# Very Short (15 s – 15 s) Interval-Training Around the Critical Velocity Allows Middle-Aged Runners to Maintain $\dot{V}O_2$ max for 14 minutes

V. L. Billat[1], J. Slawinksi[1], V. Bocquet[2], P. Chassaing[1], A. Demarle[1], J. P. Koralsztein[2]

[1] Laboratoire d'étude de la motricité humaine, Université de Lille II, Faculté des Sciences du Sport, Ronchin, France
[2] Centre de Médecine du Sport C.C.A.S., Paris, France

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**The purpose of this study was to compare the effectiveness of three very short interval training sessions (15 – 15 s of hard and easier runs) run at an average velocity equal to the critical velocity to elicit $\dot{V}O_2$ max for more than 10 minutes. We hypothesized that the interval with the smallest amplitude (defined as the ratio between the difference in velocity between the hard and the easy run divided by the average velocity and multiplied by 100) would be the most efficient to elicit $\dot{V}O_2$ max for the longer time. The subjects were middle-aged runners (52 ± 5 yr, $\dot{V}O_2$ max of 52.1 ± 6 mL × min$^{-1}$ × kg$^{-1}$, v$\dot{V}O_2$ max of 15.9 ± 1.8 km × h$^{-1}$, critical velocity of 85.6 ± 1.2 % v$\dot{V}O_2$ max) who were used to long slow distance-training rather than interval training. They performed three interval-training (IT) sessions on a synthetic track (400 m) whilst breathing through the COSMED K4b$^2$ portable metabolic analyser. These three IT sessions were: A) 90 – 80 % v$\dot{V}O_2$ max (for hard bouts and active recovery periods, respectively), the amplitude = (90 – 80/85) 100 = 11 %, B) 100- 70 % v$\dot{V}O_2$ max amplitude = 35 %, and C) 60 × 110 % v$\dot{V}O_2$ max amplitude = 59 %. Interval training A and B allowed the athlete to spend twice the time at $\dot{V}O_2$ max (14 min vs. 7 min) compared to interval training C. Moreover, at the end of interval training A and B the runners had a lower blood lactate than after the procedure C (9 vs. 11 mmol × l$^{-1}$). In conclusion, short interval-training of 15 s – 15 s at 90 – 80 and 100 – 70 % of v$\dot{V}O_2$ max proved to be the most efficient in stimulating the oxygen consumption to its highest level in healthy middle-aged long-distance runners used to doing only long slow distance-training.**

**Key words:** Intermittent-training, oxygen consumption, critical velocity.

## Introduction

Nowadays many runners are middle-aged (40 – 60 yr) and participate in amateur events run over 5 to 100 km. After several years of long slow distance training their performance no longer improves. Moreover, following this type of training, these long distance runners have a high endurance index defined as the ability to use a high fraction of maximal oxygen consumption $\dot{V}O_2$ max for a given running duration [24]. Therefore, in order to improve their performances, they need to increase $\dot{V}O_2$ max and the velocity associated with $\dot{V}O_2$ max (v$\dot{V}O_2$ max) [5,11,20].

To achieve this improvement of v$\dot{V}O_2$ max, interval training (IT) involving repeated bouts of work, each lasting from 30 sec at v$\dot{V}O_2$ max to 5 min at 95 % of v$\dot{V}O_2$ max was introduced [11]. Gorostiaga et al. [15] showed that interval training with 30 s work at 100 % v$\dot{V}O_2$ max, separated by 30 s of rest, produced a greater increase in $\dot{V}O_2$ max than continuous training at 50 % v$\dot{V}O_2$ max.

However, as underlined by Astrand and Rodahl [2] "it is an important but unsolved question which type of training is most effective: to maintain a level representing 90 % of the maximal oxygen uptake for 40 min, or to tax 100 % of the oxygen uptake capacity for about 16 min". Today this question is still open.

However, before beginning longitudinal studies to try to answer this question, it is important to determine the metabolic response solicited by the different interval-training protocols used by trainers (very short to long, see Daniels and Scardina for review [10]).

Previous studies performed in the category of very short interval-training (less than 30 s) used passive recovery [1,2,9,10]. In these studies the runner did not reach $\dot{V}O_2$ max or just at the end of the interval training (see for review Astrand and Rodahl [2].

Nowadays this type of short IT is currently used by rowers during the rowing season [16], and middle-distance runners use it currently after periods of long slow distance running in the transition phase between two seasons of competition. The high velocity bouts are generally set around v$\dot{V}O_2$ max, and the trainers ask the runners to do this short interval-training

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for 5 to 10 min with active recovery at a velocity chosen by the runner.

