

Comparison of Continuous and Intermittent Incremental Protocols for Direct VO₂max Assessment

Carla CARDOSO, Ricardo FERNANDES, Juan MAGALHÃES, Paulo SANTOS, Paulo COLAÇO, Susana SOARES, Carla CARMO, Tiago BARBOSA, Juan Paulo VILAS-BOAS

*Faculty of Sport Sciences and Physical Education,
University of Porto, Portugal
cscardoso@oninet.pt*

Abstract

The purpose of this study was to compare two incremental protocols for VO₂max assessment and minimum swimming velocity that elicits VO₂max (vVO₂max). The sample comprised 11 Portuguese swimmers: 6 females (21.00±1.79 years, 54.83±3.71 kg, and 163.83±1.47 cm) and 5 males (25.40±2.79 years, 69.00±9.03 kg, and 175.00±9.03 cm). They performed two incremental protocols (starting at 0.9 m.s⁻¹, with increments of 0.05 m.s⁻¹ per 200-m stage) for freestyle VO₂max assessment, with a 48h interval and in the same general conditions. One protocol was a continuous test and the other an intermittent one, with 30-s rest between incremental stages for [La-] assessment. Mean values of VO₂max, vVO₂max, VE, R, HR and [La-] for continuous and intermittent protocol, were respectively 52.5±9.44 ml.kg⁻¹.min⁻¹ and 53.4±8.74 ml.kg⁻¹.min⁻¹, 1.16±0.099 m.s⁻¹ and 1.15±0.099 m.s⁻¹, 95.3±26.32l.min⁻¹ and 95.8±26.60 l.min⁻¹, 1.00±0.044 and 1.00±0.053, 183.1±9.47b.min⁻¹ and 187.5±8.44 b.min⁻¹, 7.36±1.1313mM.l⁻¹ and 8.86±1.931mM.l⁻¹. [La-] was the only different parameter between both protocols (p ≤ 0.05). Results pointed out that both protocols were suitable for VO₂max and vVO₂max assessment in swimming.

Key words: Swimming; VO₂max assessment; maximal aerobic swimming velocity.

Introduction

With the very significant increase in training volume in the past recent years, especially during the eighties, recovery procedures and, mainly, improvements on training efficiency, seem to be the strategies to elicit performance improvement. Training efficiency, meanwhile, seems to be strongly determined by the availability of objective data about the particular needs, and capacities of each subject. So, training efficiency can only be improved, if we are also able to improve the methodology used for the specific evaluation of the determinant performance parameters of swimmers.

Aerobic energy seems to be very important for most of the competitive swimming events, especially after the recent recognition of a shift of the bioenergetic supply partition to a more aerobic zone, for any particular duration of a maximal competitive exercise [Gastin (2001)]. Besides anaerobic threshold, the maximal oxygen consumption (VO₂max) and the minimum swimming velocity that elicits VO₂max (vVO₂max), seem to be some of the most important parameters for the evaluation of a swimmer's aerobic potential [Holmér, (1972), Holmér et al. (1972a), Bonen et al. (1980), Cazorla et al. (1983), Monpetit et al. (1983), Billat et al. (1996, 1996a, 1999)]. Other parameters, such as the time that the swimmer is able to sustain on

$v\text{VO}_2\text{max}$, normally known as Time Limit, and the swimming economy, considered as the inverse of the swimming energy cost of locomotion, should be considered as also very important parameters to characterise the swimmer's performance capacity.

The evaluation of VO_2max , $v\text{VO}_2\text{max}$, $\text{Time}v\text{VO}_2\text{max}$, and economy on swimming subjects, requires specific oxymetry procedures and protocols. Normally, the first two parameters are evaluated using progressive protocols, without resting periods between stages [Billat et al. (1996, 1996a, 1999)]. However, swimming economy assessment requires both aerobic and anaerobic energy expenditure evaluations [Vilas-Boas and Santos (1994)], if possible at different swimming velocities to allow the computation of an economy curve. To do so, it is necessary to collect not only respiration parameters, but also blood parameters, such as lactate concentrations ($[\text{La-}]$), which imposes the interruption of the protocol just after each stage. However, to our knowledge, it has not yet been demonstrated that an intermittent progressive protocol, even with small rest intervals, allow the assessment of the same values as a traditional continuous one.

The purpose of this study was to compare two progressive protocols for VO_2max assessment and minimum swimming velocity that elicits VO_2max ($v\text{VO}_2\text{max}$): one continuous, and one intermittent to allow the collection of earlobe blood samples.

Methods

The subjects were eleven Portuguese water-polo players, triathletes, former swimmers, and/or physical education students, whose physical characteristics are given in Table 1. All were previously informed about the protocol, and freely participated in this project.

