
Dear Dr. Watanabe

Thank you for having carefully reviewed our article. We have followed all the recommendations brought by the referees and we hope that they will satisfied.

Here are enclosed the revised version and our answer to each referee

referee 1

At first thank you for your very relevant suggestions. I followed all you recommendations and corrected the mistakes.

Referee(s)'s comments

GENERAL COMMENTS

The English grammar in this manuscript is below average that makes the manuscript difficult to understand. Prior to submission, this paper should be checked by a native English speaker.

Yes I did

The discussion needs to be significantly reduced. The discussion should focus on things that are directly related to the primary purpose of the study. The discussion is long and rambling. A large part of page 20 and page 21 can be eliminated or reduced. Is the logic consistent? The underlying logic and ideas are sound. However, there is a significant amount of unrelated information presented in the discussion that should be omitted.

Yes, I deleted 2 pages of discussion (pages 20,21) in order to be more focused on the rationale.

SPECIFIC COMMENTS

Page 5, paragraph 3, line 1 - Whereas it is clear that the aim of the present study is to analyze the metabolic components of middle distance running on the track, there is insufficient justification for examining these components according to gender. Although this is an important consideration, there is little argument in the introduction for why men and women should differ.

Methods

- Page 8, paragraph 3, line 1 and 2 - For consistency, please use AO2 deficit rather than AOD as AO2 demand and AO2 uptake are used here but not separately defined.: Yes I replaces AOD by AO2 deficit

- Page 8, paragraph 3, line 3 - Please explain how the product of velocity and economy is calculated to be an AO2 demand: For that I added the equation 2.

- Page 9, paragraph 1, line 4 - The citation used here refers to a very different method of determining and calculated the AO2 deficit and should not be directly used to support the reliability of the methods used in the present study. Yes I changed this paragraph.

- Delete Figure 1.: Yes I did
Discussion
- Page 18, paragraph 1, line 1 - This entire paragraph is confusing as the author skips from anaerobic power to anaerobic capacity. Yes I deleted it
REFeree 2

At first thank you for your very relevant suggestions. I followed all you recommendations and corrected the mistakes.

General Comments
The writing style is a weakness of this paper. We rewrote most of these paragraph with a native speaker.

The authors need to carefully read the 'instructions to authors' for this journal. For example, in the results sections it is stated that 'quantitative observations are often better presented graphically than in tables'... 'Tables should be kept to a minimum, and should contain as few rows and columns as possible'. However, the present manuscript contains seven tables! Furthermore, the referencing format is incorrect for this journal.

Yes the referee N°1 ask me to delete the figure 1 that I did and I gathered the table 1a and 1b, 2a and 2b, 3a and 3b. I think that individual data are needed because this is the first time that such data collected in elite athletes on track are available. Perhaps some readers will want to calculate the aerobic and anaerobic power applying this method on some of the individual data to check if they are all right with the method that they will be able to apply on their proper athletes.

Specific Comments
Abstract: all corrections made

Introduction
The introduction needs to be developed a little more to provide a clear rationale for the study.: Yes, we rewrote the introduction

Methods
As mentioned in the general comments, there is one significant limitation in the methodological design. The authors need to clearly acknowledge this limitation.: yes we did P 5, L 8 - '...two days of interval'; re-word.: yes
P 5, L 10 - define abbreviation 'Cr'. yes
P 6, L 2 - what were the environmental conditions? We added them
P 7, L 3-5 - what about RER > 1.1 etc as a criteria of VO2max? yes we added this point
P 7, L 11 - Cr in brackets, as this is a abbreviations: yes
P 8, L 2 - 'which is strictly true only if the respiratory quotients equals 0.96', provide a reference for this point: yes we added it
P 8, L 3-6 - re-word sentence, this is unclear. Also, need to briefly state why the 600m test was used in the introduction, as this is the first time this is explained: yes we added it in the introduction.

P 8, L 6-7 - 'This distance was chosen along with the national team coaches to elicit the oxygen deficit at its maximum...' As stated in the general: yes we modified this paragraph. comments it is very unlikely that a MAOD was attained within the relatively short duration of the male athletes (87 s). (see comments in the discussion section):yes we agree and we rewrote half of the discussion
P 8, L 9-11 - re-word sentence, write more 'scientifically': yes
P 8, L 11-12 - '...we respected this specific aspect'; re-word: yes
P 8, L 20 - 'AO2', explain abbreviation: yes
P 8, L 22-24 - '...600m run was not considered as the 'maximal AO2 deficit...' This is a contradictory statement (see P 8, L 6-7) discuss further: yes we modified this paragraph
P 9, L5-9 - this point should be re-worded, it is unclear to the reader: yes we did it
P 9, L 5 - '...calculated by doing the ratio...', must write more formally /scientifically: yes we rewrote it
P 10, L 12 - 'η should be Cr? No it is the efficiency η
P 10, L 19 - '...to make easier the comparison...', re-word P 11, L 4 - re-word sentence: yes we re-worded it
P 11, L 9-10 - re-word sentence (unclear), also be consistent with units (i.e., 'two months' - '2 months'): yes
P 11, L 10 - delete 'on' and insert 'in the': yes
P 11, L 16 - '...considering negligible the possible decrease in the energy cost of running...' re-word (unclear): yes we did

Results
In general, the results section reads quite well. However, as stated in the general comments section, there are too many tables (7 in total). I do not think that data for each individual subject is required for each experimental variable. Therefore, only present mean +/- SD or figures of individual data for a couple of important variables.

Yes but as recalled above we tried to gather some table without loosing the availability of individual data which can be relevant for some readers.

