Oxygen uptake in the 1500 metres

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ABSTRACT

The main aim of this two-part study was to evaluate the time course of oxygen uptake in the1500m. In part one, races of 49 world-class and national-class runners were analysed to identify the pacing model used by elite performers. In part two, eleven trained middle distance runners performed a progressive increment test to determine VO_2max and a full effort time trial (the mean running velocity corresponding to 107.6 + 2% of maximum aerobic speed) using the identified pacing model. In both tests, performed on the track, VO_2 response was measured with a portable telemetric gas exchange system. It was found that the mean value of VO_2max recorded during the progressive test (66.1 + 7.0 $ml/mn^{-1}/kg^{-1}$) was reached 459 + 59.6 metres (55.9 + 7.5 seconds) after the start. It was also found that VO_2 decreased (8%) at the end of the run for 8 of 10 of the subjects.

AUTHORS

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Introduction

Recent studies on the evolution of oxygen uptake over the 800m distance have demonstrated that results obtained in treadmill tests (SPENCER ET AL 1996; DRAPER ET AL 2005) are not the same as those obtained on the track (HANON ET AL 2002, THOMAS ET AL 2005). It should be noted that the design for the treadmill tests mentioned called for the subjects to run at a constant pace while the track test called for a careful start and a fast finish of the race. Contrary to constant pace treadmill running, it seems that starting faster than the average running speed for the distance, as is common in 800m races, leads to the athlete reaching his/her VO_2max (maximum oxygen uptake) during the race (THOMAS ET AL 2005). However, for the 1500m distance, also run at above the speed associated with VO_2max, neither treadmill nor track tests show the achievement of VO_2max (SPENCER ET AL 1996; SPENCER, GASTIN, 2001).

The aim of the present study was to evaluate the time course of oxygen uptake during a 1500m run at full effort based on the strategy most commonly used in competition. To do so, it was necessary to examine the pacing strategies of national and international level 1500m runners and then to test the kinetics of VO_2 during a time trial based on the model identified. Therefore, the study consisted of two parts. The first, named "Pacing Strategy Analysis" aimed to propose a model of pacing used during national and international 1500m races. The second, called "1500m Study" consisted of two different tests: a test to determine VO_2max on the track and a test to determine the maximal VO_2 value obtained during a 1500m time trial (VO_21500).

Pacing strategy analysis

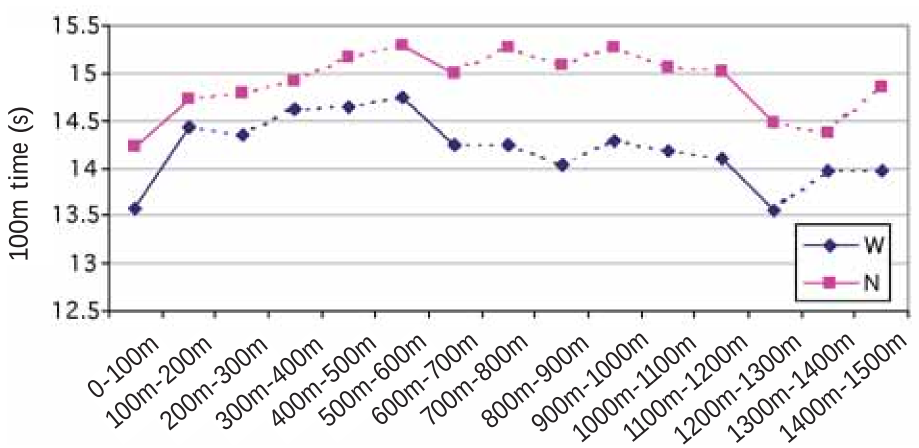
Method

In order to describe the strategy of elite 1500m runners, races of 49 different athletes in 13 different competitions (performances between 3:28 and 3:45) were analysed. The data were collected from images of television or from personal films. The split times for each 100m were determined by means of a time code or a stopwatch. The races of athletes who performed 3 seconds or more over their best performance were not analysed.

Results

According to our analyses (Figure 1), world-class (<3:35) and national-class (3:35 – 3:45) performances share some common characteristics:

1) The first 100m is always significantly the fastest part of the race.
2) A deceleration is observed in the second 100m.
3) Except for the segment from 500m to 600m, the athletes run relatively regularly between 200m and 1200m.



-----: the difference between the two 100m segments is non-significant
___: the difference between the two 100m segments is significant
W = World level, N= National level

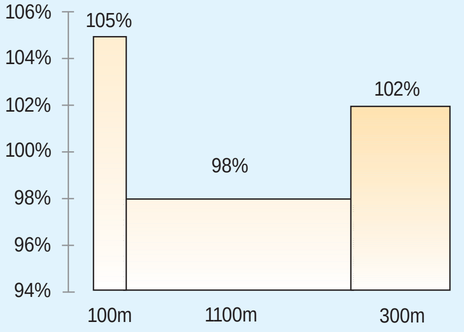
Figure 1: Time course of running velocity during world-class and national-class 1500m races

4) Acceleration is noted from 1200 to 1300m. At the world-class level, this acceleration was highly significant ($p < .0001$).
5) During the last 300m, the higher velocity (relative to the middle of the race) is maintained.
6) Finally, there is no acceleration in the final straight, at either level of performance.

