. 2017). Factors such as the horizontal position of the body (Cerretelli et al. 1979) inducing greater hydrostatic pressure, reduced blood flow and muscle perfusion and the conditions of the aquatic environment with "diving bradycardia" evidence (Bentley et al. 2005), as well as the requirement of a lower muscle mass with predominance of upper limbs in exercise (which involve a greater relative percentage of "fast" fibers than the lower limbs) (Schneider et al. 2002), may slow the $\dot{V}O_2$K response (Sousa et al. 2017). However, other studies also showed somewhat fast $\dot{V}O_2$K in well-trained swimmers, probably due to specific adaptations (Bentley et al. 2005; Espada et al. 2015; Pessôa Filho et al. 2012; Reis et al. 2012a, b; Sousa et al. 2013).

Several studies in swimming reported that the $\dot{V}O_2$K remains remarkably constant between different constant intensities, as around the maximal lactate steady state intensity (Espada et al. 2015) between the moderate and heavy domains (Reis et al. 2017), between heavy and severe domains (Pessôa Filho et al. 2012; Reis et al. 2012b) and around the maximal aerobic velocity (Sousa et al. 2014). Conversely, other studies performed at maximal velocities (individual pacing strategies allowed) showed an acceleration of the $\dot{V}O_2$K in exercises with higher intensities (Rodríguez et al. 2003; Sousa et al. 2013).

It is well known that the three energetic systems contribute in all exercise intensities, even though each system could be best suited to provide energy for each stimulus (Rodríguez and Mader 2011). Therefore, all energy systems play a significant role in the determination of performance, especially in high intensity exercises. For example, it is suggested that a maximal exercise effort of 75 s results in an equal amount of energy produced by the aerobic and anaerobic energy systems (Gastin 2001).

In swimming, although some recent studies have analyzed the energetic contributions and $\dot{V}O_2$K in severe and extreme domains (Campos et al. 2017; Ribeiro et al. 2015; Rodríguez et al. 2003, 2016; Sousa et al. 2013, 2014), the majority of studies focus mainly on submaximal transitions, although ~ 86% of indoor swimming events are performed at maximal or supramaximal intensities. Furthermore, the few studies that analyzed female swimmers, or compared the differences between sexes, reported similar $\dot{V}O_2$K in submaximal intensities (Reis et al. 2017) or in the 100 and

400 m distances (Rodríguez et al. 2003, 2016). However, there is a lack of information about the other competitive swimming events.

The aim of this study was to analyze the energy system contribution and the $\dot{V}O_2K$ response at supramaximal swimming intensities, using simulated competition events of 50, 100 and 200 m. We also wanted to determine which metabolic and cardiopulmonary variables are related with short and middle distance swimming performance. We hypothesize that: (1) swimmers will present faster $\dot{V}O_2K$ and lower $\dot{V}O_{2peak}$ values as the distance becomes shorter and the exercise more intense; (2) swimming performance will be associated with faster $\dot{V}O_2K$, higher $\dot{V}O_{2peak}$'s and greater aerobic contributions; (3) higher anaerobic contributions will be associated with short distance performance and (4) both sexes will show similar $\dot{V}O_2K$ and bioenergetics profiles.

Methods

Participants

Twenty-eight well trained swimmers, 14 males and 14 females, gave their written informed consent to participate in the study (or their legal guardians when they were under 18 years old). Participants were instructed to avoid strenuous exercise in the 24 h before each test session, to attend well hydrated and to abstain from caffeine and alcohol consumption 3 h before each testing session. All swimmers had at least 4 years of competitive training, performing 7–8 training sessions per week with a weekly volume of around 31.8 ± 10.9 km as the base schedule of training (14 weeks) and had regularly competed in state and national championships, at least in the 3 years' period prior entering this study. Furthermore, all swimmers were fully familiarized with the equipment and with the test procedures that were used in the study prior to the beginning of the test sessions, having the possibility to practice swimming with all the equipment used for as long as each one needed to be completely adapted. The study was approved by the Ethics Council of the Faculty of Human Kinetics (CEFMH: 39/2015) and conducted in accordance with the 1964 Declaration of Helsinki (Harriss et al. 2017). Anthropometrical data and swimmers personal best short course competition times (PB: obtained at official competitions in the last 3 months before the beginning of the test sessions) in the 50, 100, and 200 m events (PB50, PB100 and PB200, respectively) are presented in Table 1.

Table 1 Mean ± SD of the anthropometrical data and personal short course best times in competition of the swimmers

Variable	Female	Male
Age (years)	15.6 ± 2.6	16.6 ± 1.8
Height (cm)	163.4 ± 6.7	178.5 ± 8.1
Total body mass (kg)	56.0 ± 6.7	70.5 ± 9.9
Body fat (%)	22.5 ± 4.1	12.2 ± 2.8
PB50 (s)	29.6 ± 1.5	25.2 ± 1.4
PB100 (s)	65.4 ± 3.5	55.7 ± 3.2
PB200 (s)	138.6 ± 7.0	121.2 ± 6.0

PB50, PB100 and PB200: short course personal bests of the swimmers, respectively at the 50, 100, and 200 m freestyle events

Experimental design

All swimmers performed four swimming tests, separated by at least 48 h: (1) a discontinuous incremental test; and (2), in randomized order, three maximal trials (MT) of 50, 100 and 200 m. To minimize the effect of circadian rhythms or differences in prior exercise, the same environmental conditions were applied to all tests, namely time of day (± 2 h), water temperature (~ 28 °C), and relative humidity (~ 50%). All participants performed the same pre-test warm up protocol, composed by arm/legs swing exercises with stretching out of the pool and by 800 m at moderate swimming velocity, kicking technique practice, and pulling inside the pool.

A telemetric portable breath-by-breath gas analyzer (K4b^2, Cosmed, Italy), connected to the swimmer by a respiratory snorkel and valve system (new-AquaTrainer®, Cosmed, Italy) was used in all tests to measure the respiratory and gas exchange variables for cardiorespiratory analysis (Baldari et al. 2012; Reis et al. 2010). The K4b^2 was calibrated before each test according to manufacturer's instructions. All tests were performed in front crawl swimming with in-water starts and open turns without underwater gliding.