We hypothesized that, to elicit $\dot{V}O_2$ at its maximum with this "short – short" interval training, active pauses might be preferable to passive recovery. Moreover, in order to achieve this, a small range between high and low velocity bouts would be preferable, especially in groups of runners who had been used to training in a continuous way for more than 10 years.

The aim of the present study was to devise a new training regime that could stimulate and increase $\dot{V}O_2$ max and $v\dot{V}O_2$ max in a group of middle aged runners. We hypothesized that the lower amplitude, i.e. the difference between the highest and lowest velocities [26], would allow them to spend a longer time at $VO_2$ max without an accumulation of high blood lactate.

In our study, in order to elicit $\dot{V}O_2$ max, the average velocity of the interval training was chosen to correspond to the critical velocity, i.e. the vertical asymptote of the velocity-time relationship. The critical velocity is known to be above the maximal lactate steady-state and to be sustained for about 30 min [23] and is the velocity above which runners reach $\dot{V}O_2$ max with exercising time [14]. We chose the critical velocity as the average intensity of the interval training for the subject to reach $VO_2$ max [14].

## Methods

### *Subjects*

Seven endurance trained male athletes (age 51 ± 6 yr, height 175.0 ± 5 cm and weight 71 ± 4 kg) volunteered to participate in this study. They had been training through continuous running below or at their lactate threshold (i.e. 50–80% $v\dot{V}O_2$ max) 4 times per week (65 ± 18 km/week) for at least 10 years. They were not familiar with severe (intermittent or continuous) training and wanted to try the interval-training procedure at a higher speed than those they were used to running. Prior to participation in this study all subjects provided voluntary written informed consent in accordance with the guidelines of the University of Lille.

All subjects had a preliminary medical visit with an exhaustive test on a cycle ergometer for cardiological assessment.

The experiment was carried out in May. Since the determination of the critical velocity is time-consuming [17], the critical velocity was calculated from the runner's best performance obtained during the last season during 3, 5 and 10 km races. The critical velocity was calculated according to the equation of Ettema [13]: Dlim = a + b × tlim, where 'a' is considered to be the anaerobic running capacity and the slope 'b' is termed the critical velocity [17]. Their critical velocity was 85 ± 1% of $\dot{V}O_2$ max (Table **1**) and was used to determine the interval training velocity as a percentage of $v\dot{V}O_2$ max.

### *Experimental design*

Subjects performed four all-out tests. Only one test was carried out on a given day, and all tests were separated by ≥ 48 h and were completed within the period of a week. All tests were performed on a synthetic 400 m track at the same time of day in a climate of 19 to 22 °C without wind. On the day separating the two tests subjects were asked either to rest or to do a limited amount of jogging. They were also asked to refrain from food or beverages containing caffeine prior to testing.

The first test was needed to determine $\dot{V}O_2$ max, the velocity associated with $\dot{V}O_2$ max ($v\dot{V}O_2$ max), and the running velocity at the lactate threshold (vLT) [3].

The initial speed was set at 10 km × $h^{-1}$ and increased by 1 km × $h^{-1}$ every 2 min. Each stage was separated by a 30 sec rest when a capillary blood sample was obtained from the finger-tip and analysed for lactate concentration. Runners followed a pacing cyclist travelling at the required velocity. In order to achieve this, the cyclist received audio cues *via* a walkman, the cue rhythm determining the speed needed to cover 20 m. Visual marks were set at 20 m intervals along the track (inside the first lane).

After this preliminary test the subjects performed, in a random order, the three different types of interval-training whose characteristics differed only by the amplitude according to the interval-training characteristics proposed by Saltin et al. [26].

**Table 1** Individual incremental test data. See legend in text

| Subjects | Age (yr) | $v\dot{V}O_2$ max (km×$h^{-1}$) | $v\dot{V}O_2$ max (ml×$min^{-1}$ × $kg^{-1}$) | $HR_{max}$ (bpm) | Blood lactate (mM) | CV (% $v\dot{V}O_2$ max) | vLT (km×$h^{-1}$) | vLT (% $v\dot{V}O_2$ max) | HR at vLT (bpm) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 60 | 16.0 | 54.3 | 186 | 10.1 | 87.5 | 13.0 | 81.2 | 178 |
| 2 | 48 | 16.0 | 56.0 | 181 | 10.2 | 85.0 | 13.0 | 81.2 | 165 |
| 3 | 51 | 16.0 | 48.5 | 181 | 11.0 | 84.4 | 13.0 | 81.2 | 160 |
| 4 | 60 | 17.0 | 61.0 | 171 | 10.9 | 87.6 | 14.0 | 82.3 | 151 |
| 5 | 46 | 12.0 | 40.4 | 181 | 11.5 | 85.8 | 11.0 | 91.7 | 170 |
| 6 | 50 | 17.0 | 53.3 | 172 | 10.8 | 84.7 | 14.0 | 82.3 | 155 |
| 7 | 52 | 17.0 | 51.0 | 175 | 10.5 | 84.7 | 14.0 | 82.3 | 161 |
| Mean | 52 | 15.9 | 52.1 | 178 | 10.8 | 85.7 | 13.1 | 83.2 | 163 |
| Standard Deviation | 5 | 1.8 | 6.0 | 5 | 0.5 | 1.4 | 1.1 | 3.8 | 8 |