P 12, L 20 - change 'significant' to 'significantly different': yes
P 12, L 22 - '...mono-exponential...' insert 'fit': yes
P 13, L 4 - '...initial oxygen deficit...', explain - what does that mean?: yes we added the explanation
P 13, L 16 - '...had not significantly different values...', re-word phase: yes we did
P 13, L 20 - delete 'looked at' and insert 'investigated': yes we did
P 14, L 5 - '...values are in indicated...', re-word: yes we did
P 14, L 18 - '...not any more significantly different...', re-word: yes we did
P 15, L 22-23 - re-write sentence (unclear): yes we did
P 16, L 9 - '...allowed a prediction of the variance in performance...', re-word: yes we did

P 30 - change MAOD to AOD in table title, as it is likely that this was not 'maximal': yes we did
P 31 - is above point: yes we did
P 32 - Time over 600m - 86.5 s in table but 87.3 s in results (which is correct?): yes you are right but we wanted to cancel one decimal and then 86.5=87. But we replace it by the same data than on the table.
P 33 - Time over 600m - 101.6 s in table but 102 in results: yes see above
P 35, L 3 - wrong reference (10)? Yes but we deleted the figure 1 as asked by the referee 1.
Discussion
As indicated below, there are many grammatical errors. Furthermore, the discussion does not 'flow' nicely. The authors need to order their points in a logical and concise manner for further drafts of this manuscript.
we rewrote half of the discussion with a native English speaker canceling the page 20 and 21.
P 16, L 20-21 - remove sentence: yes
P 17, L 4-7 - re-word sentence (unclear): yes
P 17, L 20 - '...on track and (this - insert) is the next...': yes
P 17, L 22 - '...which is a bit surprising...', re-word (more formal): yes
P 18, L 2-3 - given this statement, why did you use the 600m test? We added the explanations in discussion.
P 18, L 9-14 - discussion of the MAOD in males should be minimal, as it is likely that this data is incorrect (not maximal AOD): yes we deleted this paragraph.
P 18, L 7-8 - re-word (incomplete sentence): yes we did
P 18, L 20-22 - re-word sentence (unclear): yes we did
P 19, L 20 - found not 'founded': yes sorry
P 20, L 7 - 'This is not true inside for each separate gender', re-word (unclear): yes we did
P 20, L 12-14 - re-word sentence (be concise): yes we did
P 20, L 16 - '...as we are going to discuss now.' – delete: yes we did
P 20, L 21 - '...all-out run on (a - insert) treadmill...': yes we did
P 20, L 22 - '...speed is (not?) imposed...': yes we did
P 21, L 1-3 - re-word sentence - must write in a clear and concise manner: yes we did
P 21, L 12-15 - This needs to be stated in the introduction as a justification of using the 600m test. Yes we added this point in the introduction section.
P 21, L 16-18 - re-word sentence (unclear): yes we did
P 21, L 21-22 - however, as it has been acknowledged previously, this wasn't maximal for males! - the authors must be consistent on this important methodological issue: yes we insisted n that point
P 22, L 1-4 - re-word (unclear, be concise): yes we did
P 22, L 5 - re-write sentence (correct English): yes we did
P 23, L 5 - '...no significantly different value...' (re-word): yes we did
P 23, L 9 - '...which is not so bad...' (re-word - write more: yes we did scientifically)

Conclusion
The conclusion needs to be more concise and provide adequate summary of the study. yes we did.
P 24, L 4 - '...which is nowadays analysed as a black box...' (re-word - write more scientifically): yes the “black box” was cancelled

References
Check the format of references for this journal, this appears to be incorrect

Sorry we modified all the format in accordance with the JJP recommendations.
The Japanese Journal of Physiology

Energetics of middle-distance performance in male and female junior middle-distance runners using track measurements.

VERONIQUE BILLAT\textsuperscript{1,3}, LEPRETER PIERRE-MARIE\textsuperscript{1}, HEUGAS ANNE-MARIE\textsuperscript{2}, KORALSZTEIN JEAN PIERRE\textsuperscript{3}

1. Faculty of Sport Sciences, University of Evry-Val d’Essonne, Evry, France
2. Faculty of Sport Sciences, University of Paris 11, Orsay, France
3. Sport Medicine Center CCAS, Paris, France

7 tables and 2 figures

Running head: Energetics in middle-distance running.

Address for correspondence:

4. Véronique L. Billat PhD, Sport Medicine Center CCAS, Paris, France, 2 Avenue Richerand, F-75010 Paris, France. E-mail: veronique.billat@wanadoo.fr