Discussion

It is notable that 1500m races with the aim of maximising time performance at both the world-class and national-class levels are run according to a relatively common pace model. This model shows that the pacing is not based on the regularity of speed but on a fast departure from the start to 100 or 150m, followed by a velocity plateau of 1100m in length and then an acceleration between the 1200m and 1300m marks. Contrary to the visual impression given by the athletes, there is no significant acceleration in the final straight at either level of performance. A specific speed for the 1500m does not exist. There are, instead, three distinct specific speed phases.

Our 1500m study used this chronometric model to calibrate the pacing of the athletes studied (Figure 2).



The velocities are expressed in % of the mean velocity

Figure 2: Pace profile model for the 1500m

1500m study

Experimental design

Ten middle-distance runners (age: 22.6 ± 4.7 years, height: 174.9 ± 4.4cm, body mass: 65.4 ± 3.9kg) volunteered for the study. They trained for the 1500m 5-10 times per week and were successful in regional or national races (average performance: 3:56, range: 3:43 to 4:05).

A progressive test was used to determine VO_2max and a controlled1500m time trial was used to determine VO_21500. In both tests, each athlete's VO_2 was recorded continuously by means of a gas exchange telemetric system (Cosmed K4, Roma, Italy). HR (heart rate) was measured and recorded continuously with a heart rate monitor (Sport Tester PE 3000, Polar, Kempele, Finland). Blood lactate was collected from the ear lobe and measured with the Lactate Pro analyser (Arkray, Japan).

Progressive test

The test used is called TUB II (Test of the University of Bordeaux II) and was developed by CAZORLA and LÉGER (1993). It consists of running on a track, with markers every 25m, for a succession of stages each of 3 minutes duration. The athlete begins at a pace of $14km/h^{-1}$ and increases his/her speed in each stage by $2km/h^{-1}$ up to $18km/h^{-1}$, then by $1km/h-^{1}$ to the superior speeds. The stages are separated by one minute of recovery to allow a sample of blood to be taken. In each stage, the athlete must follow the speed imposed by broadcast sound signals. The test is stopped when the athlete is no longer capable of maintaining the rhythm imposed by the signals and is unable to reach the required mark by the time of the signal.

During the test, the MAS (maximal aerobic speed) corresponds to the first stage where VO_2max is attained (mean of the three consecutive highest values) and where the subsequent increase in VO_2 is less than 2.1 $mmol/kg^{-1}$ for an increase in speed of 1 km/h^{-1}. Moreover VO_2max must be associated with a blood lactate value, a respiratory exchange ratio and a heart rate equal to 8 to 12 $mmol/l^{-1}$, 1.1 and minimum 90% of the theoretical maximal HR (220-age in years) respectively.

1500m time trial

The athletes were asked to perform a set warm-up (jogging, stretches, mobility exercises, strides) plus 3 x 150m at 1500m start pace. This was followed by a break of four minutes. During the warm-up, the runners were gradually equipped (heart-rate monitor, K4). The athletes then performed a 1500m time trial on the track. For each runner, the speed was pre-determined for the first 1200m according to the pacing model described previously. The last 300m was to completed as quickly as possible. Whistle signals every 50m on the basis of established times allowed to the athletes to adjust their pace accordingly. An experimenter on bicycle accompanied and encouraged each athlete.

A blood sample was taken from the earlobe at the end of the warm-up, at the end of the 1500m and 3, 5, 7, and 10 minutes after the run. All the tests were filmed to make it possible to determine a posteriori the exact speed.

Since performances were different between athletes, cardio-respiratory and kinematic data obtained as a function of time every five seconds during the 1500m were averaged over 50m intervals in order to normalise data for all subjects.

