

## ***Critical Velocity and Time Spent at a High Level of $\dot{V}O_2$ for Short Intermittent Runs at Supramaximal Velocities***

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### **Catalog Data**

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**Key words:** *intermittent exercise, maximal oxygen consumption, performance, training*

**Mots clés:** *exercice intermittent, consommation d'oxygène, performance, entraînement*

### **Abstract/Résumé**

*This study was designed to determine the intermittent critical velocity, the time spent at maximal oxygen uptake ( $\dot{V}O_{2max}$ ) and the time spent above 90% of  $\dot{V}O_{2max}$  for short intermittent runs of 15 s at supramaximal velocities, alternating with 15 s of passive recovery. Nine male subjects performed 5 field-tests to exhaustion (tlim): 4 intermittent runs at 110%, 120%, 130% and 140% of maximal aerobic speed (MAS) and 1 continuous run at 100% of MAS. Results have shown the mean intermittent critical velocity ( $4.82 \pm 0.41 \text{ m}\cdot\text{s}^{-1}$ ) was not significantly different from MAS ( $4.63 \pm 0.37 \text{ m}\cdot\text{s}^{-1}$ ). Intermittent runs at 110% and 120% of MAS and the continuous run at 100% of MAS lead all subjects to reach  $\dot{V}O_{2max}$ . However, intermittent runs at 120% of MAS ( $202 \pm 66 \text{ s}$ ) allowed subjects to spend a significantly longer time at  $\dot{V}O_{2max}$  ( $p < .05$ ) than intermittent runs at 110% ( $116 \pm 42 \text{ s}$ ), 130% ( $50 \pm 47 \text{ s}$ ), 140% ( $48 \pm 59 \text{ s}$ ) of MAS and continuous run at 100% of MAS ( $120 \pm 42 \text{ s}$ ). The time spent between 90 and 100% of  $\dot{V}O_{2max}$  was significantly longer ( $p < .05$ ) for intermittent runs at 110% ( $383 \pm 180 \text{ s}$ ) and for 120% ( $323 \pm 272 \text{ s}$ ) of MAS than for intermittent runs at 130% ( $135 \pm 133 \text{ s}$ ), 140% of MAS ( $77 \pm 96 \text{ s}$ ) and for continuous run at 100% of MAS ( $217 \pm 114 \text{ s}$ ). Consequently, this kind of intermittent exercise with intensities from intermittent critical velocity to 120% of MAS could be introduced in a training program when the purpose is to increase  $\dot{V}O_{2max}$ .*

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*Le but de cette étude est de déterminer la vitesse critique intermittente, le temps passé à la consommation maximale en oxygène ( $\dot{V}O_{2max}$ ) et le temps passé à plus de 90% de  $\dot{V}O_{2max}$  lors de courses intermittentes brèves de 15 s à des vitesses supramaximales, alternées avec des périodes de récupération passive de 15 s. Neuf sujets masculins ont réalisé 5 tests de terrain jusqu'à épuisement : 4 courses intermittentes à 110%, 120%, 130%, 140% de la vitesse maximale aérobie (VMA) et une course continue à 100% de la VMA. Les résultats montrent que les valeurs de vitesse critique intermittente ( $4.82 \pm 0.41 \text{ m.s}^{-1}$ ) ne sont pas significativement différentes de la VMA ( $4.63 \pm 0.37 \text{ m.s}^{-1}$ ). Les courses intermittentes à 110% et à 120% de la VMA, ainsi que la course continue à 100% de la VMA, permettent à tous les sujets d'atteindre  $\dot{V}O_{2max}$ . Cependant, la course intermittente à 120% de la VMA ( $202 \pm 66 \text{ s}$ ) permet aux sujets de maintenir plus longtemps  $\dot{V}O_{2max}$  ( $p < .05$ ) que les courses intermittentes à 110% ( $116 \pm 42 \text{ s}$ ), 130% ( $50 \pm 47 \text{ s}$ ), 140% ( $48 \pm 59 \text{ s}$ ) de la VMA et que la course continue à 100% de la VMA ( $120 \pm 42 \text{ s}$ ). Le temps passé entre 90 et 100% de  $\dot{V}O_{2max}$  était significativement plus long lors des courses intermittentes à 110% ( $383 \pm 180 \text{ s}$ ) et 120% ( $323 \pm 272 \text{ s}$ ) que lors des courses intermittentes à 130% ( $135 \pm 133 \text{ s}$ ), 140% de la VMA ( $77 \pm 96 \text{ s}$ ) et lors de la course continue à 100% de la VMA ( $217 \pm 114 \text{ s}$ ). Par conséquent, ce type d'exercice intermittent à des allures de course comprises entre la vitesse critique intermittente et 120% de la VMA pourrait être introduit dans un programme d'entraînement lorsque le but est d'augmenter  $\dot{V}O_{2max}$ .*

## Introduction

Some studies have investigated the effects of training through intermittent exercise on maximal oxygen uptake ( $\dot{V}O_{2max}$ ; Fox et al., 1973; Gorostiaga et al., 1991; Tabata et al., 1997). The improvements in  $\dot{V}O_{2max}$  are generally explained by the fact that the exercises allow a high level of  $\dot{V}O_2$  to be elicited. According to Wenger and Bell (1986), the greatest challenge to aerobic power occurs when intensity is from 90 to 100% of  $\dot{V}O_{2max}$ . Nevertheless, we still do not know which type of training is most effective, for example to maintain 90% of the  $\dot{V}O_{2max}$  for 40 min or to reach 100% of the  $\dot{V}O_{2max}$  for about 16 min (Åstrand and Rodahl, 1986). According to these authors, it could be necessary to determine the longest time that exercise allows subjects to spend at  $\dot{V}O_{2max}$  or between 90 and 100% of  $\dot{V}O_{2max}$ . Some studies have focused on the time spent at  $\dot{V}O_{2max}$  for continuous runs and for intermittent runs with active recovery (Billat et al., 1999, 2000; Hill and Fergusson 1999). However, numerous exercise intensities allow subjects to reach  $\dot{V}O_{2max}$  or a high level (i.e., from 90% to 100% of  $\dot{V}O_{2max}$ ). Hill and Fergusson (1999) emphasised that critical velocity (CV; i.e., the slope of the relationship between running time to exhaustion [tlim] and distance limit [dlim]), was the threshold speed above which continuous exercise of sufficient duration leads to the attainment of  $\dot{V}O_{2max}$ . For continuous runs at velocities ranging from 90 to 140% of MAS, the CV represented 83.7% of MAS, while the velocity allowing  $\dot{V}O_{2max}$  to be maintained for the longest time corresponded to 100% of MAS (Billat et al., 1999). Moreover, like continuous exercises, intermittent exercises allow subjects to elicit  $\dot{V}O_{2max}$ . For example, Christensen et al. (1960) demonstrated that intermittent runs of 15 s at supramaximal velocity alternating with 15 s of passive recovery allow  $\dot{V}O_{2max}$  to be attained. But, these authors did not measure the exercise time to exhaustion of their subjects and consequently the time spent at  $\dot{V}O_{2max}$ . This kind of exercise, i.e. short intermittent runs at supramaximal

