The 400-m race: the last straight line.

Biomechanical and metabolic characteristics

Christine Hanon[1], Claire Thomas[1,2], Bruno Gajer[3]

1) INSEP, France : christine.hanon@insep.fr
2) University of Evry, France: claire.thomas@univ-evry.fr
3) French Athletics Federation: gajer.bruno@wandoo.fr

Abstract

Previous study has demonstrated that the top elite 400-m runners are characterized by a 23% fatigue index (peak velocity- final velocity/peak velocity). Then, this presentation aimed to describe the biomechanical and metabolic evolutions occurring in the last 100 of a 400-m race. A portable gas analyser was used to measure the oxygen uptake ($\dot{V}O_2$) of 10 specifically trained runners racing on an outdoor track. The tests included 1) a maximal 400-m running test (400T) and 2) a 300-m running test (300T) reproducing the exact pacing pattern of the 400T. Furthermore, blood lactate [La], bicarbonate concentrations [HCO_3^-] and pH, were analysed at rest and 1, 4, 10 min after the end of the 400T and 300T. A significant decrease in $\dot{V}O_2$ ($P < 0.05$) was observed in all subjects during the last 100 m. The metabolic responses measured after the 300 and after the 400 m were significantly different, indicating a large fatigue increase in the last 100 m. Additionally, the velocity decrease observed in the last 100m was inversely correlated with [HCO_3^-] and pH at 300T ($r = -0.83$, $P < 0.001$, $r = -0.69$, $P < 0.05$, respectively). These track running data demonstrate that intermediate acidosis affect both $\dot{V}O_2$ response and velocity decrease during the final 100-m of a 400 m trial.

Introduction

As small differences in performance generally determine a competition outcome, information concerning the best way to expend the limited energetic sources available is of considerable interest. However, given the obvious importance of pacing on performance, there are relatively few studies available on this topic. The 400-m event, symbolizes the most demanding athletic event. In this discipline, which is intermediate between sprint and middle-distance, the runners must be able to preserve the optimal technical characteristics of stride in spite of intense fatigue. For these reasons, understanding the biomechanical and energetic factors in such a distance is critical to performance and is of interest to the national coaches to identify area for improvement to reach world-class levels.

A previous study of our team (Hanon & Gajer, 2009) has shown that the velocity decrease in the last part of the 400m was more dramatic in the word-class runners than in less trained conterparts. This velocity decrease is due primarily to the decrease in the stride length (at 200 to 300m), then (at 300-350m) to both the stride length and frequency and finally to the stride frequency in the last 50m. Furthermore, the fatigue index (peak velocity-final velocity/peak velocity)*100 was shown to be 23%.

On the other part, in addition to the high aerobic contribution demonstrated in the literature (Duffield et al, 2005 Hanon et al 2010) , the anaerobic contribution during a 400-m race is also important and has been reported to range from 57 to 65 % of the total energetic needs during a race (Duffield et al. 2005, Spencer and Gastin 2001). The importance of the anaerobic system is reinforced by the strong relationship (r = 0.85, $P < 0.01$) between anaerobic glycolysis, as estimated by the maximal lactate levels (above 20 $mmol.l^{-1}$), and the average velocity sustained during the 400-m race in highly-trained athletes (Lacour et al. 1990). This large anaerobic contribution, and subsequent accumulation of metabolites (Kindermann et al. 1977) may contribute to the decrease in velocity observed during the final 100 m of a 400-m race (Hanon & Gajer 2009).

Therefore, the aim of the presentation was to describe the biomechanical parameters observed during the last 100 m and to study the blood metabolic response between 300 and 400m of a 400-m race performed by well-trained athletes according to the pacing strategy used by the best athletes.

Methods

Subjects

Ten 400-m runners (eight men and two women, age 21.8 ± 4.9 years, height 1.76 ± 0.06 m, and body mass 66.3 ± 6.6 kg) volunteered for the study. They trained 3-5 times per week for the 400-m race and were successful in regional and national running races (average performance of 50.9 ± 1.2 s for the men and 57.4 ± 3.7 s for the women). The study conformed to the recommendations of the Declaration of Helsinki, and participants gave voluntary written consent to participate in this experiment, which was approved by the local ethics committee.