The heart rate (HR) was recorded telemetrically during exercise with a HR monitor (Polar®, Finland) coupled to the snorkel and synchronized with the K4b^2 system. For the blood lactate concentration ([La$^-$]) analysis (YSI, 2300 STAT, Yellow Springs, USA), capillary blood samples (25 µl) were collected from the earlobe, carefully dried, sterilized, and first blood drop discharged to avoid contamination before each sampling, before the start of each test, during the breaks of the discontinuous incremental test and after all tests (at minutes 1, 3, 5 and 7). The rate of perceived exertion (RPE) was also recorded through the Borg's CR-10 scale (Borg 1990). For the swimming velocity control of the discontinuous incremental test, an underwater visual pacer (Pacer2Swim®, KulzerTEC, Portugal) was placed along the bottom of the pool. This system, composed by 26 lights that subsequently lit up, gives the swimmer an accurate notion of the correct velocity for each step.

The sessions were performed in a 25-m swimming pool in the beginning of the preparatory period of the second macrocycle of the swimmers competitive season, after a period of 2 weeks for training adaptation.

Discontinuous incremental test

Firstly, all swimmers performed a discontinuous incremental test composed by 6 sets of 250 m plus 1 set of 200 m at maximal intensity, with 30 s rest in-between for blood lactate collection (Espada et al. 2015). The velocity of the first repetition was set at 50% of the swimmers 200 m' velocity and increments of 5–10% were imposed in the rest of the repetitions such as the final repetition could be performed at maximal intensity or until swimmers' voluntary exhaustion.

Maximal oxygen uptake (Peak-$\dot{V}O_2$) was recorded as the highest 30 s average of the $\dot{V}O_2$ values and maximal aerobic velocity (MAV) was considered as the minimal velocity at which Peak-$\dot{V}O_2$ values were reached (Billat and Koralsztein 1996). Both were reached by all swimmers in the last 2 repetitions, with the exception of one swimmer who reached at the 5th repetition.

Simulated swimming events

In complementary days, and in randomized order, swimmers performed three maximal trials (MT) of 50, 100, and 200 m. $\dot{V}O_2$ peak ($\dot{V}O_{2peak50}$, $\dot{V}O_{2peak100}$, $\dot{V}O_{2peak200}$, respectively), velocity (v), percentage velocity of MAV (%MAV), oxygen deficit at the onset of exercise ($O_{2InitialDef}$), blood lactate determination ([La$^-$]) and $\dot{V}O_2$K were determined for each distance. Since in this kind of swimming events it is not unusual for swimmers to spend the first meters of swimming in apnea, the swimmers were instructed to breath continuously since the beginning of the exercise to contribute for a highest resolution of the $\dot{V}O_2$K response. The $\dot{V}O_2$ of the recovery phase (8 min after the end of the exercise) was also recorded for determination of total expenditure of energy and energy systems contribution. The swimmers were encouraged to give their maximal effort and to complete the distances in the minimal possible time.

Data analysis

Breath-by-breath $\dot{V}O_2$ data were first cleaned by exclusion of values lying more than three standard deviations from the local mean, for exclusion of outliers caused by abrupt breaths or coughing. For $\dot{V}O_2$ peak determination a 30 s moving average of data was used for the incremental and the 200 m tests considering the highest value as the peak. For the 100 and 50 m maximal trials a moving average of 15 and 5 s were respectively applied, not to influence the results given the shorter duration of these tests.

The $\dot{V}O_2$K parameters [time delay (TD), time constant (τ), mean response time (MRT = τ + TD) (Marwood et al. 2010) and amplitude (A)] of the maximal trials analysis, were calculated using 1-s values interpolation and monoexponential modeling. Given the nature of these supramaximal efforts, we did not observe the occurrence of a secondary rise on the $\dot{V}O_2$ response (slow component), similarly to other studies (Rodríguez et al. 2003; Sousa et al. 2014). To remove the influence of the cardiodynamic phase on the subsequent $\dot{V}O_2$ response, we chose to remove the first 20 s of data from analysis (Espada et al. 2015; Pessôa Filho et al. 2012; Reis et al. 2012a, b). We also calculated an individual "snorkel delay" (ISD) for each swimmers' test. The ISD, that corresponds to the difference between the onset of exercise and the time when the following breaths summed up a tidal volume superior to the outlet tube volume, was then integrated into the time delay of the $\dot{V}O_2$ response, as described before by Reis et al. (2012a), adapted to the specific characteristics of the snorkel device used in this study.

$\dot{V}O_2$K parameters were calculated through an iterative procedure, by minimizing the sum of the mean squares of the differences between the modeled and the measured $\dot{V}O_2$ values. Therefore, we modeled the $\dot{V}O_2$ kinetics according to the equation:

$$\dot{V}O_2(t) = \dot{V}O_{2base} + A\left(1 - e^{-(t-TD)/\tau}\right), \tag{1}$$

where $\dot{V}O_{2(t)}$ represents the relative $\dot{V}O_2$ at a given time; $\dot{V}O_2$ $_{base}$ represents the $\dot{V}O_2$ at rest, which was calculated as the average of the first 30 s of the last minute before the start of the exercise (after 10 min of passive rest); TD, τ, and A, represent the time delay, the time constant (time that is needed to complete 63% of the $\dot{V}O_2$ response) and the amplitude of the exponential response of the $\dot{V}O_2$.

Since we analyzed a very short event, with approximately 30 s duration (50 m test), where the $\dot{V}O_2$ response does not have time to clearly stabilize, we chose to apply a secondary treatment of the $\dot{V}O_2$K data, to confirm our results. Therefore, we analyzed the growth rate of the $\dot{V}O_2$ response ($\Delta\dot{V}O_2/t$) between the 20th (to exclude the cardiodynamic phase) and the 30th second (to allow a comparison between all distances) of exercise, by averaging the time derivatives of $\dot{V}O_2$ between those two points. The procedure was applied for all the distances that were analyzed in this study.