velocities alternating with short recoveries periods, could also be used to improve aerobic power (Tabata et al., 1997). To our knowledge, no study has focused on CV and on the time spent at a high level of  $\dot{V}O_2$  for short intermittent runs at supramaximal velocities. Based on short intermittent runs (15 s) at supramaximal velocities, the purposes of this study were to determine (a) the intermittent critical velocity and (b) the time spent at  $\dot{V}O_{2,max}$  and between 90 and 100% of  $\dot{V}O_{2,max}$ . As the interest of intermittent runs is to increase the running time at a determined velocity, we hypothesised that time spent at a high level of  $\dot{V}O_2$  was longer for intermittent runs than for a continuous run at 100% of MAS.

## Methods

### SUBJECTS

Nine male physical education students participated in this study. All subjects were volunteers and gave their written consent to participate in these experiments in accordance with the consultative committee for the protection of persons in biomedical research of Lille (France). Their mean  $\pm$  standard deviations (SD) for age, mass and height were  $25.0 \pm 2.8$  years,  $73.8 \pm 7.9$  kg and  $179 \pm 6$  cm, respectively.

### EXPERIMENTAL PROTOCOL

All subjects performed six field-tests until exhaustion at the same time of the day, separated by at least 48h, but all were completed within 2 weeks. For each test, subjects were verbally encouraged to continue for as long as possible. The subjects were considered as exhausted when they could not maintain the required speed associated with visible exhaustion. All tests were performed in a 200 m indoor tartan track. Before the tests, the subjects were familiarised with the exercise procedure and with the analysers. The subjects were required to rest the day before the test and to have their last meal 3 hours before the test.

They first performed an incremental test and then, in a random order, 4 intermittent exercises and 1 continuous exercise. These 5 tests were preceded by a standardised warm up which consisted of 10 minutes of continuous running at 60% of MAS, following by 5 minutes of stretching exercises and a few short bursts of acceleration on the track. The test began 2 minutes after this warm up.

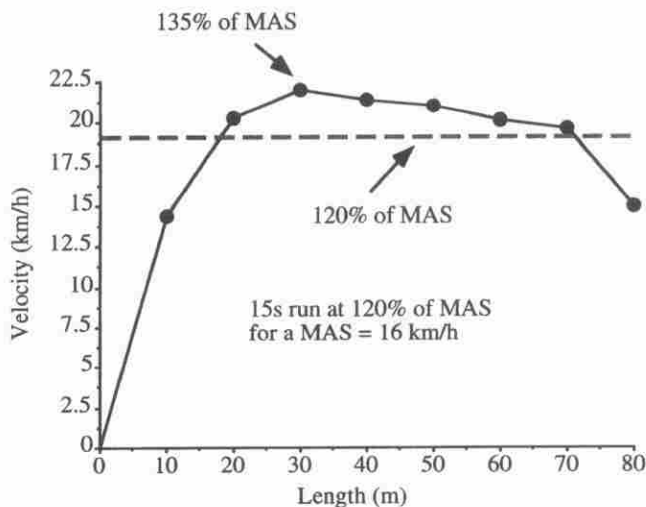
*Incremental exercise.* Cones were set at 25 metre intervals along the track (inside the first lane). The running pace was given by a tape recording which indicated by means of a brief sound the moment when the subject had to pass near a cone to maintain a constant speed. Longer sound marked the changes in the running stage. The speed of the soundtrack was checked prior to the beginning of each session. At each sound, the subjects had to be within 2 metres from the mark. The initial speed was  $10 \text{ km}\cdot\text{h}^{-1}$  and it was increased by  $1.5 \text{ km}\cdot\text{h}^{-1}$  every 3 minutes to  $17.5 \text{ km}\cdot\text{h}^{-1}$  and then by  $0.5 \text{ km}\cdot\text{h}^{-1}$  every minute. The test ended with voluntary exhaustion, or when the subjects were unable to maintain the required velocity. Velocity at the last completed stage was considered as MAS. The accuracy of MAS was  $0.5 \text{ km}\cdot\text{h}^{-1}$ . This method is in agreement with previously publications (Berthoin et al., 1996; Billat and Koralsztein, 1996; Lacour et al., 1991) that have demonstrated that increments of  $1 \text{ km}\cdot\text{h}^{-1}$  every 2 minutes (or  $0.5 \text{ km}\cdot\text{h}^{-1}$  every minute or  $1.5 \text{ km}\cdot\text{h}^{-1}$  every 3 minutes) provide an accurate estimation of MAS. For

moderately trained subjects, Berthoin et al. (1996) found that MAS (i.e., the velocity at the last completed stage) was not significant for the velocity determined as recommended by Morgan et al. (1989) or Lacour et al. (1991).

*Continuous exercise.* The continuous exercise consisted in running at 100% of MAS. For this exercise, running pace was given by sounds emitted by a loud-speaker controlled by a computer. The test was ended as for the incremental exercise.

