Oxygen Uptake Response to an 800-m Running Race

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Abstract

We tested the hypothesis that time course of O_2 uptake (VO_2) measured during a supramaximal exercise performed in the field is driven to maximal oxygen uptake (VO_{2max}). On an outdoor track, five middle-distance male runners first performed a test to determine VO_{2max} and a supramaximal 800-m running test at least two days apart. VO_2 response was measured from the start to the end of exercise with the use of a miniaturised telemetric gas exchange system (Cosmed K4). VO_{2max} was reached by all subjects 45 ± 11 s (mean ± SD) after the onset of the 800-m race (i.e., 316 ± 75 m), and was maintained during the next 33 ± 6 s (i.e., 219 ± 41 m). The mean relative exercise intensity of the 800 m was 120% VO_{2max}. An unexpected significant decrease in VO_2 ($24.1 \pm 7.0\%$; $p < 0.05$) was observed in all subjects during the final 38 ± 17 s (i.e., the last 265 ± 104 m). We concluded that, at onset of a simulated 800 m running event, VO_2 is quickly projected towards the VO_{2max}, and then becomes limited by the achievable VO_{2max}. This race profile shown by all athletes is in some contrast to what can be expected from earlier findings in a laboratory setting.

Key words

Supramaximal exercise · maximal oxygen consumption · athletics

Introduction

During the adjustment to an abrupt increase in work rate such as an 800-m race, the oxygen uptake (VO_2) response increases with a definite time course, reaching a steady level after a short period of time. For a constant running velocity, many investigations showed [1, 9, 11, 21] or assumed [18, 23] that this steady level corresponds to maximal oxygen uptake (VO_{2max}) over a large range of intensities (severe and heavy exercise domains); VO_{2max} being a measure of the fastest rate at which oxygen can be utilised by the body during high-intensity exercise. During a supramaximal exercise such as an 800-m running event, Lacour et al. [18] as-

sumed with the help of an empirical model that VO_{2max} is reached. But this model did not take into account the effects of the possible intensity changes during such exercise. In another way, it has been suggested that at the onset of supramaximal exercise, the time to reach VO_{2max} is inversely related to exercise intensity [1, 13]. Indeed, during supramaximal exercise the "steady state" to be attained is likely higher than VO_{2max}.

Without mathematical analysis of the oxygen uptake response, it has been reported in other studies that the VO_2 responses during a short supramaximal exercise rose to a new submaximal exercise steady state, that is at a value below VO_{2max} level [24, 27 -

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30]. Spencer and Gastin [27] who simulated the duration of a supramaximal 800-m race on a treadmill with highly-trained athletes, showed that only $88 \pm 2\%$ of VO_{2max} was attained at the end of an 800-m test, performed in less than two minutes at a constant supramaximal velocity. However, running pace is not really steady during outdoor competitive 800-m running events [7] and regardless of the performance level, 800-m runners do not maintain an even pace throughout the race; e.g., pace is faster at the beginning, then remains at a plateau and shows a decrease at the end of the race [7]. Treadmills are generally too slow to respond to intended variations in velocity to allow meaningful race simulations. Surprisingly, no study has determined simultaneously VO_2 response and running pace profiles during an 800-m race on an outdoor track. Therefore, new data are needed to determine VO_2 response profile during such a supramaximal exercise in the field to gain insight into the aerobic processes in such an exercise. With the advent of lightweight, ambulatory respiratory gas exchange measurements, it is now feasible to perform competitive simulations in the field rather than in the laboratory. A more complete understanding of the energetics of 800-m exercise in the field is essential for a better training prescription.

The present study was designed to determine the profile of VO_2 response to an 800-m race on an outdoor track in trained middle-distance runners. We hypothesised that maximal cardiorespiratory stress assessed by maximal oxygen uptake would be reached by the end of the 800-m race due to the high running intensity occurring usually at the beginning of the 800-m race [7]. This study was possible using a portable telemetric gas exchange system, which measured the time course of VO_2 from the start to the end of exercise in real conditions.