1. The intensity defined as the average power output was equal to the critical velocity as recently proposed by Brickley et al. [7].
2. The time-ratio for the high and low level exercise; in the present study this ratio was equal to 1 since exercise and active pauses were of the same duration (15 seconds).
 The variable parameters in the three different interval-training procedures were:
3. The amplitude which, as described above, is the ratio of the difference between the intensity of different periods (heavy or recovery run) and the average velocity. The three types of short interval-training examined in this study differed by their amplitude.
4. Since the interval-training was performed in all cases until exhaustion, the durations and the distances run during high and low velocity bouts became dependent variables.

The three types of short interval-training exercise were:

a) An intermittent exercise of 15 s runs alternating between 90% and 80% $v\dot{V}O_2$ max. Since the average velocity was set at 85% of $v\dot{V}O_2$ max, the amplitude was low: ([90 – 80]/85) ×100 = 11%
b) An intermittent exercise of 15 s runs alternating between 100% and 70% $v\dot{V}O_2$ max. Since the average velocity was set at 85% of $v\dot{V}O_2$ max, the amplitude was medium: ([100 – 70]/85) ×100 = 35%
c) An intermittent exercise of 15 s runs alternating between 110% and 60% v $vVO_2$ max. Since the average velocity was set at 85% of $vVO_2$ max., the amplitude was high: ([110 – 60]/85) ×100 = 59%.

The distances of the three interval-training types varied according to $v\dot{V}O_2$ max. For instance for the interval-training which alternated bouts at 90 and 80% of $v\dot{V}O_2$ max, a runner who had a $v\dot{V}O_2$ max equal to 16 km/h (4.44m/s) was required to cover:

15 s × 4.44 × 0.9 = 60 m in the first 15 s performed at 90% $v\dot{V}O_2$ max and 15 s × 4.44 × 0.8 = 53 m in the following 15 s performed at 80% $v\dot{V}O_2$ max. In the short interval training, the runners followed the pace hearing a whistle.

These three types of training were preceded by 15 min of warming-up at 50% $v\dot{V}O_2$ max.

*Material and measurement*

Measurement of $\dot{V}O_2$ was carried out throughout each test with a telemetric system (K4b², Cosmed, Roma, Italy). The response times of the oxygen and carbon dioxide analysers are less than 120 ms to reach 90% of the flow sample. The ventilation range of the flow-meter is from 0 to 300 L × min$^{-1}$. The time delay (time necessary for the gas to transit through the sampling line before being analysed) is about 500 ms. This time delay is automatically measured and considered in the calculations when a delay calibration procedure is performed according to the manufacturer's specifications. The algorithms used in the K4b² have been developed according to the following authors: Beaver et al. [4], Sue et al. [27], Wasserman et al. [28]. Before each test the $O_2$ analysis system was calibrated using ambient air, whose partial $O_2$ composition was assumed to be 20.9% and a gas of known $CO_2$ concentration (5%) (K4b² instruction manual). The calibration of the turbine flowmeter of the K4 was performed with a 3-L syringe (Quinton Instruments, Seattle, WH).

To follow the time course of oxygen uptake during the short interval-training, expired gases were measured breath by breath and averaged every 5 seconds.

During the incremental test $\dot{V}O_2$ was averaged every 15 s. $\dot{V}O_2$ max was defined as the highest $\dot{V}O_2$ obtained in two successive 15 second-interval runs. In this incremental protocol, $VO_2$ max was defined as the lowest running speed maintained for more than one minute that elicited $\dot{V}O_2$ max [5].

The highest 15 s value for $\dot{V}O_2$ was recorded as the maximal $VO_2$ obtained at least four times during the intermittent exercise; this rule was also applied to values for heart rate (HR). Blood lactate samples were collected after the warm-up and at 1, 3 and 5 min after the onset of exercise. The highest of these values was taken as the maximal blood lactate for this interval-training.

Blood sample was obtained from the finger-tip and analysed for lactate concentration (YSI 27, Yellow Spring instrument, Yellow Springs, OH).

In this study the velocity at the lactate threshold (vLT) was defined as the velocity corresponding to the starting point of an accelerated lactate accumulation of around 4 mM and was expressed as a %$v\dot{V}O_2$ max [3] (Table **1**).