*Intermittent exercises.* The 4 intermittent exercises consisted in repeating as long as possible 15 s runs at 110%, 120%, 130% and 140% of MAS alternating with 15 s passive recovery periods. For these exercises, running paces were given by a manual timer, with the sound interval (15 s) kept constant up to the end of the exercise. The subjects had to cover a determined distance, according to their own MAS and the imposed percentage of MAS in 15 s. They were allowed to stop running within the 3 meters after the stop line. After 15 s rest, they turned round to run in the opposite direction. The start was carried out at nil initial velocity. As a consequence, the peak velocity during the run was higher than the mean velocity. To analyse the pattern of the run, nine subjects performed a 15 s run at 120% of MAS with photocells (Brower Timing Systems IRE and IRD-T175) placed 10 m apart. For each run, the highest velocity over 10 m was retained and expressed as a percentage of MAS. For the group, the highest velocity attained over 10 m represented  $139.2 \pm 6.0$  of MAS. The pattern of the velocity versus distance is presented in Figure 1 for a subject running 80 meters in 15 s, or 120% of MAS for a MAS equal to  $4.44 \text{ m}\cdot\text{s}^{-1}$  ( $16 \text{ km}\cdot\text{h}^{-1}$ ).

Effective running time ( $t_{lim}$ ) was measured for each intermittent exercise. Recovery periods were not included in the  $t_{lim}$ . The distance limit ( $d_{lim}$ ) was calculated as the number of 15 s runs times the distance to be covered, for each relative velocity. The test ended with voluntary exhaustion, or when the subjects were unable to maintain the required velocity.



**Figure 1.** An example of the velocity versus distance relationship for a subject who performed 80 meters run within 15 s.

*Intermittent critical velocity determination.* For each subject, the individual linear relationship between  $t_{lim}$  and  $d_{lim}$  was calculated from the performance in intermittent exercises:  $d_{lim} = b \cdot t_{lim} + a$ . Intermittent critical velocity (ICV) corresponded to slope "b" of this relationship and "a" was assumed to represent the distance run using oxygen reserves and anaerobic metabolism (Ettema, 1966).

*Respiratory gas exchange and heart rate.* During all the tests, heart rate (HR) was monitored and respiratory gas exchanges were analysed breath by breath using a portable system (Cosmed K4b<sup>2</sup>, Rome, Italy). This analyser has previously been validated for measuring oxygen uptake over a wide range of exercise intensities (MacLaughlin et al., 2001). Before each test, the O<sub>2</sub> and CO<sub>2</sub> analysis systems were calibrated using ambient air, which was assumed to contain 20.93% of O<sub>2</sub> and 0.03% of CO<sub>2</sub>, and with gas of known O<sub>2</sub> concentration 16.7% and CO<sub>2</sub> concentration 5.7%. The calibration of the turbine flowmeter of the K4b<sup>2</sup> was performed using a 3 l syringe (Quinton Instruments, Seattle, USA). HR was continuously measured by a telemetric system (Polar Electro, Kempele, Finland). For the incremental test and continuous runs,  $\dot{V}O_2$ ,  $\dot{V}CO_2$  and HR values were averaged over 15 s, while for intermittent runs these values were averaged over 5 s.

*Blood sample collection and treatment.* Two minutes after each test, finger tip blood samples (10  $\mu$ l) were collected. The blood samples were analysed within the 15 min following the end of this test, and lactate concentration ([La]) was determined by a spectro-photometer technique (Dr. Lange, miniphotometer + LP20, type LPG 344), which had previously been validated (Kamber, 1992). The accuracy of the analyser was checked before each test by standard solutions in lactate concentration.

*$\dot{V}O_{2max}$  and  $\dot{V}O_{2peak}$  determination.* The  $\dot{V}O_{2max}$  corresponded to the average highest  $\dot{V}O_2$  attained in 4 successive 15 s periods for the incremental test. It was judged that subjects had reached their  $\dot{V}O_{2max}$  when 3 or more of the following criteria were met: (a) a plateau in  $\dot{V}O_2$  despite increasing running speed, (b) a final respiratory ratio higher than 1.1, (c) an inability to maintain the required velocity, (d) a lactate concentration higher than 9 mmol.l<sup>-1</sup>. For continuous and intermittent runs, the highest  $\dot{V}O_2$  attained for 2 successive periods was assumed to correspond to  $\dot{V}O_{2peak}$ .

*Time spent at  $\dot{V}O_{2max}$  and time spent between 90 and 100% of  $\dot{V}O_{2max}$ .* Times spent at  $\dot{V}O_{2max}$  and between 90 and 100% of  $\dot{V}O_{2max}$  were measured for intermittent and continuous exercises. It was assumed that the subjects reached  $\dot{V}O_{2max}$  during these exercises when  $\dot{V}O_{2peak}$  was at least higher than 95% of  $\dot{V}O_{2max}$ . A value equal to 95% of  $\dot{V}O_{2max}$  was chosen, as Katch et al. (1982) had demonstrated that the intra-individual variability in  $\dot{V}O_{2max}$  is within 5%. For the subjects who satisfied this condition, the time at  $\dot{V}O_{2max}$  and time spent between 90 and 100% of  $\dot{V}O_{2max}$  were calculated. Time spent at  $\dot{V}O_{2max}$  corresponded to  $\dot{V}O_2$  values included between  $\dot{V}O_{2peak}$  and 95% of  $\dot{V}O_{2peak}$ ; time spent between 90 and 100% of  $\dot{V}O_{2max}$  corresponded to  $\dot{V}O_2$  values included between  $\dot{V}O_{2peak}$  and 90% of  $\dot{V}O_{2peak}$ .

#### STATISTICAL ANALYSIS

Results are expressed as means  $\pm$  SD. A one-way analysis of variance for repeated measurements with Student-Newman-Keuls' post hoc tests was used to compare

$\dot{V}O_{2peak}$ , HRpeak, dlim, tlim, [la], time spent at  $\dot{V}O_{2max}$  and time spent from 90 to 100% of  $\dot{V}O_{2max}$  between the 5 exercise procedures (the 4 intermittent runs at 110%, 120%, 130%, 140% of MAS and the continuous run at 100% of MAS). A Pearson Product Moment correlation was used to assess the relationship between variables. In all analyses, the level of significance was set at  $p < 0.05$ .

