Time Limit at vVO2max and VO2max Slow Component in Swimming. A Pilot Study of University Students

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Abstract

The aim of this study was to measure in swimming-pool conditions, the time to exhaustion at the minimum velocity that elicits maximal oxygen consumption (TLim-vVO_2max) and to verify the existence of an oxygen uptake slow component (O_2SC) in freestyle swimming. Ten university students performed a continuous incremental protocol for vVO_2max assessment. Forty-eight hours later, they swam to exhaustion at vVO_2max to assess TLim-vVO_2max and O_2SC. VO_2 was directly measured and swimming velocity was controlled by a visual pacer. Blood lactate concentrations ([La-]) and heart rate (HR) values were also measured. Mean VO_2max for the incremental test was 54.2±8.2 ml.kg^{-1}.min^{-1}, and the correspondent vVO_2max was 1.19±0.08 m.s^{-1}. The mean duration of the TLim-vVO_2max test was 325±76.5 s. O_2SC appeared in the all-out swim at vVO_2max (279.0±195.2 ml.min^{-1}) and it was found to significantly correlate with the TLim-vVO_2max ($r = .74$, $p < .05$). These results demonstrated that O_2SC is observed also in swimming-pool conditions and that TLim-vVO_2max values are in accordance with typical formulations of aerobic power training sets for swimmers.

Key words: Swimming, maximal oxygen uptake, time limit, VO_2 slow component.

Introduction

The determination of the time of exercise to exhaustion at the minimum velocity that elicits maximal oxygen consumption (TLim-vVO_2max) has arisen in the last years, and seems to be a very interesting matter for assessing various aspects of performance and training of endurance athletes [Billat et al. (1994)] Although swimming is not considered to be a typical endurance sport, it seems very important to study the swimmer's ability to sustain intensities that elicit their maximal aerobic power. This is not a new issue in physiological assessment of athletes, but almost all studies have been conducted in nonspecific training and competition conditions. Reviewing the literature for this topic, Billat and Koralsztein (1996) found 17 experimental approaches published from 1979 until 1995, almost all of them using laboratory procedures, and performing the TLim-vVO_2max tests in special ergometers (namely on a treadmill and cycle ergometer).

In swimming, the investigation of the TLim-vVO_2max is much more recent. To our knowledge, there are only 3 studies available in this area [Billat et al. (1996) Faina et al. (1997) and Demarie et al. (2001)]. Nevertheless, none of them was conducted in free swimming conditions, but in a swimming flume. In fact, presumed technical differences between swimming in a pool *vs* in a

flume, could justify changes in some physiological parameters such as TLim-vVO_2max and oxygen uptake slow component (O_2SC).
The purpose of this pilot study was first to measure the TLim-vVO2max in freestyle swimming, and second to verify the existence of an O_2SC in swimming in swimming-pool conditions as it was observed for Demarie et al. (2001) in a swimming flume for pentathletes.

Methods

Ten physical education university students voluntarily participated in this study. The subjects' characteristics (mean ± SD) were as follows: age = 23.1 ± 3.3 years, height = 1.69 ± 0.08m and weight = 61.9 ± 9.3 kg. All subjects were informed of the protocol before beginning the measurement procedures.
In a 25m indoor pool, each subject performed a continuous incremental protocol for freestyle vVO_2max assessment, starting at $0.9m.s^{-1}$, with increments of $0.05m.s^{-1}$ per 200m stages. VO_2 was directly measured using a *Sensormedics 2900* oximeter [Yorba Linda - California, USA] mounted on a special *chariot* running along the pool [Vilas-Boas and Santos (1994)], and connected to the swimmer by a respiratory valve [Toussaint et al. (1987)]. Expired gas concentrations were averaged every 20s. Swimming velocity was controlled using a visual pacer [TAR.1.1, GBK, Aveiro, Portugal] with flashing lights every 2.5m. VO_2max was considered to be reached according to traditional physiological criteria [Lacour et al. (1991), Howley et al. (1995)] and vVO_2max was consider as the swimming velocity correspondent to the first stage that elicits VO_2max. If a plateau less than $2.0\ ml.min^{-1}.kg^{-1}$ higher could not be demonstrated before exhaustion, the vVO_2max was calculated using an equation proposed by Kuipers et al. (1995):

