Effect of Training on the Physiological Factors of Performance in Elite Marathon Runners (Males and Females)

V. Billat[1,3]
A. Demarle[1]
M. Paiva[2]
J. P. Koralsztein[3]

Abstract

This study examined the effect of 8 weeks of specific marathon training before the Olympic trials on the physiological factors of the marathon performance in top-class marathon runners. Five males and four females, age 34 ± 6 yr (± SD) with a marathon performance time of 2 h 11 min 40 s ± 2 min 27 s for males and 2 h 35 min 34 s ± 2 min 54 s for females, performed one test ten and two weeks before the trials. Between this period they trained weekly 180 ± 27 km and 155 ± 19 km with 11 ± 7 and 7 ± 0% of this distance at velocity over 10000 m for males and females, respectively. The purpose of this test was to determine in real conditions i. e. on level road: $\dot{V}O_2$peak, the energy cost of running and the fractional utilisation of $\dot{V}O_2$peak at the marathon velocity (vMarathon). They ran 10 km at the speed of their personal best marathon performance on a level road and after a rest of 6 min they ran an all-out 1000 m run. $\dot{V}O_2$peak increased after the 8 weeks of pre-competitive training (66.3 ± 9.2 vs 69.9 ± 9.4 ml × min^{-1} × kg^{-1}, $p = 0.01$). Moreover, since the oxygen cost of running at vMarathon did not change after this training, the fractional utilization (F) of $\dot{V}O_2$peak during the 10 km run at vMarathon decreased significantly after training (94.6 ± 6.2% $\dot{V}O_2$peak vs 90.3 ± 9.5% $\dot{V}O_2$peak, $p = 0.04$). The high intensity of pre-competitive training increased $\dot{V}O_2$peak and did not change the running economy at vMarathon and decreased the fractional utilization of $\dot{V}O_2$peak at vMarathon.

Key words
Training · oxygen uptake · running · female

Introduction

The variability of the average speed of performance in marathon has been reported to be explained by 50% for $\dot{V}O_2$max alone to attain 72% in combination with the fractional utilisation of $\dot{V}O_2$max (F) and the energy cost of running (Cr) [19]. This was shown in an heterogeneous group of runners, their performances varying from 149 to 226 min [19]. These physiological factors involved in the marathon performance [15,18,39] have been reported to be sensitive to training [34]. Recently, Billat et al. [13] have reported that $\dot{V}O_2$max was the discriminant factor of performance (average speed on marathon) between elite runners (<2 h11 min) and high-level runners (2 h 11 min 01 s – 2 h 16 min). However, to our knowledge, no study has measured F and Cr in real conditions i. e. on the road and at the marathon velocity. Indeed in most of the studies F has been calculated from a $\dot{V}O_2$max measured on an inclined treadmill [37].

During the 20th century, interval-training has been used empirically by elite long-distance runners and validated by scientists [7,8]. Recently, it has been shown that high-level runners trained at a relatively faster velocity than their low-level counterparts [13] especially at velocities close to the velocity v3000m-v10000m which elicited $\dot{V}O_2$max [1,12,16]. Indeed, in elite runners, the velocity over 10000 m (v10000) corresponds to vΔ50 which was defined as the median velocity between the velocity associated with $\dot{V}O_2$max in an incremental test (v$\dot{V}O_2$max) and

Affiliation
[1] Faculty of Sport Science, University of Lille, France
[2] Faculty of Sport Science, University of Porto, Portugal
[3] Centre de médecine du Sport CCAS, Paris, France

Correspondence
V. Billat · Centre de médecine du sport CCAS · 2 avenue Richerand · 75010 Paris · France ·
Phone: +33 1 42 02 08 18 · Fax: +33 1 42 39 20 83 · E-Mail: veronique.billat@wanadoo.fr

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the velocity at the lactate threshold (vLT). Moreover, v∆50 has been described as being a velocity for which the slow component of oxygen uptake may lead the oxygen consumption to its maximum [12,16,23].