PHONE: 33 1 42 02 08 18

FAX: 33 1 42 39 20 83
ABSTRACT

The aim of this study was to determine the energetic factors of middle-distance running performance in junior elite runners according to gender and using measurements performed on the track. Fifteen elite runners (8 males and 7 females) were investigated using in an incremental test and an all-out run over 600m performed with a two day interval. We calculated 1°) the aerobic maximal power ( \( \dot{E}_r_{\text{max}_{\text{aero}}} \), in W.kg\(^{-1}\)) including \( \dot{V}O_2\text{max} \) and the delay of attainment of \( \dot{V}O_2\text{max} \) in the 600m run; 2°) the anaerobic power ( \( \dot{E}_r_{\text{max}_{\text{anaero}}} \) i.e. the oxygen deficit (joules.kg\(^{-1}\)) divided by the duration of the 600 run. Despite the difference in race duration (87±3 vs. 102±2 s), the 600m run was run at the same relative value of the velocity associated with \( \dot{V}O_2\text{max} \) (\( v\dot{V}O_2\text{max} \)) in males and females (122±8 vs. 120±8 % \( \dot{V}O_2\text{max} \), \( P = 0.7 \)). \( \dot{E}_r_{\text{max}_{\text{aero}}} \) explained most of the variance in the performance (the personal best performed 8 weeks later) between genders: 65% and 79% over 800m (T\(_{800}\)) and 1500m (T\(_{1500}\)). For females, \( \dot{E}_r_{\text{max}_{\text{aero}}} \) explained most of the variance of T\(_{1500}\) (\( r^2=0.66 \)) while \( \dot{E}_r_{\text{max}_{\text{anaero}}} \) improved this prediction (\( r^2=0.84 \)). No energetic factor predicted the performance in males and over 800m according to gender. In elite junior athletes, the energetic model with individual data measured over an all-out 600m performed on track, provides an explanation for most of the variance in middle-distance performance between gender. The distinction between aerobic and anaerobic power allowed an improvement in the prediction of middle-distance performance.
**Key words**: anaerobic, maximal oxygen uptake, gender, adolescent.
INTRODUCTION

Middle distance running performance (800-1500m) relies on both aerobic and anaerobic metabolisms (23). The relative contribution of each metabolic pathway during a middle-distance run has already been reported in elite athletes but using a simulation on a treadmill and for males only (24). Weyand et al. (29) have demonstrated that middle-distance performance depended more on aerobic than anaerobic capacity. Indeed, Weyand et al. (29) have shown that, in sub-elite runners (2min01s±5s and 2min32s±6s over 800m for males and females), the peak oxygen deficit was a moderately strong predictor of middle-distance performance (38% and 27% of the variance of the performance over 800 and 1500m). Therefore, the energetic factors of performance were expressed with different units: the anaerobic one was reported as capacity (the “anaerobic work capacity in joules) while the aerobic one was expressed as a power (the maximal aerobic power in watts).

Wilkie’s model (see method section) gives a physiological background of the hyperbolic function between the total power output (\( \dot{E}_t \)) and exercise duration. According to the equation of Wilkie (30), the aerobic and anaerobic factors of performance can be calculated with the same dimension as it allows the aerobic power (\( \dot{E}_{\text{max,aero}} \)) to be distinguished from the anaerobic power (\( \dot{E}_{\text{max,anaero}} \)) to help understand how human athletes produce power in middle-distance events. This has been validated for middle distance performance by di Prampero et al. (8). However, this study (8) included in Wilkie’s model, standard values for maximal anaerobic capacity and a \( \dot{V}O_2 \text{max} \) measured on a cycle ergometer or on a treadmill, while the performance and the energy cost of running were measured on the track – not clear. It is well known, however, that \( \dot{V}O_2 \text{max} \) is lower in cycling compared with running exercise (22) and that the energy cost of running is not similar on the treadmill and the track (3, 6). Since this study performed 10 years
 ago, technological progresses have made it possible to measure all the factors in field experiments using breath-by-breath portable oxygen analyzers. Elite athletes, who generally are not available for testing in laboratory conditions are often more open to field tests. The first purpose of this present study was to carry out all the measurements on the field, which is a positive factor considering previous studies have only examined predictor variables in the laboratory.

If it is agreed that females have a lower aerobic power than males ($\text{mLO}_2\text{.kg}^{-1}\text{.min}^{-1}$) (13), this is less reliable concerning the anaerobic work capacity (3, 25, 27). A significant difference was reported between trained male and female adolescents (19). Naughton et al. (19) have reported that the maximal accumulated oxygen deficit (MAOD) in trained 14 yrs old adolescents (male and female national level badminton players) was lower in females (53.2 mL.kg$^{-1}$) than in males (68.6 mL.kg$^{-1}$). This was not the case in a study performed in adult high-level male and female middle-distance runners (49 and 40 mL.kg$^{-1}$ for the males and females respectively, $P > 0.05$) (3). However this last study was performed on the treadmill and no studies have compared the anaerobic work capacity between gender on the track in elite athletes. This possible difference of $\dot{E}_\text{max}_{\text{anaero}}$ between gender should also contribute to the lower power output value on middle-distance running and hence, the lower performance over 800 and 1500m.

Since males and females ran over the same distance and that athletes did not want to be tested on the full racing distance for psychological reasons, we chose in agreement with the national team coaches to test them over an all-out 600m run. We were aware of the fact that the same distance would take a longer time for females compared with the males and could have an impact on the anaerobic work capacity. However, the purpose of this study was to compare the
influence of the aerobic and anaerobic power on performance. Hence the anaerobic power
depends on the anaerobic capacity and also the run duration.

Therefore, the aim of this study was to analyze the variance in performance, by examining
the partitioning of metabolic power into aerobic and anaerobic components over a 600m maximal
run on the track according to gender, in junior elite male and female middle-distance runners.

METHODS

Subjects were fifteen middle-distance runners (8 males and 7 females) all members of the
French national junior team, who volunteered to participate in this study. Their individual
physical characteristics and performances are given in Table 1. Before participation, all subjects
were informed of the risks and stress associated with the training program, and gave a written
voluntary informed consent in accordance with the guidelines of the Hospital Saint Louis of
Paris.

