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Pacing Strategy and VO₂ Kinetics during a 1500-m Race

Authors
C. Hanon¹, J.-M. Leveque¹, C. Thomas², L. Vivier³

Affiliations
¹ DSS, INSEP, Paris, France
² LEPHE, Université Evry Val d’Essonne, Evry, France
³ INSEP, FFA, Paris, France

Abstract
We investigated the oxygen uptake response (VO₂) to a 1500-m test conducted using a competition race strategy. On an outdoor track, eleven middle-distance runners performed a test to determine VO₂max, velocity associated with VO₂max (v-VO₂max) and a supramaximal 1500-m running test (each test at least two days apart). VO₂max 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-VO₂max. The maximal value of oxygen uptake recorded during the 1500-m test (VO₂peak) was reached by subjects at 75.9 ± 7.5 s (mean ± SD) (i.e., 459 ± 59 m). The time to reach VO₂max (TVO₂peak) and the start velocity (200- to 400-m after the onset of the 1500 m) expressed in % v-VO₂max 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 VO₂max 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.
was also designed to determine the consequence of the VO2 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 VO2max and maximal aerobic speed (v-VO2max) 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 (VO2), minute ventilation (VE), volume of carbon dioxide released (VCO2), respiratory frequency (RF) and tidal volume (VT) 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. The start velocity was defined as the velocity observed at 250 m from 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.

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 peak 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-VO2max.

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, TVO2peak 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

VO2max and v-VO2max (minimal speed at which the athlete was running when VO2max 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-VO2max, 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 VO2peak and TVO2peak respectively. For each 1500-m run, athletes were videotaped by a researcher standing on the top of terrace, 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

<table>
<thead>
<tr>
<th>Variable</th>
<th>VO2max (ml·kg⁻¹·min⁻¹)</th>
<th>v-VO2max (km·h⁻¹)</th>
<th>HR at v-VO2max (beats·min⁻¹)</th>
<th>[Lact]max (mmol·L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2max</td>
<td>66.1 ± 7</td>
<td>19.9 ± 1.1</td>
<td>195 ± 7</td>
<td>12.8 ± 1.5</td>
</tr>
</tbody>
</table>

VO2max: VO2max determined during the incremental test; v-VO2max: minimal speed at which the athlete was running when VO2max occurred; HR: heart rate; [Lact]max: peak blood lactate measured at the end of the incremental test.
Table 2  Peak values (Mean ± SD) measured during (cardiorespiratory variables) and after (blood lactate) the 1500-m test

<table>
<thead>
<tr>
<th></th>
<th>VT (l)</th>
<th>HR (beats·min⁻¹)</th>
<th>VE (l·min⁻¹)</th>
<th>RF (breaths·min⁻¹)</th>
<th>[Lact] (mmol·l⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak values</td>
<td>2.6 ± 0.3</td>
<td>192 ± 8</td>
<td>154.3 ± 21.2</td>
<td>63.8 ± 6.9</td>
<td>14.9 ± 0.9</td>
</tr>
</tbody>
</table>

VT: tidal volume; HR: heart rate; VE: minute ventilation; RF: respiratory frequency; [Lact]: blood lactate concentration

Discussion

The results of the present study suggest that VO₂max 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. VO₂peak reached the VO₂max 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-VO₂max. 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-VO₂max, 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 VO₂max. 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 VO₂ response, it did increase the amplitude to which VO₂ may rise following the onset of perimaximal-intensity exercise. According to these results,
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 O2 availability by right-shifting the HbO2 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 V˙O2 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 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 V˙O2max. The attainment of V˙O2max 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 V˙O2max.

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 V˙O2 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 V˙O2max 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 V˙O2max 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-V˙O2max and 114% v-V˙O2max, which is much greater than in the usual experimental design (i.e., 112 and 102% v-V˙O2max on 800 and 1500 m, respectively [20]).

It has been suggested that at the onset of supramaximal exercise, the time to reach V˙O2max is inversely related to the exercise intensity [1, 11]. Surprisingly, in our study, the time to reach V˙O2peak was not significantly correlated with the start velocity expressed in m·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, TV˙O2peak was significantly correlated with the start velocities expressed as % v-V˙O2max. Recent research provides a scientific rationale for the adoption of fast-start pacing strategies by athletes. The V˙O2 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 V˙O2 [17].
While a fast start may help to speed VO2 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 %VO2max) and distance to VO2peak. 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 %VO2max and time, if a starting pace of 114% VO2max 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 VO2max without damaging the final performance. The examination of the races of the subject D (Fig. 4a), 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 VO2max 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.

Fig. 4a 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 VO2 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.

Then, the difficulty could be in setting the mean power resulting in VO2max 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 considered as a conflict of demands: start fast to allow the achievement of VO2max 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-VO2max already mentioned by Lacour et al. [13] is easy to understand. Apart from the fact that v-VO2max and 1500-m velocity are very close, a high value of v-VO2max could therefore allow a faster start velocity without increasing the O2 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 VO2max 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. VO2max is attained in a shorter time as the start velocity, expressed in %v-VO2max, becomes higher, but our results indicate that a fast-start does not necessarily optimise performance.

Acknowledgements

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