

Boro Štrumbelj
Anton Ušaj
Jernej Kapus

LACTATE PRODUCTION AND OXYGEN UPTAKE DURING 200 METRES FRONT CRAWL AT DIFFERENT INTENSITIES

PRODUKCIJA LAKTATA IN PRIVZEM KISIKA MED 200 M KRAVL PRI RAZLIČNIH INTENZIVNOSTIH

ABSTRACT

The purpose of the study was to establish whether anaerobic lactic production and oxygen uptake could limit the energy supply during 200 m front crawl swimming. Twelve male swimmers performed four swims of 200 m crawl at intensities from 80%, 90%, 100% to 110% (until exhaustion) on separate days with a swimming snorkel. Respiratory parameters (V_E , Vo_2), blood parameters (pH, [LA⁻]) and heart rate (HR) were measured. The results demonstrate that limitations in V_E , Vo_2 and HR during swimming occur during supramaximal swims (no further increase in measured maximal parameters and time-constant parameters) in comparison to maximal swims. We also found limitations in the obtained maximal [LA⁻] and minimal pH values. It is possible to conclude that individual limitations in V_E , Vo_2 , HR and consequently acidosis could be limiting factors of individual 200 m front crawl performances due to energy supply restrictions.

Key words: swimming, front crawl, energetics, incremental performances

University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia

Corresponding author:

Boro Štrumbelj
University of Ljubljana
Faculty of Sport
Gortanova 22, 1000 Ljubljana
Tel. +386 1 520 77 00, +386 1 520 77 37
E-mail: boro.strumbelj@fsp.uni-lj.si

IZVLEČEK

Namen raziskave je bil ugotoviti ali lahko anaerobna produkcija mlečne kisline in privzem kisika omejujeta potrebno preskrbo energije v plavalnem nastopu na 200 m krawl. Dvanajst moških merjencev je opravilo 4 nastope na 200 m krawl z obremenitvijo od 80 %, 90 %, 100 % do 110 % (do izčrpanosti) v različnih dneh s plavalno dihalko. Merjeni so bili dihalni kazalci (V_E , Vo_2), kazalci v krvi (pH, [LA⁻]) in frekvenca srca (FS). Iz rezultatov je razvidno, da pride do omejitve V_E , Vo_2 in FS med supramaksimalnim plavanjem (ni prisotnega nadaljnega povečanja maksimalnih kazalcev in časovnih kazalcev) glede na maksimalna plavanja. Ugotovili smo tudi omejitve v doseženih maksimalni [LA⁻] in minimalnih pH vrednostih. Zaključimo lahko, da prihaja do individualnih omejitev v V_E , Vo_2 , FS in posledično nižjega pH med in po naporu, kar bi lahko predstavljalo omejitvene dejavnike pri preskrbi energije za nastop na 200 m krawl.

Ključne besede: plavanje, krawl, energija, večstopenjski nastopi

INTRODUCTION

Maximal performances in swimming depend on the maximal metabolic power of the athlete and on the economy of locomotion. The amount of metabolic energy spent in transporting the body mass of the subject over a unit of distance has been defined as the energy cost of locomotion (di Prampero, 1986). Energy during swimming is estimated as the sum of the energy derived from alactic (AnAl), lactic (AnL) and aerobic (Aer) processes. The amount of metabolic energy expended during supramaximal swims (E , kilojoules) is assumed to be the sum of three terms:

$$E = E_{an} + \alpha VO_{2max} t_p + \alpha VO_{2max} \tau(1 - e^{-t_p/\tau}) \quad (\text{Equation 1})$$

where α is the energy equivalent for O_2 , assumed to be equal to $20.9 \text{ kJ} \cdot \text{l}^{-1}$, τ is the time constant for the attainment of VO_{2max} from the onset of exercise, E_{an} is the amount of energy derived from the use of anaerobic energy stores, t_p is the performance time, and VO_{2max} (litres per second) includes VO_2 at rest (Capelli, Pendergast, & Termin, 1998).