Experimental design. The tests were performed in March before the competition period
during a national training camp in the South of France. All the tests were performed on a
synthetic 400-m track in a climate of 16 to 18 °C without wind (< 2 m/s, anemometer,
WINDWATCH, ALBA, SILVA, SWEDEN). The tests were performed by each runner at the
same hour of the day, with a two day interval. The subjects performed: i) an incremental test to
determine maximal oxygen uptake (\(\dot{V}O_2\) max), the velocity associated with the attainment of
\(\dot{V}O_2\) max (\(v\dot{V}O_2\) max), the velocity at the lactate threshold (\(vLT\)), the energy cost of running
(Cr), and ii) an all-out test over 600m in order to determine the time over 600m (T\(_{600}\)). This test
was performed like a competition and the athletes ran three by three (for one female group) or
four by four (for one female group and two male groups). For both tests, each subject was
instructed by the coaches and encouraged to give their maximum effort. The tests were performed by a given subject at the same time of day, in a climate-controlled environment. All test sessions were carried out on a 400-m covered synthetic track. Throughout the incremental test, the subjects adopted the required velocity thanks to an audio-visual system. This system included guide marks set at 25-m intervals along the track (inside the first lane), and audio signals determining the speed needed to cover 25-m intervals. The velocity of locomotion was strictly controlled throughout the tests with photoelectric cells set every 50 m (Brower Timing Systems, Salt Lake City, UH).

*Procedures.* Throughout the two tests, the respiratory and pulmonary gas exchange variables were measured using a breath-by-breath portable gas analyzer (Cosmed K4b2, Cosmed, Roma, Italy), which was calibrated before each test according to the manufacturer’s instructions (10,15). The device weighs 800 g and is placed near the center of mass of the body. Breath-by-breath data were later reduced to 30-s (for the incremental test) and 5-s (for the all-out test on 600m) stationary averages (Data management software, Cosmed, Roma, Italy). Fingertip capillary blood samples were collected into a capillary tube, and were analyzed for lactate concentration using a Doctor Lange lactate analyzer (Lange GmbH, Berlin, Germany). This lactate analyzer was calibrated before the tests with several solutions of known lactate concentrations.

The subjects firstly performed an incremental test with 3-min stages. The initial velocity was set at the average velocity maintained over 3000 m, which has been described as being close to the velocity associated with $\bar{V}O_2$ in an incremental test ($v\bar{V}O_2$ max) minus 6 km.h$^{-1}$, so that the exhaustion occurs within 20 minutes for each subject (3). The velocity increments between the stages were set at 1 km.h$^{-1}$. All stages were followed by a 30-s period of rest. During this
period, a fingertip capillary blood sample was collected. In addition, other fingertip capillary
blood samples were collected before the test, immediately and three minutes after the test.

\( \dot{V}O_2 \) max was defined as the highest 30-s oxygen uptake value reached during this incremental
test with a respiratory exchange ratio (RER = \( \dot{V}CO_2 / \dot{V}O_2 \)) greater than 1.05, blood lactate
greater than 8 mM and a peak heart-rate at least equal to 90% of the age-predicted maximum.

\( v \dot{V}O_2 \) max was defined as the minimal velocity at which \( \dot{V}O_2 \) max occurred (3). When
\( v \dot{V}O_2 \) max was maintained for half, rather than for all of the last stage, it was then considered as
the median velocity maintained during the last two stages (5). \( vLT \) was defined as the velocity for
which an increase in lactate concentration corresponding to 1 mmol.l\(^{-1}\) occurs between 3.5 and 5
mmol.l\(^{-1}\) (1). \( vLT \) was determined by two independent reviewers.

The net energy cost of running \( Cr \) is defined as the energy required above resting
(estimated by \( \dot{V}O_2 - \dot{V}O_2 \) rest) to transport the subject’s body over one unit of distance (8).

\[
Cr = ( \dot{V}O_2 - \dot{V}O_2 \) rest \) / v \quad \text{(eq.1)}
\]

Where \( \dot{V}O_2 \) is the oxygen uptake at the velocity \( v \) and is expressed in mL.kg\(^{-1}\).min\(^{-1}\); \( \dot{V}O_2 \) rest is the
\( \dot{V}O_2 \) at rest assumed to be equal to 5 mL.kg\(^{-1}\).min\(^{-1}\) according to the intercept of the \( \dot{V}O_2 \) -
speed regression line obtained by Medbo and Tabata (16); \( v \) is in m.min\(^{-1}\), then \( Cr \) is in mL.kg\(^{-1}\).
m\(^{-1}\). Therefore, \( Cr \) is estimated by the oxygen uptake at a sub maximal speed (< \( vLT \)) at which
the anaerobic metabolism part of energy yielded is negligible and at which there is no slow
kinetics of oxygen uptake (8). The energy cost of running is independent of the speed until 20
km.h\(^{-1}\) (8). Therefore, we estimated the energy cost of running from the rate of oxygen uptake
which was averaged between the second and the third minute of the stage run at a stage and an
intensity 1 km.h\(^{-1}\) below the lactate threshold velocity (\( vLT \)) (3). Throughout this paper, \( Cr \) is
expressed in joules per meter according to the assumption that 1 mL O₂ consumed in the human body yields 20.9 J (which is strictly true only if the respiratory quotients equals 0.96) (14).

The subjects subsequently performed an all-out test over 600m in order to determine the time over this distance (T₆₀₀). After a 25-min warm-up period at 60 % v ̇V O₂ max followed by two 100m runs at a faster pace (17s for female and 15 s for males) and a 5-min rest period, the subjects were instructed to run as fast as possible over a distance of 600m. A fingertip capillary blood sample was collected before the test, immediately, three and eight minutes after the test. A lap time was taken every 200m to focus on the speed variation during this free-pace exhaustive 600m run.