This high-intensity interval-training is performed in the pre-competitive phase of training i. e. 6 – 8 weeks before the competition. Hewson and Hopkins [26] examined the specificity of training for 6 months and its relation to the performance of experienced middle- and long-distance runners from 800 m to the marathon (their personal best was of 82 % of sex- and age- group world records). They reported that the pre-competitive phase lasted 6 weeks (after the build-up of 12 weeks and before the competitive and post competitive ones of 5 and 3 weeks respectively). During this pre-competitive phase, the intensity of hard continuous running increased by 1 km × h^{-1} (18 vs 17 km × h^{-1}), the time run in interval training increased by almost two thirds (30 min vs 18 min) and the duration of moderate running decreased by about 12 %. This study accurately described the training input in the four different phases of the competitive year. However, this report did not provide data concerning changes in physiological factors during endurance performance but only the modifications of performance (average velocity computed from the time on the distance run and expressed in percentage of the world record of the distance).

In general and especially during the Olympic year, marathoners run 2 marathons per year. During the Olympic year they have to run trials 5 months before the Olympic Marathon. The purpose of this study was to examine the impact of the 8 weeks pre-competitive phase on the physiological factors of marathon performance in top-class male and female runners: $\dot{V}O_2$max, the energy cost of running and the fractional utilization of $\dot{V}O_2$max at the marathon velocity (vMarathon) [26].

Methods

Subjects

Nine elite marathon runners from the Portuguese and French national teams were 5 males and 4 females (mean ± SD), age 34 ± 6 years; height 172 ± 3 and 162 ± 5 cm; body mass 60 ± 3 and 50 ± 5 kg, for males and females respectively. They had a marathon performance time of 2 h 11 min 40 s ± 2 min 27 s and 2 h 35 min 34 s ± 2 min 54 s for males and females respectively. Written informed consent was given before participation in the experiments in accordance with the institutional human subject's guidelines (University of Lille).

Experimental design

Since it is extremely difficult to ask Olympic athletes to run several tests during the Olympic year, only one test was carried out before and after the pre-competitive training phase. In this test, the subjects ran 10 km on a level road at their personal best marathon performance. This velocity was the marathon velocity (vMarathon). The experiments were carried out between 10 : 00 h and 18 : 00 h according to the subject's choice in a climate of 8°-13 °C in France and 13°-18 °C in Portugal without wind. The runners were asked to have the same training and food as before a marathon. Runners followed a pacing cyclist travelling at the required velocity. The pace was checked every 200 m during the first km and then every 500 m. Visual marks were set at 100 m intervals along the road for the first km and then every 500 m.

After a warming-up similar to that prior to a race (20 min of easy running at 60 % of the marathon velocity), subjects ran 10 km on a level road at their vMarathon. Six minutes after, the subject had to run as fast as possible over 1000 m to determine $\dot{V}O_2$peak according to Astrand and Saltin [1] who reported that an all-out exercise lasting between 3 and 8 min allowed to reach $\dot{V}O_2$max and to Billat et al. [12] for shorter events [12]. The average velocity over 1000 m was termed v1000 m and was expressed as a percentage of vMarathon.

Data collection procedures

Blood lactate samples were collected: after the warm-up, (at the third kilometer of the 10 km run when the runners stopped for 15 seconds) then 1 and 3 minutes after the end of the 10 km and the end of the maximal 1000 m run. Blood lactate samples were duplicated in the recovery phase. The highest of these post-run blood lactate values was taken as the maximal blood lactate for 10 km at vMarathon and v1000 m. The capillary blood sample obtained from the finger-tip was analysed for lactate concentration (Ysi 27 analyser, Yellow Spring Instrument, Yellow Spring, OH).