The energy cost of front-crawl swimming (Capelli et al., 1998; Zamparo, Capelli, Cautero, & Di Nino, 2000; Poujade, Hautier, & Rouard, 2002) and the factors affecting energy cost at different intensities of swimming have been studied by many researchers (Lavoie & Montpetit, 1986; Toussaint & Hollander, 1994). It has been found that high-level swimmers have a better capacity to maximise their energy input (VO_{2max} , $[LA^-]$ production, minimal velocity at VO_{2max}) than lower level swimmers (Fernandes et al., 2006). High-level swimmers are also more economical and efficient than swimmers at a lower level (Toussaint, 1990; Fernandes et al., 2006). In a review of energetics and biomechanics as determining factors of swimming performance, one of the conclusions was that swimming performance is strongly related to the energetic profile and this in turn to the technical level and that high-level swimmers are more economical in that regard (Barbosa et al., 2010). A valuable practical consideration for coaches is the importance of monitoring energetic adaptations within the season and whether their swimmers can improve their performance by improving their aerobic or anaerobic capacity. To improve energetic adaptations it is also important to know how they limit performances in swimming.

The aim of this study was to establish whether measured aerobic and anaerobic lactate parameters could limit the energy supply during a 200 m front crawl swim and consequently affect the performance during supramaximal swimming.

METHODS

Participants

Twelve male swimmers (age: 24 ± 3 yrs; height: 181 ± 9 cm; body mass: 77 ± 13 kg) volunteered to participate in this study. All subjects had a minimum of eight years' competition swimming experience and considered front crawl their best stroke. The subjects were informed of the risks involved in the experiment before they agreed to participate. The study was approved by the National Ethics Committee of the Republic of Slovenia.

Testing protocol

All swims were performed using the front crawl stroke in a 25 m indoor swimming pool. The temperature of the water was 27°C . Each swimmer performed four swims of 200 m crawl at

intensities from 80%, 90%, 100% to 110% (until exhaustion) on separate days with a swimming snorkel (Toussaint et al. 1987). First, the swimmers performed a maximal 200 m front crawl swim. Thereafter, they performed submaximal swims at 80% and 90% of their maximal 200 m front crawl swim velocity. Finally, the swimmers performed a supramaximal swim with 110% velocity until exhaustion (on average, they were able to swim 113.8 ± 17.0 m). A light leader was used to ensure an even pace during the swimming at submaximal and supramaximal intensities.

Arterialised blood samples (20 μ l) were collected from the earlobe after a warm up and at 1, 3 and 5 minutes of recovery after the swimming and analysed for blood lactate concentration ($[LA^-]$) using a Kodak Ektachrome analyser (Kodak, USA). At the same time, arterialised blood samples (60 – 80 μ l) were collected and analysed for pH with an ABL5 analyser (Radiometer Copenhagen, Denmark). Calibration of the equipment was performed every six samples with a standard lactate and pH solution, respectively. The maximal measured $[LA^-]$ and minimal pH obtained values were analysed.

Ventilation (V_E) and O_2 uptake (VO_2) were measured using a portable respiratory gas analyser METAMAX 2 (Cortex, Germany) adapted to measurements with a swimming snorkel made by Toussaint et al. (1987). Average data for a 10-second period were recorded after the warm up, during swimming and 5 minutes after the end of each swim. The flow meter was calibrated with a syringe of a known volume (3.0 l). The gas analyser was calibrated by known standard gases.

Heart rate (HR) was measured using POLAR S-610 heart rate monitors (Polar, Finland). Average data for a 10-second period were recorded after the warm up, during swimming and 5 minutes after the end of each swim. From all obtained data of heart rate values in the rest were excluded to observe relative changes.

Data analysis

The maximum values of HR between the 200 m swims were determined by the arithmetic average of the sequence of the two highest measured values while swimming (a period of 10 seconds).

To compare the measured HR values while swimming, the initial values were subtracted at rest (moving the curve obtained to point 0) to obtain the HR values for analysis. HR during exercise usually increases exponentially (Lamarre, 1990). Therefore, the kinetics of HR during swimming was defined by an exponential curve with equation 2, where the HR(t) were calculated between 200 m swims in the time of observation (t) and the ap (the value is positive) and bp calculated ratio equation.

$$HR(t) = a_p \cdot (1 - e^{-bp \cdot t}) \quad (\text{Equation 2})$$

The resulting curve of interpolated values of HR was analysed so that we compared the curve of each swimmer scanned every 10 seconds. The last statistically analysed values were within 60 seconds at a 110% load of the swimming. The fastest swimmer at that time had already completed the swim at a 110% load of swimming due to exhaustion.

Measured values for all breathing parameters (V_E and VO_2) were calculated in the same way.

Statistical analysis

Means and standard deviations were computed for all variables. A one-way ANOVA was used for multiple test comparisons in the measured parameters, followed by Bonferroni's post-hoc

tests if significant differences were apparent. Statistical significance was accepted at the $p \leq 0.05$ level. All statistical parameters were calculated using the statistics package SPSS (version 15.0, SPSS Inc., Chicago, USA) and the graphical statistics package Sigma Plot (version 9.0, Jandel, Tübingen, Germany).