**AO₂ deficit calculation.** The accumulated oxygen deficit (AO₂ deficit) was calculated as the difference between the AO₂ demand and the AO₂ uptake (both in mL.kg⁻¹) measured during the 600m run. AO₂ demand was estimated according the equation (2):

\[
\text{AO₂ demand} = v₆₀₀ \times (\text{V} \dot{\text{O}}₂ \text{ at vLT–1})/(\text{vLT–1})
\]  

(eq. 2)

Where v₆₀₀ is the velocity over 600m (600/T₆₀₀) and vLT – 1 is the velocity at the lactate threshold minus 1 km.h⁻¹. The speeds are expressed in km.h⁻¹ while V̇O₂ is expressed in mL.kg⁻¹.min⁻¹.

The AO₂ deficit calculated for the 600m run was not considered as the “maximal AO₂ deficit” (MAOD) since it was a bit shorter than 2 minutes (especially for the males) even if it was performed at supra-maximal speed (120% of v ̇V O₂ max) to be close to the intensity recommended in cycling by Medbo et al. (16, 18) at a work rate equal to 120% V̇O₂ max and then applied by numerous studies and has been extensively used (17, 26, 27, 28). The percentage of the anaerobic contribution in the 600m was calculated according to the following equation (3):

\[
\% \text{ ANAE} = (\text{AO₂ deficit} / \text{AO₂ demand}) \times 100
\]  

(eq. 3)
Hence, the percentage of the aerobic contribution in the 600m was equal to 100 - %ANAE.

Oxygen uptake kinetics. 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 a mono-exponential model (8) using an iterative non-linear regression by Sigma Plot software (SPSS, Chicago, IL, USA):

\[
\dot{V}O_2 (t) = A_0 + A_1 \times [1 - e^{-(t-\text{TD}_1)/\tau_1}] \quad \text{(eq.4)}
\]

where, \(A_0\) is the baseline value (mL.min\(^{-1}\)), \(A_1\) is the asymptotic amplitude for the exponential term (mL.min\(^{-1}\)), \(\tau_1\) is the time constant (s), \(\text{TD}_1\) is the time delay from the onset of exercise (s).

The model of energetics in middle-distance running according to the model of di Prampero (8).

Firstly, we calculated the metabolic power (\(\dot{E}_r\)) according to the following equation:

The metabolic power (\(\dot{E}_r\)) for running the 600m at speed \(v\) is given by (8)

\[
\dot{E}_r = C_r \times 600/T_{600} \quad \text{(eq.5)}
\]

\[
\dot{E}_r = C_r \times v_{600} \quad \text{(eq.6)}
\]

Where \(C_r\) is expressed in joules per kilogram per meter and 600 is the distance in meters and \(T_{600}\) is the time needed to achieve the distance of 600m and then \(v_{600}\) is in meters per second and \(\dot{E}_r\) is in watts per kilogram. \(C_r\) is determined for running at constant speed. However, because maximal performances in track running are performed from a stationary start, the overall energy cost, inclusive of the energy spent to accelerate the body from zero to final speed (\(C_{r,\text{tot}}, J.m^{-1}.kg^{-1}\)), is given by (8):

\[
C_{r,\text{tot}} = C_r + (0.5Mv^2\eta^{-1} \times d^{-1}) \times M^{-1} \quad \text{(eq.7)}
\]
Where $M$ is the mass of the subject, $d$ is the distance run and $\eta$ is the efficiency of transformation of metabolic energy into kinetic energy. The latter can be assumed to be 0.25, since in the initial acceleration phase no recovery of elastic energy can take place and hence the overall running efficiency must approach the efficiency ($\eta$) of muscular contraction (8). If $\eta$ is assumed to be equal to 0.25 (25%), Eq. 7 reduces to:

$$C_{r, \text{tot}} = C_r + 2v^2d^{-1} \quad \text{(eq. 8)}$$

We then calculated the maximal metabolic power of the runner (8)

$$\dot{E}_{\text{r, max}} = AnS \times te^{-1} + \text{MAP} - \text{MAP} \times k^{-1} \times (1-e^{-kte}) \times te^{-1} \quad \text{(eq. 9)}$$

where $AnS$ is the maximal amount of energy released by anaerobic (lactic + alactic) sources and MAP is the subject’s maximal aerobic power, $k$ is the velocity constant at which $\dot{V}O_2$ max is attained at the onset of exercise and $k = 1/\tau$. At the end, we can write the equation 9 as following:

$$\dot{E}_{\text{r, max}} = AnSte^{-1} + \text{MAP} - \text{MAP} \times \tau \times (1-e^{-kte}) \times te^{-1} \quad \text{(eq. 10)}$$

The third term of Eq. 10 is due to the fact that $\dot{V}O_2$ max cannot be instantaneously reached at the onset of work. Therefore, Eq. 10 allows calculation of $\dot{E}_{\text{r, max}}$ on which the runner can rely as a function of the time run called the exhaustion time, $te$, provided that the subject’s AnS and MAP are known. AnS was replaced by $AO_2$ deficit and MAP by $\dot{V}O_2$. The time to exhaustion ($te$) was $T_{600}$. Then we distinguished the first and second term of the right side of the equation 10:

$\dot{E}_{\text{r, max, anaero}}$ (the oxygen deficit in joules.kg$^{-1}$ divided by $te$) from $\dot{E}_{\text{r, max, aero}}$ ($\dot{V}O_2$ max in W.kg$^{-1}$ balanced by the delay of attainment of $\dot{V}O_2$ max). Therefore $\dot{E}_{\text{r, max, aero}} = \text{MAP} - \text{MAP}k^{-1} \times (1-e^{-kte}) \times te^{-1}$ and so, $\dot{E}_{\text{r, max, anaero}} = AnSte^{-1}$.

