Effect of expertise on post maximal long sprint blood metabolite responses Maximal running exercise and acid-base status in elite versus regional athletes

Christine Hanon, Mathieu Rabate, Claire Thomas

Effect of expertise on post maximal long sprint blood metabolite responses

Hanon Christine [1], Rabate Mathieu [1], Thomas Claire [1,2]

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[1] French National Institute of Sports (INSEP), Laboratory of biomecanics and physiology - 11 Tremblay Avenue, 75012 PARIS, France.

[2] University of Evry Val d'Essonne, STAPS department. EA 3872, François Mitterrand Boulevard 91025 Evry, France.

Corresponding author: Hanon Christine

Address for correspondance: C Hanon

Laboratory of biomechanics and physiology

INSEP

Tremblay Avenue, 11

75012-PARIS, France

Tel: 0033 1 41 74 43 57

Fax: 00 33 1 41 74 45 35

e-mail : christine.hanon@insep.fr

[1] French National Institute of sports (INSEP), Laboratory of biomecanics and physiology - 11 Tremblay Avenue, 75012 PARIS, France.

Phone : +33 (0) 141744357. Fax : 33 (0)141744535.

E-mail : christine.hanon@insep.fr

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3. Abstract

The aim of this study was to describe and compare the blood metabolic responses obtained after a single maximal exercise in elite and less-successful athletes, and to investigate whether these responses are related to sprint performance. Eleven elite (ELI) and fourteen regional (REG) long sprint runners performed a 300-m running test as fast as possible. Blood samples were taken at rest and at 4 min after exercise for measurements of blood lactate [La] and acid-base status. The blood metabolic responses of ELI compared to REG subjects for pH (7.07 $\pm$ 0.05 versus 7.14 $\pm$ 1.5), sodium bicarbonate concentration [HCO_3^-] (8.1 $\pm$ 1.5 versus 9.8 $\pm$ 1.8 $mmol.L^{-1}$), haemoglobin O_2 saturation (SaO_2) (94.7 $\pm$ 1.8 versus 96.2 $\pm$ 1.6 %) were significantly lower ($P < 0.05$) and blood lactate concentration [La] was significantly higher in ELI (21.1 $\pm$ 2.9 versus 19.1 $\pm$ 1.2 $mmol.l^{-1}$, $P < 0.05$). The 300-m performance (in % world record) was negatively correlated with pH ($r=-0.55$, $P < 0.01$), SaO_2 ($r=-0.64$, $P < 0.001$), [HCO_3^-] ($r=-0.40$, $P < 0.05$), and positively correlated with [La] ($r=0.44$ $P < 0.05$). In conclusion, for a same quantity of work, the best athletes are able to strongly alter their blood acid-base balance compared to underperforming runners, with larger acidosis and lactate accumulation. To obtain the pH limits with acute maximal exercise, coaches must have their athletes perform a distance run with duration of exercise superior to 35 s. The blood lactate accumulation values ($mmol.L^{-1}.s^{-1}$) recorded in this study indicate that the maximal glycolysis rate obtained in the literature from short sprint distances is maintained, but not increased, until 35 s of exercise.

Key-words: Maximal sprint running, pH, training, elite runners

A. INTRODUCTION

Highly-trained athletes systematically demonstrate better chronometric performance in competition than less-trained subjects due to innate capacities and daily physical training, which enhance their abilities to run both faster, and for a longer time. Analysis of the differences in metabolic responses between the elite and less-successful athletes should help to highlight the limiting factors on a specific human task such as a maximal running exercise. However, few studies have analysed elite performance in order to determine the effect of expertise on metabolic responses after a maximal long sprint exercise in the field. As anaerobic energy production from glycolysis is one of the most important factors in sprint performance, blood pH and lactate concentration [La] could be considered an indicator of this anaerobic energy expenditure. It has been reported that [La] is greater in sprinters than in middle-distance runners after a supra-maximal exercise (19), and that a positive relationship exists between velocity and post-competition [La], in elite 400- and 800-m runners (26), and in 400-m swimmers (4). These results suggested that increase in [La] could be related to long sprint performance, and could be indicative of a training-induced increase, which is considered as one of the main goals of sprint training. However, these relationships between performance and post-competition [La] are not confirmed on shorter distances, such as 100 or 200 m (17, 18), which could be explained by the greater contribution of both phosphagen energy and mechanical factors (17).

