# Pacing Strategy and V×O 2 Kinetics during a 1500-m Race

C. Hanon, J.-M. Leveque, C. Thomas, L. Vivier

# Pacing Strategy and $\dot{V}O_2$ Kinetics during a 1500-m Race

Authors C. Hanon[1], J.-M. Leveque[1], C. Thomas[2], L. Vivier[3]

Affiliations [1] DSS, INSEP, Paris, France
[2] LEPHE, Université Evry Val d'Essone, Evry, France
[3] INSEP, FFA, Paris, France



**Key words**
- middle-distance running
- supramaximal exercise
- maximal oxygen consumption

## Abstract

We investigated the oxygen uptake response ($\dot{V}O_2$) to a 1500-m test conducted using a competition race strategy. On an outdoor track, eleven middle-distance runners performed a test to determine $\dot{V}O_{2max}$, velocity associated with $\dot{V}O_{2max}$ (v-$\dot{V}O_{2max}$) and a supramaximal 1500-m running test (each test at least two days apart). $\dot{V}O_{2max}$ response was measured with the use of a miniaturised telemetric gas exchange system (Cosmed, K4, Roma, Italy). The 1500-m running test was performed at a mean velocity of 107. 6 + 2% v-$\dot{V}O_{2max}$. The maximal value of oxygen uptake recorded during the 1500-m test ($\dot{V}O_{2peak}$) was reached by subjects at 75.9 + 7.5 s (mean + SD) (i.e., 459 ± 59 m). The time to reach $\dot{V}O_{2max}$ (T$\dot{V}O_{2peak}$) and the start velocity (200- to 400-m after the onset of the 1500 m) expressed in % v-$\dot{V}O_{2max}$ were negatively and significantly correlated ($p < 0.05$), but our results indicate that a fast start does not necessarily induce a good performance. These results suggest that $\dot{V}O_{2max}$ is reached by all the subjects at the onset of a simulated 1500-m running event and are therefore in contrast with previous results obtained during treadmill running.

## Introduction

In the 1960s, it has been reported [1,15] that oxygen uptake reached a maximal steady state during short (from 2 to 7 min), high-intensity exercise. Nevertheless, several studies investigating high-intensity exercise lasting 45 s to 4 min have reported contradictory results concerning the attainment of maximal oxygen uptake [4,5,20,21]. These different results may be due to the design of the experiment since in these different studies, exercises were performed either at a constant running velocity [4,5,21] or at a manipulated pace with a strategy of a slower start and a faster finish than the mean speed of the race [20]. When a simulation of an outdoor track 800-m running competition was performed in field conditions, we showed in a recent study that all middle- to high-class athletes attained their maximal oxygen uptake [23]. In this study, the exercise protocol reproduced the real conditions of an 800-m running competition, and particular attention was carried out with respect to the competition strategy.

Recently, analysis of performance in middle-distance races performed in field conditions has shown large variations of running velocity [8, 10]. These last studies have pointed out that the best chronometric performance is obtained when the pace at the beginning of the 800-m and 1500-m running races is faster than the mean pace of the race. This could be explained by tactical reasons. However, it is of note that the specialists of other supramaximal activities such as kayak, rowing and track-cycling perform the same model of pacing without drafting opportunity [6].

Concerning longer supramaximal exercise, the impact of a high-intensity starting strategy during running performance has not been yet studied. The velocity at the beginning of the race is slower during a 1500-m running race [10] than in a 800-m race [21]. In addition, because of the duration of a 1500-m exercise, those same authors have pointed out that aerobic metabolic cost is higher. We therefore hypothesised that competition race strategy on a long supramaximal exercise such as a 1500-m race may also influence the oxygen uptake response. In an attempt to verify this hypothesis, we investigated the $\dot{V}O_2$ response profile during such a supramaximal exercise. Furthermore, the present study

**accepted after revision**
January 1, 2007

**Bibliography**
**DOI** 10.1055/s-2007-965109
Published online Sept. 13, 2007
Int J Sports Med 2008; 29: 206–211 © Georg Thieme Verlag KG Stuttgart · New York · ISSN 0172-4622

**Correspondence**
***Dr. Christine Hanon***
DSS
INSEP
11 Avenue de Tremblay
75012 Paris
France
Phone: + 33 1 41 74 43 57
Fax: + 33 1 41 74 45 35
christine.hanon@insep.fr

was also designed to determine the consequence of the $\dot{V}O_2$ response profile on 1500-m athletic performance.