Methods

Subjects

Five middle-distance runners (age 27.4 ± 2.7 years, height 179.4 ± 6.9 cm, and body mass 68.2 ± 5.8 kg) volunteered for the study. They trained 5 - 6 times per week for 800-m and were successful in regional and national running races (average performance of – 1 min 55 s, range of 1 min 50 to 1 min 58). 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 events in June and July (temperature of 19.1 ± 4.9 °C [mean $\pm$ SD] and barometric pressure of 752 ± 5 mmHg) on the same outdoor track, separated by at least two days. The aim of the first test was to determine VO_{2max} and maximal aerobic speed (v-VO_{2max}) for each athlete. The second test was a supramaximal 800-m exercise reproducing the conditions of competition in a suitable form.

For both tests, oxygen uptake (VO_2), minute ventilation (VE), amount of carbon dioxide released (VCO_2), frequency respiratory (FR), tidal volume (V_T) were recorded continuously by means of a gas exchange telemetric system (Cosmed K4, Roma, Italy). The

Cosmed K4 system is lightweight (700 g) with the main sample unit attached to the back and a battery pack on the chest for better comfort. This design permitted high-level performance with no serious interference with running. This system has been favourably previously compared with a standard cart system [12]. Before each test, the O_2 analysis system was calibrated using ambient air, which was assumed to contain 20.9% of O_2 (K4 instructions manual). The calibration of the turbine flowmeter of the K4 was performed by using a 3-L syringe (Quinton Instruments, Seattle, USA). 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 ear lobe in 25 µl heparinised capillary tubes and analysed by an automated enzymatic method with an electrode (Microzym-L analyzer, SGI, Toulouse, France). This lactate analyser was calibrated before the tests with several solutions of known lactate concentrations.

Incremental test

VO_{2max} was estimated using a multistage incremental test on an outdoor 400-m track marked every 25 m. The running pace was given by sounds emitted through a speaker controlled by a computer software program to ensure precise control of speed by setting an audible cadence. This test was derived from the protocol proposed by Léger and Boucher [19] and is regularly used in our Sport Science Institute to evaluate high-level athletes. The initial speed was 14 km $\cdot$h^{-1} and was increased by 2 km $\cdot$h^{-1} up to 18 km $\cdot$h^{-1}, then 1 km $\cdot$h^{-1} until the end of the test. Each stage consisted of a 3-min exercise period followed by a 1-min recovery period necessary for blood collection at the ear lobe. This protocol might be however a minor limitation in our data. Each subject was encouraged to exert a maximum effort. The test was stopped when the athlete could not maintain the required velocity, and the mean value in VO_2 during the last elapsed minute at this stage was used to determine VO_{2max}. For attainment of VO_{2max} all subjects fulfilled at least three of four following criteria: a plateau in VO_2 despite an increase in running speed, a respiratory exchange ratio greater than 1.10, a maximal HR near the predicted maximal theoretical heart rate (220 - age), a blood lactate concentration higher than 8.0 mmol $\cdot$l^{-1}, and the apparent exhaustion of the subject [22]. v-VO_{2max} (in km $\cdot$h^{-1}) was then defined as the lowest running speed at which VO_{2max} occurred during the incremental exercise protocol.

Supramaximal 800-m running test

The supramaximal exercise was an 800-m race. The warm-up was standardised according to regular pre-event 800-m warm-up 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 800-m test according to their best individual 800-m performance and their own experiences. A researcher beside the athlete on a bike gave verbal encouragement throughout the test period. Athletes were provided feedback of their current time and velocity at 50, 100, 200, 300, and 400 m. Blood samples were taken from the ear lobe immediately before and after the supramaximal exercise, then at 3, 5, 7, and 10 min during the recovery following the 800 m, in order to detect the peak blood lactate