Total energy system contribution complied the aerobic (Aer), anaerobic alactic (AnaAlac), and anaerobic lactic (AnaLac) systems participation in each time trial. The aerobic contribution was determined as the time integral of the net $\dot{V}O_2$ during exercise by the trapezoidal method and the results expressed in litters of oxygen (LO_2), as following:

$$\text{Aer} = \int_{t_0}^{t_{\text{Lim}}} \dot{V}O_2 \times dt - (\dot{V}O_2 b \times t_{\text{Lim}}), \tag{2}$$

where $\dot{V}O_2b$ is baseline $\dot{V}O_2$ response and t_{Lim} is MT time performance. For the anaerobic alactic system determination a bi-exponential fitting on the $\dot{V}O_2$ data of the 8 min of rest after each test was applied, accordingly to Scheuermann et al. (2001):

$$\dot{V}O_{2\text{off}}(t) = \text{EE}\dot{V}O_2 - A_{1\text{off}}\left[1 - e^{-(t-\text{TD}_1/\tau_1)}\right] - A_{2\text{off}}\left[1 - e^{-(t-\text{TD}_2/\tau_2)}\right], \qquad (3)$$

where $\dot{V}O_{2\text{off}(t)}$ represents the relative $\dot{V}O_2$ at a given time; $\text{EE}\dot{V}O_2$ is the oxygen uptake at the end of exercise; TD, τ, and A, represent the time delay, the time constant and the amplitude, and 1 and 2 represent for the fast and slow component, respectively, for the bi-exponential response of the $\dot{V}O_2$. The product between the time constant and amplitude of the fast component of post-exercise oxygen consumption was considered as the anaerobic alactic contribution expressed in LO_2. Finally, the anaerobic lactic system was determined by the difference between maximal [La$^-$] after exercise and resting [La$^-$] expressed as a delta value (Δ[La$^-$]) (Beneke et al. 2002), considering 3 ml O_2 kg^{-1} as a metabolic equivalent for each 1 mmol l^{-1} of Δ[La$^-$] (di Prampero 1981).

Statistical analysis

Normality of data was checked with Shapiro–Wilk test. The independent *T* tests were applied to all variables to check the differences in $\dot{V}O_2$K and energy releasing or contribution between sexes for each MT performance. The group differences in $\dot{V}O_2$K and energy releasing or relative contribution between distances were tested for statistical significance using ANOVA for repeated measures with Bonferroni correction. The Pearson's linear correlation coefficient was used to establish the significant associations between physiological measures and swimmers performances in short and middle distance events. Statistical significance was accepted at $p < 0.05$. All statistical analyses were performed with the Statistical Package for the Social Sciences (SPSS, version 25.0, Chicago, IL, USA).

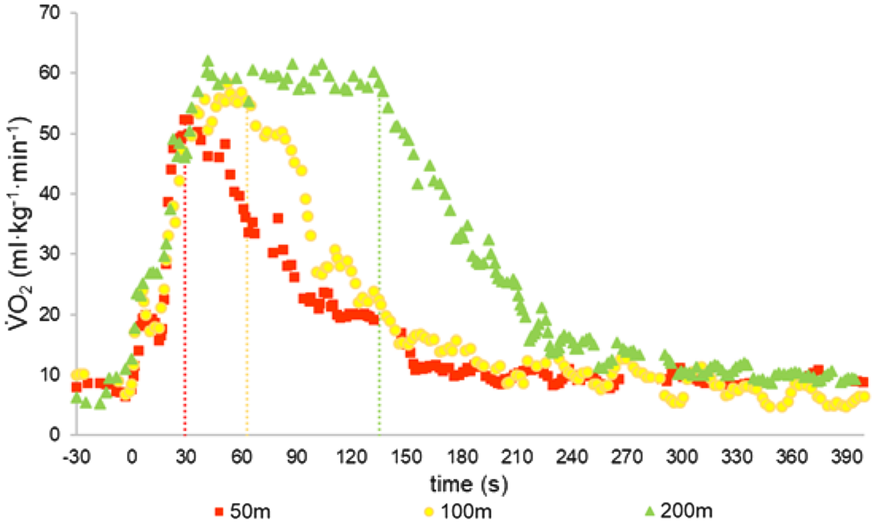
Results

Significant correlations were found between the time for 50, 100, and 200 m performances and swimmers PB's in competition ($r = 0.86$, $r = 0.83$ and $r = 0.84$, $p < 0.01$, respectively for 50, 100, and 200 m distances), showing consistency of the simulated swimming events. A typical response of $\dot{V}O_2$, is showed in Fig. 1.

In the incremental test, absolute and relative Peak-$\dot{V}O_2$, MAV, maximal HR, and maximal [La$^-$] were 4.01 ± 0.39 l min^{-1}, 57.47 ± 5.7 ml kg^{-1} min^{-1}, 1.31 ± 0.07 m s^{-1}, 180.4 ± 7.8 *b* min^{-1} and 8.63 ± 3.6 mmol l^{-1}, respectively for male and 2.98 ± 0.25 l min^{-1}, 53.53 ± 4.21 ml kg^{-1} min^{-1}, 1.20 ± 0.07 m s^{-1}, 191.3 ± 8.4 *b* min^{-1}, and 9.12 ± 2.9 mmol l^{-1}, respectively for female swimmers. The $\dot{V}O_2$K parameters of the maximal trials are described in Table 2.

Male swimmers presented higher absolute and relative $\dot{V}O_{2\text{peak}}$ in all maximal tests. The Peak-$\dot{V}O_2$ was significantly different from the $\dot{V}O_{2\text{peak}50}$, but not from the $\dot{V}O_2$

Fig. 1 $\dot{V}O_2$ response profiles of the participant nº 6 at the maximal trials



$\dot{V}O_2$ response profiles of the participant nº 6 at the 50 (red squares), 100 (yellow circles) and 200 (green triangles) meters maximal trials. End of exercise marked with dashed lines for the 50 (red), 100 (yellow) and 200 (green) meters tests, respectively

Table 2 Mean ± SD of the $\dot{V}O_2$ on and off kinetics and physiological parameters of the swimmers at the maximal trials