Measurement of $\dot{V}O_2$ was carried out throughout each test using a telemetric system weighing 0.7 kg which was worn on the back and abdomen ($K4b^2$, Cosmed, Roma, Italy) [25]. Expired gases were measured, breath-by-breath, and averaged every 5 seconds for the modelling of oxygen kinetics (see below) and every 30 seconds for the determination of $\dot{V}O_2$peak. $\dot{V}O_2$peak was defined as the highest 30-s oxygen uptake value reached in the all-out run on 1000 m. The response times of the oxygen and carbon dioxide analysers are less than 120 ms to reach 90 % of the flow sample. The ventilation range of the flow-meter is from 0 to 300 L × min^{-1}. The time delay of the gas analyser (time necessary for the gas to transit through the sampling line before being analysed) is about 500 ms. This time delay is automatically measured and is considered in the calculations when a delay calibration procedure is performed according to the manufacturer's specifications. The algorithms used in the $K4b^2$ have been developed according to Beaver et al. [4]. Before each test, the O_2 analysis system was calibrated using ambient air, whose partial O_2 composition was assumed to be 20.9 % and a gas of known CO_2 concentration (5 %) ($K4b^2$ instruction manual). The calibration of the turbine flow- meter of the $K4b^2$ was performed with a 3-L syringe (Quinton Instruments, Seattle, WH). In the 1000 m exhaustive run, maximal $\dot{V}O_2$ was defined as the highest $\dot{V}O_2$ obtained in two successive 15 s interval runs.

Oxygen kinetics parameters

The breath-by-breath oxygen uptake data were reduced to 5 s stationary averages. These data were then smoothed, using a 3-step average filter, to reduce the noise so as to enhance the underlying characteristics (Data management software, Cosmed, Roma, Italy). These data were finally fitted to distinct models [3,36,37] using an iterative nonlinear regression in Sigma Plot software (SPSS, Chicago, IL, USA). The Fisher test, which was performed by the Sigma Plot software, was used to choose the model for which the fit was associated with the highest F value.

Energy cost of running

Bernard et al. [6] demonstrated that the $\dot{V}O_2$ slow component after the third minute would modify the gross energy cost of running. To compute the energy cost of running, we checked that at vMarathon the oxygen kinetics was monoexponential, and that our subjects reached their $\dot{V}O_2$ steady-state (they achieved more than 99% of the asymptotic increment in $\dot{V}O_2$ above the resting value) in a duration equal to $5 \times \tau$ due to the mathematical property of the monoexponential. Therefore, all of the subjects had reached their $\dot{V}O_2$ steady-state before the second kilometer (run in 6 min 10 s for the faster runner of this study).

The energy cost of running (Cr in $ml \times km^{-1} \times kg^{-1}$) was measured according to the equation of di Prampero [18)]:

$$Cr = \dot{V}O_2marathon/vMarathon \quad (eq.\ 1)$$

Where $\dot{V}O_2$marathon is the average $\dot{V}O_2$ ($ml \times min^{-1} \times kg^{-1}$) measured between the second and the third kilometer at the marathon velocity (vMarathon in $km \times min^{-1}$). Since the $\dot{V}O_2$ at rest is included, this is the gross energy cost of running.

The blood lactate accumulation was not taken into account in the calculation of the energy cost of running. Indeed even blood lactate accumulation was considered as negligible in the calculation of the energy cost of running since it represents only 3 ml $O_2 \times kg^{-1} \times mM^{-1}$ of blood lactate which is the oxygen equivalent of the lactate according to Margarian et al. [30]. For instance, for a male of 60 kg having a blood lactate accumulation of 7 mM, this represents an oxygen equivalent of 3 ($ml \times min^{-1} \times kg^{-1}$) × 60 (kg) × 7 (mM accumulated during the10 km) = 1.260 L, i.e. 1% of the volume of oxygen consumed for the 10 km run in 31 min: 0.9 (F) × 72 ($\dot{V}O_2max$ in $ml \times min^{-1} \times kg^{-1}$) × 60 (kg) × 31 (min) = 120.5 L.

Training log analysis

Before participation, the subjects performed longer weekly distance but with less intensive effort (only one session per week instead of two) (see results section). This 8 weeks of pre-competitive training for the marathon trials was analysed from the training log of the coach. Moreover the runner was asked for his/her typical week. Training sessions were classified according to the range of velocities: < vMarathon, = vMarathon, = v1/2-marathon (21.1km), = v10000 m and = v3000 m. The total distance and number of sessions run per week were also computed.