$$vVO_2max = V + \Delta V.\ (n/N) \qquad (1)$$

where V is the velocity correspondent to the last stage accomplished, ΔV is the velocity increment, n indicates the number of seconds that the subjects were able to swim during the last stage and N the theoretical number of seconds of this step.
Capillary samples for blood lactate concentration ($[LA^-]$) analysis were collected from the ear lobe at rest, and immediately after exercise, and at 3 min and, if necessary, 5 min during the recovery period. Those analyses were obtained from a *YSI1500LSport* auto-analyzer [Yellow Springs Incorporated, Yellow Springs - Ohio, USA]. Heart rate (HR) was monitored and registered continuously each 5 sec through a heart rate monitor system [Polar Vantage NV, Polar Electro Oy, Kempele, Finland].
Forty-eight hours later, all subjects swam to exhaustion at their vVO_2max to assess TLim-vVO_2max. This protocol consisted of three different phases: (i) a 10 min warm-up at an intensity correspondent to 60 % vVO2max, followed by a short rest (20s); (ii) a 50 m distance performed at progressive velocity, enabling the swimmers to reach their individual vVO_2max, and (iii) the maintenance of that swimming velocity (vVO_2max) until exhaustion. The VO_2max determined in the incremental test was compared with the peak VO_2 reached in the TLim-vVO_2max test. O_2SC was calculated as the difference between the last VO_2 measurement of the TLim test and the one measured during the 3rd minute of exercise [Whipp and Wasserman (1972)]. $[LA^-]$ were, again, measured before and immediately after exercise from ear lobe blood samples, and at 3min and, if necessary, at 5min of the recovery period. HR was also registered continuously, using the same procedure previously described.
Swimmers were instructed to use an open turn, always performed at the same lateral wall side, without underwater gliding, and encouraged to perform as long as possible during the test period. Both tests were carried out in the same conditions for each subject (e.g. water and air temperature, and time of the day).

Statistical procedures included means and standard deviation computations for descriptive analysis, and Pearson correlation coefficient and paired *t*-test Students were used for correlation and mean differences analysis. All statistical procedures were conducted through SPSS statistical package. The level of significance was set at $\alpha = .05$.

Results

Data concerning VO_2max (in absolute and relative values), vVO_2max, TLim-vVO_2max, [LA^-] and HR from the present study, and those from the previously published studies conducted in swimming flume, are presented in Table 1. Note that, in all these studies, VO_2max was assessed through direct methods and continuous test protocols.

Non statistical significant differences were noticed in VO_2max and HRmax values between the incremental and TLim-vVO_2max tests. Moreover, VO_2max (relative and absolute) and HRmax presented a high correlation value between those two tests ($r = .86$, .94 and .82, respectively - $p < .05$). Nevertheless, [LA^-]max was significantly different between the two tests ($p=.001$).

Table 1: Age, weight, and height, VO_2max, vVO_2max, TLim-vVO_2max, [LA^-] and HR values in the final of the incremental (Inc) and TLim-vVO_2max (TLim) tests. Results of the present study are presented in comparison with those from [Billat et al. (1996), Faina et al. (1997) and Demarie et al. (2001)].

Parameters	Tests	Present study (n=10)	Billat et al. (96) (n=9)	Faina et al. (97) (n=8)	Demarie et al.(01) (n=6)
Age (years)	---	23.1 ± 3.3	18.4 ± 2.3	18 ± 2	18.8 ± 2
Weight (kg)	---	61.9 ± 9.3	74.5 ± 8.9	75 ± 2	62.4 ± 6
Height (m)	---	1.69 ± .008	1.81 ± 0.7	183 ± 7	1.69± 0.01
VO_2max ($ml.min^{-1}.kg^{-1}$)	Inc	54.2 ± 8.19	59.6 ± 6.7	60 ± 4	50.5 ± 3.3
	TLim	57.0 ± 9.90	----	----	----
VO_2max ($ml.min^{-1}$)	Inc	3372 ±842	4444 ± 729	----	3100 ± 358
	TLim	3536 ± 863	4419 ± 716	----	3560 ± 586
vVO_2max ($m.s^{-1}$)	Inc	1.19 ± 0.08	1.46 ± 0.09	1.54 ± 0.1	1.28 ± 0.07
TLim (s)	TLim	325 ± 76.5	287 ± 160	302 ±136	375 ± 38
[LA^-]max ($mmol.L^{-1}$)	Inc	7.8 ± 1.38	4.3 ± 1.6	----	7.1 ± 3.5
	TLim	10.9 ± 2.33	4.9 ± 1.2	----	8.2 ± 4.4
HRmax ($beats.min^{-1}$)	Inc	184 ± 8 184±	179 ± 5	----	----
	TLim	9	177 ± 8	----	----

In Fig. 1, it is possible to observe a typical VO_2 pattern during the TLim-vVO_2max test. Notice the three moments of this test: (i) the warm-up followed by a short pause for blood collection (20 sec); (ii) the 50m progressive velocity distance, and (iii) the maintenance of the swimming workload correspondent to vVO_2max until exhaustion.