## Results

### INCREMENTAL EXERCISE

For this test, the total exercise time was  $16.5 \pm 2.8$  min. The mean values for MAS,  $\dot{V}O_{2max}$  and respiratory exchanges ratio were  $4.63 \pm 0.37$  m.s<sup>-1</sup> ( $16.7 \pm 1.3$  km.h<sup>-1</sup>),  $54.1 \pm 6.8$  ml.kg<sup>-1</sup>.min<sup>-1</sup> and  $1.16 \pm 0.04$  respectively. For this test, lactate concentration values were  $11.2 \pm 2.3$  mmol.l<sup>-1</sup> and HRmax values were  $194 \pm 10$  beats.min<sup>-1</sup>.

### INTERMITTENT EXERCISES AND CONTINUOUS EXERCISE

Table 1 summarises the number of subjects eliciting  $\dot{V}O_{2max}$  and the values of  $\dot{V}O_{2peak}$ , HRpeak, tlim, dlim and [la] for continuous and intermittent exercises. The time spent at  $\dot{V}O_{2max}$  and the time spent between 90 and 100% of  $\dot{V}O_{2max}$  are presented in Figures 2 and 3, respectively. Figure 4 shows an example of  $\dot{V}O_2$  versus time relationship for the different tlim.

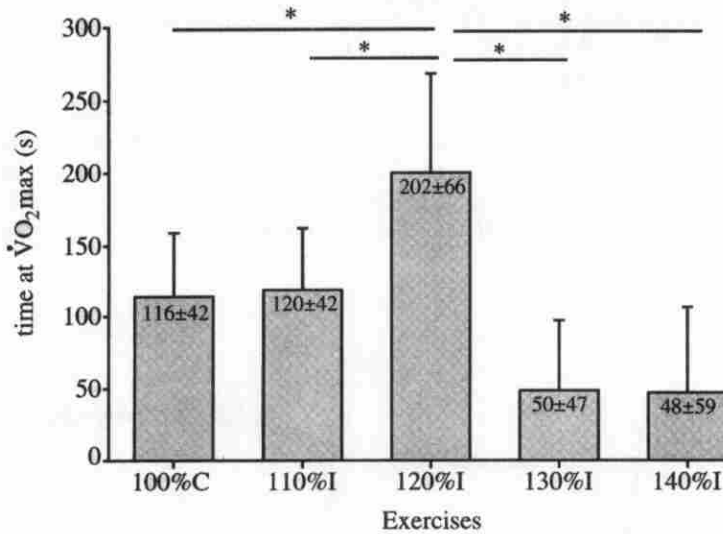
The time spent at  $\dot{V}O_{2max}$  represented  $32.1 \pm 7.4\%$ ,  $17.2 \pm 7.0\%$ ,  $58.2 \pm 19.4\%$ ,  $30 \pm 24.2\%$ ,  $48.3 \pm 64.4\%$  of the tlim at 100%, 110%, 120%, 130% and

**Table 1** Number of Subjects Who Elicit  $\dot{V}O_{2max}$  and Means  $\pm$  Standard Deviations of  $\dot{V}O_{2peak}$ , HRpeak, dlim, tlim and Lactate Concentration ([la]) Values for Continuous and Intermittent Runs

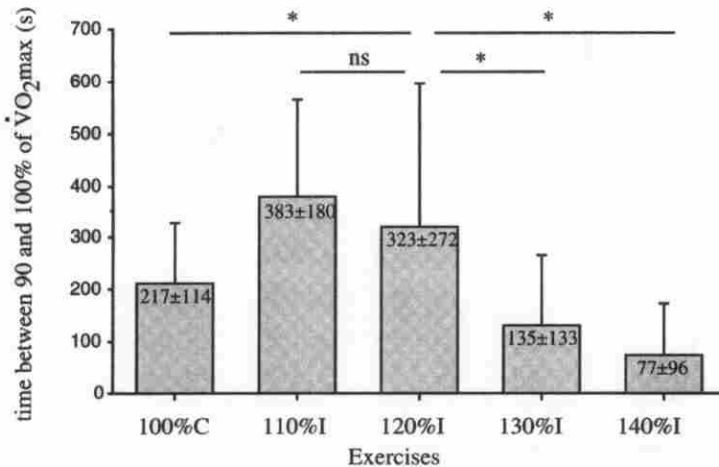
	100%C	110%I	120%I	130%I	140%I
Number of subjects who elicit $\dot{V}O_{2max}$	9	9	9	7	4
$\dot{V}O_{2peak}$ (ml.kg <sup>-1</sup> · min <sup>-1</sup> )	$55.8 \pm 6.2$	$54.7 \pm 6.0$	$56.0 \pm 5.6$	$55.0 \pm 6.5$	$52.2 \pm 3.6^*$
HRpeak (beats · min <sup>-1</sup> )	$189.2 \pm 5.7$	$187.0 \pm 10.8$	$192.8 \pm 12.9$	$192.9 \pm 8.5$	$188.8 \pm 7.3$
dlim (m)	$1669 \pm 487$	$3534 \pm 1738^*$	$1899 \pm 1240$	$995 \pm 415^*$	$640 \pm 308^*$
tlim (s)	$362 \pm 109$	$698 \pm 355^*$	$347 \pm 234$	$167 \pm 70^*$	$100 \pm 50^*$
[la] (mmol · l <sup>-1</sup> )	$10.3 \pm 3.5$	$11.1 \pm 2.5$	$13.1 \pm 3.7$	$14.7 \pm 4.9^*$	$13.5 \pm 2.9$

\*Significantly different from 100%C ( $p < 0.05$ ).

100%C: continuous runs at 100% of MAS; 110%I: intermittent runs at 110% of MAS; 120%I: intermittent runs at 120% of MAS; 130%I: intermittent runs at 130% of MAS; 140%I: intermittent runs at 140% of MAS. dlim: distance limit; tlim: time limit; [la]: lactate concentration.