Table 1 Individual values of the different variables (during the simulated 800-m run, maximal oxygen uptake VO_{2max}, maximal aerobic speed v-VO_{2max}, maximal minute ventilation VE_{max}, maximal heart rate HR_{max}, and blood lactate) measured at the end of the incremental test. Peak blood lactate and individual performance time values obtained after the 800-m run are also reported

Subject Time (s)	VO_{2max} (ml · min^{-1}·kg^{-1})	v-VO_{2max} (km· h^{-1})	VE_{max} (l· min^{-1})	HR_{max} (beats·min^{-1})	Blood lactate (mmol·l^{-1}) Incremental	800 m
1 (120.4)	69.1	20	145	200	11.3	17.2
2 (121.6)	68.4	20	128	192	13.8	19.0
3 (117.0)	65.7	20	123	196	9.0	18.7
4 (126.1)	64.3	20	115	175	10.6	16.8
5 (118.9)	64.0	19	135	172	8.4	15.9
Mean ± SD	66.3 ± 2.3	19.8 ± 0.4	129.2 ± 11.5	187 ± 13	10.6 ± 2.1	17.5 ± 1.3

value [6]. For each 800-m run, athletes were videotaped by a researcher standing on the top of terracing, who used panoramic video system (Panasonic Super-VHS, sampling rate of 50 Hz) from fixed spot to determine athlete's velocity each 25-m distance intervals along the track.

Data analysis

Since 800-m performance was different between athletes, cardiorespiratory and kinematics data obtained as a function of time every five seconds during the 800-m race were averaged over 25-m distance intervals in order to normalise data for all subjects. The relationship between the submaximal steady-state one-minute VO_2 and running velocity was determined by linear regression for each athlete during the incremental test. The relation was forced through a y-intercept of 5 ml · min^{-1} · kg^{-1} [23]. The required O_2 demand was determined by extrapolating this relationship to the velocity measured each 25-m distance intervals in the supramaximal running test.

Statistical analyses

The 800-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 25-m distance intervals, followed by multiple comparisons (Student-Newman-Keuls). The Friedman rank test was used when the normality or the equality of variance was violated. Linear regressions were calculated according to the least square method. Data were reported as mean ± SD. The level of significance was set at $p < 0.05$.

Results

Individual values obtained in the incremental test are presented in Table 1. VO_{2max} during the incremental test was equal to $66.3 ± 2.3$ ml · min^{-1} · kg^{-1} and v-VO_{2max} corresponded to $19.8 ± 0.4$ km · h^{-1}.

Cardiorespiratory responses during the 800-m running test

As shown in Fig. 1, VO_2 reached VO_{2max} level $316 ± 75$ m (or $45 ± 11$ s) after the onset of the 800 m. VO_2 values were not significantly different from VO_{2max} during the next $219 ± 41$ m (or $33 ± 6$ s). Finally, VO_2 decreased significantly ($p < 0.05$) from
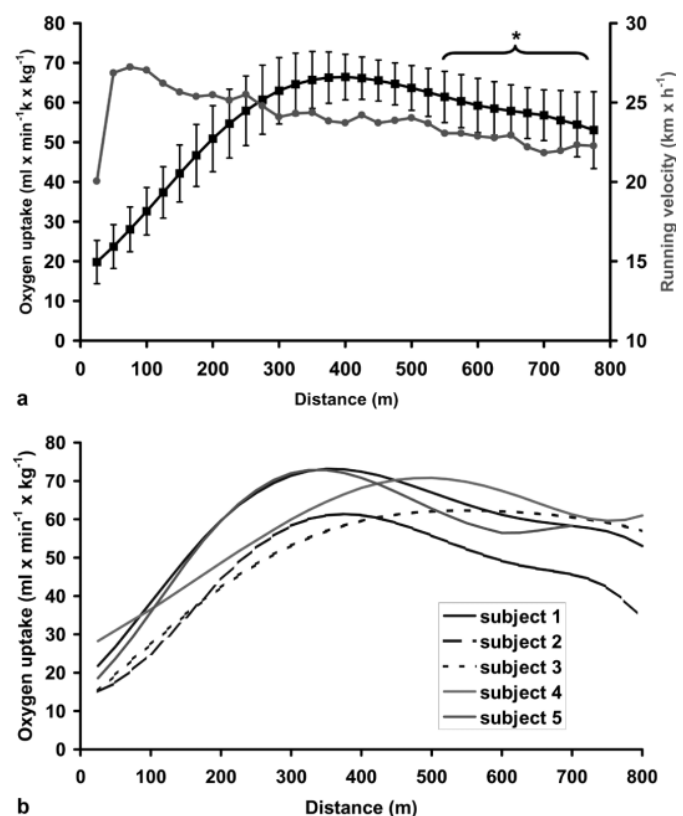