Results - progressive test

The mean values of the different variables obtained in the progressive test are presented in Table 1. During this test, VO_2max and v-VO_2max were equal to 64.2 ± 6.5 $ml/min^{-1}/kg^{-1}$ and 20.3 ± 1.1 km/h^{-1}

Table 1: Mean and standard deviations of the parameters observed during the progressive incremental test

VO_2max ($mlO_2/min^{-1}/kg^{-1}$)	HRmax ($batt/min^{-1}$)	MAS (km/h^{-1})	Maximal lactatémia ($mmol/l^{-1}$)
64.2 ± 7.5	195.3 ± 6.5	20.3 ± 0.6	12.4 ± 1.6

VO_2max: maximum oxygen uptake
HRmax: maximum heart rate
MAS: maximum aerobic velocity
Maximal lactatémia:

Table 2: Peak values (Mean + SD) of blood lactate and cardio-respiratory parameters observed during the 1500m time trial

VT (l)	HR ($batt/min^{-1}$)	VE (l/min^{-1})	FR ($cycle/min^{-1}$)	Blood Lactate ($mmol/l^{-1}$)
2.6 ± 0.3	192.2 ± 7.4	155.1 ± 19.8	63.8 ± 6.9	15.0 ± 0.9

VT: tidal volume
HR: heart rate
VE: minute ventilation
FR: respiratory frequency

Results - 1500m time trial

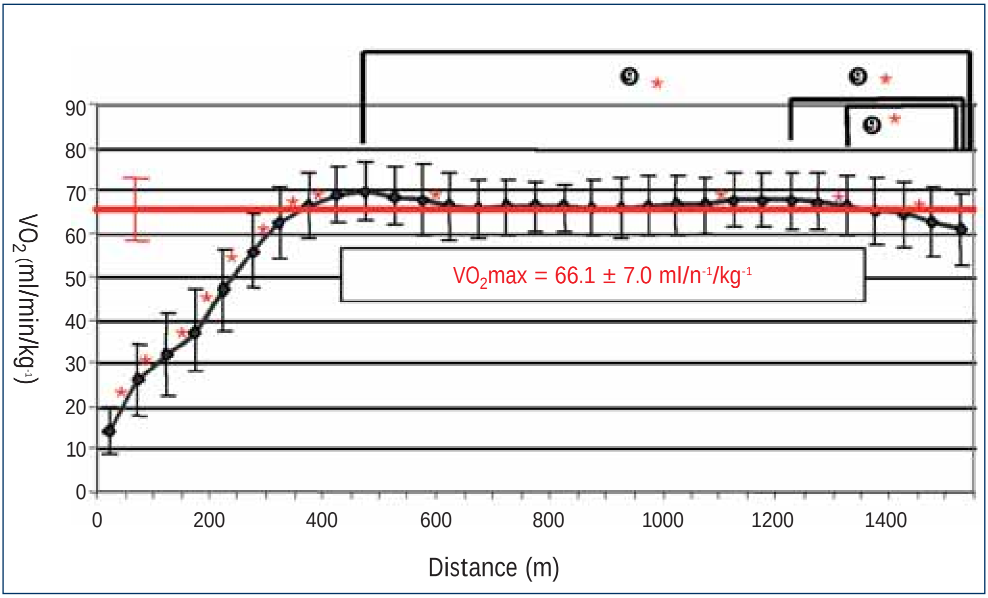
The mean performance in the 1500m time trial (3:56 + 9.9sec) can be considered as a supra-maximal exercise with regard to the average velocity achieved (21.8 km/h^{-1}), which is 107.6% of MAS.

As expected from the preliminary study, running velocity presented some large variations. Until 1100m, the athletes in the test respected the designed pacing strategy. In the last 300m, the speed increased (102.2% of the average 1500m speed) as observed in the preliminary study, but the actual acceleration varied among the subjects between 95 and 107% of the average 1500m speed. Because of the experimental conditions, some subjects did not achieve the final expected time. Nevertheless, at all moments of the race and for all the subjects the speed stayed greater than the maximal aerobic speed.

As shown in Figure 3, VO_2 attained during the 1500m ($VO_2$1500) reached VO_2max (determined in the incremental test) (459.1 ± 59.6 metres or 56.0 ± 7.5 seconds) after the start of the 1500m. These $VO_2$1500 values (69.5 + 6.5 mlO_2/min^{-1}/kg^{-1}) although slightly higher were not significantly different from VO_2max (66.08 + 7 mlO_2/min^{-1}/kg^{-1}). The time constant (τ) with which $VO_2$1500 was reached was 30.1 + 4.4 sec. At the end of the time trial, the $VO_2$1500 decreased significantly (7.9 + 7.6%) between 1300 and 1500m. This fall was observed in 8 of 10 subjects.

Relationships between velocity, time course of oxygen uptake and performance

It is noteworthy that the performances realised during the 1500m time trial are strongly correlated to v-VO_2max ($r = 0.73$, $P < 0.001$).



* : the increase or decrease of VO_2 is significant between two consecutive values, $p < 0.05$

—: VO_2max obtained during incremental test

Ⲓ: S-D for VO_2max incremental test

⊓: the increase or the decrease is significantly different between two non-consecutive values, p<0.05.

Figure 3: Average time course of oxygen uptake (in ml/min-1/kg-1) during the 1500m time trial

The start velocities (200 to 400m after the start of the 1500m) expressed in % of v-VO_2max are significantly correlated with the time at which $VO_2$1500 is reached ($p<0.05$). Nevertheless, these velocities are negatively correlated with final performance ($p<0.05$).