Variable	50 m MT			100 m MT			200 m MT		
	Male	Female	Combined	Male	Female	Combined	Male	Female	Combined
A (ml kg^{-1} min^{-1})	45.8 ± 6.9*	38.3 ± 4.0c	42.1 ± 6.8bc	48.3 ± 6.2*	41.1 ± 4.6	44.7 ± 6.5a	48.5 ± 5.8	42.4 ± 4.8a	44.7 ± 6.2a
TD (s)	11.3 ± 3.8	12.0 ± 3.6	11.7 ± 3.7	9.3 ± 4.5	11.8 ± 3.4	10.5 ± 4.2	10.4 ± 3.2	11.1 ± 4.5	10.7 ± 4.0
τ (s)	8.1 ± 2.1bc	9.1 ± 2.4bc	8.6 ± 2.3bc	11.2 ± 2.2ac	11.7 ± 2.2ac	11.5 ± 2.4ac	17.0 ± 6.4ab	16.4 ± 4.5ab	16.7 ± 5.5ab
MRT (s)	19.4 ± 4.9c	21.3 ± 4.9c	20.3 ± 4.2c	20.6 ± 4.1c	23.4 ± 4.1c	22.0 ± 4.2c	27.3 ± 8.4ab	27.5 ± 8.4ab	27.4 ± 7.5ab
$\Delta\dot{V}O_2/t$ (ml kg^{-1} min^{-1} s^{-1})	2.2 ± 0.4*c	2.1 ± 0.5bc	2.1 ± 0.4bc	1.9 ± 0.5ac	1.7 ± 0.3ac	1.8 ± 0.4ac	1.2 ± 0.3ab	1.3 ± 0.4ab	1.3 ± 0.3ab
$\dot{V}O_{2peak}$ (l min^{-1})	3.5 ± 0.4*bc	2.3 ± 0.3bc	2.9 ± 0.6bc	3.9 ± 0.4*a	2.8 ± 0.3a	3.3 ± 0.7ac	4.0 ± 0.4*a	2.9 ± 0.3a	3.5 ± 0.6ab
$\dot{V}O_{2peak}$ (ml kg^{-1} min^{-1})	49.5 ± 4.7*bc	41.9 ± 4.1bc	45.7 ± 5.8bc	55.6 ± 5.9*a	49.8 ± 5.0a	52.7 ± 6.2ac	57.7 ± 6.3*a	52.5 ± 4.2a	55.1 ± 5.9ab
%Peak-$\dot{V}O_2$ (%)	86.6 ± 8.4*bc	78.3 ± 6.0bc	82.5 ± 8.4bc	96.8 ± 4.0*bc	93.1 ± 5.1bc	94.9 ± 5.0ac	100.4 ± 3.8bc	98.2 ± 3.5bc	99.3 ± 3.8ab
v (m s^{-1})	1.7 ± 0.1*bc	1.5 ± 0.1bc	1.6 ± 0.1bc	1.5 ± 0.1*ac	1.3 ± 0.1ac	1.4 ± 0.1ac	1.3 ± 0.1*ab	1.2 ± 0.1ab	1.3 ± 0.1ab
%MAV (%)	128.0 ± 10.2bc	121.8 ± 6.5bc	124.8 ± 9.1bc	114.6 ± 6.9ac	111.6 ± 5.2ac	113.1 ± 6.3ac	102.9 ± 2.6ab	102.2 ± 2.4ab	102.6 ± 2.5ab
Peak HR (b min^{-1})	167.3 ± 5.8bc	168.0 ± 9.5bc	167.9 ± 9.1bc	173.6 ± 8.1a	174.1 ± 7.1a	173.8 ± 7.9a	172.5 ± 7.3a	177.5 ± 5.8a	175.1 ± 7.1a
Peak [La^{-1}] (mmol l^{-1})	9.8 ± 2.6	9.8 ± 3.1	9.8 ± 2.9	12.0 ± 3.1	12.2 ± 2.9	12.1 ± 3.0	10.1 ± 3.1	11.0 ± 3.7	10.5 ± 3.5
RPE (0–10 units)	6.4 ± 2.2bc	7.1 ± 1.7bc	6.8 ± 2.0bc	8.4 ± 1.4a	8.4 ± 1.3a	8.4 ± 1.4a	8.4 ± 1.8a	9.2 ± 0.9a	8.8 ± 1.5a
$O_{2InitialDef}$ (l)	0.9 ± 0.2c	0.8 ± 0.2c	0.9 ± 0.2bc	1.0 ± 0.3	1.0 ± 0.2c	1.0 ± 0.2ac	1.3 ± 0.4*a	1.2 ± 0.4ab	1.2 ± 0.4ab
A_1 off-K (l min^{-1})	2.2 ± 0.7*	1.7 ± 0.4	1.9 ± 0.6	2.6 ± 0.8*	1.6 ± 0.6	2.1 ± 0.9	2.3 ± 0.7*	1.5 ± 0.7	1.8 ± 0.8
A_1 off-K (ml kg^{-1} min^{-1})	31.2 ± 9.8	30.2 ± 10.4	30.7 ± 10.1	37.1 ± 13.3	28.1 ± 11.1	33.0 ± 13.2	31.8 ± 8.3	28.4 ± 15.7	30.0 ± 12.9
τ_1 off-K (s)	57.4 ± 10.4	61.1 ± 11.8	59.2 ± 11.3	55.4 ± 19.2	55.0 ± 13.9	55.2 ± 17.0	54.1 ± 16.9	53.3 ± 19.9	53.6 ± 18.6

A, *TD* and τ: amplitude, time delay and time constant of the $\dot{V}O_2$K, *MRT* mean response time; $\Delta\dot{V}O_2/t$ growth rate of the $\dot{V}O_2$ response between the 20ths and the 30ths of exercise, $\dot{V}O_2$ *peak* absolute and corrected to body mass $\dot{V}O_2$ maximal values of the MT, *%Peak-*$\dot{V}O_2$ percentage of $\dot{V}O_2$ to Peak-$\dot{V}O_2$, *v* velocity, *%MAV* percentage of velocity to maximal aerobic velocity, *Peak HR and Peak [La^{-1}]*: maximal HR and [La^{-1}] of the MT, $O_{2InitialDef}$ oxygen deficit at the onset of the exercise, A_1 *off-K and* τ_1 *off-K* amplitude and time constant of the fast component of the recovery phase

*Differences between sexes in the corresponding test ($p < 0.05$); a, b and c: statistical differences with the 50, 100 and 200 m tests, respectively, for the same sex ($p < 0.05$)