*Data analyses*

A one-way analysis of variance for repeated measurements with Scheffes' post hoc tests was used to compare heart rate, blood lactate, oxygen consumption and time spent at $VO_2$ max between the three training procedures (A, B, C).

The results are presented as mean ± standard deviation (SD). Statistical significance was set at $P < 0.05$.

## Results

*Incremental test*

Individual data obtained in the incremental test are presented in Table **1**. It is important to note that the subjects have a rather low maximal aerobic power ($\dot{V}O_2$ max: 52.1 ± 6.0 ml × min$^{-1}$ kg$^{-1}$, $v\dot{V}O_2$ max: 15.9 ± 1.8 km × h$^{-1}$) and a relatively high velocity at LT (83.2 ± 3.8% $v\dot{V}O_2$ max, 13.1±1.1 km×h$^{-1}$), in accordance with their previous type of training (long slow distance). The critical velocity was also at a high percentage of $v\dot{V}O_2$ max: 85.7 ± 1.4% $v\dot{V}O_2$ max (13.6 ± 1.5 km × h$^{-1}$).

*Comparison of the physiological response in the three intermittent runs*

In all three types of interval-training runners reached the maximal heart rate and the maximal oxygen uptake obtained in the incremental test (Table **2**).

It should be noted that the 110 – 60% $v\dot{V}O_2$ max interval training (interval-training C) elicits different physiological responses compared with the 90- 80% and 100 – 70% $v\dot{V}O_2$ max (in-

**Table 2** Individual data in the three intermittent runs until exhaustion. See legend in text

| Subjects | max $\dot{V}O_2$ ($ml \times min^{-1} \times kg^{-1}$) | tlim at $\dot{V}O_2$ max min:sec | Max blood lactate (mM) | Number of hard intervals (n) | *Total distance run at high velocity | §Total distance run at lower velocity | Total distance run Hard + recovery run |
|---|---|---|---|---|---|---|---|
| 1A | 54.0 | 15:00 | 6.4 | 50 | 2900 | 2580 | 5580 |
| B | 57.0 | 19:54 | 8.4 | 42 | 2714 | 1898 | 4612 |
| C | 51.0 | 7:06 | 9.4 | 18 | 1278 | 698 | 1976 |
| 2A | 55.0 | 9:06 | 10.4 | 38 | 2280 | 2026 | 4306 |
| B | 59.0 | 15:42 | 10.0 | 34 | 2264 | 1588 | 3852 |
| C | 60.0 | 6:20 | 12.1 | 16 | 1172 | 640 | 1812 |
| 3A | 47.5 | 9:00 | 9.7 | 22 | 1276 | 1136 | 2412 |
| B | 53.0 | 8:10 | 10.1 | 22 | 1422 | 994 | 2416 |
| C | 48.0 | 5:55 | 11.0 | 18 | 1278 | 698 | 1976 |
| 4A | 64.0 | 17:45 | 9.6 | 42 | 2680 | 2382 | 5062 |
| B | 66.0 | 7:45 | 10.8 | 32 | 2266 | 1588 | 3854 |
| C | 66.0 | 4:45 | 10.6 | 10 | 780 | 426 | 1206 |
| 5A | 44.0 | 14:40 | 10.0 | 36 | 1688 | 1502 | 3190 |
| B | 43.0 | 11:30 | 11.9 | 30 | 1560 | 1080 | 2640 |
| C | 44.0 | 9:15 | 11.7 | 22 | 1254 | 682 | 1936 |
| 6A | 55.5 | 15:40 | 9.3 | 60 | 3828 | 3402 | 7230 |
| B | 58.0 | 21:36 | 7.7 | 50 | 3540 | 2480 | 6020 |
| C | 54.0 | 10:25 | 13.4 | 30 | 2338 | 1260 | 3598 |
| 7A | 51.5 | 19:20 | 8.9 | 48 | 3062 | 2720 | 5782 |
| B | 54.0 | 17:00 | 10.0 | 36 | 2548 | 1786 | 4334 |
| C | 53.0 | 8:20 | 11.2 | 18 | 1148 | 1020 | 2168 |
| Mean ± SD | | | | | | | |
| A | 53.1 ± 6.0 | 14:21 ± 4:00 | 9.2 ± 1.3 | 42 ± 12 | 2530 ± 862 | 2250 ± 768 | 4780 ± 1630 |
| B | 55.7 ± 7.0 | 14:31 ± 5:30 | 9.8 ± 1.4 | 36 ± 10 | 2330 ± 716 | 1630 ± 504a | 3960 ± 1222 |
| C | 54.1 ± 7.3 | 7:24 ± 2:00ab | 11.3 ± 1.3ab | 18 ± 6ab | 1320 ± 480ab | 774 ± 276ab | 2096 ± 730ab |
| | NS | | | | | | |