Experimental protocol

Subjects performed two track-running tests during the summer competition period, on the same 400-m outdoor track, separated by at least two days: a 400-m race performed according to the normal competition pacing strategy (400T) and a paced 300-m trial (300T). During this second trial, the subjects were asked to replicate the exact pacing strategy of the previous 400T.

For the three tests, oxygen uptake ($\dot{V}O_2$), minute ventilation (VE), respiratory frequency (RF) and tidal volume (VT) were recorded continuously breath by breath by a portable gas exchange system (Cosmed *K4b²*, Roma, Italy). Calibration of both the Cosmed turbine (3-liter syringe) and gas analysers was performed according to the manufacturer's instructions before each test for each subject. Heart rate (HR) was measured and recorded continuously with a heart rate monitor (S810i and T61 electrode belt, Polar Electro, Kempele, Finland) for each athlete.

Before and after the maximal sessions, arterialised capillary blood samples (85 µL) were taken from hyperemized ear-lobes in order to measure blood pH, arterial oxygen saturation (SaO_2) and bicarbonate concentration ($[HCO_3^-]$) with an i-STAT dry chemistry analyser (Abbott, Les Ulis, France).

Statistical Analyses

The effect of distance on velocity, stride rate and length were determined by repeated-measures analysis of variance. The significance level was set at $P \leq 0.05$.

Results

Performance

The mean performance of the 400T was 52.2 ± 2.4 s for the men and 60.6 ± 4.5 s for the women, and corresponded to 97 % of their best performance. The mean 400-m velocity was equal to 144.7 ± 9.8 % of their v-$\dot{V}O_{2max}$. The peak start velocity (average of the individual distance at which peak start velocity was attained) was reached 67 ± 22 m after the onset of the race, and the velocities in the final 100 m were 8.37 ± 0.35 $m.s^{-1}$ (i.e., 164.2 % v-$\dot{V}O_{2max}$) and 6.93 ± 0.68 $m.s^{-1}$ (i.e., 136.0 ± 10.5 % v-$\dot{V}O_{2max}$) for the 300 and 400T. During the 400-m running test, the mean velocity decrease in the last 100 m, expressed as a percentage of the velocity at 300 m, was 9.9 ± 5.5 % (range from 2.2 to 20.4 %) and the fatigue index was 22.5 ± 6.7 %, (range from 11.8 to 34.1 %).

Stride parameters

The mean stride length and frequency between 125 and 175 m after the onset of the race was 2.21 ± 0.11 m and 3.71 ± 0.12 Hz, respectively. At the end of the race (between 325 and 375 m after the onset of the 400T) these values were 1.95 ± 0.16 m and 3.52 ± 0.13 Hz which corresponded to a significant decrease of 11.5 ± 3.7 % and 5.1 ± 3.8 % for the stride length and the frequency, respectively during 400-m test (P < 0.01).

VO_2 response

During the 400T, the $\dot{V}O_{2peak}$ value was detected at 192 ± 21 m (that is 24.4 ± 3.2 s after the onset of the test). This value corresponded to 93.9 ± 3.9 % of $\dot{V}O_{2max}$. From 200 m until the end of the test, a significant decrease in $\dot{V}O_2$ was observed (P<0.0001). In the last 100 m this significant decrease in $\dot{V}O_2$ (P<0.05) was equal to 8.5 ± 3.9 mL.min^{-1}.kg^{-1} (15.6 ± 6.5 % of $\dot{V}O_{2\ peak}$) and was observed in all subjects.

Metabolic response

The metabolic results measured before and after the running tests are presented in table 1.

Table 1 Mean (SD) values for blood parameters measured during the 400- and 300-m running sessions.

		pre-run	1	4	7	10
pH	300	7.40 (0.04)	7.19 (0.05)	7.16 (0.05)	7.18 (0.05)	7.23 (0.05)
	400	7.39 (0.04)	7.08 (0.04)	7.00 (0.07)	7.00 (0.04)	7.00 (0.06)
[Lac]	300	3.5 (1.2)	14.6 (1.5)	16.6 (1.3)	16.8 (1.5)	15.8 (1.9)
	400	3.8 (0.8)	16.4 (0.9)	21.2 (2.1)	22.0 (1.9)	20.0 (2.4)
[HCO_3^-]	300	20.7 (2.3)	13.5 (1.9)	10.5 (1.7)	10.0 (2.2)	10.7 (2.2)
	400	19.5 (1.4)	9.9 (1.2)	6.4 (1.1)	5.5 (1.4)	4.9 (1.3)
SaO_2	300	97.8 (0.4)	96.0 (1.6)	96.9 (1.2)	97.3 (0.5)	97.5 (1.0)
	400	97.9 (0.3)	95.4 (1.0)	95.5 (1.9)	95.8 (1.0)	96.4 (1.8)