## Method

### Subjects

Eleven elite male middle-distance runners (age 22.6 ± 4.7, height 174.9 ± 4.4 cm, and body mass 65.4 ± 3.9 kg) volunteered for the study. They trained 5–10 times per week for the 1500-m race and were successful in regional and national running races (average performance of ~ 3 min 56 s, range of 3 min 43 to 4 min 05). All subjects consented to participate in the experiment upon being informed of the purpose of the study and the protocol, and provided written informed consent, which was approved by the local ethics committee.

### Experimental protocol

Subjects performed two track-running tests just before the competition period (temperature of 18.6 ± 2.6 °C), on the same 400-m outdoor track, separated by at least two days. The aim of the first test was to determine $\dot{V}O_{2max}$ and maximal aerobic speed (v-$\dot{V}O_{2max}$) for each athlete. The second test was a supramaximal 1500-m exercise reproducing the conditions of competition. In order to test the influence of the pacing strategy, we asked a subject to participate in two distinct 1500-m races.

For both tests, oxygen uptake ($\dot{V}O_2$), minute ventilation ($\dot{V}E$), volume of carbon dioxide released ($\dot{V}CO_2$), respiratory frequency (RF) and tidal volume ($V_T$) were recorded continuously by means of a telemetric gas exchange system (Cosmed K4, Roma, Italy). The description of the Cosmed K4 system was previously reported by Thomas et al. [23]. Ventilatory data were averaged every 5 s for subsequent analysis. During the course of the experiment, the receiving unit of the Cosmed K4 was positioned beside the running track in the outdoor stadium. Heart rate (HR) was measured and recorded continuously with a heart rate monitor (Sport Tester PE 3000, Polar, Kempele, Finland) for each athlete. Blood lactate was collected from the earlobe and measured with the Lactate Pro analyser (Arkray, Japan).

### Incremental test

$\dot{V}O_{2max}$ and v-$\dot{V}O_{2max}$ (minimal speed at which the athlete was running when $\dot{V}O_{2max}$ occurred) were determined with a test derived from the protocol proposed by Léger and Boucher (TUB2) which is regularly used in our Sport Science Institute to evaluate high-level athletes. The initial speed was 14 km·h$^{-1}$ and was increased then by 2 km·h$^{-1}$ up to 18 km·h$^{-1}$, then 1 km·h$^{-1}$ until the end of the test. Each stage consisted of a 3-min exercise period followed by 1-min rest necessary for blood collection at the earlobe.

### Supramaximal 1500-m running test

The supramaximal exercise was a 1500-m race. The warm-up was standardised according to a regular pre-event 1500-m warm-up (20 min of jogging between 60 and 70% v-$\dot{V}O_{2max}$, stretching, sprints (2 × 150 m at 1500-m mean-pacing velocity and 1 × 150 m at 1500-m start velocity) and was followed by a 4-min recovery period before the start of the test. Athletes selected their own pace during the course of the 1500-m test according to their best individual 1500-m performance and their own experiences. A researcher beside the athlete with a bike gave verbal encouragement throughout the test period. Athletes were provided feedback of their current time and velocity at 50, 100, 200, 300, 400 m and every 200 m until the 1200-m mark. Blood samples were taken from the earlobe immediately before and after the supramaximal exercise, then at 3, 5, 7 and 10 min during the recovery following the 1500 m in order to detect the peak blood lactate value. The peak oxygen uptake value recorded during 1500 m and the time at which it was observed were named $\dot{V}O_{2peak}$ and T$\dot{V}O_{2peak}$, respectively. For each 1500-m run, athletes were videotaped by a researcher standing on the top of terracing, who used a panoramic video system (Panasonic Super-VHS, Osaka, Japan, sampling rate of 50 Hz) from a fixed spot to determine the athlete's velocity at each 50-m interval along the track.