In response to short and high-intensity exercise, it has been pointed out that trained-athletes present an increase in [La] values superior or equal to 15-20 $mmol.L^{-1}$, which is associated with a decrease in the concentration of bicarbonate ion [HCO_3^-] to about 10 $mmol.L^{-1}$, and with a reduction of blood pH between 7.15 and 7.00 (13, 33). However, some very low pH values have been observed in world-class athletes (23, 34). The absolute lowest (6.74) value was recorded after a competitive 2000-m rowing exercise performed by one of the Olympic gold medallists (34), which was obtained with a great muscle mass and after a

long exercise duration (about 6 min), and was considered by the author (34) as the lowest possible value reached in humans. This pH value was lower than the 6.88 value recorded after a running exercise, in an elite 400-m runner, who performed a 95 s treadmill exercise until exhaustion (23). The [H^+] corresponding to these low pH values was increased more than four-fold compared with rest values, and was twice that of the usual reported post-maximal exercise values in trained athletes (16, 37).

According to the literature, these low pH values should have deleterious physiological effects, such as inhibition of muscle contractile activity (10, 40), inhibition of muscle oxidative metabolism (20), and decrease in O_2 saturation of haemoglobin (SaO_2) (37). Then, it could appear as a contradiction that the elite athletes may be able to obtain the most extreme metabolic responses, whereas excess H^+ has been shown to impair high intensity exercise performance (46). Surprisingly, to our knowledge, few comparative data between elite and less-successful athletes are available on the blood metabolic responses after the same short maximal exercise. The only comparison between elite and less-successful runners has been made in 400-m runners, but the data resulted from different exercise durations (time-limit performed at 22 $km.h^{-1}$) (23), whereby the results could be the consequence of exercise duration/relative velocity and/or expertise effect.

Therefore, as it has been reported that at least 40 s of heavy work are at least necessary to reach maximal acidosis after a single running distance in athletes (22), the purpose of the present study was, at first, to describe the metabolic response to a single and typical maximal long sprint training distance (300-m) in elite runners (running the 300-m in less than 40 s for women, and, 35 s for the men); and secondly, to investigate whether post-maximal exercise pH and [HCO_3^-] values are similar between elite (ELI) and regional (REG) runners. This study described herein tests the following hypothesis: 1) pH, [HCO_3^-] and SaO_2 values of ELI athletes after a 300-m running distance performed at maximal velocity are lower than REG athletes; and, 2) pH, [HCO_3^-] and SaO_2 values are related to the 300-m performance.

B. METHODS

Experimental approach of the problem

To examine the effects of expertise on the blood metabolic responses following a maximal sprint, 25 elite and regional trained runners performed an all-out 300-m test. This comparison was based on blood metabolic data such as pH, [HCO_3^-], SaO_2 and [La].

Subject

11 (5 men and 6 women) elite and 14 male regional subjects took part in this study. (Age (yrs), height (cm) and body mass (kg): 23.2 $\pm$ 1.4, 176.5 $\pm$ 6.0, 71.03 $\pm$ 11.7 for ELI and 22.1 $\pm$ 3.3, 177.4 $\pm$ 7.3, 72.5 $\pm$ 11.2 REG). All of them gave their written informed consent before the experimentation. ELI runners were all involved as athletes in the national training centre (7 to 9 training sessions a week) and have been selected at least once for the national team (best performances on 400m: 47, 2 $\pm$ 0.5 s for the men and 52.8 $\pm$ 0.8s for the women). All of them had practiced sprint for at least 5 years and none of them were on creatine, beta-alanine or any supplementations. REG runners were active runners (3 to 5 sessions a week). They have been involved in specific anaerobic training in the three last weeks before the experiment (3 long sprint training sessions each week, composed with 3 to 4 repetitions of 150 to 250-m sprints). Because of different studies (25, 26, 42) which have demonstrated the absence of differences attributable to gender in metabolic results, no distinction of gender was made in this experimental design.