Each subject performed two incremental protocols for freestyle VO_2max assessment in a 25 m pool, with a 48h interval and in the same general conditions. One was a continuous test, and the other an intermittent one, with 30-s rest between incremental stages for $[\text{La-}]$ evaluation. Both protocols started at $0.9 \text{ m}\cdot\text{s}^{-1}$, with increments of $0.05 \text{ m}\cdot\text{s}^{-1}$ per 200-m stage. VO_2max was considered to be reached according to traditional physiological criteria, and $v\text{VO}_2\text{max}$ was considered as the swimming velocity correspondent to the first stage that elicits VO_2max according to the criteria of Lacour et al. (1991).

Expired gas was collected using a Toussaint and al. (1987) respiratory valve and VO_2 , averaged each 20 s, was directly measured using a Sormedics 2900 oximeter mounted on a special chariot running along the poolside.

Swimming velocity was controlled using a visual pacer (GBK-Portugal). $[\text{La-}]$ were measured before, during the intermittent test, immediately and 3 min after both tests, using an YSI-1500 auto-analyzer. Heart rate (HR) was continuously monitored with a Polar advantage system.

The HR, $[\text{La-}]$ ventilation (VE), ventilatory equivalent for oxygen (EVO_2), respiratory quotient (R), $v\text{VO}_2\text{max}$, tidal volume (TV), respiratory rhythm (RR), and VO_2max , obtained with both protocols, were treated for means difference statistical significance using a paired Student t-test.

Table 1: Physical characteristics of the subjects.

Subjects	Sex	Age	Height (cm)	Weight (kg)
(Student)	F	23	163	54
(Student)	F	20	164	54
(Swimmer)	F	21	162	52
(Swimmer)	F	18	165	52
(Water-polo)	F	22	166	62
(Water-polo)	F	22	163	55
(Mean ± SD)		21.0 ± 1.79	163.8 ± 1.47	54.8 ± 3.71
(Triathletes)	M	23	181	69
(Triathletes)	M	26	172	65
(Triathletes)	M	28	171	61
(Water-polo)	M	28	187	80
(Swimmer)	M	22	164	70
(Mean ± SD)		25.4 ± 2.79	175.0 ± 9.03	69.0 ± 7.11

Results

The main results of the study are presented in Table 2. The same results are presented in Table 3 averaged by gender. VO_2max , vVO_2max , VE, R, HR, EVO_2 , RR presented no significant differences between the continuous and intermittent incremental protocols. Meanwhile, blood lactate and tidal volume (TV) were significantly different between the studied protocols. [La-] for the intermittent progressive protocol was significantly higher than the obtained concentrations for the continuous one, and the TV was, on the other hand, significantly higher for the continuous test.

Table 2: Main results of the study comparing continuous and intermittent protocols.

Parameter	Continuous	Intermittent	p
VO_2max (ml.min ⁻¹)	3069.7 ± 812.91	3136.6 ± 785.77	0.463
VO_2max (ml.kg ⁻¹ .min ⁻¹)	52.5 ± 9.44	53.4 ± 8.74	0.550
vVO_2max (m.s-1)	1.16 ± 0.099	1.15 ± 0.099	0.341
VE (l.min ⁻¹)	95.3 ± 26.32	95.8 ± 26.60	0.809
R	1.00 ± 0.044	1.00 ± 0.053	0.940
HR (bat.min ⁻¹)	183.1 ± 9.47	187.5 ± 8.44	0.167
[La-] (mM.l ⁻¹)	7.36 ± 1.313	8.86 ± 1.931	0.002*
EVO_2 (ml.min ⁻¹)	29.8 ± 3.31	28.5 ± 3.88	0.208
RR (breathing.min ⁻¹)	44.3 ± 7.02	46.4 ± 7.66	0.180
TV (ml)	2.20 ± 0.624	2.05 ± 0.575	0.032*

* p<0.05

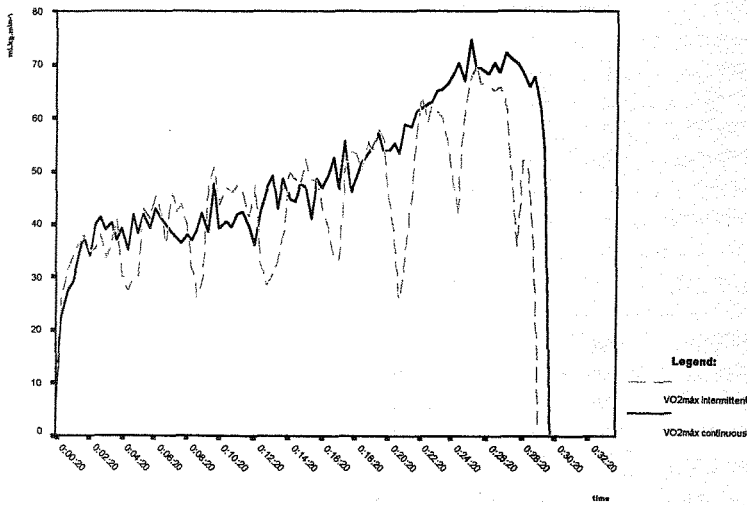


Fig. 1: VO₂max values obtained during continuous and intermittent protocols.