A)15 seconds at 90% $v\dot{V}O_2$ max alternated with 15 seconds at 80% of $v\dot{V}O_2$ max
B)15 seconds at 100% $v\dot{V}O_2$ max alternated with 15 seconds at 70% of $v\dot{V}O_2$ max
C)15 seconds at 110% $v\dot{V}O_2$ max alternated with 15 seconds at 60% of $v\dot{V}O_2$ max
* The high velocity is the highest velocity run in the interval training:
A) 90% of $v\dot{V}O_2$ max, B) 100% of $v\dot{V}O_2$ max and C) 110% of $v\dot{V}O_2$ max
§ The lower velocity is the lowest velocity run in the interval training:
A) 80% of $v\dot{V}O_2$ max, B) 70% of $v\dot{V}O_2$ max, and C) 60% of $v\dot{V}O_2$ max
a and b significantly different from A and B, respectively

terval-training A and B). Moreover, time to exhaustion at $\dot{V}O_2$ max is half for C compared with A and B (7:24 ± 2:00 min : s vs 14:21 ± 21 and 14:31 ± 5:30 min : s, respectively) (Table **2**). Blood lactate end values averaged 9.2 ± 1.3 and 9.8 ± 1.4 mM in A and B (P = 0.36), both being significantly lower than those obtained in C (11.3 ± 1.2 mM) (P = 0.05 and 0.04, for A vs. C and B vs. C, respectively). However, only A (the lowest amplitude interval- training: 90 – 80% $v\dot{V}O_2$ max) was significantly lower than the blood lactate measured after the incremental test (10.7 ± 0.5 mM, P = 0.01).

The total distance run during the hard bouts was half for 110-60% $v\dot{V}O_2$ max compared with the other two runs (Table **2**).

For each of these interval-training procedures $\dot{V}O_2$ did not vary significantly between each 15 seconds of hard and light work (P = 0.70, 0.61, 0.22 for A, B and C, respectively). Likewise heart rate did not vary significantly during the intermittent training session (p = 0.65, 0.58, 0.41 for A, B and C, respectively). Figs. **1 a – c** show the typical time course of heart rate, $\dot{V}O_2$ and the ventilation minute with expiratory oxygen fraction $FEO_2$ (%) in one subject for each of these interval-training protocols (A, B and C). The stability or slight increase in $\dot{V}O_2$ was due to the concomitant increase of VE and the decrease or stability of $FEO_2$.

Maximal blood lactate for C (60- 110% $vVO_2$ max) was significantly higher than those measured at the end of A and B (Table **2**) (P = 0.01 for both) but was not significantly different from those of the incremental test (P = 0.21).

In fact all seven runners reached their $\dot{V}O_2$ max in each of the three interval-training procedures and sustained it for 14 min 21 s ± 4 min 00 s and 14 min 31 s ± 5 min 30 s during the 90 – 80 and 100 – 70% $v\dot{V}O_2$ max intermittent run procedures respectively.

## Discussion

The purpose of this study was to compare the effectiveness of three very short interval-training sessions to elicit $\dot{V}O_2$ max for the longest time. These three kinds of very short interval-training (15 s – 15 s of hard and easier runs) of different amplitudes were all run at an average velocity equal to the critical