Two months after this 600m-test, the athletes achieved their personal best over 800 and 1500m. During these two months, the athletes undertook high-intensity training runs based on
interval training set at speeds at and above $v\dot{VO}_2$ max (2). As these elite athletes were not available for testing during the period of competition, we calculated the speed over 600m which the runners would have been able to run during the period of competition in order to estimate their progress. This was estimated from their performances over 400, 800 and 1500m according to the speed-race distance relationship proposed by di Prampero et al. (8). We checked that all the subjects decreased their time over 600m (i.e. improved their performance) in an homogenous way (coefficient of variation less than 15%).

**Anthropometry.** Height and weight, were measured. Five skin-fold measurements were made (triceps, biceps, suprailiac, subscapular, mid-thigh) and % body fat calculated using the formula of Durnin and Womersley (9).

**Statistics.** Because of the small sample size in this study ($n = 7$ and $n = 8$), the normality of the distribution and the equality of the variance were checked by SigmaStat (Jandel, CHICAGO, IL). We performed an analysis of variance (ANOVA) test at one factor (gender) to measure the gender effect on each parameter of the energetic model for middle-distance running (Staview 5.5, Statsoft, Berkeley, CA, U.S.A.). Step-by-step regression ($F$ to enter = 4) was used to determine the factor of performance over 800 and 1500m. Correlations between each bioenergetic parameter and between $\dot{E}r$ and $\dot{E}r$max were determined using the Pearson product moment correlation coefficient. The level of significance was set at 5% ($P \leq 0.05$). All results are presented as means ± SD.
RESULTS

Despite the difference in run duration (T600) between gender (86.5±2.8 vs. 101.6±2.0 s), the 600m was run at the same relative value of v\(^\text{VO}_2\)\(_{\text{max}}\) and lactate threshold velocity in males and females (122±8 vs. 120±8 % \(\text{VO}_2\)\(_{\text{max}}\) respectively, \(P = 0.70\) and 138.4±6.0 and 139.2±12.9 % vLT, \(P = 0.73\) in males and females respectively) (Table 2). Moreover, the coefficient of variation of the speed between the three 200m was homogenous within these elite middle-distance runners and was not significantly different between gender (6.1 ± 0.5 vs. 5.6 ± 0.4 % for males and females, respectively, \(P = 0.06\)).

The increase in \(\text{VO}_2\) during the all-out 600m fit a mono-exponential model with a time constant which was not significantly different between males and females (24.7±11.5 vs. 31.9±12.0 s, \(P = 0.27\), respectively). During the 600m run, males and females elicited 99.3±1.9 vs. 100.5±2.9% of \(\text{VO}_2\)\(_{\text{max}}\) (\(P = 0.08\)) and all the subjects reached at least 97% of \(\text{VO}_2\)\(_{\text{max}}\). The time constant for oxygen kinetics was not correlated with the performance over the 600m (\(r = 0.09\), \(P = 0.76\), n=15). The initial oxygen deficit (i.e. the oxygen deficit before the attainment of \(\text{VO}_2\)\(_{\text{max}}\)) accounted for 58.5±13.0 and 56.8±14.0 % of AO2 deficit in males and females, respectively (\(P = 0.80\)). The relative contribution of the anaerobic metabolism to the energy spent over the 600m was not significantly different between gender (38.2±12.3 and 41.5±12.3% for males and females respectively, \(P = 0.62\)) (Table 3).

Females had more than twice the body fat mass than males (18.8±2.3 vs. 9.0±1.5 %) (Table 1). The fat body mass explained 78 % of the variance of T600 and 80 % of the variance of T800 and T1500 performance between gender but not significantly within gender. Indeed, if males had higher \(\text{VO}_2\)\(_{\text{max}}\) than females (71.4±3.0 vs. 60.5±5.1 mL.kg\(^{-1}\).min\(^{-1}\), \(P < 0.001\)), this difference was not any more significant when the maximal aerobic power was expressed by kilogram of
lean body mass (78.5±3.1 vs. 74.6±6.0 mL.kg⁻¹ free fat mass.min⁻¹, P = 0.13, Table 1). The individual aerobic and anaerobic capacities for the males and females are indicated in Tables 2. In contrast to the maximal oxygen uptake, the anaerobic capacity was not significantly different between males and females (45.5±14.9 vs. 52.1±16.44 mL.kg⁻¹, P = 0.42 and 50.0±16.0 vs. 64.2±20.5 mL.kg⁻¹ free fat mass, P = 0.15) (Table 2). There was also no significant difference in the energy cost of running between gender (Table 2). We then examined the role of the aerobic and anaerobic power output in performance.

After having investigated these classical factors of performance used in previous studies, we focused on those provided and adapted from the model of Wilkie (30): the maximal metabolic power (Êₚ max) and their aerobic anaerobic component (Êₚ maxaer and Êₚ maxanaer). Firstly, we checked that the energetic model proposed by Wilkie (30) worked with all the measurements collected on the track. This was the case as there was no significant difference between the total power output on the 600m run (Êₚ) and the maximal metabolic power (Êₚ max) among the 15 subjects (1.74±3.1 vs.1.72±0.45 kW for Êₚ and Êₚ max, t = 0.18, P = 0.86) and among males and females (Êₚ = 1.98±0.20 vs. 2.00±0.41 kW, t = -0.17, P = 0.87 in males and 1.47±0.11 vs. 1.39±0.17 kW, t = 1.12, P = 0.28 in females). For an easier comparison between the genders, Êₚ and Êₚ max are also indicated by kilogram of body weight in Table 3. There was a significant correlation between Êₚ and Êₚ max for the whole group (r= 0.869, P < 0.0001, figure 1).