**Table 1** Mean values of different variables measured at the end of the incremental test

| $\dot{V}O_{2max}$ (ml·kg$^{-1}$·min$^{-1}$) | v-$\dot{V}O_{2max}$ (km·h$^{-1}$) | HR at v-$\dot{V}O_{2max}$ (beats·min$^{-1}$) | [Lact]max (mmol·l$^{-1}$) |
|---|---|---|---|
| 66.1 ± 7 | 19.9 ± 1.1 | 195 ± 7 | 12.8 ± 1.5 |

$\dot{V}O_{2max}$: $\dot{V}O_{2max}$ determined during the incremental test; v-$\dot{V}O_{2max}$: minimal speed at which the athlete was running when $\dot{V}O_{2max}$ occurred; HR: heart rate; [Lact]max: peak blood lactate measured at the end of the incremental test

### Data analysis

Since 1500-m performances were different between athletes, cardiorespiratory and kinematics data, obtained as a function of time every five seconds during the 1500-m race, were averaged over 50-m intervals in order to normalise data for all subjects. The start velocity was defined as the velocity observed at 250 m after the onset of the 1500-m test. It was expressed in m·s$^{-1}$ or in % of v-$\dot{V}O_{2max}$.

### Statistical analyses

The 1500-m running test response for respiratory variables, HR and running velocity was evaluated by a one-way analysis of variance (ANOVA) with repeated-measures across each 50-m interval. Individual relationships between variables (running velocity at different times of the race, T$\dot{V}O_{2peak}$, and 1500-m performance) were studied by means of linear regressions. All statistical analyses were conducted using Statview software (Berkeley, USA, version 5.0). Data was reported as mean ± SD. The level of significance was set at $p < 0.05$.

## Results

### Incremental test

The mean values of different variables obtained in the incremental test are presented in **Table 1**. During this test, $\dot{V}O_{2max}$ and v-$\dot{V}O_{2max}$ were equal to 66.1 ± 7.0 ml·min$^{-1}$·kg$^{-1}$ and 19.9 ± 1.1 km·h$^{-1}$, respectively.

### Velocity changes during the 1500-m running test

The mean performance during the 1500-m race was 245.4 ± 6.04 s (4 min and 5.4 s) and was, on average, 4.7 ± 1.9% above their previous best performance. The 1500-m race corresponded to a supramaximal exercise with the average velocity achieved (22 km·h$^{-1}$) representing 107.6 ± 2% of v-$\dot{V}O_{2max}$. Several phases of distribution of the exercise could be distinguished (**Fig. 1**): velocity peaked at 23.1 ± 0.8 km·h$^{-1}$ or 113. 9 ± 3.7% of v-$\dot{V}O_{2max}$

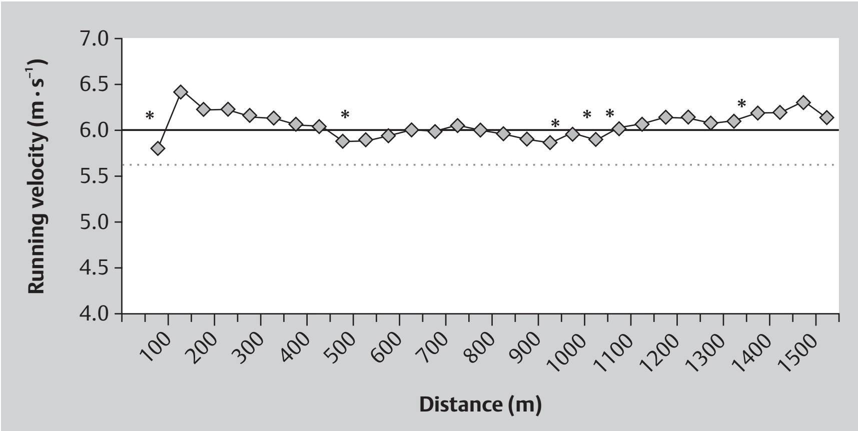


**Fig. 1** Mean running velocity during the 1500-m race. Continuous and broken lines represent respectively mean velocity and v-$\dot{V}O_{2max}$ (velocity associated with $\dot{V}O_{2max}$) expressed in $km \cdot h^{-1}$; SD bars are not included for more clarity. * significantly different from previous 50-m velocity, $p < 0.05$.