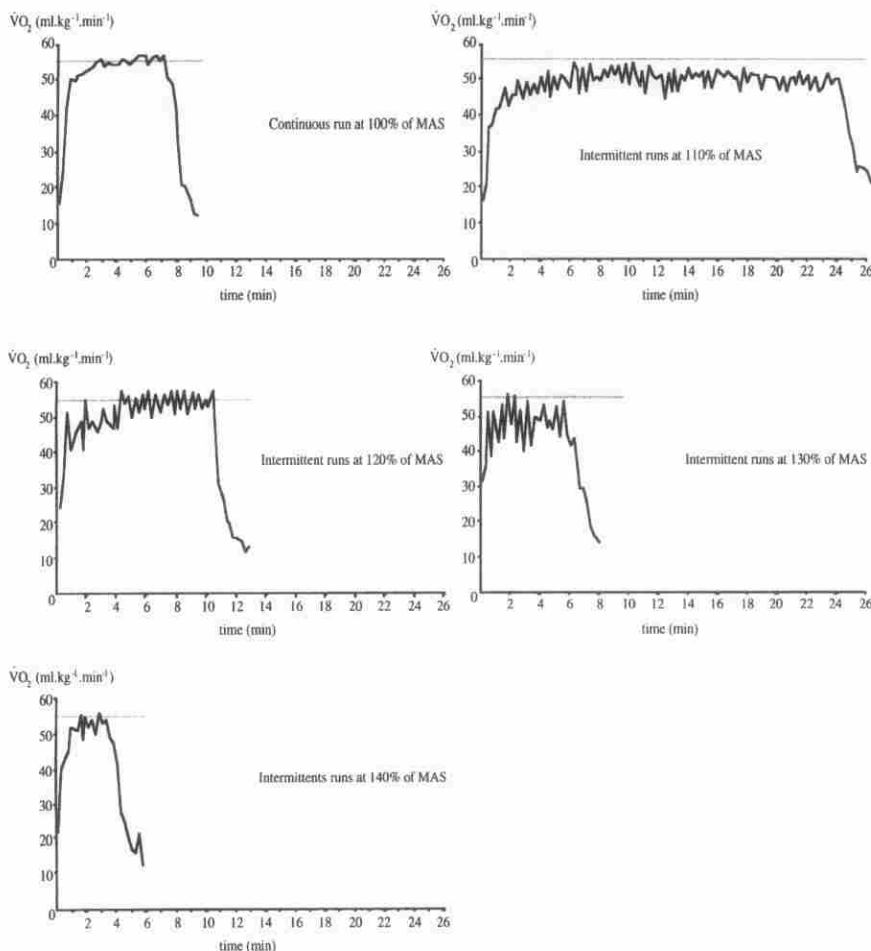
**Figure 2.** Time spent at  $\dot{V}O_{2\max}$  (means  $\pm$  standard deviations) for continuous and intermittent runs. \*Significantly different from 120%I ( $p < 0.05$ ). 100%C: continuous runs at 100% of MAS; 110%I: intermittent runs at 110% of MAS; 120%I: intermittent runs at 120% of MAS; 130%I: intermittent runs at 130% of MAS; 140%I: intermittent runs at 140% of MAS.



**Figure 3.** Time spent between 90 and 100% of  $\dot{V}O_{2\max}$  (means  $\pm$  standard deviations) for continuous and intermittent runs. \*Significantly different from 120%I ( $p < 0.05$ ). 100%C: continuous runs at 100% of MAS; 110%I: intermittent runs at 110% of MAS; 120%I: intermittent runs at 120% of MAS; 130%I: intermittent runs at 130% of MAS; 140%I: intermittent runs at 140% of MAS.

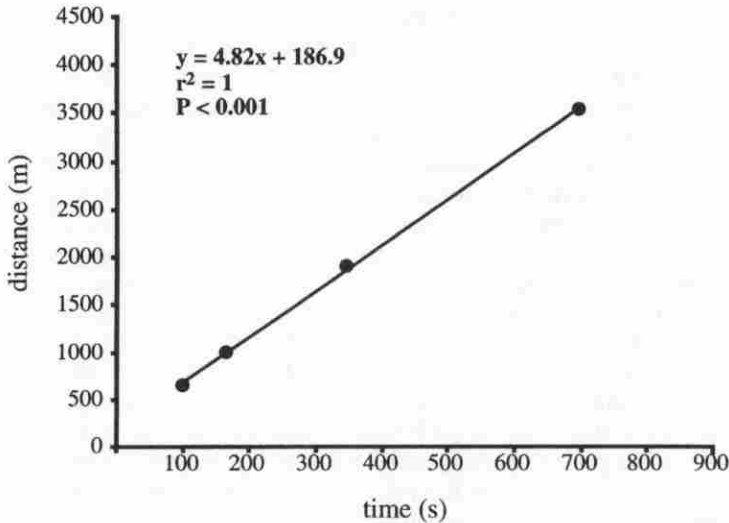
140% of MAS, respectively. The time spent between 90 and 100% of  $\dot{V}O_{2\max}$  represented  $59.8 \pm 15.5\%$ ,  $54.9 \pm 20.2\%$ ,  $93.3 \pm 23.1\%$ ,  $81 \pm 48.5\%$ ,  $76.7 \pm 53.0\%$  of the tlim at 100%, 110%, 120%, 130% and 140% of MAS, respectively.

The mean relationship between dlim and tlim for intermittent runs is presented in Figure 5. For each subject, the relationship between tlim and dlim was highly significant ( $0.99 \leq r^2 \leq 1$ ;  $p < 0.01$ ). Regression analysis shows that ICV was equal to  $4.82 \pm 0.41 \text{ m}\cdot\text{s}^{-1}$  (corresponding to  $104.11 \pm 4.31\%$  of MAS) while the constant "a" was  $186.9 \pm 86.0 \text{ m}$ . The ICV was not significantly different from MAS.



**Figure 4.** An example of the  $\dot{V}O_2$  versus time relationship for the 4 intermittent runs and the continuous run for the same subject. The solid line indicates the  $\dot{V}O_{2\max}$  value determined during the incremental test.