The power output (Êₚ) equaled 1.98 ±0.20 vs. 1.47±0.11 kW in males and females respectively and was significantly different between gender since males ran faster than females with the same energy cost of running. Furthermore, when Êₚ was expressed by kilogram of body weight it remained significantly higher for males (32.1±2.3 vs. 28.1±1.3 W.kg⁻¹ P < 0.01) but not
when expressed by kilogram of lean body mass (32.3±2.2 vs. 31.9±1.7 W.kg⁻¹ free fat mass, \( P = 0.69 \)) (Table 3). In the same way, the maximal metabolic power on 600m (\( \dot{E}_r \text{ max} \)) was significantly higher in males than in females in absolute value (2.00±0.41 kW vs. 1.39±0.17 kW, \( P < 0.01 \)) and relative value to the body mass (32.3±4.5 vs. 28.1±1.3 Watts.kg⁻¹, \( P < 0.01 \)). This was no longer the case when \( \dot{E}_r \text{ max} \) was expressed by kilogram of lean body mass (35.3±2.4 vs. 34.6±1.7 Watts.kg⁻¹ free fat mass, \( P = 0.53 \)). This is in accordance with the fact that when they were expressed by kilogram of lean body mass, \( \dot{V}_O_2 \text{ max} \) and \( A_O_2 \text{ deficit} \) were not any more significantly different between gender. Then the aerobic and anaerobic power outputs (\( \dot{E}_r \text{ max}_{\text{aero}} \) and \( \dot{E}_r \text{ max}_{\text{anaero}} \)) were considered separately from \( \dot{E}_r \text{ max} \). \( \dot{E}_r \text{ max}_{\text{aero}} \) was significantly higher in males than in females even when it was expressed by kilo of body mass (25.0±1.0 vs. 21.2±1.8 W.kg⁻¹, \( P < 0.001 \)) in contrast with \( \dot{E}_r \text{ max}_{\text{anaero}} \) (14.0±3.4 vs. 11.2±1.8 W.kg⁻¹, \( P = 0.08 \)) (Table 3). However, \( \dot{E}_r \text{ max}_{\text{aero}} \) was no longer significantly different between gender when it was expressed by kilogram of lean body mass (27.4±1.1 vs. 26.1±2.1 Watts.kg⁻¹ free fat mass, \( P = 0.13 \)) and this was always true for \( \dot{E}_r \text{ max}_{\text{anaero}} \) (15.4.0±3.9 vs. 13.8±2.4 W.kg⁻¹ free fat mass, \( P = 0.37 \)).

After having focused on the energetic characteristics of each gender, the ability of \( \dot{E}_r \text{ max}_{\text{aero}} \) and \( \dot{E}_r \text{ max}_{\text{anaero}} \) to explain the variance in performance over 800 and 1500m was examined. Firstly, we checked the correlation between the time over 600m and the performance over 800 and 1500m (performed eight weeks later in competition) as the energetic characteristics of the subjects were collected during this 600m run. The time over the 600m-test run was correlated with the time over 800m achieved two months later during the competition period for all the runners and for females (\( r = 0.88, P < 0.001, n = 15 \) and \( r = 0.78, P = 0.04 \) but not for the males (\( r = 0.10, P = 0.81 \)). \( T_{600} \) allowed a very rough prediction of the performance over 800m
between gender and within males (at the nearest 4s) but more accurately within females (at the nearest 1.4s). $T_{600}$ was correlated with the time over 1500m for the whole 15 runners ($r = 0.88$, $P < 0.001$, $n = 15$) but not considering each group of gender separately ($r = 0.51$, $P = 0.26$ for females and $r = 0.20$, $P = 0.69$ for males). The runners performed their personal best over 800m, at an average velocity representing $101\pm7$ and $105\pm71\%$ of the velocity over 600m performed in the test (for males and females respectively, $P = 0.16$). Furthermore, the 800m run during the competitive period was not only faster than the 600m run but also longer $+ 33\pm10\%$ and $+27\pm2\%$ in males and females respectively ($P = 0.17$). This corresponds to a new performance over 600m improved by $4.2 \pm 5.9s$ and $7.2 \pm 1.5s$ for males and females ($P = 0.19$).

In contrast with $\dot{E}_r$, max, $\dot{E}_r$, max$_{aero}$ and $\dot{E}_r$, max$_{anaero}$ explained most of the performance in middle-distance running. Indeed, $\dot{E}_r$, max$_{aero}$ explained 65% and 79% of the variance of $T_{800}$ and $T_{1500}$ (predicting the performance at the nearest 1.5s and 2.3s, respectively) (Table 4). When $Cr$ was added to $\dot{E}_r$, max$_{aero}$ these two factors explained 74% of the variance of $T_{800}$ (Table 4). However, $Cr$ gave no additional accuracy in the prediction of the variance of $T_{1500}$. Within gender, but for females only, $\dot{E}_r$, max$_{aero}$ explained 66% of the variance of $T_{1500}$ and 84% when it was combined with $\dot{E}_r$, max$_{anaero}$ (Table 4). For males, no energetic factors allowed a prediction of the 800 and 1500m performance.
DISCUSSION

The purpose of this study was to determine the energetic factors of middle-distance running performance in junior elite runners according to gender and using measurements performed on a track during a 600m all-out run. All the subjects reached \( \dot{V}O_2 \) max during their 600m-run in accordance with previous data which showed that subjects reached \( \dot{V}O_2 \) max even on a 400m all-out run (4, 12). The results showed that the aerobic power was the main performance factor between gender and within females. However, the anaerobic power allowed an improvement in the prediction of performance within gender but for females only. No energetic factor allowed a prediction of performance within males. The aerobic power (expressed by kilogram of lean body mass) was higher for males but not the anaerobic power.