Fig. 1 a and b a Time course of oxygen uptake (black line and square symbol) and running velocity (grey line and circle symbol) at each 25-m distance intervals for the supramaximal 800 m. Data are mean values ± SD only for oxygen uptake for more clarity. * Significantly different from 535 m, $p < 0.05$. b Individual oxygen uptake response profile to an 800-m race. Note the three characteristics phases for all subjects: a rapid elevation, a plateau, and a drop-off in oxygen uptake.

$66.3 ± 2.3$ to $53.0 ± 7.1$ ml · min^{-1} · kg^{-1}. This decrease (mean of 24%) was observed in all the subjects (Fig. 1) and lasted $38 ± 17$ s (or during the last $265 ± 104$ m of the 800-m race). After reaching a steady state, a significant decrease in V_T ($p < 0.05$) was observed from 600 m (i.e., at 90 s) to the end of the race. The decrease in V_T was significantly related to the decrease in VO_2 over the same period ($r = 0.98$, $p < 0.05$). This decrease occurred after a time delay of − 12 s with respect to the onset of the decrease in VO_2. Meanwhile FR increased and attained a plateau from 640 m (i.e., at 95 s), then slightly drifted upward for all athletes, but this
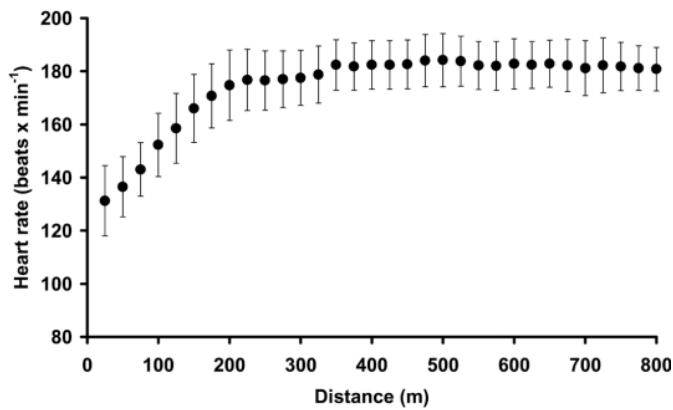
Fig. 2 Time course of heart rate during the 800 m. Data are mean values ± SD.

trend was however not significant ($p > 0.05$). Maximal HR values were not significantly different during the 800-m race and the incremental test ($p > 0.05$). Five subjects reached a HR plateau (186 ± 1 beats $\cdot min^{-1}$) which was maintained until the end of the 800-m running test (Fig. 2).

Blood lactate concentrations were 2.3 ± 0.6 mmol $\cdot l^{-1}$ before the 800-m test and reached peak values of 17.5 ± 1.3 mmol $\cdot l^{-1}$ between the 5th and 7th minutes in the recovery period for all subjects.