Procedures

Maximal 300-m running test (300-m)

The maximal exercise was a 300-m race achieved on a synthetic outdoor track and the running times were measured by a stopwatch. In order to pool male/female data, the performances were expressed in % of the 300-m world record that is 30.85 s and 34.10 s for the men and the women, respectively. The test was performed during a regular training session, at the beginning of the competition phase during late afternoon (between 4 and 6 P-M) at least 4 h after the last meal. They were instructed not to consume food and beverages (other than water) in the 2 h before testing. All participants were also asked to refrain from alcohol consumption and not to perform vigorous exercise in the 24 h preceding testing. The warm-up was standardised according to a regular pre-event competition warm-up (15 min of jogging, stretching, 2 successive sprints: 1x50 m and 1x100 m) and was followed by a 7-min recovery period before the onset of the test. Athletes were asked to run as fast as possible. Strong vocal support was given from the start to the finish line.

Blood samples

Before and 4 min after the maximal test, 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). These measurements, anaerobically collected (cartridges closed hermetically), have been found to be reliable (ICC=0.77-0.95 following maximal exercise). Because of the limited range of the i-STAT system (0.30-20 $mmol.L^{-1}$) and when the [La] was greater than 20 $mmol.L^{-1}$ (6 times in ELI and 5 times in REG), the [La] was determined from pH values with the use of a regression ($y = -44.6x + 335$), $r^2 = 0.85$ n= 77, where y = [La] and x = pH results (unpublished data). Blood samples were taken from the ear lobe just before the start of 300-m (that was 7 min after the end of the warm-up period) and then at 4 min during the passive recovery following each test. The mean lactate accumulation (peak lactate value in $mmol.l^{-1}$/300-m time in sec) expressed in $mmol.L^{-1}.s^{-1}$ is calculated for each subject.

Statistical Analyses

The data are presented as means and standard deviations (SD). In order to compare the post-300 m metabolic responses (pH, $[HCO_3^-]$, SaO_2 and [La]) of ELI and REG groups, the Student *t*-test for unpaired data was applied. Effect sizes (ES) and power medium were calculated using Cohen's *d*. The Pearson test (and corresponding 95% confidence intervals, 95% CI) was used to determine whether there was a significant relationship between correlate blood metabolic data for the 25 subjects and 300-m performances (expressed in % women and men world record). Effect sizes of 0.8 or greater, around 0.5 and 0.2 or less were considered as large, moderate, and small, respectively. The level of significance was set at $P < 0.05$. All statistical analyses were conducted using Statview software (version 5.0), excepted for ES (45).

C. RESULTS

Performance

The mean performances for REG and ELI subjects are presented in Table 1.

Table 1: Mean ± SD values of 300-m performances expressed in seconds (s) and percentage of 300-m men (30.85 s) and women (34.1 s) world record respectively (%) in elite (ELI) and regional (REG) athletes

	REG n=14	ELI (men) n=5	ELI (women) n=6
300-m performance (s)	41.2 ± 1.8	33.9 ± 1.4	38.9 ± 1.4
300-m performance (%)	75.0 ± 3.4	89.2 ± 5.8	

Metabolic responses

No difference between the post warm-up metabolic data was observed between ELI and REG groups (P>0.05). These metabolic data post 300m are reported in Table 2, and were significantly different between ELI and REG runners. Four minutes after the end of the 300-m test, the lowest pH, SaO_2, [HCO_3^-] values were observed among elite runners (6.98, 93 % and 6.1 mmol.L^{-1}). The greatest [La] was estimated in an elite runner (27 mmol.L^{-1}). The mean lactate accumulation expressed in mmol.L^{-1}.s^{-1} is estimated to 0.47 ± 0.06 for REG runners and 0.59 ± 0.11 for ELI runners, reaching 0.75 for the best runner.