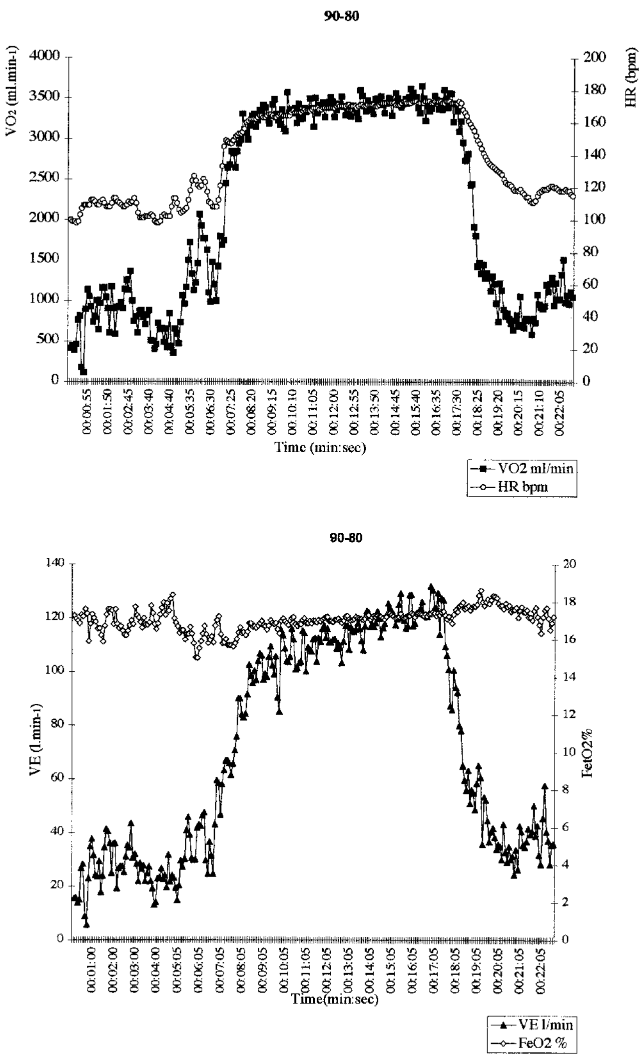


**Fig. 1 a** Oxygen consumption (black squares), heart rate (open circles), ventilation per minute (black triangles), expired oxygen fraction (open diamonds), time course during the three Intermittent exercise procedures (Subject 3): The intermittent training session consisted of 15 s runs at an average velocity equal to 85% of v$\dot{V}O_2$ max (the critical velocity), alternating at: **a** 90% and 80% of v$\dot{V}O_2$ max, the amplitude being therefore equal to ([90 – 80]/85) × 100 = 11%.

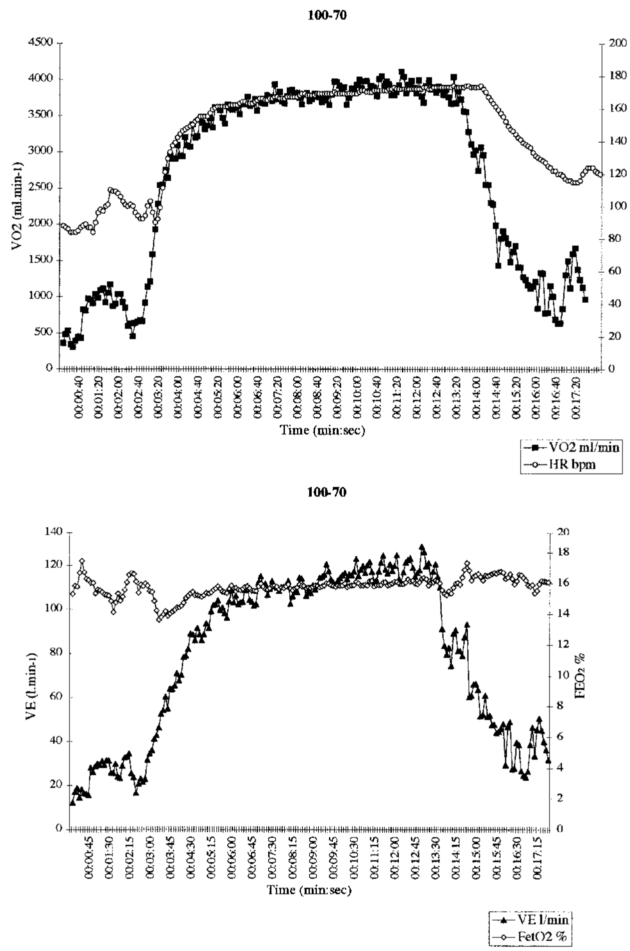


**Fig. 1 b** Oxygen consumption (black squares), heart rate (open circles), ventilation per minute (black triangles), expired oxygen fraction (open diamonds), time course during the three Intermittent exercise procedures (Subject 3): The intermittent training session consisted of 15 s runs at an average velocity equal to 85% of v$\dot{V}O_2$ max (the critical velocity), alternating at: **b** 100% and 70% of v$\dot{V}O_2$ max, the amplitude being therefore equal to ([100 – 70]/85) × 100 = 35%.

velocity. We hypothesized that the very short interval-training with the smallest amplitude would be the most efficient for this purpose since $\dot{V}O_2$ would be maintained at a high level during the recovery run at a high velocity.

However, this does not mean that the interval training allowing to sustain the longest time at $\dot{V}O_2$ max is the most efficient to improve $\dot{V}O_2$ max. We only wanted to ascertain whether this type of short IT exercise would allow these middle-aged runners, using slow long distance running, to reach and sustain $\dot{V}O_2$ max for longer without high blood lactate concentration, and to determine which amplitude was preferable for this purpose.

This data shows that in this group of middle-aged runners, who were not familiar with interval-training, the IT with the lowest and intermediate amplitudes were the most effective in eliciting $VO_2$ max for the longest time (almost 15 min).

### *The effect of the interval-training on the time spent at $VO_2$ max*

Astrand and Rodahl [2] recommended this exercise procedure to maximally elicit the oxygen-transport system. Using this exercise configuration (10 s runs and 5 s pauses) a runner was able to run for 30 min which resulted in an effective run time at v$\dot{V}O_2$ max of 20 min (since the work:rest ratio was 1/2). The end blood lactate was low (4.8mM).