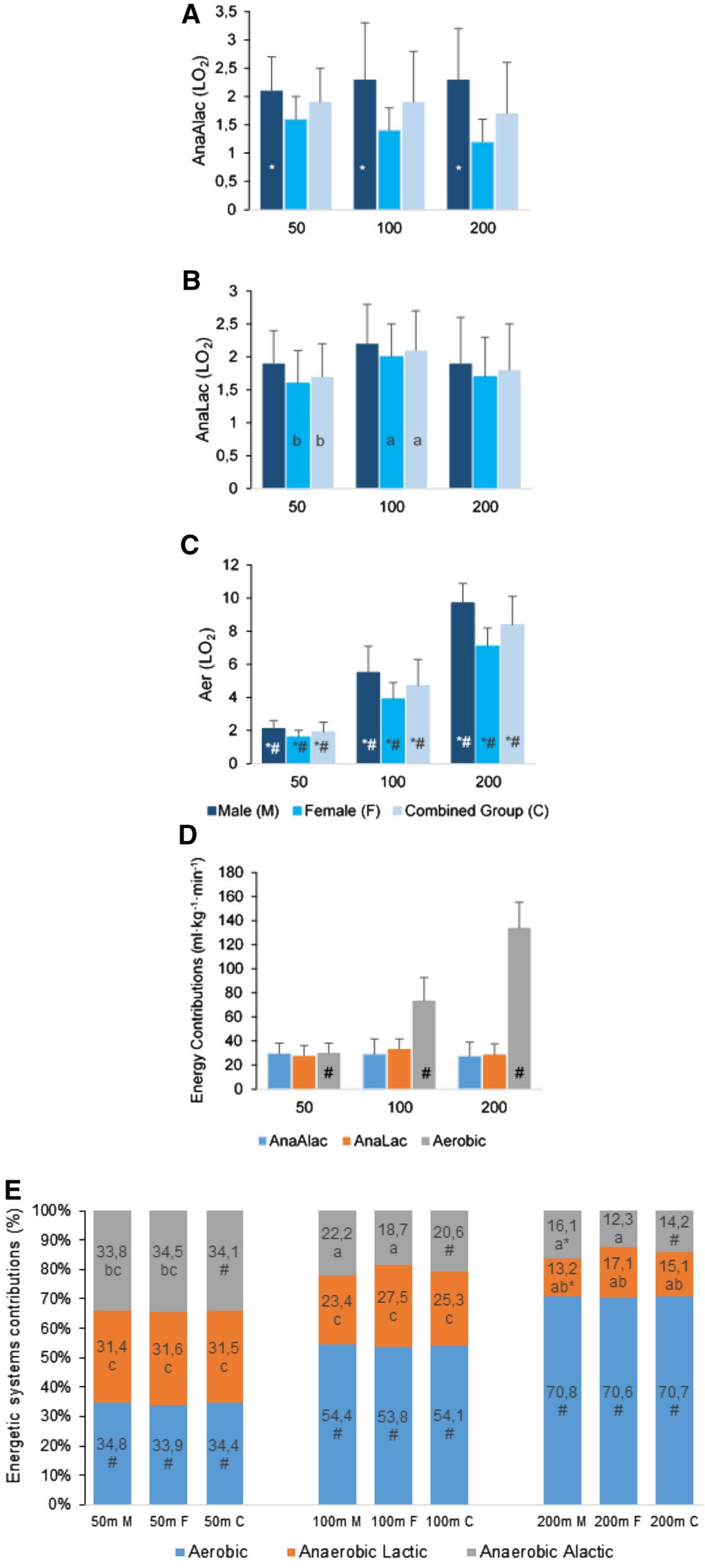


Fig. 2 Energy systems contributions of the 50, 100, and 200 m tests. Anaerobic alactic (**a**), anaerobic lactic (**b**) and aerobic (**c**); values corrected for body weight of the combined group (**d**); relative contributions for the total expenditure energy (**e**). *Differences between sexes; $^{\#}$statistical differences among the three distances; **a**, **b** and **c** statistical differences to the 50, 100, and 200 m tests, respectively

$_{\text{peak100}}$ or $\dot{V}O_{2\text{peak200}}$, in the male group, and from the $\dot{V}O_{2\text{peak50}}$ and the $\dot{V}O_{2\text{peak100}}$, in the female group. MAV was significantly lower than the 50 and 100 m tests velocity but did not showed significant differences with the 200 m test velocity, for both sexes. Although we observed statistical differences in the velocity of each test between sexes, the relative velocities to MAV were similar between groups.

The time delay and amplitude did not present any significant differences between distances with the exception of the amplitude of the 50 m test that was lower than the remaining tests. However, the time constant was reduced as the exercise became shorter and more intense. The same profile occurred with MRT with significant differences between the 100 and the 200 m tests. The growth rate showed an inverse profile with the time constant, declining as the distances became higher and the exercise less intense. Although with similar profiles at both sexes, male swimmers showed higher rates of $\dot{V}O_2$ response.

Oxygen deficit at the onset of exercise of the maximal trials showed significant differences between the three maximal tests, rising as the distance becomes longer. The rate of perceived exertion was significantly lower at the 50 m test, with no differences observed between the 100 and 200 m tests.

Absolute Peak-$\dot{V}O_{2\text{peak}}$ and MAV were significantly correlated with swimmers performance at PB50 ($r = -0.81$ and $r = -0.70$, $p < 0.01$), PB100 ($r = -0.82$ and $r = -0.77$, $p < 0.01$) and PB200 ($r = -0.75$ and $r = -0.75$, $p < 0.01$), respectively. Also, the $\dot{V}O_{2\text{peak}}$ of each maximal test was correlated with the swimmers PBs at the corresponding distances ($r = -0.82$, $r = -0.84$, and $r = -0.76$, $p < 0.01$, for the 50, 100 and 200 m tests, respectively), as well as the amplitude of the primary phase at the 50 and 100 m tests ($r = -0.39$, $p < 0.05$ and $r = -0.58$, $p < 0.01$, respectively). The time constant of the 50 and 200 m tests was correlated with the percentage to Peak-$\dot{V}O_2$ achieved in the corresponding tests ($r = -0.53$, $p < 0.01$ and $r = -0.41$, $p < 0.05$), being the time constant of the 200 m test also correlated with the $O_{2\text{InitialDef}}$ ($r = 0.76$, $p < 0.01$). Both the MRT and the $O_{2\text{initialdef}}$ were correlated between the 50 and the 100 m tests ($r = 0.44$, $p < 0.05$ and $r = 0.49$, $p < 0.01$, respectively) and between the 100 and 200 m tests ($r = 0.49$ and $r = 0.59$, $p < 0.01$, respectively).

The energy system contributions for the maximal tests are showed in Fig. 2.

Both sexes showed a similar profile between the 3 distances. Even though male swimmers showed higher absolute values of the anaerobic alactic and aerobic systems, these differences did not exist when relative values for body weight were considered (panel D).

The anaerobic alactic system contribution was not different between distances. This system contribution was significantly correlated with the swimmers PBs in the 50 and 200 m distances ($r = -0.52$ and $r = -0.61$, $p < 0.01$, respectively). The anaerobic lactic system contribution was higher in the 100 m test, showing significant differences only with the 50 m test. The aerobic contribution significantly increased as the distance became longer (~ 19.7 and 36.3% between the 50 m test to the 100 and to the 200 m tests, respectively). Swimmers PBs at the 50, 100 and 200 m distances were correlated with the aerobic contribution ($r = -0.44$, $p < 0.05$, $r = -0.52$, $p < 0.01$, and $r = -0.66$, $p < 0.01$, respectively).