Table 2: Mean ± SD values for blood parameters measured 4 min after the end of the 300-m running test in elite and regional subjects.

		pH	**[HCO_3^-]**	**SaO_2**	**[La]**
ELI	PWU	7.41 ± 0.03	23.8 ± 2.3	96.2 ± 2.1	3.2 ± 1.9
	P300	**7.07**** ± 0.05	**8.1** * ± 1.5	**94.7** * ± 1.8	**21.1** * ± 2.9
REG	PWU	7.43 ± 0.04	25.0 ± 2.8	96.0 ± 2.8	4.3 ± 2.9
	P300	7.14 ± 0.05	9.8 ± 1.8	96.2 ± 1.6	19.1 ± 1.2
d (PM)		-1.40 (0.84)	0.85 (0.72)	0.87 (0.73)	-0.82 (0.73)

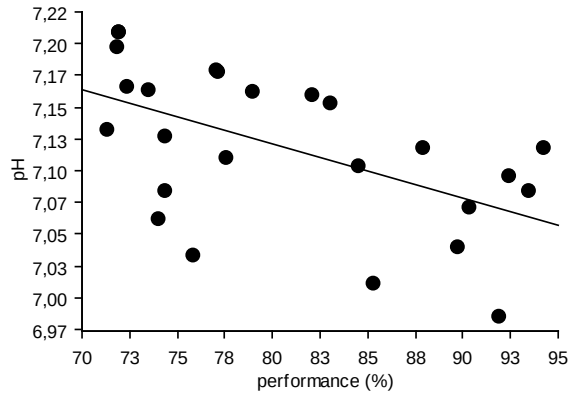
PWU: post warm-up, P300: post 300m

In bold, significant difference between P300 ELI (elite) and REG (regional) after the 300-m test, ** P<0.01, * P < 0.05, *d* = Cohen's d (*Power Medium*), (SaO_2): haemoglobin O_2 saturation in %, [HCO_3-] sodium bicarbonate concentration and [La] blood lactate concentration in mmol.L^{-1}.

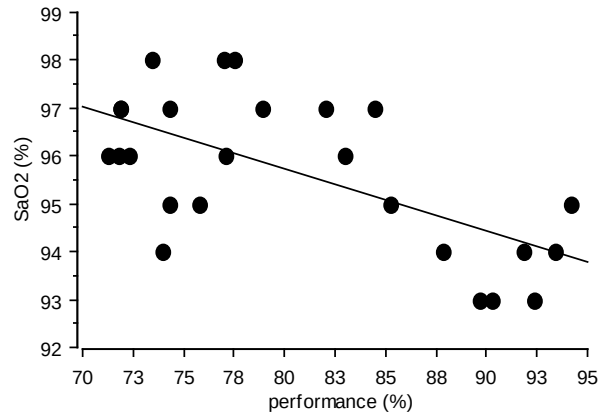
Relationships

When considered together (ELI and REG, n=25), performance (in % of the world record) was related to metabolic responses for pH (r=-0.55, P < 0.01, CI (-0.77 to -0.20); Figure 1a), SaO_2 (r=-0.64, P < 0.001, CI (-0.82 to -0.33); Figure 1b) and [HCO_3^-] (r=-0.40, P < 0.05, CI (-0.68 to -0.00) and [La] (r=0.44, P < 0.05, CI (0.05 to 0.71).

Figure 1a and 1b: Relationship between the 300-m performance expressed in % world record (elite and regional) and blood pH (a) and SaO_2 (b) values measured 4 min after the 300-m test.

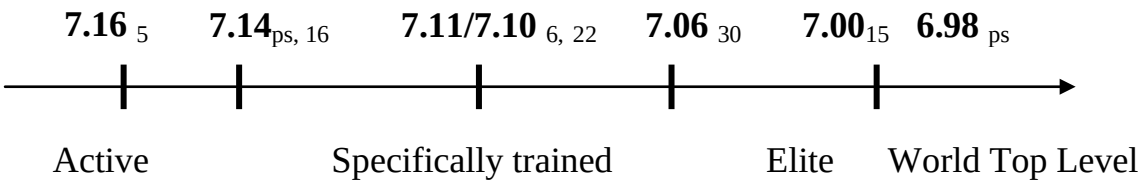


1 a: n= 25, r=-0.55, P<0.005



1 b: n=25, r=-0.64, P<0.0005

Figure 2: Published values of pH recorded after around 30 sec of maximal exercise
In italic the references, ps= present study