Astrand and Rodahl [2] pointed-out that in all these short interval-training procedures, the oxygen uptake and pulmonary ventilation were also high during the interspersed resting periods.

This is in accordance with our results as shown in the typical example in Fig. **1** Moreover, their recoveries were passive and

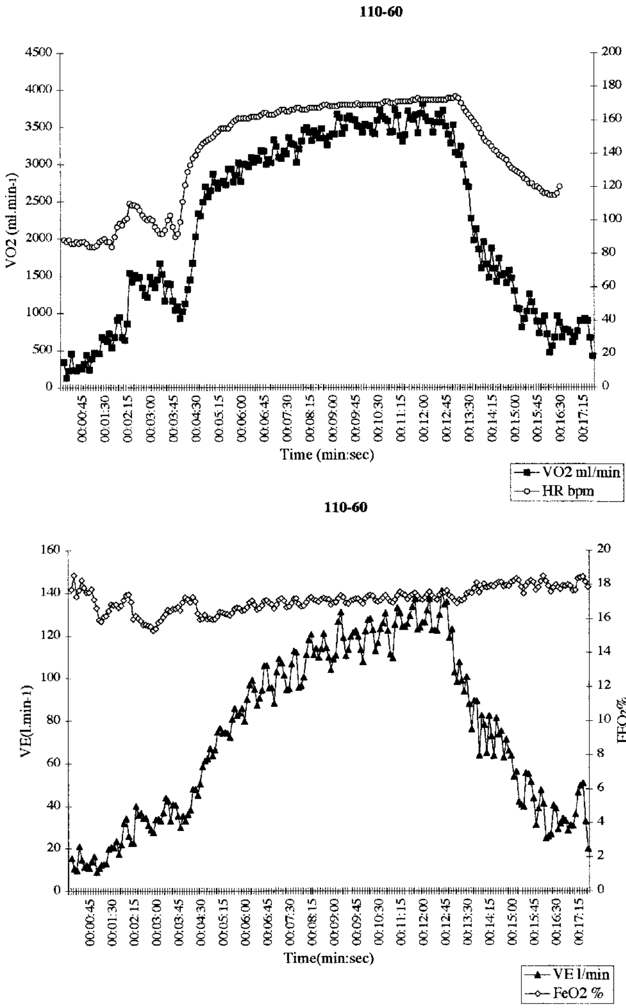


**Fig. 1 c** Oxygen consumption (black squares), heart rate (open circles), ventilation per minute (black triangles), expired oxygen fraction (open diamonds), time course during the three Intermittent exercise procedures (Subject 3): The intermittent training session consisted of 15 s runs at an average velocity equal to 85 % of $vVO_2$ max (the critical velocity), alternating at: **c** 110 % and 60 % of $vVO_2$ max, the amplitude being therefore equal to ([110- 60]/85)×100 = 59 %.

consequently, their amplitudes were equal to 100 %. If Astrand and Rodahl [2] considered that the duration of exercise and resting periods are critical with respect to the peak load on the oxygen-transport system, we can now add that the amplitude is also important.

We are aware of only one study that has focused on interval training based around the critical power [7]. Recently Brickley et al. [7] reported that in intermittent exercise (cycling) and continuous exercise performed for 30 min at the same average power was equal to 90 % of the critical power (CP90). The subjects (six trained male) exercised for 30 s at 175 % of CP90 (i.e. 157 % of CP) followed by 240 s at 81.25 % CP90. From muscular biopsies (from the vastus lateralis) they reported that the metabolic responses (muscle glycogen, lactate, and phosphocreatine concentration and pH) were similar to the continuous exercise performed at the same average power output (90 % of CP). They concluded that the lack of metabolic differences after intermittent and continuous exercise was a consequence of the recovery period being matched to ensure that the same average work-rate was achieved in both exercise bouts. However, they did not analyse the proportion of type I and IIa fibres that could have been differently depleted in creatine phosphate and glycogen due to the high power output used in their intermittent training procedure.

This type of IT was different from those used in our study as the high exercise duration was performed at a higher intensity and for a longer hard exercise duration with a greater amplitude (103 %).

### *Blood lactate accumulation during interval training*

In this study the interval-training procedure C was found to be significantly different from the two other interval-training procedures A and B.