The total anaerobic contribution showed negative correlations with all PBs ($r = -0.55$, $p < 0.01$, $r = -0.43$, $p < 0.05$, and $r = -0.51$, $p < 0.01$, for the 50, 100 and 200 m, respectively), similarly to the total energy expenditure ($r = -0.53$, $p < 0.01$, $r = -0.49$, $p < 0.05$, and $r = -0.66$, $p < 0.01$ for the 50, 100, and 200 m, respectively).

Discussion

The aim of our study was to analyze the energy system contribution and the oxygen uptake response at supramaximal swimming intensities, seeking to understand if physiological variables are related with short and middle-distance swimming performance. Even though the literature has already studied the $\dot{V}O_2$K and bioenergetics in swimming in different exercise domains, most of the studies focus on intensities that do not correspond to those found in competitive swimming, or were performed at constant load velocities, not reflecting the specific pacing strategies used in competition. To provide a better understanding of the changes of bioenergetics and $\dot{V}O_2$ response on the spectrum of the competitive swimming distances, the present study analysed maximal trials performances in 50, 100 and 200 m swimming events. To the best of our knowledge, this is the first study approaching energy requirements from $\dot{V}O_2$ "on" and "off" response comparing three competitive swimming distances performed by different sexes.

The main findings of our study are: (1) both $\dot{V}O_2$K and $\dot{V}O_{2\text{peak}}$ were significantly different among the three distances in study, showing a slower $\dot{V}O_2$ response with a higher uptake as the distance becomes longer and the exercise less intense; (2) swimming performance was not related with faster $\dot{V}O_2$K, but it was correlated with higher $\dot{V}O_{2\text{peak}}$'s, and aerobic contribution in all distances; (3) the anaerobic contribution showed the highest correlation with the shorter distance in our study, despite being significantly correlated with all distances, highlighting the importance for short and middle distance performance; (4) finally, even though male swimmers had higher $\dot{V}O_{2\text{peak}}$'s and absolute values for the metabolic contributions, we observed that the differences at the response profile between distances were similar between sexes, with the exception of the 100-MT where the male group trend to reach the Peak-$\dot{V}O_2$. Also, no differences were registered between sexes for the TD's or time constants and for relative values or energy contributions during all MT's.

The strong correlations found between the maximal tests and swimmers PBs, demonstrate the representativeness of the analysis. The correlations found between swimmers performances with the absolute Peak-$\dot{V}O_2$, MAV, $\dot{V}O_{2peak}$'s and amplitudes of the primary phase of the maximal tests, seems to suggest these variables as the best predictors of performance in 50, 100, and 200 m freestyle swimming events, as it was found in other studies for the 400 and 800 m performances (Espada et at. 2015; Reis et al. 2012b).

Regarding the $\dot{V}O_2K$ parameters, TD and amplitude showed similar values between tests, with the exception of the amplitude at the 50 m test that was significantly lower. On the other hand, the time constant was significantly different between all distances, decreasing as the exercise becomes shorter and more intense. It could suggest that both the rate of O_2 delivery to muscle and mitochondrial phosphorylation had different adjustments over time to match target aerobic energy requirements along the different MT's (Whipp and Rossiter 2005).

These differences found at $\dot{V}O_2K$ contradicts several comparative studies where the time constant remained unchanged between intensities: around the maximal lactate steady state (Espada et al. 2015); between heavy and severe domains (Pessôa Filho et al. 2012; Reis et al. 2012b); or at intensities around the MAV (Sousa et al. 2014). Conversely, our results are in accordance with other studies which analyzed maximal velocities without imposed pacing strategies, in swimming (Rodríguez et al. 2003; Sousa et al. 2013), cycling (Hettinga et al. 2009), or running (Carter et al. 2006).

In fact, the first $\dot{V}O_2K$ study focused on simulated swimming events similar to the present study, Rodríguez et al. (2003) reported significant differences on the time constant between the 100 and 400 m distances (22.7 vs 27.9 s for men and 23.1 vs 30.6 s for women, respectively). Also, Sousa et al. (2013) reported that the $\dot{V}O_2K$ was slower in moderate than in maximal velocity, in a 200 m test, suggesting that, since the time constant describes the adaptation of the cardiovascular and muscular systems, the sudden and exponential need of $\dot{V}O_2$ in the maximal test could be able to explain the lower values of this parameter. Our results are in line with these studies contributing for the thesis that the $\dot{V}O_2K$, at supramaximal intensities or when tests are performed in a time trial mode, are faster than in lower exercise intensities.

Jones et al. (2008) demonstrated that in a fast-start strategy the $\dot{V}O_2$ truly increased more rapidly towards its peak, which justifies the highest $\dot{V}O_2$ in the first 120 s of the exercise and extended times to exhaustion, when compared with the even-pace strategy or with the slow-start strategy. Overall, it is possible to conclude that a fast-start pacing strategy might actually enhance the exercise tolerance, since it increases the oxidative contribution to the energy turnover and therefore spares some of the anaerobic capacity across the transition to higher intensity exercises.

Hence, the fast $\dot{V}O_2$ response reported in the present study, with time constant values between 8 and 17 s, are in line with other studies performed in terrestrial environments (Carter et al. 2006; Hettinga et al. 2009) contradicting those who predict lower kinetics in swimming due to the constraints of the aquatical environment and the nature of the exercise (Sousa et al. 2017). As a matter of fact, our results are in line with recent studies that showed fast kinetics in well trained swimmers (Espada et al. 2015; Pessôa Filho et al. 2012; Reis et al. 2012a, b, 2017; Ribeiro et al. 2015; Rodríguez et al. 2016; Sousa et al. 2011, 2013). These fast kinetics and the statistical differences observed in the three studied swimming distances, could be explained by a fast start strategy that induces a rapid increase in the oxidative contribution to exercise (Jones et al. 2008), also observed in cycling (Hettinga et al. 2009) in all-out sets.

Also, the correlations found at the MRT and the $O_{2initialDef}$ between the 50 and the 100 m tests, demonstrate that the swimmers with fast kinetics and with lower O_2 initial deficits in one distance, also showed better results in the other distance. The fact that this relation repeats between the 100 and 200 m tests, but not between the 50 and the 200 m tests support the idea that a closely physiological relation could be found in the 50/100 and 100/200 distances, existing a separation in the efforts' physiological logic. That could explain why the majority of swimmers specialized in the 50 m distance usually also swim the 100 but not the 200 m distance and, on the other hand, swimmers that are specialized in the 200 could also swim the 100 m, but not (usually) the 50 m distance.