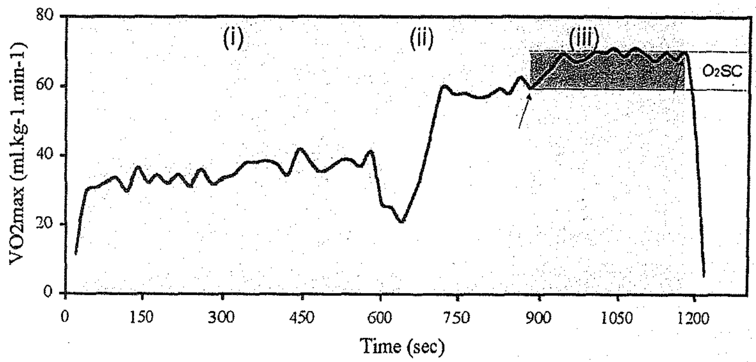

Fig. 1: A typical example of the VO2 pattern during the TLim-vVO2max test. The arrows delimit the period where the O2SC was calculated.

It was possible to observe an O_2SC in the TLim-vVO_2max test of all subjects, presenting a mean value of 279.0±195.2 ml.min^{-1}. This O_2SC was found to significantly correlate with the TLim-vVO_2max ($r = .74$, $p = .014$). No correlation ($r = -.18$, $p = .61$) was found between O_2SC and [LA-]max in the TLim-vVO_2max test.

Discussion

The values of VO_2max (expressed in absolute and relative forms) obtained in the incremental test with direct oximetry are in accordance with those previously published for unskilled swimmers or non-specialized athletes in swimming [Troup (1990), Demarie et al. (2001). However, they were lower than those obtained by many authors for elite freestyle swimmers [Holmér et al (1974), Troup (1990), Billat et al. (1996) and Faina et al. (1997)]. This "medium" level of swimming proficiency of the subjects of the present study can be noticed from the obtained low values of vVO_2max.

The non existence of significant statistical differences between the VO_2max values assessed from the incremental and TLim-vVO_2max tests are also in accordance with previously published reports [Billat et al. (1996), Demarie et al. (2001)].

HRmax did not show statistical difference between the two tests as found by Billat et al. (1996). The obtained mean value is very similar to the 186 beats.min^{-1} value reported for elite middle distance swimmers by Holmér et al. (1974). Is seems that, for this kind of intensity of exercise (aerobic power zone) values ranging from 180 to 200 beats.min^{-1} are consensual [Maglischo (1988)].

The significantly higher value of [LA$^-$]max obtained in the TLim-vVO_2max test compared with the incremental one, may be explained by a hypothetical higher anaerobic energy contribution associated with less low intensity periods of exercise, as can be observed in the beginning of the incremental test. One other and more controversial possibility was presented by Poole et al. (1991) assuming the possibility of a major recruitment of fast twitch muscle fibers associated with the fatigue of the previously recruited ones. This hypothesis is also associated to the possible explanation of O2SC through an increased number of recruited motor units [Poole et al. (1991), Barstow (1994)]. This is in accordance with Faina et al. (1997) who referred that the anaerobic energy contribution is not negligible in such exercise. Nevertheless, [Billat et al. (1996) and Demarie et al. (2001)] did not report statistically significant difference between the two tests in [LA$^-$]max values.

As it was possible to observe in Table 1, the mean value of TLim-vVO_2max of the present study ranges between the lower values obtained by Billat et al. (1996) and Faina et al. (1997), and the higher values presented by Demarie et al. (2001). Those results suggest a lower variation of this parameter in swimming, compared with the results presented in other sports by Billat et al. (1994), namely treadmill running (range 4-11 min). The inverse relationship between TLim-vVO_2max and VO_2max (and vVO_2max), proposed by Billat et al. (1994, 1996) for running, and by Billat et al. (1996) and Faina et al. (1997) for swimming, was not observed in this study. On this basis, it was not possible to confirm the possibility that the athletes who had the highest VO_2max and the highest vVO_2max reach their exhaustion earlier.

A slow component of VO_2 kinetics appeared in the TLim-vVO_2max test, as it has been reported by Demarie et al. (2001). This O_2SC superimposed upon the rapid phase of the VO_2 rise, is well documented on Figure 1. Notice that, in accordance with Whipp (1994), this slow phase continues until a delayed steady state is attained, or values equal to, or higher, than VO_2max are reached.

The amplitude of the O_2SC measured in this group of subjects is in agreement with the report of Demarie et al. (2001), and seems to be different from running and cycling [Billat et al. (1998)]. Billat (2000) referred that the values of O_2SC can reach 500 $ml.min^{-1}$ and is generally considered to be significant when the value is above 200 $ml.min^{-1}$. The physiological aetiology of the O_2SC remains unclear [Saunders et al. (2000), Demarle et al. (2001)] but the O_2SC differences between sports are probably attributable to a different muscular contraction regimen and different mechanical efficiencies [Jones and McConnel (1999)]. The obtained strong relationship between O_2SC and TLim-vVO2max is not in accordance with the lack of significant correlation ($r = -.009$) presented by Demarie et al. (2001), and seems to traduce that the higher the TLim-vVO2max amplitude, the higher O_2SC.

In conclusion, O_2SC is observed also in swimming-pool conditions, and it is correlated with TLim-vVO2max. Meanwhile, TLim-vVO2max is in accordance with typical formulations of aerobic power training sets for swimmers.

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