**Table 2** Peak values (Mean ± SD) measured during (cardiorespiratory variables) and after (blood lactate) the 1500-m test

| | $V_T$ (l) | HR (beats·min⁻¹) | $\dot{V}E$ (l·min⁻¹) | RF (breaths·min⁻¹) | [Lact] (mmol·l⁻¹) |
|---|---|---|---|---|---|
| Peak values | 2.6 ± 0.3 | 192 ± 8 | 154.3 ± 21.2 | 63.8 ± 6.9 | 14.9 ± 0.9 |

$V_T$: tidal volume; HR: heart rate; $\dot{V}E$: minute ventilation; RF: respiratory frequency; [Lact]: blood lactate concentration

between 100 and 150 m, and was higher than the average speed for the first 300 m; velocity then stabilised at a level lower than the average speed. At the end of the race, the speed increased gradually from the 1000-m mark, with differences between athletes in the last 100 m (5 out of 10 athletes accelerated up to the finishing line). At any time during the race, and for all the subjects, the speed remained higher than the previously determined v-$\dot{V}O_{2max}$.

### Cardiorespiratory responses during the 1500-m running test

As shown in ▶ **Fig. 2**, $\dot{V}O_{2peak}$ reached $\dot{V}O_{2max}$ 459. 1 ± 59. 6 m (or 75.9 ± 7.5 s) after the onset of the 1500-m test. These $\dot{V}O_{2peak}$ values ($69.5 \pm 6.5\ mlO_2 \cdot min^{-1} \cdot kg^{-1}$), although slightly higher, were not significantly different from $\dot{V}O_{2max}$ ($66.08 \pm 7\ mlO_2 \cdot min^{-1} \cdot kg^{-1}$). The time constant ($\tau$) with which $\dot{V}O_{2peak}$ was attained during the 1500-m test was 30.1 ± 4.4 s. After reaching $\dot{V}O_{2peak}$, we observed in all subjects (▶ **Fig. 2**), a significant decrease in oxygen uptake between 450 and 550 m after the onset of running. The oxygen uptake then remained constant during the following 800 m with a value equal to 93 ± 3.5 % of $\dot{V}O_{2peak}$ or 100 % of $\dot{V}O_{2max}$. The heart rate reached 90 % of maximal value 150 m after the onset of the race, increased gradually and attained its maximal value at the end of the 1500 m. Maximal HR values were not significantly different during the 1500-m race and the incremental test.

### Blood lactate concentration

Blood lactate concentration was $3.1 \pm 0.7\ mmol \cdot l^{-1}$ after warm-up and reached a peak value of $14.9 \pm 0.8\ mmol \cdot l^{-1}$ between the 5th and 7th minute of the recovery period (▶ **Table 2**).

### Relationships between T$\dot{V}O_{2peak}$, start velocity and final performance

No correlation was observed between T$\dot{V}O_{2peak}$ and start velocity when velocity was expressed in $m \cdot s^{-1}$ However, when the start velocity was expressed as a % of v-$\dot{V}O_{2max}$, the correlation is negative and significant with T$\dot{V}O_{2peak}$ (i.e., r = – 0.68, between T$\dot{V}O_{2peak}$ and velocity at 250 m, $p < 0.05$ [▶ **Fig. 3**]). Nevertheless, the start velocity (expressed in % of v-$\dot{V}O_{2max}$) was negatively correlated with final performance (r = – 0.63, $p < 0.05$). Finally, it is also noteworthy that 1500-m time was strongly correlated with v-$\dot{V}O_{2max}$ (r = 0.85, $p < 0.001$).

## Discussion

The results of the present study suggest that $\dot{V}O_{2max}$ was attained during an exercise protocol which reproduced the conditions of a 1500-m running competition: a fast-start strategy followed by an even-pacing velocity. $\dot{V}O_{2peak}$ reached the $\dot{V}O_{2max}$ level 459 ± 59.6 m (or 75.9 ± 7.5 s) after the onset of the race and this delay was inversely related to the start velocity expressed as a % of v-$\dot{V}O_{2max}$. However, it appears that the fastest start is not necessarily the optimal start as there was a significant and negative relationship between start velocity, expressed as a % of v-$\dot{V}O_{2max}$, and final performance.

These results confirm those that our team has reported with a similar methodology for the 800-m race [23]. In contrast, the present results contradict the data obtained on treadmill running for 1500-m [20,21], for 800-m [4] and for 5-min exercise [5]. In these studies, subjects reached respectively 94, 94, 85 and 98.5 % of $\dot{V}O_{2max}$. Although the performance level of the subjects was essentially the same in these studies (performance times for the 1500-m race ranged from 3 min 55 to 4 min 07), the most likely hypothesis explaining the differences of the results concerns the methodology.