RESULTS

Maximal V_E increased at intensities ranging from 80% ($78.2 \pm 13.5 \text{ l} \cdot \text{min}^{-1}$) to 100% ($117.4 \pm 18 \text{ l} \cdot \text{min}^{-1}$) ($p < 0.05$), but at 110% intensity it was similar to the values at 100% intensity. Something similar happened with Vo_2 (80% = $2.65 \pm 0.5 \text{ l} \cdot \text{min}^{-1}$, 100% = $2.76 \pm 0.6 \text{ l} \cdot \text{min}^{-1}$) ($p < 0.05$). Between 100% and 110% intensity there were no differences (Table 1).

Table 1. Average maximal measured values of VE , and VO_2 during swimming with different intensities (\pm SD)

	80% load	90% load	100% load	110% load
$V_E \text{ l} \cdot \text{min}^{-1}$	78.18 ± 13.49	91.43 ± 13.61	117.40 ± 17.98	108.72 ± 17.19
$Vo_2 \text{ l} \cdot \text{min}^{-1}$	3.09 ± 0.51	3.44 ± 0.49	3.81 ± 0.51	3.70 ± 0.51

With ANOVA significant changes were found between interpolated values of V_E from 10 to 80 seconds ($p < 0.05$). With the post hoc test we found a significant difference between V_E at 80% intensity and V_E at 110%, from 10 to 80 seconds ($p < 0.05$). V_E values at 80 seconds were found to be different between intensity values of 90% and 110% intensities and 110% ($p < 0.05$) (Figure 1).

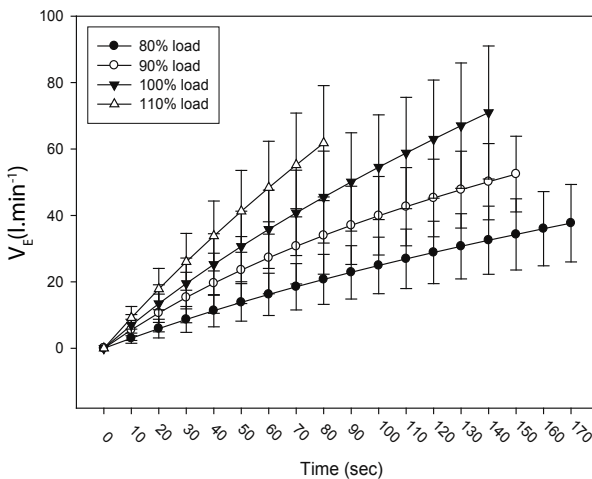


Figure 1. V_E (ventilation) kinetic responses of interpolated data to the value of $0 \text{ l} \cdot \text{min}^{-1}$ during swimming at different intensities to the moment when all swimmers were able to perform the predefined load

With ANOVA significant changes were found between interpolated values of Vo_2 from 20 to 80 seconds ($p < 0.01$). Using the post hoc test we found significant difference between Vo_2 at an 80% intensity and Vo_2 at 110% ($p < 0.05$). Vo_2 values at 80 seconds were different between 90% and 100% intensities and at 110% intensity values ($p < 0.05$) (Figure 2).

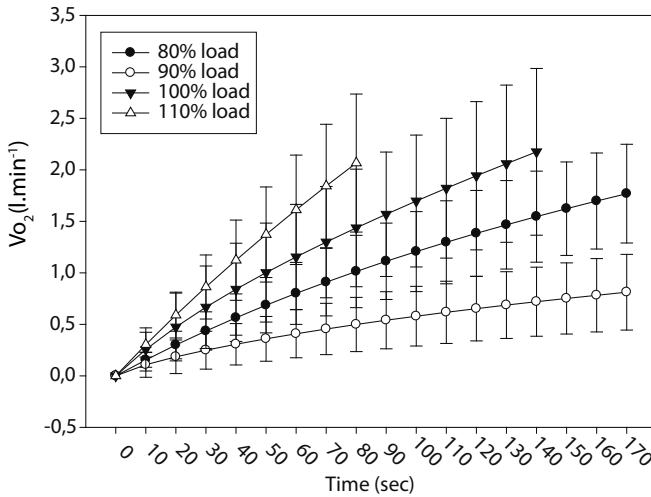


Figure 2. Vo₂ (oxygen uptake) kinetic responses of interpolated data to the value of 0 l.min⁻¹ during swimming at different intensities to the moment when all swimmers were able to perform the predefined load

The most notable change of pH was from 90% (7.31±0.04) to 100% intensity (7.18±0.06) (p<0.001) (Table 2.). Between 100% and 110% intensity there were no changes. Something similar applies to [LA⁻] (7.8±1.4 mmol.l⁻¹ at 90% intensity in comparison with 14.2±2.5 mmol.l⁻¹ at 100 % intensity) (p<0.001). Between 100% and 110% intensity there were no differences (Table 2).