**Figure 5.** Means relationship between distance limit (dlim) and time limit (tlim) for short intermittent runs.

## Discussion

The first purpose of the study was to determine the ICV for short intermittent runs at 110%, 120%, 130% and 140% of MAS. For continuous runs, the determination of the relationship between dlim and tlim is only linear over a determined range of tlim. For example, Vandewalle et al. (1997) showed that data corresponding to tlim longer than 35 min were under the regression line calculated from the values of tlim ranging between 3.5 min and 35 min. To calculate CV for continuous runs, Hill (1993) recommended performing tlim ranging between 1 to 10 min with duration of long and short trials of 5 min. To our knowledge, no study has focused on the linearity of the dlim versus tlim relationship for intermittent runs. This point was particularly underlined by Kachouri et al. (1996) and Vandewalle et al. (1997). In addition, according to Hill (1993), 4 to 5 exercises are optimal to reduce the error associated with the parameters estimates. In the present study, 4 tlim were performed; and the duration of the shortest trial ( $100 \pm 50$  s) as for the longest trial ( $698 \pm 355$  s) was within the range recommended by Hill (1993) with at least 5 min between the shortest and the longest trials. Our results confirm the linearity of the relationship between dlim and tlim for all subjects ( $0.99 \leq r^2 \leq 1$ ;  $p < 0.01$ ) using 4 intermittent runs. A practical aspect of this relationship could be the estimation of an athlete's performance on a wide range of intermittent velocities, and thus to more accurately individualize training sessions (i.e. the number of repetitions that a subject can run at a selected velocity). The intermittent critical velocity was not significantly different to MAS, and corresponded to  $104.1 \pm 4.3\%$  of MAS. For continuous runs, Billat et al. (1999) and Kachouri et al. (1996) obtained CV lower than MAS (83.7% and 89.8% of MAS, respectively). Likewise, for intermittent runs with long intervals, i.e. mean periods corresponding to 108.5 s and

357.5 s, Kachouri et al. (1996) obtained CV corresponding to 89.1% of MAS. These differences between CV could come from the process used to supply energy to muscle during the running period and recovery process. For the short intermittent exercises used in this study, it could be hypothesised that a considerable amount of energy comes from  $O_2$  bound to myoglobin and from phosphocreatine (PCr) stores, which are quickly reloaded during recovery. Indeed, Astrand et al. (1960) suggested that, for short intermittent runs, the myoglobin should represent an oxygen store used during the initial running phase, and would have time to reload with oxygen before the next running period. In another study, Essen et al. (1977) showed that, for intermittent exercises of 15 s at 110% of  $\dot{V}O_{2\max}$  alternating with 15 s of rest, the mainly aerobic energy release during each work period was partly caused by myoglobin functioning as an oxygen store; this factor was estimated to be more important than adenosine triphosphate (ATP), PCr or lactate level oscillations. The oxygen uptake during the rest periods is thus able to recharge the myoglobin store. More recently, Christmass et al. (1999) found that for short intermittent runs of 12 s at 120% of  $\dot{V}O_{2\text{peak}}$  alternating with 18 s recovery periods, the level of relative oxyhaemoglobin of the quadriceps muscle was characterised by a cycling decline in oxygenation during runs followed by re-oxygenation during recovery. Furthermore, following short-term high-intensity exercise, one of the functions of recovery is to restore PCr. In fact, during recovery periods, PCr increased rapidly, then increased slowly. According to Bogdanis et al. (1995), for 30 s sprints, 65% of PCr was reloaded after 1.5 min. We can hypothesise that a considerable part of  $O_2$  stores binding to myoglobin and a part of PCr are reloaded during each 15 s recovery period. Conversely, with long intervals (Kachouri et al., 1996) or with continuous runs (Billat et al., 1999), the  $O_2$  bound to myoglobin and PCr stores contribute to only a small part of the energy yielded to restore ATP, and are of little importance (Astrand et al., 1960). Thus, for short intermittent exercise, CV would include energy from these reloaded  $O_2$  stores and from the part of resynthesised PCr. It could explain that CV (in % of MAS) is higher for short intermittent runs than for continuous runs or for intermittent runs with longer intervals. For intermittent runs, parameter "a" ( $187 \pm 86$  m) was similar to that reported for continuous runs ( $216 \pm 59$  m) by Billat et al. (1999) for a similar population, while Kachouri et al. (1996) obtained  $171 \pm 51$  m.

For Hill and Fergusson (1999), CV is the threshold velocity above which exercise of sufficient duration will lead to attainment of  $\dot{V}O_{2\max}$ . We can hypothesise that ICV determined from short intermittent runs can be maintained for a long time and represents a threshold velocity above which subjects reach  $\dot{V}O_{2\max}$ . Indeed, an intermittent run at 110% of MAS was the lowest velocity tested, and this intensity was sufficient to lead all subjects to reach  $\dot{V}O_{2\max}$ . All subjects elicited  $\dot{V}O_{2\max}$  for 100%I, 110%I, 120%I. Conversely, only 7 and 4 subjects attained  $\dot{V}O_{2\max}$  for 130%I and 140%I, respectively. It could be hypothesis that for these relative velocities, the duration of exercises was too short to allow subjects to reach  $\dot{V}O_{2\max}$ .