Data analysis

After having checked the equality of the variance, a paired Student's *t* test was used to compare physiological factors with marathon performance before and after the eight weeks of the pre-competitive phase. Correlation between energetic parameters and marathon performance times were determined using the non-parametric test of Spearman. These results are presented as mean ± standard deviation (SD) test. Significance was set at $p < 0.05$ for all statistical analysis.

Results

Training (Table 1)

During this period runners trained weekly 180 ± 27 km and 155 ± 19 km with 11 ± 7 and 7 ± 0% of this distance at v10000 m or v3000 m for males and females respectively. This weekly total distance run represented 90% of the weekly training distance of the previous training phase (build up phase). The marathon runners maintained one long run of more than 105 min every 10 days in which they included 10 km at vMarathon.

Table **1** Training log during the pre-competitive Marathon phase

Training characteristics	*Males (n = 5)*	*Females (n = 4)*
Total weekly distance (km)	180 ± 27	155 ± 19
Number of sessions per week (n)	12.0 ± 2	11 ± 2
Duration of long training session (min)	116 ± 26	93 ± 24
Weekly distance run @ vMarathon (km) inside the long training session	12.5 ± 3.3	8.7 ± 1.8
Weekly distance run @ v1/2 marathon (km)	12.5 ± 3.5	8.8 ± 1.9
Weekly distance run @ v10000 m (km)	11.2 ± 1.1	6.8 ± 2.2
Weekly distance run @ v3000 m (km)	8.4 ± 0.8	5.5 ± 0.7
% of weekly distance run @ v3000 m or v10000 m	11 ± 7	7 ± 1

Effect of training on physiological factors for performance on marathon (Table 2)

The maximal oxygen consumption increased significantly ($p = 0.01$) after 8 weeks of this pre-competitive training (Table **2**). The marathon runners improved significantly ($p = 0.03$) their velocity over 1000 m after training (Table **2**). However, the improvement of the velocity over 1000 m was not correlated with the one of $\dot{V}O_2peak$ (rho = 0.325, $p = 0.26$).

Moreover, since the oxygen cost of running at vMarathon did not change after this training, the fractional utilization (F) of $\dot{V}O_2peak$ during the marathon decreased significantly (94.6 ± 6.2% $\dot{V}O_2peak$ vs. 90.3 ± 9.5% $\dot{V}O_2peak$, $p = 0.04$) after training. Blood lactate accumulation between the start and the end of 10 km-run was unchanged after training and remained high (7.2 ± 2.6 vs 7.3 ± 3.4 mM, $p = 0.7$). However blood lactate accumulation between the 3rd and the 10th kilometer decreased significantly (3.9 ± 1.9 vs 2.0 ± 1.3 mM, $p = 0.01$). This means that after training athletes stabilized their blood lactate more between the third and the tenth after the early increase in the first three kilometers.

The $\dot{V}O_2$ time course during the 10 km run at vMarathon and during the all-out 1000 m run was better fitted by the single exponential model. The time constant of the oxygen uptake kinetics (i.e. the time to reach 63% of the $\dot{V}O_2$ steady state) during both the 10 km run at vMarathon and the all-out 1000 m run remained unchanged after training (Table **2**).

Table **2** Physiological factors for marathon performance time before and after pre-competitive training phase