Table 2. Average maximal obtained values of pH and [LA⁻] during swimming at different intensities (± SD)

	80% load		90% load		100% load		110% load	
	1. min	Max	1. min	Max	1. min	Max	1. min	Max
pH	7.34	7.33	7.32	7.31	7.24	7.18	7.29	7.23
	±0.03	±0.03	±0.04	±0.04	±0.06	±0.06	±0.04	±0.05
[LA ⁻](mmol.l ⁻¹)	5.7	6.1	7.4	7.8	12.7	14.2	9.9	12.0
	±1.1	±1.5	±1.0	±1.4	±2.4	±2.5	±1.5	±1.9

Significant changes were found (p<0.001) when the changes in lactate concentration before and after the swims with regard to the time were compared. Between 80% and 90% intensities there were no changes. Significant changes were found between 90% (0.4±0.01 mmol/l · s⁻¹) and 100% (0.08±0.01 mmol/l · s⁻¹) intensity calculated values and 100% to 110% (0.13±0.02 mmol/l · s⁻¹) intensity calculated values (p<0.001) (Figure 3).

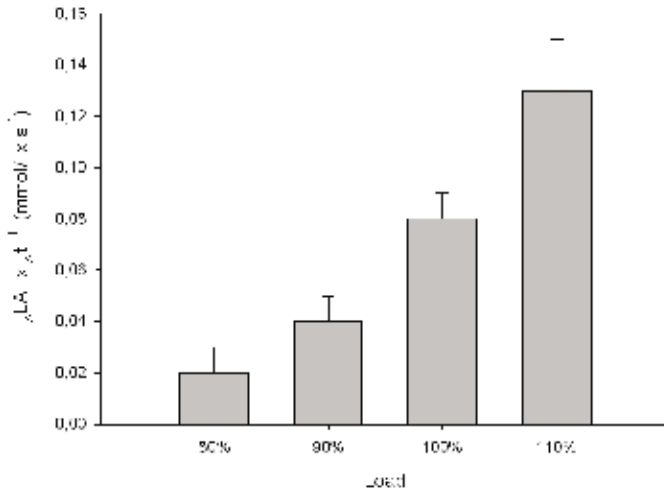


Figure 3. Increased rate of blood lactate concentration (rest concentration against maximal lactate concentration after the swims) with regard to the time of swimming at different intensities

The most notable change of HR was from 90% (165±10 b·min⁻¹) to 100% (177±11 b·min⁻¹) intensity (p<0.05). Between 100% and 110% intensity there were no significant differences (Table 3).

Table 3. Average maximal measured values of heart rate during swimming at different intensities (± SD)

	80% load	90% load	100% load	110% load
Heart rate (b·min ⁻¹)	155±16	165±10	177±11	171±11

With ANOVA significant changes were found between interpolated heart rate values from 10 to 60 seconds (p<0.01). Using the post hoc test we found a significant difference between the HR values at 80% intensity and the HR values at 100% and at 110% intensity (p<0.01). No changes were found between the HR values at 100% and 110% intensity (Figure 4).

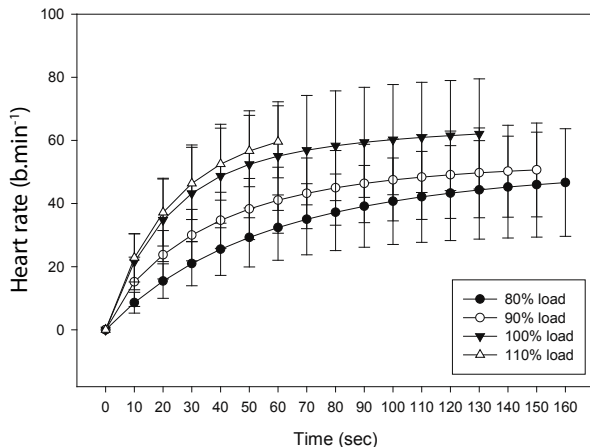


Figure 4. Heart rate kinetic responses of interpolated values during swimming at different intensities to the moment when all swimmers were able to perform the predefined load

DISCUSSION

The energy cost of swimming increases as a function of speed. With an increase in swimming speed the sum of energy supply during swimming should increase from either alactic (AnAl), lactic (AnL) and aerobic (Aer) processes. Our results allow us to conclude that an insufficient energy supply due to limitations in aerobic and anaerobic lactic processes could limit the maximal speed of swimmers in a 200 m front crawl.