In our study design, the subjects were asked to complete three 150-m sprints four min before the onset of the 1500-m during the warm-up. Indeed, Wilkerson et al. [25] have suggested that although the priming intense exercise did not influence the time constant of the primary-component $\dot{V}O_2$ response, it did increase the amplitude to which $\dot{V}O_2$ may rise following the onset of perimaximal-intensity exercise. According to these results,

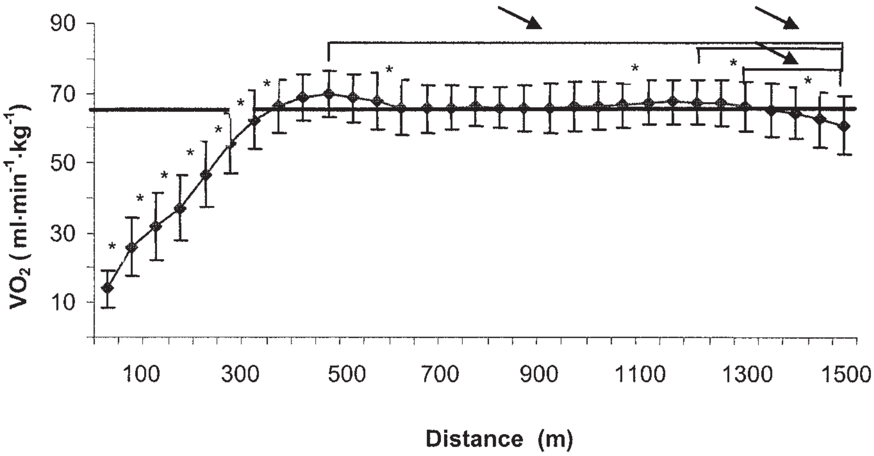


**Fig. 2** Time course of oxygen uptake (in ml $O_2 \cdot mn^{-1} \cdot kg^{-1}$) during the 1500-m race. Data are mean values ± SD; solid line: $\dot{V}O_{2max}$. * significant $\dot{V}O_2$ decrease or increase between two consecutive data points, $p < 0.05$. ↓ significant decrease between two nonconsecutive points.

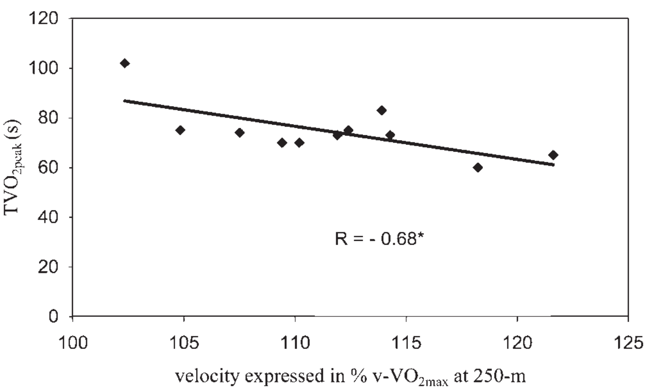


**Fig. 3** Relationship between velocity expressed as a % of v-$\dot{V}O_{2max}$ 250 m and $T\dot{V}O_{2peak}$ m s. v-$\dot{V}O_{2max}$ = velocity associated with $\dot{V}O_{2max}$ (n = 11); * $p < 0.05$.

prior multiple-sprint exercise resulted in significantly higher heart rates before and throughout subsequent performance. Furthermore, this type of protocol elevated whole blood lactate concentration and resulted in a greater metabolic acidosis. This is likely to have increased muscle vasodilatation and increased the potential for the enhancement of muscle blood flow as well as facilitating muscle $O_2$ availability by right-shifting the $HbO_2$ dissociation curve.

In contrast to our previous [23] and the present study, Spencer and Gastin [20] and Draper et al. [5] specified that the athletes follow "their usual procedure" of warm-up without clarifying the content and Draper et al. [4] asked their subjects to stretch but not to achieve accelerations. The consequences of the types of warm-up on the $\dot{V}O_2$ asymptotic amplitude suggest that it may be important to insert sprint phases in the experimental procedures or at least to discuss the presence or absence of these accelerations.

Another considerable difference in the experimental design concerns the pacing strategies used throughout the 1500-m run. Previous races were either realised at a constant power [4,5,20, 21] or with an individual strategy (even-paced race or a slower initial pace and an accelerating finish) [20]. Only our previous [23] and present studies are based on pacing strategies observed [8,10] in running competitions, i.e., fast-start followed by a transition to an even-pacing strategy. To date, these are the only two studies realised in the modality of supramaximal running exercise during which all the subjects reached $\dot{V}O_{2max}$. The attainment of $\dot{V}O_{2max}$ has also been observed during supramaximal exercise with an all-out start during cycling activity [9] and paddling [2], and provides further support for the importance of initial pacing strategy on the solicitation of $\dot{V}O_{2max}$.