Variables	***Before training***	***After training***	***p***
Mass (kg)	54.9 ± 12.8 59.4 ± 2.2♂ 49.2 ± 4.9♀	55.8 ± 6.3 60.0 ± 2.5♂ 50.6 ± 5.7♀	0.08
F$\dot{V}O_2$peak (%) at vMarathon	94.6 ± 6.2	90.3 ± 9.5	0.04*
Cr (ml × km^{-1} × kg^{-1})	204 ± 17	206 ± 22	0.76
v1000m (km × h^{-1})	20.2 ± 2.1	20.7 ± 2.0	0.03*
Δ Lactate 10 – 3 km (mM)	3.9 ± 1.9	2.0 ± 1.3	0.01***
Δ Lactate 10 – 0 km (mM)	7.2 ± 2.6	7.3 ± 3.4	0.76
HR at 3rd km at vMarathon (bpm)	166 ± 5	167 ± 7	0.58
HR at 10th km at vMarathon (bpm)	170 ± 5	169 ± 7	0.38
$\dot{V}O_2$peak (ml × min^{-1} × kg^{-1})	66.3 ± 9.2 69.8 ± 11.0♂ 62.6 ± 4.1♀	69.9 ± 9.4 73.9 ± 11.5♂ 65.0 ± 0.8♀	0.01***
HR_{max} (bpm)	175 ± 6	173 ± 6	0.57
RER_{max}	1.07 ± 0.06	1.06 ± 0.07	0.41
Maximal blood lactate (mM)	10.9 ± 3.6	10.9 ± 3.1	0.44
τ_1 at vMarathon (s)	31 ± 3	35 ± 3	0.21
τ_1 at v1000 m (s)	27 ± 17	22 ± 12	0.11

* $p < 0.05$; **$p < 0.02$; ***$p < 0.01$. $\dot{V}O_2$peak is the maximal $\dot{V}O_2$ reached in the all-out 1000 m run (data were also done for male "♂" and female "♀" separately). F$\dot{V}O_2$-peak is the fractional utilisation of $\dot{V}O_2$peak at the marathon velocity (vMarathon); Cr is the gross energy cost of running; v1000 m is the average velocity over the all-out run on 1000m; Δ Lactate 10 – 3 km is the blood lactate accumulated between the third and the tenth kilometer of the 10-km run at vMarathon; Δ Lactate 10 – 0 km is the blood lactate accumulated between the start and the tenth of the 10-km run at vMarathon; HR at 3rd kilometer at vMarathon is the heart rate at the third kilometer of the 10-km run at vMarathon; HR at 10th kilometer at vMarathon is the heart rate at the tenth kilometer of the 10-km run at vMarathon; HR_{max} is the maximal heart rate obtained in all the 1000 m all-out runs; RER_{max} is the maximal rate of expiratory ratio obtained in all the 1000 m all-out runs; Maximal blood lactate is the maximal blood lactate obtained at the end of the 1000 m all-out run; τ_1 at vMarathon is the time necessary to reach 63 % of the steady-state $\dot{V}O_2$ value at vMarathon; τ_1 at v1000 m is the time necessary to reach 63 % of the steady-state $\dot{V}O_2$ value in the all-out 1000 m run.

Discussion

To our knowledge, this is the first report concerning the training of high-level marathoners in the pre-competitive phase and its effect on the physiological determinants of marathon performance in real conditions. Even in these high-level runners, $\dot{V}O_2$max was improved by 5.4 % after 8 weeks of intensive training including 10 % of the distance at velocities above v10000. Among these 9 runners only 2 (males) were finally selected for the Olympics (one finished at the 11th and the other at the 18th place after having received a flag poke from a spectator at the 19th kilometer).

Training

The pre-competitive phase of marathon training included interval-training at v3000m and v10000m. These intensities are supposed to elicit $\dot{V}O_2$max and it has been reported that such interval-training sessions allow the athlete to elicit $\dot{V}O_2$max for a long time (about 10 minutes) [11,16]. The runners performed one weekly session of short interval-training at v3000 m (20 × 400 m with active pauses of 100 m run in 45 s or 4 – 5 × 1000 m with active pauses of 400 m run in 2 min) and at v10000 (3 – 4 × 2000 m with active pauses of 400 m run in 2 min). This kind of interval-training which is efficient in improving $\dot{V}O_2$max in a non athletic population [35] also seems to be efficient in improving $\dot{V}O_2$max in high-level marathoners even after the build-up period where training focuses on long-distance run at velocity equal or below vMarathon. The total distance run weekly was equal to 90 % of that previously run (180 km vs 200 km for males and 155 km vs 170 km for females). This overall distance was less than the one reported in the literature for high-level marathoners [31]. However, qualitative rather than quantitative training could be essential to be successful in marathon for the 21th century where the velocity is close to 20 km × h^{-1} for males and 18 km × h^{-1} for females. Males can, however, have two successive winter weeks for reaching 220 – 240 km and 190 km for females.