Although our results do not demonstrate that an insufficient energy supply is a limiting factor of maximal performance in front crawl swimming, we could show that when certain levels of V_E , Vo_2 , HR, pH and lactate concentration were reached similar to those at maximal intensity the swimmers were no longer able to swim at the selected supramaximal intensity (Figure 2, Table 2).

At the beginning of the swimming, the swimmers were able to compensate for the insufficient energy supply by aerobic processes with an increased energy production by anaerobic lactic processes since we found increased lactate production per unit of time at an increasing intensity of swimming (Figure 3). However, when the level of acidosis and lactate concentration at 110% intensity was similar to that at 100% intensity the swimmers were no longer able to swim at that intensity (Table 2).

The energy cost of swimming at velocities ranging from moderate to maximal has been studied by many researchers (Holmer, 1974; Monpetit, Lavoie, & Cazorla, 1988; Toussaint et al. 1988; di Prampero, 1986; Capelli et al. 1998; Zamparo, Pendergast, Mollendorf, Termin, & Minetti, 2005). The energy cost of swimming increases as a function of the speed and depends, among other things, upon the swimming style, the technical skill of the swimmer, the gender, the anthropometric features of the swimmer, as well as the individual's buoyancy, passive and active drag and propelling efficiency (Zamparo et al., 2000).

The aim of our study was not to estimate the energy cost of front crawl swimming at different speeds of swimming but to establish whether any of the energy supply systems could potentially be a limiting factor for a maximal performance during 200 m front crawl swimming.

Since the anaerobic alactic system may be considered a stable system to provide energy, we focused on anaerobic lactic and aerobic processes. It is visible from our results that with an increasing intensity of swimming V_E and Vo_2 increases from 80% intensity to 110% intensity when V_E and Vo_2 kinetics were observed during swimming at different intensities. However, when we compared the maximal obtained values of both parameters we found that the swimmers were no longer able to swim at 110% intensity when similar values to that at 100% intensity were reached (Table 1). Something similar was observed with the maximal heart rate values (Table 3). In addition, we found that the kinetics of the HR frequency was similar at 110% intensity to that at 100% intensity (Figure 4). Based on our results, it may be concluded that the aerobic energy supply to working muscles could be limited by the cardiovascular system at supramaximal intensities (no further increase of the maximal heart rate and kinetic responses of the heart rate). Cardiovascular adaptations to increased swimming intensity are important since heart rate is considered a limiting factor of Vo_2 max (Astrand & Rodhal, 1986) and this is in accordance with the results of our study.

Fatigue, defined as the failure to maintain the required or expected power output, is a complex problem since multiple factors are clearly involved, with the relative importance of each being dependent on the fibre type composition of the contracting muscles, and the intensity, type and duration of the contractile activity. The primary sites of fatigue appear to be within the muscle cell itself and for the most part do not involve the central nervous system or the neuromuscular junction (Fitts, 1994).

The maximal $[LA^-]$ can be used as an aerobic capacity estimation (Avlonitou, 1996). Previous studies found that maximal $[LA^-]$ increases throughout the season (Anderson, Hopkins, Roberts, & Pyne, 2006) and was positively correlated with performance (Bonifazi, Sardela, & Lupo, 2000; Termin & Pendergast, 2000). This can be explained with an improved anaerobic capacity which allows the swimmer to reach higher velocities at an increased oxygen debt and with reduced muscle fatigue (Costa, Bragada, Marinho, Silva, & Barbosa, 2012).

On the other side, there seems to be little consensus regarding the Vo_2 max status throughout the season. Of the two studies found, only one presented an increase in Vo_2 max within the season (Termin & Pendergast, 2000), while the other one observed that Vo_2 max remained slightly unaltered with training (Houston, Wilson, Green, Thomson, & Ranney, 1981).

It is clear that there are significant relationships between the bioenergetic profile, biomechanical characteristics and swimming performance (Costa et al., 2012). From our results and other studies we can conclude that, in order to improve performance, either aerobic or anaerobic capacity should be improved with training or the biomechanical characteristics of the stroke can be altered so as to improve the mechanical efficiency.

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