Table 3: Main results of the study comparing continuous and intermittent protocols by gender.

PARAMETER	TESTS	FEMALES (N=6)	MALES (N=5)	P
VO ₂ max (ml.min ⁻¹)	Continuous	2641 ± 353.6	3853 ± 618.5	.003*
	Intermittent	2680 ± 325.8	4072 ± 449.7	.000*
VO ₂ máxrel (ml.kg ⁻¹ .min ⁻¹)	Continuous	48.49 ± 7.372	56.22 ± 9.651	.166
	Intermittent	49.03 ± 6.582	59.03 ± 5.557	.025*
vVO ₂ max (m.s-1)	Continuous	1.12 ± 0.125	1.19 ± 5.477	.287
	Intermittent	1.16 ± 0.138	1.19 ± 5.062	.631
HRmax (bat.min ⁻¹)	Continuous	185.7 ± 10.25	179.8 ± 6.87	.305
	Intermittent	191.3 ± 5.75	183.2 ± 8.61	.094
[La-] (mM.l ⁻¹)	Continuous	7.05 ± 1.663	7.74 ± 0.731	.418
	Intermittent	8.47 ± 2.370	9.32 ± 1.344	.497
EVO ₂ (ml.min ⁻¹)	Continuous	29.0 ± 3.52	30.8 ± 3.11	.398
	Intermittent	28.2 ± 4.79	29.0 ± 2.92	.743
R	Continuous	1.00 ± 0.043	1.00 ± 0.051	.891
	Intermittent	0.99 ± 0.026	1.01 ± 0.076	.592
VE (l.min ⁻¹)	Continuous	76.2 ± 11.05	118.6 ± 19.68	.001*
	Intermittent	73.9 ± 6.43	117.1 ± 21.29	.001*
RR (breath.min ⁻¹)	Continuous	44.7 ± 6.62	43.8 ± 8.23	.851
	Intermittent	46.5 ± 6.44	46.2 ± 9.73	.952
TV (ml.breath ⁻¹)	Continuous	1.72 ± 0.123	2.78 ± 0.427	.000*
	Intermittent	1.60 ± 0.148	2.58 ± 0.381	.000*

Male swimmers showed significantly higher values of VO₂max, VE and TV in both tests than their female counterparts. When the VO₂max was expressed in ml.kg⁻¹.min⁻¹, it was only

significantly different between genders for the intermittent incremental protocol. $v\dot{V}O_{2\max}$, HR, [La-], R, $E\dot{V}O_2$ and RR, were not significantly different between genders, for both the continuous and intermittent incremental protocols.

Discussion

The cardio respiratory results obtained in this study were in close agreement with those published previously by [Astrand and Saltin (1961), Holmér (1972), Holmér and Astrand (1972), Magel et al. (1974), Lavoie et al. (1983), and Butts et al. (1986)]. However, they were lower than those presented by [Magel and Faulkner (1967), Armstrong and Davies (1981), McKay et al. (1983), Handel et al. (1988), Alves (1995) and Billat et al. (1996)]. The relatively low swimming proficiency and training status of our sample, mainly composed of former swimmers, Physical Education students, triathletes, and water-polo players, may contribute to explain this finding: similarities with old results obtained from competitive swimmers, and lower values when compared with more recent groups of competitive swimmers. The smaller cardio respiratory values obtained, in this study, for the female subgroup can also contribute to reinforce the low values observed in our sample.

In fact, the values obtained for females seem to be especially low when compared to the literature, despite they were similar to those obtained by Butts et al. (1986) before subjects were submitted to a training program. Meanwhile, the results obtained for the male subgroup were similar to those presented by [Magel et al. (1974), Eriksson et al. (1978), McKay et al. (1983), Lavoie et al. (1983), Nomura (1983), Butts et al (1986) and Billat et al. (1996)].

Continuous and intermittent protocols provided similar results, both for $\dot{V}O_{2\max}$ and for $v\dot{V}O_{2\max}$. The only significant difference was found on [La-], but results were, nevertheless, very similar. These differences can be attributed to an systematic prevalence of anaerobic metabolism after each rest interval during the intermittent test, which may be confirmed also through the higher R values found before $\dot{V}O_2$ rise.