Training effect on the physiological factors of performance during the marathon

A novel finding of our study was that in elite marathoners a high-intensity interval-training performed during 8 weeks of the pre-competitive phase allowed them to improve both $\dot{V}O_2$max and the ability to run an all-out 1000 m run after 10 km run at vMarathon in a faster time. This fact had already been reported in less trained subjects but for v$\dot{V}O_2$max only [10,17,33]. In these studies, $\dot{V}O_2$max has been reported to be enhanced by 5 to 10 % even in already endurance fit athletes by a programme of interval-training (twice a week for 4 weeks). The velocity of interval training used was equal to the minimal velocity associated to $\dot{V}O_2$max in an incremental test (v$\dot{V}O_2$max) and the duration was between 50 to 75 % of the time limit at v$\dot{V}O_2$max. This training protocol at v$\dot{V}O_2$max was close to the interval-training at v3000 m used by these high-level marathon runners. Moreover, at v3000 m the velocity was not different from v1000 m (20.7 ± 2 vs 21.2 ± 1.8 k × h^{-1} for v1000 and v3000 m, respectively, $p = 0.09$). These runners also carried on long interval-training at v10000 m i.e. 3 – 4 × 2000 m in 5 min 40 s with a recovery of 400 m run in 2 min. However, in less trained runners, Demarie et al. [16] have reported that a very similar interval-training protocol with 4 repetitions at vΔ50 for 5 min (half of the time to exhaustion at vΔ50) and a recovery run at 50 % of v$\dot{V}O_2$max (for 25 % of the time to exhaustion at vΔ50) elicited $\dot{V}O_2$max for 11 minutes. Despite the fact that high-level runners have currently no $\dot{V}O_2$ slow component at vΔ50 [9], we can hypothesize that these marathon runners reached $\dot{V}O_2$max at least in the last repetitions of the long interval training run at v10000 m. Further investigations may confirm this hypothesis.

This study reported no acceleration of the oxygen uptake kinetics (decrease of the time constant τ) which is not in accordance with previous studies performed on less trained subjects at the same and higher relative intensity (70 – 90 % of $\dot{V}O_2$max) [24,32,40]. In a recent study, our group reported that the time constant (τ_1) was reduced by 46 % after 8 weeks of interval-training with two weekly sessions at vΔ50 [17].

We did not observe any improvement in the oxygen cost of running at vMarathon. This could be due to the fact that runners ran a too short weekly distance at vMarathon (6.9 ± 1.9 % and 5.6 ± 1.1 % of weekly distance for males and females, respectively). Blood lactate accumulated on the tenth kilometer was similar before and after training, therefore any modification of blood lactate accumulation or oxygen deficit would not affect the evaluation of the energy cost of running at vMarathon by the oxygen cost of running. The runners have a relatively high gross energy cost of running compared with those reported in the literature. In our study, some of these high-level marathoners who are more than 34 years old (36 yr for one of the two males selected for Sydney) were previously high-level middle-distance runners. Lacour et al. [29] demonstrated that the best v$\dot{V}O_2$max values were found in middle-distance runners and neither were associated with the lower energy cost of running.

Similarly we did not observe an improvement of $F\dot{V}O_2$max which was very high after the build-up training phase at the beginning of this intensive training period. $F\dot{V}O_2$max was higher than the one reported in the literature where F has probably been underestimated due to the fact that $\dot{V}O_2$max was measured on an inclined treadmill (eliciting a larger muscle mass). After intensive training, $F\dot{V}O_2$max decreased due to the increase of $\dot{V}O_2$max without any modification of the oxygen cost of running.