Recently Billat et al. [6], using 30 s run at 100 % of $v\dot{V}O_2$ max alternated with 30 s run at 50 % of $v\dot{V}O_2$ max, showed that subjects reached $VO_2$ max with a lower blood lactate than at the end of the incremental test to determine $v\dot{V}O_2$ max. They reported that 5 of the 8 subjects reached $\dot{V}O_2$ max in the intermittent exercise with an associated blood lactate at a steady-state below 4 mM from the third to the 6 th minute. Hence for at least one minute these 5 runners were at $\dot{V}O_2$ max with only 4mM of blood lactate. This is in contrast to previous studies which have examined blood lactate accumulation during intermittent exercise and have reported that a high value of blood lactate accompanies a $\dot{V}O_2$ value at its maximum [1]. This is due to the fact that these studies used long intervals of 2 – 3 min to elicit $\dot{V}O_2$ max with complete rest between repetitions that did not allow a high rate of lactate clearance.

Interval training performed at velocities around the velocity associated with $\dot{V}O_2$ max ($v\dot{V}O_2$ max), as well as maximising the improvement in $\dot{V}O_2$ max, may also induce significant improvements in mitochondrial density [8]. In fact, in addition to these aerobic ($O_2$ transport) training benefits, interval-training stimulates the rate of lactate removal which depends directly on its concentration (i.e. the higher the concentration, the greater the rate of removal) [8]. Therefore interval training which increases blood lactate levels will also stimulate an improvement in lactate removal. For this reason Brooks et al. [8] recommended activity during the rest interval to stimulate lactate removal and hence avoid blood lactate accumulation. Despite high lactate production at these high velocities (i.e. above the lactate threshold), walking or jogging in the rest phase of intermittent exercise would tend to stimulate oxidative recovery [12,18]. Therefore we suggest that active recovery rather than passive recovery should be used since it not only elicits and maintains $VO_2$ max but also stimulates lactate removal whilst remaining close to the maximal blood lactate steady-state.

### *Distance-run at a high velocity during an interval-training exercise and the peripheral adaptation for middle distance and long-distance performances*

Central factors related to oxygen uptake are not the only limiting factor even in long-distance running. In addition to the aerobic process, neuromuscular and anaerobic characteristics are also involved [21,22]. Paavolainen et al. [22] reported that the velocity over 5 km was positively correlated with the maximal velocity, the contact time, and the stride rates over 20 m (running start). Both the velocities over 5 km and 10 km were correlated with the mean contact time of the constant velocity laps during 5 km and 10 km. The ability of fast force production during maximal and submaximal running was related to both the 5 km and the 10 km performance [22]. The same group of researchers also showed that explosive strength training (various sprint, jumping exercise, leg press, and knee extensor-flexor exercises) replacing 32% of the training volume induced a significant increase in the 5 km time. This increase in performance was related to the improved running economy and the velocity reached in an anaerobic treadmill running test ($V_{MART}$) [25].

In accordance with Noakes [19,20], the benefits of training also depend on the distance covered at a high velocity determining the muscular adaptation, maximising the number of powerful muscle contractions. For this purpose, the 100–70% of $v\dot{V}O_2$ max could be preferable to the 90–80% of $v\dot{V}O_2$ max.

In fact the intermittent exercise training at $v\dot{V}O_2$ max, not only allows the cardiovascular function to be stimulated at its maximum (at $\dot{V}O_2$ max) for a longer time but allows the run to be made at a higher velocity ($+1.6\ km \times h^{-1}$). Therefore both from the cardiovascular and muscular adaptation point of view intermittent exercise at $vVO_2$ max is likely to produce increased performance for middle-distance runners.

## Conclusion

These data show that in a group of middle-aged runners, who were not familiar with intermittent exercise, interval-training with the lowest and intermediate amplitude were the most effective in eliciting $\dot{V}O_2$ max for the longest time (almost 15 min) while maintaining the lower blood lactate concentration compared with the highest amplitude of IT.

In addition, the intermittent exercise alternating runs at $v\dot{V}O_2$ max and 70% $v\dot{V}O_2$ max not only allowed a longer stimulation of cardiovascular function at its maximum (at $\dot{V}O_2$ max) but were run at a higher velocity ($+1.6\ km \times h^{-1}$) than during the 90- 80% of $vVO_2$ max and with the same blood lactate accumulation (around 9 mM). Before speculating on the cause of $\dot{V}O_2$ max improvement from a given training design, it was and it is essential to examine the effect of this stimulus on cardiovascular and metabolic responses. In the absence of this information we can only hypothesize that the benefit of these training procedures on aerobic capacity (and especially on $\dot{V}O_2$ max) is dependent not only on the time spent at $\dot{V}O_2$ max but also on the distance run at a high velocity. With this in mind we are then able to discriminate between the benefits gained from either interval or constant load tests.

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Corresponding Author:

V. L. Billat, PH. D.

Centre de Médecine du Sport C. C. A. S.
2 Avenue Richerand
75 010 Paris
France

Tel. + 33 (1) 42 02 08 18
Fax: + 33 (1) 42 39 20 83
E-mail: veronique.billat@wanadoo.fr