[Lac]: blood lactate concentration, [HCO_3^-]; bicarbonate concentrations
1, 4, 7, 10: blood samples obtained 1, 4, 7, 10 min after the end of the test

D. DISCUSSION

In the present study, a $\dot{V}O_2$ decrease was observed during the final 100 m in all athletes, confirming previous results obtained during other maximal, exhaustive running exercises realized at a constant pace (Nummela and Rusko 1995, Perrey et al. 2002) or in field conditions (Hanon et al. 2007, Thomas et al. 2005). Although undiscussed by the respective authors, this phenomenon also appears in the figures of other studies incorporating paddling or cycling exercise (Bishop et al 2002, Yamamoto and Kanehsia 1995, Zamparo et al 1999, Williams et al 2006). Nevertheless, in previous studies no decrease has been observed at the end of 400-m running tests that could be explained by the sampling window used by the authors (200m (Duffield et al 2005) and 30 s (James et al 2007)) which do not allow this observation during such intense and brief exercise. Nummela et al (1995) who observed a $\dot{V}O_2$ decrease at the end of a maximal 50-s treadmill exercise used a 5-s sampling window.

In the present study, this decrease in $\dot{V}O_2$ appeared to be related to the peak [lactate]. The peak blood lactate concentration measured in the present study (22.0 $\pm$ 1.9 $mmol.L^{-1}$), which was similar to values traditionally observed after a competitive 400-m race (Kindermann et al. 1977, Lacour et al. 1990), but was higher than all recent experimental data on 400-m races (Duffield et al. 2005, Reis et al. 2004) (≈ 13 to 16 $mmol.L^{-1}$); these differences may have contributed to the absence/presence of this phenomenon.

In the last 100 m, additional significant decreases in pH (7.18 to 7.00) and [HCO_3^-] (10.7 to 4.9 $mmol.l^{-1}$) were observed, and the pH and [HCO_3^-] values measured at the onset of the $\dot{V}O_2$ decrease (300 m) were significantly related to the 400T end $\dot{V}O_2$ values. This final metabolic state aggravation, observed at the end of the 400T, is in accordance with the depletion revealed in blood bicarbonate after competitive rowing (Nielsen 1999), as well as the decrease in muscle buffering capacity observed after 45 s of exhausting exercise (Bishop et al. 2007), with the result being that the organism is unable to prevent an additional acidosis. Then, the decrease in $\dot{V}O_2$ and in velocity could be related to acidosis-induced inhibition of oxidative phosphorylation in contracting muscles (Jubrias et al. 2003) and consequently, with the large decrease in ATP observed at the end of a 400-m race (Hirvonen et al. 1992). It should be noted however, that the decrease in $\dot{V}O_2$ observed in the present study was not correlated to the pH values at 300-m (r=-0.56, *P*= 0.10).

Blood metabolic perturbations, which could reflect changes in the muscle, could contribute to greater muscle fatigue during the last 100 m since the velocity strongly decreased (stride length in particular) until values above the velocity associated with $\dot{V}O_{2max}$ in each athletes. This velocity drop was negatively and significantly correlated to blood pH post 300T and to the [HCO_3^-]. The progressive reduction in running speed could then be the result of a combination of changes occurring in the muscle resulting in an incapacity to compensate for fatigue (Nummela et al. 1992). The significant correlation between the metabolic values at 300 m (blood pH and [HCO_3^-]) and the subsequent velocity decrease suggests that the ability of the athletes to finish strongly during this type of exhausting exercise may be linked to the level of acidosis when approaching the finish line.

In conclusion, in the last straight line, when a large decrease in velocity is observed, a large alteration of the blood metabolic state can be noted. This drop in the velocity was positively correlated with both the blood pH and [HCO_3^-] measured after the 300T. Furthermore, in this last 100 m, a decrease in $\dot{V}O_2$ corresponding to 15% of $\dot{V}O_{2\,peak}$ was observed in all subjects.

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