Best performances for durations of exercise between 60 s and 4 min 30 should be realised with a fast start followed by a quick transition to an even-pacing strategy as observed in competition [8] for running and as evaluated in manipulating start strategy for cycling [6] and for paddling [2]. This fast-start could speed up $\dot{V}O_2$ kinetics and then improve supramaximal performance by increasing the total number of fibres and/or the proportion of type II fibres involved and then the rate of ATP turnover required to fuel exercise of fixed distance or duration [2,12]. As emphasised by Gaesser and Poole [7], and Poole and Richardson [18], the oxygen uptake can attain the $\dot{V}O_{2max}$ level on brief and intense exercise provided that the duration is sufficient for the required intensity. It would then seem, according to previous results [20], that the average speeds used on the one hand and the duration of the exercises on the other hand were not sufficient to achieve $\dot{V}O_{2max}$ during tests carried out at constant power. In our previous (800 m) [23] and present study (1500 m), our subjects started respectively at speeds of 136% v-$\dot{V}O_{2max}$ and 114% v-$\dot{V}O_{2max}$, which is much greater than in the usual experimental design (i.e., 112 and 102% v-$\dot{V}O_{2max}$ on 800 and 1500 m, respectively [20]).

It has been suggested that at the onset of supramaximal exercise, the time to reach $\dot{V}O_{2max}$ is inversely related to the exercise intensity [1,11]. Surprisingly, in our study, the time to reach $\dot{V}O_{2peak}$ was not significantly correlated with the start velocity expressed in $m \cdot s^{-1}$. This result could be due to the homogenous subject group and hence to the small inter-subjects velocity variations (variation coefficient: 3.5%). Nevertheless, $T\dot{V}O_{2peak}$ was significantly correlated with the start velocities expressed as % v-$\dot{V}O_{2max}$. Recent research provides a scientific rationale for the adoption of fast-start pacing strategies by athletes. The $\dot{V}O_2$ response at the onset of an intense exercise increased in connection with decreasing phosphocreatine concentration [PCr] and decreasing ATP/ADP ratio [19] which results in an increased rate of glycolysis [3]. Therefore, a significantly greater start pace is supposed to lead to greater rates of PCr breakdown and, consequently, so stimulating the system of resynthesis of the ATP by the oxidative processes and result in a speeding of the kinetics of $\dot{V}O_2$ [17].