Regarding the energy system contribution, we observed an increase of the relative aerobic contribution while the anaerobic follows an opposite direction from the 50 to the 200 m tests. Even though male swimmers present higher absolute values at the aerobic and anaerobic alactic systems, probably caused by the higher $\dot{V}O_2$'s achieved during the MT's, a similar profile between groups was observed when relative values for the total energy expenditure were considered.

In line with the energy metabolism interplay suggested for Gastin (2001), and reported also for swimming by Holmér (1979), Toussaint and Hollander (1994) and Rodríguez and Mader (2011), the anaerobic alactic releasing reaches it maximal contribution during the first ~ 30 s in trails performed maximally, as observed in the present study for all MT's. Correlations with swimmers' performances in the 50 and 200 m tests showed the anaerobic alactic system relevance both in the shorter and the longer distance. On the other hand, the anaerobic lactic system reached its maximal value in the 100 m test, only with significant differences to the 50 m test. Considering the total anaerobic contribution, both sexes presented a remarkable similar response, with no significant differences between distances.

The present study highlights the higher supply, in terms of the absolute values, of the alactic and aerobic energy for men than women for all trials, despite lactic energy supply did not differ between sexes and distances. The total anaerobic energy differed between male and female swimmers, but not the relative contribution of each energy pathway, except the alactic and lactic percentages during the 200-MT. Furthermore, the absolute differences were observed for alactic component for all MT's (but not for lactic values), which can be attributed to muscle mass differences between sexes, but also other physiological and anthropometrical factors, as: enzymatic LDH inhibition/activation rulers, redox potential ($NADH/NAD^+$), glycogen source and dilution space (Weber et al. 2006), or even body surface and buoyancy (Chatard et al. 1991). However, when values were corrected for body mass values, no differences between sexes were observed.

Although we observed the highest correlation of the anaerobic system with the 50 m test and of the aerobic system with the 200 m test, both systems were related with swimmers' performances in all distances, showing that both contribute significantly to their swimming performance and should be carefully included in the training routines, especially, when training for the 100 m freestyle event, where both systems have similar relative contributions.

Campos et al. (2017) using backward extrapolation, concluded that the contribution of the anaerobic system influences swimming performances up to the 400 m' distance, corroborating the findings of our study. However, they found a significant increase in the anaerobic alactic contribution between the 50 to the 100 and to the 200 m distances, contradicting our findings, where this value stayed constant. Maybe, the methodological differences regarding alactic assessment account to the lack of similarities between alactic contributions in both studies, despite the present results being better align with theoretical assumptions for alactic energy supply during trials performed maximally.

The observed aerobic energy contributions are also aligned with other studies in swimming. For the maximal performance in 100 (Hellard et al. 2018; Ribeiro et al. 2015) and 200 m distances (Sousa et al. 2011), has been reported a significant increase of aerobic energy releasing as the distance increases and velocity decreases. Such profile for aerobic energy contribution was replicated for others swimming circumstances around the MAV (Sousa et al. 2014) and running (Spencer and Gastin 2001). In this last study the authors highlight the significant and greater participation that is traditionally accepted of the aerobic contribution in the 30 s time period especially for the 400–1500 m running events, corroborating our results.

Studying elite athletes, Capelli et al. (1998) observed energy requirements attained ~ 3.33 kW, ~ 2.72 kW, and ~ 1.94 kW, respectively during performance in 45.7, 91.4 and 182.9 m for crawl stroke at ~ 1.97 m s^{-1} (~ 139%-MAV), 1.75 m s^{-1} (~ 123%-MAV) and 1.6 m s^{-1} (~ 114%-MAV). In the present study, crawl swimming during 50, 100, and 200 m performed at ~ 1.64 m s^{-1} (~ 124.8%-MAV), ~ 1.43 m s^{-1} (~ 111.6%-MAV) and 1.29 m s^{-1} (~ 102.6%-MAV), required respectively ~ 3.16 kW, ~ 1.86 kW, and ~ 1.25 kW. The study of Capelli et al. (1998) engaged only men and therefore the comparison to the present results needs caution. The swimmers in Capelli et al. (1998) study did present higher velocity for each distance than the swimmers of the present study. Probably, the higher performances in Capelli's study also reflect the higher fractions of anaerobic supply at 45.7 m [~ 15.3% aerobic and ~ 84.7% anaerobic (~ 58.9% lactic and ~ 25.8% alactic)], at 91.4 m [~ 33.3% aerobic and ~ 76.7% anaerobic (~ 47.2% lactic and ~ 19.6% alactic)] and at 182.9 m [~ 61.5% aerobic and ~ 38.5% anaerobic (~ 24.7% lactic and ~ 13.8% alactic)], than the fractions of energy contributions observed in the present study (see Fig. 2e). These differences could be linked to a higher performance level of the swimmers in Capelli's study and to the lower distances performed.

On the other hand, Hellard et al. (2018) investigated the metabolic profile for the whole 100 m distance and for each quarter of the race and reported for juniors swimmers (age group similar to our study) that the 100 m showed absolute values of energy release attaining ~ 27 kJ (~ 1.3 LO_2 or ~ 19,5%) for alactic, ~ 38 kJ (~ 1.8 LO_2 or ~ 27.5%) for lactic and ~ 73 kJ (~ 3.5 LO_2 or ~ 53.0%) for aerobic requirements. The velocity during 100 m was recorded around 1.5 m s^{-1} in average for the entire sample (considering both senior and junior, or faster and slower swimmers). For these authors, the differences in energy contributions, and consequently in swimming performance, was an effect of pubertal shift in metabolism towards higher reliance on glycolytic motor units, with such enhanced energy potential accounted to the increases in height, muscle and total mass, and strength and anaerobic power. Despite the fact that the sample of the present study involved male and female swimmers, the comparisons to Hellard et al. study reveals similarities in time performance during 100 m, as well as for the contributions of each energy system during 100 m. Therefore, the present study can also support the effect of anthropometric difference (between sexes) on power production and swimming performance.