Velocity changes during the 800-m running test

The mean performance during the 800-m race was 120.8 ± 3.4 s, that is $4.9 \pm 1.6\%$ above their best performance (114.8 ± 3.6 s). The 800-m race corresponded well to a supramaximal exercise with regard to the average velocity achieved (23.8 ± 0.8 km $\cdot h^{-1}$ or 7.6 ± 0.3 m $\cdot s^{-1}$) corresponded to $120 \pm 4\%$ v-$V0_{2max}$. As expected, running velocity in the 800-m race was not steady and this pattern shows two distinct phases (Fig. 1). Velocity peaked at 27.3 ± 1.2 km $\cdot h^{-1}$ ($136 \pm 8\%$ v-$V0_{2max}$) between 75 and 100 meters, and then decreased continuously down to 21.6 ± 1.8 km $\cdot h^{-1}$ (i.e., 109% v-$V0_{2max}$) until the end of the 800-m race. Velocity changes were significantly related to the slow down period in $V0_2$ ($r = 0.93$, $p < 0.05$).

Discussion

The main finding of the present study was that $V0_{2max}$ was attained during an exercise protocol which reproduced the conditions of an 800-m running competition, supporting the first assumptions of Lacour et al. [18]. To our knowledge, this is the first time that this result is demonstrated in field conditions. In contrast, the present results did not agree with observations from a recent study by Spencer and Gastin [27], in which athletes reached only $88 \pm 2\%$ of peak $V0_2$ steady state level during an 800-m run on a moving treadmill in laboratory settings. Since the anthropometric characteristics and $V0_{2max}$ values of the 800-m runners are similar to the data reported in previous studies [4, 27, 28], the main difference in these studies consisted probably in the running test conditions. In laboratory conditions, athletes cannot make subtle adjustments in pace on a treadmill as they wish in competition [13], and race strategy is not repro-

duced, as well as effects of air resistance. During an 800-m running race in laboratory [27], athletes are constrained to maintain a constant race pace ($113 \pm 9\%$ of $V0_{2max}$ in [27]), instead of running with changes in velocity. In the present study, average running velocity during the race (23.9 ± 0.7 km $\cdot h^{-1}$) corresponding to $120 \pm 4\%$ of $V0_{2max}$ was not maintained fairly constant throughout the 800 m (Fig. 1). Indeed, during the first 75 m of the supramaximal test, athletes produced a very important acceleration and reached a peak running velocity which corresponded to an energy expenditure of $136 \pm 8\%$ of $V0_{2max}$. Compared with our study, the relative constant exercise intensity (in % of $V0_{2max}$) in Spencer and Gastin [27] might be too low and could be therefore insufficient to attain maximal oxygen uptake in less than two minutes. Similar observations may be observed in cycling where the submaximal work load is fairly constant [15]. So, start strategy related to changes in running velocity seems very important to take into account when dealing with $V0_2$ time course at the onset of a supramaximal 800-m running test. As in running [11], Bischop et al. [2] indicated that fast $V0_2$ responses were observed during a two-minute kayak ergometer performance following an all-out start strategy when compared with an even-paced strategy. In short, the maximum rate of oxygen uptake seems important within an 800-m running track event (not fairly reproduced in laboratory setting), at least for the first half of the distance. This result may be important for 800-m running coaches due to some old perceptions on the usefulness of $V0_{2max}$ in this type of event.

In the present study, $V0_{2max}$ steady state was attained in 45 ± 11 s (i. e., at a mean distance of 316 ± 75 m). This result is in agreement with a previous study [1] which indicated that the time taken to establish a plateau for maximal oxygen uptake during exercise is somewhat less than one minute during a very heavy exercise in young, healthy, and well-trained individuals. According to these authors, this time was sufficient to adjust the oxygen transport system so that maximal oxygen uptake and maximal heart rate were attained. In the present study, maximal HR was reached by 350-m of the 800-m test before remaining stable (Fig. 2).