Surprisingly, the total blood lactate accumulation (10 km-start value) did not change and remained relatively high (7 mM). Georges Brooks' group have demonstrated that endurance training enhanced the whole body and leg lactate clearance at a high relative power output [5,20]. This had already been reported by Fukuba et al. [22] who measured the kinetics of the blood lactate after a 30 W × $\min^{-1}$ ramp cycle ergometer test to exhaustion. Marathoners performed many long – slow distance runs in winter and they probably had already enhanced their lactate clearance. Moreover it may also be possible that after the intensive training performed in the pre-competitive period, the blood pH is lower for the same blood lactate concentration [28]. The blood lactate measured in two of these subjects at the end of the Paris marathon in April 2000 was much higher than those reported to be specific for marathon: 6 and 8 mM vs 3.3 mM [21]. These two marathoners had neither accelerated during the last kilometre nor performed a sprint at the arrival.

Methodological limitations

The purpose of this study was to evaluate the physiological factors of marathon by using only one test. Indeed, the runners preferred training rather than doing tests especially if the results were not satisfactory especially in the pre-tests. The first limitation of this study lies in the measurement of $\dot{V}O_2$max in an all-out 1000 m run performed after 10 km run at vMarathon (and 6 min of rest). Hence we checked in two of these subjects that $\dot{V}O_2$peak, i.e. the highest $\dot{V}O_2$ obtained in the all-out 1000 m, was not different from those measured in an incremental protocol (with stages of 3 min and increments of 1 km × h^{-1} until exhaustion). We also repeated it in 10 marathoners of average level (3 h 10 ± 10 min, unpublished data). However, high-level runners performed the 1000 m in less than 2 min 40 sec below the minimal duration (3 min) recommended by Saltin and Astrand [1] required to reach $\dot{V}O_2$max. However, as underlined in the methods section, the oxygen kinetics was rather fast in these fit runners (τ =25 s) and we can, therefore, assume that the steady-state of $\dot{V}O_2$ was reached in this delay (5 × 25 = 2 min 05 s). However, we are not sure that the runners reach a steady-state of $\dot{V}O_2$ at $\dot{V}O_2$max since the runners who had previously a $\dot{V}O_2$max test (in the context of another scientific study, in Paiva's personal communication) on an inclined treadmill had a higher value of peak $\dot{V}O_2$. We can, however, consider that the maximal $\dot{V}O_2$ on a level road represents the specific maximal oxygen consumption using the muscle mass for level running. Moreover, the end rate of expiratory ratio (more than 1.05), the heart frequency (equal and greater than 90 % of the predicted maximum for the subject's age) and the blood lactate (>10 mM) measured after the all-out 1000 m were in agreement with all the criteria of maximal $\dot{V}O_2$ attainment [2]. Moreover, Billat et al. [12] have reported less trained subjects were able to reach $\dot{V}O_2$max in all-out run equal to 1min (400 m). However, it may be preferable to fix a duration of 3 min for all the runners to determine the $\dot{V}O_2$max rather than a distance which corresponds to a different duration according to the runner's velocity.

Another methodological restriction is the possibility to estimate the energy cost of running over a marathon by only a 10 km run at the marathon velocity. Brückner et al. [14] had measured the influences of the distance covered on the energy cost of running a marathon. These measurements were carried-out in ten amateur runners on a treadmill after 15, 32 or 42 km on an indoor track at a constant speed equal to their vMarathon. The increase of Cr with the distance was equal to 0.08 % per km between the 32th and 42 th kilometer. However, we did not observe such Cr increase in an official marathon (Paris, April 2000) where a subject ran at constant speed with a K4b^2 (16.3 km × h^{-1} i.e. in 2 h 35 min, unpublished data). Therefore we can deduce that 10 km are sufficient to have a good estimate of the energy cost of running in high-level marathoners.

Conclusion

The high intensity of the pre-competitive training including 10 % of the total distance run at v3000 m and v10000 m increased significantly $\dot{V}O_2$peak in elite marathon runners. The others factors of marathon performance were not improved and the blood lactate accumulated was similar after this intensive phase. This could be due to the fact that the build up phase during winter had already improved both endurance and running economy (a low energy cost of running). Therefore, to obtain a better understanding of the inter relationship between the training phase and the physiological factors implicated in marathon at different performance levels for males and females, it may be interesting to study these runners throughout a complete season.

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