The change in predominance between energetic systems interplay was evident at 75 s of maximal exercise performance, as suggested by Gastin (2001). Such change was also observed in the present study, which is evidenced for 100 m performance lasting about ~ 71 s and showing anaerobic (~ 46%) and aerobic (~ 54%) with contributions close to 50%. Furthermore, our findings seem to corroborate the Rodríguez and Mader's (2011) schematization of the relative energy systems contributions for swimming, even though our results showed small higher aerobic contributions in the 50 m and 200 m tests, probably due to the longer exercise times observed in our study (when compared with swimming without the snorkel). In this study, the authors only presented values for male swimmers assuming that there should be no differences with female swimmers. Based on our results, we can suggest that their assumption is correct since we did not find differences between sexes at the relative contribution of the total anaerobic or aerobic systems.

The main limitation of this study relates to the 50 m test $\dot{V}O_2$K's analysis, since, due to its short duration, a typical $\dot{V}O_2$ monoexponential modeling is challenging. However, the use of the growth rate, seems to corroborate the data. Also, the inexistence of $\dot{V}O_2$K studies with this distance cannot provide a direct comparison, despite that, similar values of the time constant and amplitude were found in running (Draper and Wood 2005), or even faster in cycling (Hettinga et al. 2009). Also, some authors propose that the cardiodynamic phase determination should be constricted by the start of the fall in pulmonary gas exchange ratio ($R = \dot{V}CO_2/\dot{V}O_2$). However, the beginning of this decrease is often not sufficiently clear for this purpose and so a value of at least 20 s is commonly used (Whipp and Rossiter 2005). Since there is no clear indication for the best fit for such short and supramaximal swimming events, we chose to use the latter solution. However, we acknowledge that this method could narrow the VO_2 data set analyzed, particularly in the 50 m distance. Additionally, swimming velocity is the result of the interactions between energy input ($\dot{E}$), propelling (e_p), and mechanical efficiency (e_{mec}). Regrettably, the present study does not provide such mechanical information about swimming, which could improve the arguments regarding factors linking faster performance to higher energy requirements. Finally, the use of swimming snorkels for $\dot{V}O_2$ data collection has been reported as not bringing significant changes to swimmers $\dot{V}O_2$ response (Baldari et al. 2012; Keskinen et al. 2003; Reis et al. 2010; Rodríguez et al. 2008), or in general kinematics and swimming efficiency (Barbosa et al. 2010) and does not lead to an increase in active drag during front crawl performed at a large range of velocities and, consequently, the metabolic energy necessary to overcome total drag will not be affected (Ribeiro et al. 2015). Because of the use of the system, all tests were performed with in-water starts and open turns without underwater gliding, which could increase the turning times (Ribeiro et al. 2015) and constrain specific swimming movements like flip turns, trunk rotations, dolphin kick and lateral breathing and therefore suppress ecology (Chaverri et al. 2016) and for these reasons, and even though it seems to us the best way to evaluate the physiological parameters, here in study, we cannot say that this is the exact swimming conditions that swimmers come across in competition.

This work also provides important information to coaches, since the understanding of the bioenergetics and $\dot{V}O_2$ response could help them to plan training sessions as well as to establish new strategies to increase swimmers' performance. Therefore, according to our findings we recommend that:

- The aerobic power should have an important role on the training programs to increase the individual´s Peak-$\dot{V}O_2$ that is highly related with short and middle distance swimming performance;
- Even when training exclusively for a 50 m event, the aerobic system seems to have an important role since it represents ~ 34% of the effort, and on the other hand, the anaerobic system should not be neglected even when training for the 200 m distance (~ 29% of participation effort);
- The use of high-intensity interval training swimming sets should be also considered to promote repeated elicitation of the oxidative system which could contribute to accelerate the $\dot{V}O_2$K (Bailey et al. 2009; Berger et al. 2006; Duffield et al. 2006) and maximize the effort's efficiency, since fast kinetics allows to achieve higher $\dot{V}O_2$'s with lower $O_{2InitialDef}$.

Practical recommendations for high-intensity training include intermittent, short-term high-intensity bouts planned with large volume per training session which have shown specificity in increasing swimming velocity in short-duration (50, 100, and 200 m) events by promoting changes in strength and mechanical power (Toussaint and Vervoorn 1990), as well as metabolic parameters such as $\dot{V}O_{2max}$. In swimming, it is not practical to apply work-intervals based on a fixed time, however, according to the knowledge of how swimmers respond physiologically to the exercise, coaches can estimate defined distances for the IT repetitions. Accordingly to our results Espada et al. (2015) suggested that the time constant could provide indications for training prescription, since after four-time constants have elapsed, the $\dot{V}O_2$ response has basically reached ~ 98% of the total $\dot{V}O_{2max}$ and so, coaches can prescribe training sets similar to the duration of a 100 m repetition. Also, Sousa et al. (2018), testing the swimmers tolerance for continuous workout at intensities around the MAV, suggested the application of efforts that could last at least 60 s, since shorter exercises could not have time to tax the aerobic metabolism enough.

In conclusion, the results suggest that the $\dot{V}O_2$ kinetics are slower in longer distances where the intensities are naturally lower which can be partially explained by a rapid increase of the oxidative contribution to the energy turnover promoted by the faster initial pacing strategies usually used in the shorter distances. The fast kinetics found, even though the Peak-$\dot{V}O_2$ in the female group was reached only in the 200 m test, allowed that near maximal values of the $\dot{V}O_2$ (~ 95% for the combined group) can actually be reached within ~ 1 min of strenuous exercise, as it was seen in the 100 m test. The aerobic response seems to be more closely associated between the 50 and the 100 m tests and between the 100 and 200 m tests, which could explain why swimmers, usually, choose these distinct sets of competition events separately. Both energetic systems have an important role when training for the distances considered in our study, since they were significantly related with the performances in competition. Finally, the few differences found between sexes, when relative values are considered, in accordance to a previous study from our research group (Reis et al. 2017), suggest that the adaptations in training protocols can be applied both in male and female swimmers.

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Author contribution DPF, FA, JR, ME and TA conceived and designed the research. AS, DPF, LS and TA conducted the experiments. AS, DPF, FA, JR, LS, ME and TA reviewed and analysed the data. TA wrote the first drafted of the manuscript and DPF, FA, JR and ME commented and wrote previous versions of the final manuscript. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare no conflicts of interest that are directly relevant to the content of this manuscript.

Ethical approval All procedures performed involving human participants were in accordance with the ethical standards of the institutional research committee (CEFMH: 39/2015) and with the 1964 Helsinki declaration and its later amendments.

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