Both protocols fulfill the requirements of a maximal test for $\dot{V}O_{2\max}$ assessment, namely: near to [La-] $\approx 8 \text{ mM}\cdot\text{l}^{-1}$, R values over 1, HR higher than 85 % HR $_{\max}$, and an exertion to exhaustion. R values, nevertheless, were lower than expected, despite they were higher than 1. In the same perspective, mean [La-] values for the continuous protocol were also slightly lower than the reference value.

We can conclude that both protocols were suitable for $\dot{V}O_{2\max}$ and $v\dot{V}O_{2\max}$ assessment in swimming, and that the use of the intermittent protocol imposes the consideration of the energetic equivalents of the [La-] to be used for economy profile evaluation.

References

- Billat V., Faina M., Sardella F., Marini C., Fanton F., Lupo S., Faccini P., de Angelis M., Koralsztein J.P., Dalmonte A. (1996). A comparison of time to exhaustion at $\dot{V}O_{2\max}$ in elite cyclists, kayak paddlers, swimmers and runners. *Ergonomics*, 2 (39): 267-277.
- Billat V.L., Hill D.W., Petit B., Koralsztein J.P. (1996a). Effect of protocol on determination of velocity at $\dot{V}O_{2\max}$ and on its time to exhaustion. *Archives of Physiology and Biochemistry*, 104 (3): 313-321.
- Billat V.L., Mille-Hamard L., Petit B., Koralsztein J.P. (1999). The role of cadence on the $\dot{V}O_2$ slow component in cycling and running in triathletes. *International Journal of Sports Medicine*, 20: 429-437.
- Bonen A., Wilson B.A., Yarkoni M., Belcastro A.N. (1980). Maximal oxygen uptake during free, tethered and flume swimming. *Journal Applied Physiology*, 48 (2): 232-235.
- Butts N.K., Pein R., Stevenson M. (1986). Male and female responses to similar swim programs. In: Landers D.M. (ed), *Sport and Elite Performers*, pp. 25-31. Human Kinetics Publishers. Champaign, Illinois.

- Cazorla G., Monpetit R. (1983). Niveau d'entraînement et spécificité de la consommation maximale d'oxygène chez le nageur. *Motricité Humaine*, 1: 50-55.
- Eriksson B.O., Holmér I., Lundin A. (1978). Physiological effects of training in elite swimmers. In: Eriksson B., Furberg B. (eds) *Swimming Medicine IV*, pp. 177-187. University Park.
- Gastin P.B. (2001). Energy system interaction and relative contribution during maximal exercise. *Sports Medicine*, 31 (10): 725-741.
- Holmér I. (1972). Oxygen uptake during swimming in man. *Journal Applied Physiology*, 33 (4), pp. 502-509.
- Holmér I., Astrand P.O. (1972). Swimming training and maximal oxygen uptake. *Journal Applied Physiology*, 33 (4): 510-513.
- Lacour J.R., Padilla-Magunacelaya S., Chatard J.C., Arzac L., Barthelemy J.C. (1991). Assessment of running velocity at maximal oxygen uptake. *European Journal Applied Physiology*, 62 (2): 77-82.
- Lavoie J.M., Monpetit R.R. (1986). Applied Physiology of Swimming. *Sports Medicine* (3): 165-189.
- Magel J.R., Foglia G.F., Mc Ardle W.D., Gutin B., Pechar G.S., Katch F.L. (1974). Specificity of swim training on maximum oxygen uptake. *Journal Applied Physiology*, 38 (1): 151-155.
- Monpetit R.R., Lavoie J.M., Cazorla G. (1983). Aerobic energy cost of swimming the front crawl at high velocity in international class and adolescent swimmer. In: Hollander A.P., Huijing P.A., de Groot G. (eds), *Biomechanics and Medicine in Swimming*, pp. 228-234. Human Kinetics Publishers. Champaign, Illinois.
- Nomura T. (1983). The influence of training and age on $VO_2\text{max}$ during swimming in Japanese elite age group and Olympic swimmers. In: Hollander A.P., Huijing P.A., de Groot G. (eds), *Biomechanics and Medicine in Swimming*, pp. 251-257. Human Kinetics Publishers. Champaign, Illinois.
- Toussaint H.M., Meulemans A., de Groot G., Hollander, A.P., Schreurs A.W., Vervoorn K. (1987). Respiratory valve for oxygen uptake measurements during swimming. *European Journal of Applied Physiology*, 56: 363-366.
- Vilas-Boas J.P., Santos P. (1994). Comparison of swimming economy in three breaststroke techniques. In: Miyashita M., Mutoh A., Richardson A.B. (eds.), *Medicine and Science in Aquatic Sports*, pp. 48-54. Medicine and Sport Science, Vol. 39. Karger, Basel.