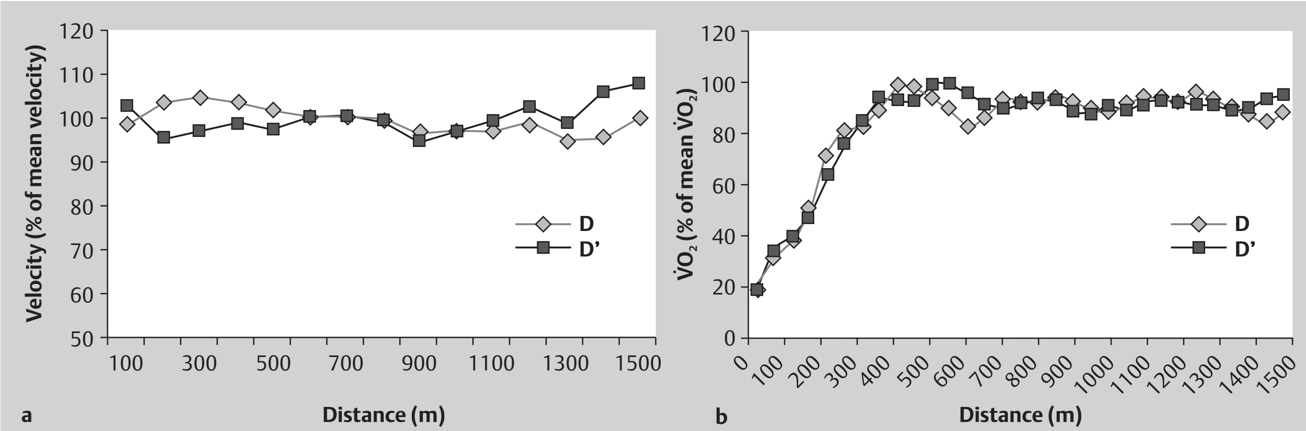


**Fig. 4 a** and **b** **a** Time course of running velocity (expressed as a % of the mean velocity) during the two 1500-m trials (D and D') performed by subject D. The subject realised 4 min 14 and 4 min 07 for trials D and D', respectively. Trial D: fastest start. **b** Time course of $\dot{V}O_2$ during the two 1500-m trials (D and D') performed by the subject D. The subject realised 4 min 14 and 4 min 07 for trials D and D', respectively. Trial D: fastest start.

While a fast start may help to speed $\dot{V}O_2$ kinetics, it also has the potential to cause premature fatigue and impair performance. In our study, a negative correlation was observed between final performance and both start velocity (in % v-$\dot{V}O_{2max}$) and distance to $\dot{V}O_{2peak}$. This negative effect of a fast-start on performance has already been shown [16, 22], but for longer submaximal exercises in quite a different context. However, according to the model presented by Léger et al. [14] and based on the relation between %$\dot{V}O_{2max}$ and time, if a starting pace of 114% $\dot{V}O_{2max}$ was maintained during the whole race, the athletes would have been able to run about 3 min (corresponding to only 1150 m). It is possible to hypothesise that an optimal speed exists which, when maintained for just a short portion of the distance, permits the athlete to attain $\dot{V}O_{2max}$ without damaging the final performance. The examination of the races of the subject D (**Fig. 4 a**), who agreed to perform two distinct 1500-m races, allows us to strengthen this hypothesis. Over the first 1500 m (D), the athlete started out more quickly and for longer and reached (**Fig. 4 b**) $\dot{V}O_{2max}$ earlier than during the second 1500 m. Nevertheless, the end performance is better in the second 1500 m: 4 min 14 versus 4 min 07.

Then, the difficulty could be in setting the mean power resulting in $\dot{V}O_{2max}$ with the smallest amount of oxygen-independent glycolysis and the better preservation of the buffering capacity. This capacity could then be used during the later stages of the race. According to Ward-Smith [24], this pacing regulation must be done with considerable precision: insufficient demands on aerobic metabolism leads to under-performance and an excessive demand will lead to proton accumulation.

The 1500-m runners, and more generally the specialists of supramaximal exercise lasting from 1 – 5 min, are faced with conflicting demands: start fast to allow the achievement of $\dot{V}O_{2max}$ and so limit the participation of the anaerobic system in the intermediate part of the race while the same fast departure increases the participation of the anaerobic metabolism in the beginning of the race and could, if too intense and too long, damage the final performance. In this context, the correlation observed between 1500-m performance and v-$\dot{V}O_{2max}$ already mentioned by Lacour et al. [13] is easy to understand. Apart from the fact that v-$\dot{V}O_{2max}$ and 1500-m velocity are very close, a high value of v-$\dot{V}O_{2max}$ could therefore allow a faster start velocity without increasing the $O_2$ deficit in this part of the race.

In conclusion, the results of this study indicate that at the onset of a simulated 1500-m running event, well-trained middle-distance runners reached $\dot{V}O_{2max}$ after 75.9 ± 7.5 s (459.1 ± 59.6 m). This race profile is in some contrast to what can be expected from earlier results obtained on treadmill running. $\dot{V}O_{2max}$ is attained in a shorter time as the start velocity, expressed in % v-$\dot{V}O_{2max}$, becomes higher, but our results indicate that a fast-start does not necessarily optimise performance.

## Acknowledgements

The authors thank the French Athletism Federation and French Sport Ministry for the grant.