To accurately determine the exercises allowing subjects to elicit  $\dot{V}O_{2\max}$  and, consequently to measure the time spent at  $\dot{V}O_{2\max}$  or the time spent between 90 and 100% of  $\dot{V}O_{2\max}$ , the challenge is to define the threshold at which the  $\dot{V}O_{2\max}$  is attained. Indeed, Katch et al. (1982) showed that biological variation leads to 5% of intra-individual variability in  $\dot{V}O_{2\max}$ . Thus, to accurately determine

the  $\dot{V}O_{2\max}$  value obtained on the day when the test is performed, it could be interesting to introduce an additional exercise that allows subjects to certainly attain  $\dot{V}O_{2\max}$ . For example, in the study of Morgan et al. (1989), subjects performed an additional test including a run at a velocity greater than the last completed stage during the initial test to verify that  $\dot{V}O_{2\max}$  was attained. In addition, Hill and Rowell (1997) have put emphasis on the effects of the criteria in the determination of time spent at  $\dot{V}O_{2\max}$ . For example, the time spent at  $\dot{V}O_{2\max}$  for a continuous run at 100% of MAS was to  $56 \pm 48$  s when the criteria corresponded specifically to the time spent at 100% of MAS against  $140 \pm 46$  s when the criteria corresponded to values above 95% of  $\dot{V}O_{2\max}$ . Consequently, the choice of the criteria is fundamental in the determination of the time spent at  $\dot{V}O_{2\max}$ . In an attempt to prevent some bias linked to the determination of the attainment of  $\dot{V}O_{2\max}$  during tlim, two hypotheses were made in this study. First, it was hypothesised that the subject's  $\dot{V}O_{2\max}$  can vary to 5% according to day to day variations (Katch et al., 1982). Second, it was hypothesis that if the  $\dot{V}O_{2\max}$  peak of tlim was higher than 95% of  $\dot{V}O_{2\max}$  (incremental), this value was assumed to the maximal value of the day. In this case, the time spent at  $\dot{V}O_{2\max}$  was based on this last measurement.

The second purpose of this study was to determine the time spent at  $\dot{V}O_{2\max}$  and the time spent between 90 and 100% of  $\dot{V}O_{2\max}$ . We have hypothesised that the time spent at  $\dot{V}O_{2\max}$  and the time spent between 90 and 100% of  $\dot{V}O_{2\max}$  were longer for intermittent runs than for continuous runs at 100% of MAS. Our results confirm this hypothesis as the time spent at  $\dot{V}O_{2\max}$  was significantly longer for intermittent runs at 120% of MAS ( $202 \pm 66$  s) than for continuous runs at 100% of MAS ( $116 \pm 42$  s), while the time spent between 90 and 100% of  $\dot{V}O_{2\max}$  was significantly longer for intermittent runs at 110% of MAS ( $383 \pm 180$  s) and at 120% of MAS ( $323 \pm 272$  s) than for continuous runs at 100% of MAS ( $217 \pm 114$  s; fig. 2 and 3). The time spent at  $\dot{V}O_{2\max}$  corresponded to  $58.2 \pm 19.4\%$  of running time for intermittent runs at 120% of MAS, whereas it corresponded to  $32.1 \pm 7.4\%$  for continuous runs at 100% of MAS and  $17.2 \pm 7.0\%$  for intermittent runs at 110% of MAS. Similarly, the time spent between 90 and 100% of  $\dot{V}O_{2\max}$  corresponded to  $93.3 \pm 23.1\%$  of running time for intermittent runs at 120% of MAS, against  $59.8 \pm 15.5\%$  for continuous runs at 100% of MAS and  $54.9 \pm 20.2\%$  for intermittent runs at 110% of MAS. Consequently, intermittent runs at 120% of MAS allowed subjects to spend a longer time both at  $\dot{V}O_{2\max}$  and from 90 to 100% of  $\dot{V}O_{2\max}$ . Other studies have also focused on the time spent at  $\dot{V}O_{2\max}$  (Billat et al., 1999, 2000; Hill and Rowell, 1997), but the criteria used to determine the time spent at  $\dot{V}O_{2\max}$  were different. Billat et al. (2000) showed that repeating 30 s runs at the velocity associated with  $\dot{V}O_{2\max}$  alternating with 30 s runs at 50% of the velocity associated at  $\dot{V}O_{2\max}$  allowed subjects to maintain  $\dot{V}O_{2\max}$  for  $471 \pm 398$  s (range from 0 to 1110 s). However, all subjects did not attain  $\dot{V}O_{2\max}$  and the authors did not specify the time spent between 90 and 100% of  $\dot{V}O_{2\max}$ .

From a practical point of view, repeated running exercises of 15 s at 120% of MAS alternating with 15 s of rest periods could be brought into a training program when the purpose is to increase  $\dot{V}O_{2\max}$ . Some authors (Tabata et al., 1996; MacDougall et al., 1998) found that training programs with supramaximal intensities could result in an increase in  $\dot{V}O_{2\max}$ . Hence, intermittent runs seem to be adapted to sustain  $\dot{V}O_{2\max}$  for a long time. In comparison with sub-maximal or maximal intensities, supramaximal velocities can enable fiber recruitment to be

elicited differently with specific physiological adaptations. Indeed, Simoneau et al. (1985) showed that a training program consisting mainly of series of supramaximal exercises lasting 15 s to 90 s allowed areas of type I and IIb fibers to be significantly increased, while a proportion of type IIa remained unchanged.

In conclusion, the results showed that for intermittent runs of 15 s at supramaximal intensities alternating with 15 s of rest periods, the ICV was not different from MAS and the time spent at a high level of  $\dot{V}O_2$ , i.e. the time spent between 90 and 100% of  $\dot{V}O_{2\max}$ , was longer for intermittent runs at 110% and at 120% of MAS than for continuous run at 100% of MAS. However, intermittent runs at 120% of MAS allowed subjects to maintain the longest time at  $\dot{V}O_{2\max}$ . Intensity combinations between 120% and ICV could be analysed to remain at  $\dot{V}O_{2\max}$  or between 90 and 100% of  $\dot{V}O_{2\max}$ . These results agree with Gullstrand's hypothesis (1996) suggesting that this kind of exercise can be successfully used as part of a training program.