About eleven years ago, Hirvonen et al. [14] noted that during the acceleration phase of a 400-m sprint, most of the ATP pool was resynthesised through the degradation of phosphocreatine. So, the $V0_2$ response at the onset of an intense exercise increased in connection with decreasing phosphocreatine concentration and decreasing ATP/ADP ratio [26], which results in an increased rate of glycolysis [3]. Meanwhile, a potential limitation of oxygen availability at the beginning of the race could result in an increased rate of glycolytic flux and hence increased lactate yielding energy processes occurring in the transient phase as shown partly by the high peak blood lactate obtained in the present study (17.5 ± 1.3 mmol $\cdot l^{-1}$) and by Lacour et al. [18] at the end of an 800-m race. Therefore, the high-energy requirement during the 800-m race demanded greatly both anaerobic and aerobic metabolism for energy production [27, 30].

An unexpected significant $V0_2$ decrease was observed at the end of the 800-m race (from 78 ± 14 s or from 535 ± 105 m). This result conflicts with the current ideas that peak $V0_2$ remains constant until the end of exercise when exercise intensity allows it

[1]. In the literature, a few studies [17, 24, 25] have however reported a decrease in $V0_2$ response at the end of exercise. For instance, Nummela and Rusko [24] have observed that at the end of a supramaximal run to exhaustion on a treadmill, $V0_2$ decreased significantly ($p < 0.05$) in 13 out of 14 well-trained subjects, although only 79% of their $V0_{2max}$ was attained. Note that a slight decrease in $V0_2$ can be also observed in some figures of different scientific papers published in the literature [2, 30, 31]. A possible limitation to these studies mentioned above was likely the characterisation of the decrease, which involved either a simple observation [24] or a total disregard of this phenomenon [2, 30, 31]. Recently, Perrey et al. [25] described the same phenomenon for 7 out of 13 endurance-trained athletes at the end of a submaximal running at 95% of $V0_{2max}$ to exhaustion where $V0_{2max}$ was achieved. Although the exercise intensity and therefore, the duration of the exercise were not similar between these studies [2, 24, 25, 30, 31], running exercise was each time performed to voluntary exhaustion like an 800-m race. Therefore, for high-intensity exercise, a decrease in $V0_2$ could reasonably occur in trained-endurance [25] and middle-distance (present study) runners. Concerning supramaximal exercise, the 800-m race required a maximal effort from the subjects to obtain their best performance. The marked decrease in velocity that occurred during the latter part of the 800-m race reflected the important exhaustion of the athletes and could contribute to the decrease in $V0_2$. During the last part of the race, the pattern of $V0_2$ changes was significantly related to variations in velocity (Fig. 1). Metabolic acidosis may impair mitochondrial respiration [10] and might lead to a decrease in running speed and, simultaneously, in $V0_2$. More important, the decrease in $V0_2$ was concomitant with a decrease in VT for all athletes ($r = 0.98$; $p < 0.05$) which was accomplished through a slight increase in FR ($p > 0.05$). This pattern, considered as an indirect sign of the development of muscles respiratory fatigue [8], was reported also by Perrey et al. [25] during exhaustive exercise running at 95% of $V0_{2max}$. Moreover, the reduction in V_T produced likely a relative alveolar hypoventilation. We hypothesised that all these events entailed a decrease in gas exchanges [20] and could limit human performance for exercise intensity above 90 - 95% of $V0_{2max}$ [16], and consequently induce a decrease in $V0_2$. Finally, the decrease in speed at the end of the race could be attributed to a decrease in contraction speed: as ATP concentration decreases and the muscle approaches exhaustion during the course of the 800 m, the shortening speed decreases and the thermodynamic efficiency increases [5].

In conclusion, we showed for the first time during an 800-m running race, that well-trained middle distance athletes reached their $V0_{2max}$ after 45 ± 11 s. These results in agreement with past 60's studies [1, 21] done in laboratory conditions, show the predominate race profile used by elite runners to undertake a simulated 800-m running race on a track. Among results, we observed an unexpected significant decrease in $V0_2$ at the end of the 800-m race for all subjects. New studies are needed to go further into the underlying mechanisms of the $V0_2$ responses at the end of exhaustive supramaximal exercise in the field.

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