D. DISCUSSION

This study was designed to determine and compare specific metabolic responses of elite and regional runners after a maximal 300-m sprint. The results demonstrated that ELI runners reached lower pH, [$HCO3^-$], and SaO_2 values and greater [La] values than the REG athletes and that the best was the 300-m performance, the lowest were the pH, SaO_2 and [HCO_3^-] values ($P < 0.01$, 0.001 and 0.05, respectively) and the greatest was the [La] ($P < 0.05$).

The present [La] values estimated for the elite and regional groups are in line, respectively, with the 21 $mmol.L^{-1}$ value observed in the field (26) for 400-m elite runners and

the 15 mmol.L^{-1} value measured in less-trained or talented counterparts (24, 39) after supramaximal exercises. In elite athletes, this greater [La] could result from an increased production of La, due to higher glycolytic flux improved with sprint training (27, 29), which could allow an increase in work performed during the acute 300-m sprint. This greater value could also result from an increase in MCT content (44) and an improvement in sarcolemmal La transport capacity between muscle and blood (21), which has been reported to be higher in well-trained athletes compared to untrained and trained subjects, with the highest lactate transport capacity measured in a bronze medallist athletes at the 1992 Olympic games in 4-km bicyclists (36). Furthermore, for the study herein, we are aware that a single instant used for the post-300-m metabolic measurements do not permit discussion about the influence of training on lactate kinetics.

Interestingly, the lactate accumulation (mmol.L^{-1}.s^{-1}) estimated in the present study (0.59) on 300-m distance, is not greater than the value calculated on very short distances (0.56 for 40 to 80 m, 0.59 for 100 m in highly-trained sprinters) (18). In the muscle, the rate of lactate production has been shown to decrease from 30 s (0.57) to 1 and 2-3 min (31) (0.43 and 0.20 mmol.s^{-1}.kg $muscle^{-1}$), which could indicate that the maximal glycolysis rate is obtained from very short durations, and is maintained, but not increased, until 35 s of exercise. To date, the 0.75 mmol.L^{-1}.s^{-1}value recorded in the present study for the best runner (world finalist) is the greatest value obtained in a running exercise, and could be considered a benchmark criterion of expertise for sprint running. Compared to the available data presented in the literature, the present results show a progressive decrease in the post-exercise pH value with the level of expertise (Figure 2). The regional and national levels are, respectively, characterized by values around 7.15 (present study and (5)), and 7.10 (30), whereas elite athletes reach values around 7.0 (15) or less for the world top-elite ones (present study, and 23). Surprisingly, elite athletes should also be characterized by a better buffering system that limits decrease in pH for a given lactate production (7) than less-successful athletes. Then, in addition to the improvement of the buffer capacity by sprint training (42), the correlation between performance and final pH demonstrates for the first time, that elite runners tend to reach a lower pH value for the same quantity of work than REG runners.

In relation to this drop in pH, lower [HCO_3^-] values are observed in elite (8.4 $\pm$ 1.5 mmol.L^{-1}) compared to REG runners (present study and (22)) and the relationship between chronometric performance and blood [HCO_3^-] also indicates an expertise effect on the drop of [HCO_3^-]. In this line, a correlation has been reported between 400-m race performance and decrease in the excess base (EB) after a running test, performed after 10 days in hypoxia (35). In addition, lower [HCO_3^-] values are reported in sprinters compared to endurance runners following a maximal 1-min exercise (30), which could also suggest an effect of the training specificity. Furthermore, the present pH and [HCO_3^-] values were higher than those obtained after a 400-m running exercise (6.81 and 5 mmol.L^{-1} after a 400-m running test performed in less than 55 s) (15) or a MART test (35). We can then speculate that the duration of an acute 300-m exercise is not long enough to induce the lowest values of blood pH and [HCO_3^-] decrease. Therefore, in order for athletes to reach their pH limits with acute maximal exercise, coaches must use a distance run with a duration of exercise superior to 35 s.