## References

- Åstrand, I., Åstrand, P.O., Christensen, E.H., and Hedman, R. (1960). Intermittent muscular work. *Acta Physiol. Scand.* 48: 448-453.
- Åstrand, P.O., and Rodahl, K. (1986). *Textbook of Work Physiology* (3rd ed.). New York: McGraw Hill.
- Berthoin, S., Pelayo, P., Lensel-Corbeil, G., Robin, H., and Gerbeaux, M. (1996). Comparison of maximal aerobic speed as assessed with laboratory and field measurements in moderately trained subjects. *Int. J. Sports Med.* 17(7): 525-529.
- Billat, V.L., Blondel, N., and Berthoin, S. (1999). Determination of the velocity associated with the longest time to exhaustion at maximal oxygen uptake. *Eur. J. Appl. Physiol. Occup. Physiol.* 80: 159-161.
- Billat, V.L., and Koralsztejn, J.P. (1996). Significance of the velocity at  $\dot{V}O_{2\max}$  and time to exhaustion at this velocity. *Sports Med.* 22(2): 90-108.
- Billat, V.L., Slawinski, J., Bocquet, V., Demarle, A., Lafitte, L., Chassaing, P., and Koralsztejn, J.P. (2000). Intermittent runs at the velocity associated with maximal oxygen uptake enables subjects to remain at maximal oxygen uptake for a longer time than intense but submaximal runs. *Eur. J. Appl. Physiol. Occup. Physiol.* 81: 188-196.
- Bogdanis, G.C., Nevill, M.E., Boobis, L.H., Lakomy, H.K.A., and Nevill, A.M. (1995). Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. *J. Physiol.* 482: 467-480.
- Christensen, E.H., Hedman, R., and Saltin, B. (1960). Intermittent and continuous running. *Acta Physiol. Scand.* 50: 269-286.
- Christmass, M.A., Dawson, B., Passeretto, P., and Arthur, P. (1999). A comparison of skeletal muscle oxygenation and fuel use in sustained continuous and intermittent exercise. *Eur. J. Appl. Physiol. Occup. Physiol.* 80: 423-435.
- Essén, B., Hagenfeldt, L., and Kaijser, L. (1977). Utilization of blood-borne and intramuscular substrates during continuous and intermittent exercise in man. *J. Physiol.* 265: 489-506.
- Ettema, J.H. (1966). Limits of human performance and energy-production. *Int. Z. Angew. Physiol. Einschl. Arbeit. Physiol.* 22: 45-54.
- Fox, E.L., Bartels, R.L., Billings, C.E., Mathews, D.K., Bason, R., and Webb, W.M. (1973). Intensity and distance of interval training programs and changes in aerobic powers. *Med. Sci. Sports* 5(1): 18-22.
- Gorostiaga, E.M., Walter, C.B., Foster, C., and Hickson, R.C. (1991). Uniqueness of interval and continuous training at the same maintained exercise intensity. *Eur. J. Appl. Physiol. Occup. Physiol.* 63: 101-107.

- Gullstrand, L. (1996). Physiological responses to short-duration high-intensity intermittent rowing. **Can. J. Appl. Physiol.** 21(3): 197-208.
- Hill, D.W. (1993). The critical power concept. **Sports Med.** 16(4): 237-254.
- Hill, D.W., and Ferguson, C.S. (1999). A physiological description of critical velocity. **Eur. J. Appl. Physiol. Occup. Physiol.** 79: 290-293.
- Hill, D.W., and Rowell, A.L. (1997). Responses to exercise at the velocity associated with  $\dot{V}O_{2max}$ . **Med. Sci. Sports Exerc.** 29(1): 113-116.
- Kachouri, M., Vandewalle, H., Billat, V., Huet, M., Thomaïdis, M., Jousselin, E., and Monod, H. (1996). Critical velocity of continuous and intermittent running exercise. An example of the limits of the critical power concept. **Eur. J. Appl. Physiol. Occup. Physiol.** 73: 484-487.
- Kamber, M. (1992). Laktatmessungen in der Sportmedizin: Messmethodenvergleich. **Schweiz. Ztschr. Sportmed.** 40: 77-86.
- Katch, V.L., Sady, S.S., and Freedson P. (1982). Biological variability in maximum aerobic power. **Med. Sci. Sports Exerc.** 14: 21-25.
- Lacour, J.R., Padilla-Magunacelaya, S., Chatard, J.C., Arsac, L., and Barthélémy, J.C. (1991). Assessment of running velocity at maximal oxygen uptake. **Eur. J. Appl. Physiol. Occup. Physiol.** 62: 77-82.
- MacDougall, J.D., Hicks, A.L., MacDonald, J.R., McKelvie, R.S., Green, H.J., and Smith, K.M. (1998). Muscle performance and enzymatic adaptations to sprint interval training. **J. Appl. Physiol.** 84: 2138-2142.
- McLaughlin, J.E., King, G.A., Howley, E.T., Bassett, D.R. Jr., and Ainsworth B.E. (2001). Validation of the COSMED K4 b2 portable metabolic system. **Int. J. Sports Med.** 22: 280-284.
- Morgan, D.W., Baldini, F.D., Martin, P.E., and Kohrt, W.M. (1989). Ten kilometer performance and predicted velocity at  $\dot{V}O_{2max}$  among well-trained male runners. **Med. Sci. Sports Exerc.** 21(1): 78-83.
- Simoneau, J.A., Lortie, G., Boulay, M.R., Marcotte, M., Thibault, M.C., and Bouchard, C. (1985). Human skeletal muscle fiber type alteration with high-intensity intermittent training. **Eur. J. Appl. Physiol. Occup. Physiol.** 54: 250-253.
- Tabata, I., Irisawa, K., Kouzaki, M., Nishimura, K., Ogita, F., and Miyachi, M. (1997). Metabolic profile of high intensity intermittent exercises. **Med. Sci. Sports Exerc.** 29: 390-395.
- Tabata, I., Nishimura, K., Kouzaki, M., Hirai, Y., Ogita, F., Miyachi, M., and Yamamoto, K. (1996). Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and  $\dot{V}O_{2max}$ . **Med. Sci. Sports Exerc.** 28: 1327-1330.
- Vandewalle, H., Vautier, J.F., Kachouri, M., Lechevalier, J.M., and Monod, H. (1997). Work-exhaustion time relationships and the critical power concept. **J. Sports Med. Phys. Fitness** 37: 89-102.
- Wenger, H.A., and Bell, G.J. (1986). The interactions of intensity, frequency and duration of exercise training in altering cardiorespiratory fitness. **Sports Med.** 3: 346-356.

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