### References


1 *Astrand PO, Saltin B.* Oxygen uptake during the first minutes of heavy muscular exercise. J Appl Physiol 1961; 16: 971 – 976
2 *Bishop D, Bonetti D, Dawson B.* The influence of pacing strategy on $\dot{V}O_2$ and supramaximal kayak performance. Med Sci Sports Exerc 2002; 34: 1041 – 1047
3 *Chasiotis D, Bergström M, Hultman E.* ATP utilization and force during intermittent and continuous muscle contractions. J Appl Physiol 1987; 63: 167 – 174
4 *Draper SB, Wood DM.* The $\dot{V}O_2$ response for an exhaustive treadmill run at 800-m pace: a breath-by-breath analysis. Eur J Appl Physiol 2005; 93: 381 – 389
5 *Draper SB, Wood DM, Fallowfield JL.* The $\dot{V}O_2$ response to exhaustive square wave exercise: influence of exercise intensity and mode. Eur J Appl Physiol 2003; 90: 92 – 99
6 *Foster C, Snyder AC, Thompson NN, Green MA, Foley M, Schrager M.* Effect of pacing strategy on cycle time trial performance. Med Sci Sports Exerc 1993; 25: 383 – 388
7 *Gaesser GA, Poole DC.* The slow component of oxygen uptake kinetics in humans. Exerc Sport Sci Rev 1996; 24: 35 – 71
8 *Gajer B, Hanon C, Marajo J, Vollmer JC.* Le 800 mètres: Analyse descriptive et entraînement. Paris: Edition INSEP-Federation Française d'Athlétisme, Collection Entraînement, 2001
9 *Granier P, Mercier B, Mercier J, Anselme F, Prefaut C.* Aerobic and anaerobic contribution to Wingate test performance in sprint and middle-distance runners. Eur J Appl Physiol 1995; 70: 58 – 65
10 *Hanon C, Levêque JM, Vivier L, Thomas C.* Oxygen uptake in the 1500 metres. New Studies Ath 2007; 22: 15 – 22
11 *Hill DW.* Energy system contributions in middle-distance running events. J Sports Sci 1999; 17: 477 – 483

12 *Hirvonen J, Nummela A, Rusko H, Rehunen S, Häkönen M.* Fatigue and changes of ATP, creatine phosphate, and lactate during the 400-m sprint. Can J Spt Sci 1992; 17: 141 – 144
13 *Lacour JR, Bouvat E, Barthelemy JC.* Post-competition blood lactate concentrations as indicators of anaerobic energy expenditure during 400-m and 800-m races. Eur J Appl Physiol 1990; 61: 172 – 176
14 *Léger L, Mercier D, Gauvin L.* The Relationship between % $\dot{V}O_{2max}$ and Running Performance Time. Champaign, IL: Ed Human Kinetics, 1986: 113 – 120
15 *Margaria R, Mangili F, Cuttica F, Cerretelli P.* The kinetics of the oxygen consumption at the onset of muscular exercise in man. Ergonomics 1965; 8: 49 – 54
16 *Mattern CO, Kenefick RW, Kertzer R, Quinn TJ.* Impact of starting strategy on cycling performance. Int J Sports Med 2001; 22: 350 – 355
17 *Medbo JI, Tabata I.* Relative importance of aerobic energy release during short-lasting exhausting bicycle exercise. J Appl Physiol 1989; 67: 1881 – 1886
18 *Poole DC, Richardson RS.* Determinants of oxygen uptake. Implications for exercise testing. Sports Med 1997; 24: 308 – 320
19 *Rossiter HB, Ward SA, Kowalchuk JM, Howe FA, Griffiths JR, Whipp BJ.* Dynamic asymmetry of phosphocreatine concentration and oxygen uptake between the on- and off-transients of moderate- and high-intensity exercise in humans. J Physiol 2002; 541: 991 – 1002
20 *Spencer MR, Gastin PB.* Energy system contribution during 200- to 1500-m running in highly trained athletes. Med Sci Sports Exerec 2001; 33: 157 – 162
21 *Spencer MR, Gastin PB, Payne WR.* Energy system contribution during 400 to 1500 meters running. New Studies Athl 1996; 11: 59 – 65
22 *Staab JS, Agnew JW, Siconolfi SF.* Metabolic and performance responses to uphill and downhill running in distance runners. Med Sci Sports Exerc 1992; 24: 124 – 127
23 *Thomas C, Hanon C, Perrey S, Le Chevalier J, Couturier A, Vandewalle H.* Oxygen uptake response to an 800-m running race. Int J Sports Med 2005; 26: 268 – 273
24 *Ward-Smith AJ.* Aerobic and anaerobic energy conversion during high-intensity exercise. Med Sci Sports Exerc 1999; 31: 1855 – 1860
25 *Wilkerson DP, Koppo K, Barstow TJ, Jones AM.* Effect of work rate on the functional "gain" of phase II pulmonary O2 uptake response to exercise. Respir Physiol Neurobiol 2004; 142: 211 – 223