Furthermore, the generation of H^+ is quantitatively linked to the accumulation of lactate, in accordance with the classical unitary H^+/lactate stoichiometry of glycolysis (28, 41), and probably to the high-intensity exercise duration. Then, in order to obtain the best performance, elite and REG athletes have to reach extreme muscle fatigue, which induces muscle, and then, blood metabolic perturbations, as observed in the present study, but also alterations in the system of regulation of lactate/proton exchange (2, 9, 11) and muscle buffer capacity (1). Although these physiological perturbations are expected to have detrimental physiological effects during acute (2, 9, 11) and chronic (3, 43) exercises, we can therefore

speculate that training in elite athletes does not protect against exhaustive exercise-induced metabolic and lactate transport alterations, but allows maintaining exercise with large metabolic perturbations since elite athletes are able to support a greater acidosis, and therefore, produce more [La] than less-trained subjects.

According to Nielsen (33), lactate is produced until amounts, which do not decrease pH until a level where a decrease in PaO_2 causes a large change in SaO_2; indeed, a pH of 6.74 would reduce SaO_2 to below 80%, and become critical for VO_2 (33). The lowest SaO_2 values (93%), recorded in the present study, were not as low as expected, and should correspond to a pH value around 7.20. In track running, there is no possibility to perform a blood collection just at the end of the exercise, due to the deceleration of the athlete, and 1 min at least is required to start the sampling. Then, we chose to collect the only sample 4 min after the end of the 300-m, and therefore the SaO_2 results did not correspond to the end of the exercise. Nevertheless, as previously demonstrated (13, 33, 37), chronometric performance is correlated to the lower SaO_2 values, which are lower in elite athletes than in less-experienced athletes.

In conclusion, this study demonstrated that despite deleterious effects on the O_2 saturation of haemoglobin (SaO_2), the 300-m performance of elite compared to less-successful athletes is followed by a greater blood acidosis. Our data also show that the better the 300-m performance is, the lower the blood pH, $[HCO_3^-]$, SaO_2 are and the greater the [La] values. Improvement in cellular regulations between muscle and blood (29, 32) allows the best trained-athletes to increase the muscle and blood H^+ concentrations, and, decrease blood $[HCO_3^-]$ to the lowest values, but further studies are required to explain how elite athletes could maintain a high rate of ATP hydrolysis before enzymatic inhibitions occur (8).

E. PRACTICAL APPLICATIONS

This study demonstrates that the best runners are characterized by a higher decrease in blood pH and $[HCO_3^-]$ values than less-trained runners for a same amount of work, indicating for coaches and scientific assistants that metabolic information from non-elite performers may not be transferable or specific enough to influence training coach practices in an individual elite athlete.

Further, elite athletes appear to be able to limit decrease in pH for a given [La] production, but also to sustain an extreme pH value before enzymatic inhibitions could occur, and therefore, to perform longer with a given pH. This was demonstrated in the field by the fact that elite 400-m athletes perform their best performances with a higher decrease in velocity in the last straight line than national athletes (14). We can then hypothesize that some specific long sprint training sessions, in which well-trained runners could reach extreme blood pH values, are necessary to achieve these characteristics. Indeed, in elite athletes, compared to 400 m (23), the 300-m distance performed around 33 s (men) and 39 s (women) could be not long enough to maximally alter blood pH and $[HCO_3^-]$ with only one repetition. Nevertheless, for these reasons, 300 m could appear as an interesting intermediate distance to stimulate the anaerobic system with beginners or young athletes, who have a less-developed anaerobic system (38)

Furthermore, the blood lactate accumulation values ($mmol.L^{-1}.s^{-1}$) recorded in this study, and compared with the literature, could indicate that the maximal glycolysis rate is obtained from the 100-m distance, and is maintained, but not increased, until 35 s of exercise. This result confirms that shorter distances or exercise durations than usually indicated (12) are adapted to improve the maximal rate of the glycolysis. To date, the 0.75 $mmol.L^{-1}.s^{-1}$value recorded in the present study is the greatest value obtained in an acute running exercise, and could be considered a benchmark criterion of expertise for sprint running.

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