The slow down period of VO_2 is correlated with the difference between peak speed and speed at 1300m. The final value of VO_2 and the 1500m performance are significantly and negatively correlated ($r= -0.65$, $p = 0.02$)

Discussion

The results of the present study demonstrate that VO_2max was attained during an exercise protocol that reproduced the pacing conditions of a 1500m competition: a fast start followed by an even velocity.

These results confirm those that our team has obtained with a similar methodology for the 800m but are in contradiction to those reported on treadmill running for 800m by DRAPER and WOOD (2005), treadmill running for 800 and 1500m by SPENCER ET AL (1996), SPENCER and GASTIN (2001) and treadmill running for a five minute duration by DRAPER ET AL (2003). In these studies, subjects reached from 85 to 98.5% of VO_2max. Moreover, with special regard to the 1500m, it is noted that these studies, carried out using constant pace, or with a careful start and a fast finish (SPENCER, GASTIN 2001), were realised at only 103% of MAS while in serious competition, the 1500m is performed between 107 and 109% of MAS (LACOUR ET AL 1990 and personal data). In the present study, the subjects performed the 1500m time trial at 107.6 + 2% of MAS.

Furthermore, it is notable that the best performances over 400m, 800m and 1500m are realised with a fast start followed by a short transition to even-pacing strategy as observed for the 400m and 800m by GAJER ET AL (2000) and for the 1500m by the present study (Pacing Strategy Analysis). The efficiency of this pacing strategy has already been experimented by FOSTER ET AL (1993) for cycling, and by BISHOP ET AL (2002) for kayak.

This fast start associated with a high relative intensity could explain the differences in VO_2 response. ÅSTRAND and SALTIN (1961) and MARGARIA ET AL (1965), among others, have suggested that the kinetic of VO_2 adaptation speeds up when the intensity of the supra-maximal exercise was greater. The VO_2 response at the onset of an intense exercise increased in connection with decreasing phosphocreatine concentration [PCr] and decreasing ATP/ADP ratio (ROSSITER ET AL 2002), which result in an increased rate of glycolysis (CHIATOSIS ET AL 1987). Therefore, a fast start pace leads to greater rates of PCr breakdown and consequently to stimulate the system of resynthesis of the ATP by the oxidative processes (MEDBÖ, TABATA 1989).

However, whereas a fast start may lead to the athlete reaching VO_2max earlier, it can also cause premature fatigue. Because the final performance is inversely related to the start-velocity (200 to 400m after the start of the 1500m) expressed in % of v-VO_2max, our study shows that, indeed, a fast start can impair the overall performance.

Furthermore, as observed previously for 800m, it emerged during the present study that there is a significant decrease of VO_2 at the end of a 1500m race. This phase appears for 8 athletes and is characterised by a decrease of 5.3 + 8% and 7.9 + 7.6% detected respectively in the last 300m and 200m. Some authors, among whom are NUMMELA and RUSKO (1995) for the 400m, GASTIN and LAWSON (1994) and PERREY ET AL (2002) have reported the same phenomenon. Although the exercise intensity and therefore the duration of the exercises were not similar, they were all performed to voluntary exhaustion.

This VO_2 decrease has been shown to be correlated with the difference between the peak speed and the speed at 1300m. Nevertheless, in spite of this decline, the speed remains superior to the MAS of the subjects (on average 110.9 ± 2.1 % of MAS in the last 50m).

Numerous physiological hypothesis are suggested to explain this VO_2 decrease: respiratory fatigue (PERREY ET AL 2002), a decrease of cardiac output and or an alteration of the arterio-venous difference (GONZALES-ALONSO ET AL 2003) or a decrease in arterial haemoglobin saturation (HARMS ET AL 2000). Indeed, further research is needed to elucidate the mechanism(s) underpinning this phenomenon.

Practical conclusion

Firstly, it is important to note that at the studied levels of performance, a 1500m race is not realised at a steady pace but is run between 103 and 114% of MAS and between 21 to 23 km/h-1. Tactical considerations are assumed to explain fast starts but a fast start can allow VO_2max to be reached during middle-distance races and more particularly, to be reached faster. This would seem to explain the fact that 100 % of the records for these distances have been achieved according to this pacing strategy. However, success seems to be a matter of starting fast and being able to accelerate again after 1200m. Therefore, a over-fast start could be as harmful as one that is too slow. According to our data, the start velocity must be inferior to 115% of v-VO_2max and the duration of this velocity should not exceed 25-30 seconds.

We can therefore conclude that the 1500m runner should perfectly regulate his pacing strategy: start fast enough to enhance VO_2 kinetics and quickly regulate his pacing to minimise energetic cost in the middle part of the 1500m in order to be able to accelerate 300m before the finish line.

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