The energetic specificity of the 600m run and its ability to estimate the anaerobic power. The present study confirms that the model of Wilkie (30) allows the calculation of maximal power from the experimental data obtained on the track during an incremental test (\( \dot{V}O_2 \) max) and an all-out test over 600m (\( \dot{E}_r \) max). We used this model to calculate aerobic and anaerobic power taking into account the duration of exercise and therefore avoiding the use of a different dimension for the both metabolisms i.e. a capacity and a power-output for the anaerobic and aerobic metabolisms respectively. During this all-out 600m run, the relative contribution of the anaerobic energy system during the 600m event in males (38%) was rather low compared to the value (44%) reported by Spencer et al. (23,24) even over a longer distance such as the 800m. This difference could be due to the fact that their subjects were older (21±3 vs. 18.6 ±0.5 yrs) but their personal bests were close: 1min50±0:02s vs. 1min52±0:03s for Spencer et al. (24) and the present study, respectively. Therefore, this difference may be due to the fact that, in our study, the athletes were still far from their personal best as will be discussed further. There are no data
available in the literature examining the aerobic and anaerobic contribution in middle-distance events for female athletes. We found no significant difference according to gender in the anaerobic metabolism contribution over 600m. This similitude of the energetic balance over 600m in males and females is in accordance with the fact that males and females run at the same fraction of $\dot{V}O_2 max$ (120%) which is surprising as regards to the shorter run duration for the males compared with females (86 vs. 101s). Despite this shorter 600m run duration for the males, their anaerobic power was not significantly different compared to females. In contrast with world-level 400m-runners who reached their maximal oxygen deficit on 400m (12), our middle-distance runner did not tax their maximal accumulated oxygen deficit in 600m. Indeed, the anaerobic capacity measured in the 600m (45 and 52 mL.kg$^{-1}$ for our males and females) was much lower than the standardized value proposed by di Prampero et al. (8) to validate the model of Wilkie for middle-distance running. Indeed, di Prampero et al. (8) took the value of 68 mL.kg$^{-1}$ as reference to the highest value of anaerobic capacity for human beings at the age of 19 and 17 yrs. Therefore, the accumulated oxygen deficit obtained for the males in this study was only 73% of this referenced anaerobic capacity (8) while we reached 93.0% for the females.

The values of time constant for oxygen kinetics which determine the delay for the attainment of $\dot{V}O_2 max$ were in the range of those measured on a treadmill or in field conditions among older athletes of the same level for lower and similar intensity (2, 5).($\tau = 24$ and 31s for males and females but with a coefficient of variation of 30%) Indeed, this value is in accordance with that reported by di Prampero et al. (8) (30s of interval from rest to work). Endurance training accelerates the oxygen kinetics and so the decrease the initial oxygen deficit (11). If our results reported a low accumulated oxygen deficit for the males, this value is nevertheless in accordance with those previously measured in elite middle-distance runners (3, 21). Furthermore studies (3)
performed in elite middle-distance runners did not show any gender effect on oxygen deficit (49 and 40 mL.kg\(^{-1}\) for the males and females respectively, \(P > 0.05\)) (3). More recently, Weber and Schneider (27) have demonstrated a lower maximal accumulated oxygen deficit (-14%) in females vs. males. This difference remained the same after 4 weeks of high-intensity interval training performed 3 times per week between 82 and 100% of the power used to estimate MAOD prior training (i.e. 100-120% \(\dot{V}O_2\) max) (27). To confirm that there is no gender effect on the accumulated oxygen deficit, we can suggest that females be tested over 600m and the males on 700m run to make both genders run over 2min which is exercise duration recommended by Medbo and Tabata for measuring MAOD (16). For this exercise duration they estimated the contribution of the anaerobic metabolism as being 35% of the energy needed for an all-out cycling-exercise lasting 2 min on the field which is however, not dissimilar from the data we obtained over the 600m even for the males.

Indeed, the aerobic and anaerobic powers measured over 600m explained the variation in performance between gender and within females but not within males. We found of course higher values of maximal power output (\(\dot{E}_r\) max) in males than in females. This was due to the highest maximal aerobic power in males and even when the aerobic power is expressed by kilo of lean body mass (13). However, this was not the case for the anaerobic power which brings some new insights to the debate of the gender difference concerning the anaerobic work capacity which did not take into account the exercise duration (3, 27).

Therefore, the main factor which explains the difference in performance between genders is the maximal oxygen uptake. This is in accordance with Weyand et al. (29) who reported that this peak oxygen deficit was the strongest metabolic predictor of 100-, 200- and 400-m performance, and that \(\dot{V}O_2\) peak was the strongest metabolic predictor of \(T_{800}\) and \(T_{1500}\). Furthermore, as
\( \dot{V}O_2 \) max relative to the lean body mass was not significantly different between genders, we can estimate that fat mass is the determinant factor in the difference in performance between genders. This is confirmed by the direct relationship between performance and fat mass when considering both genders. This is not the case any more inside for each separate gender. In our study, \( \dot{E}_{\text{max aero}} \) was not only the main predictor of \( T_{800} \) and \( T_{1500} \) between gender but also for \( T_{1500} \) for the females. The important original feature of that present study is that for females \( \dot{E}_{\text{max anaero}} \) improved the prediction of performance over 1500m. This could be due to the greatest heterogeneity of \( \dot{E}_{\text{max anaero}} \) in females due to their difference of training program. In males, no energetic parameter was a major performance factor over this distance and this is probably due to the inadequacy of the 600m run to estimate the maximal oxygen deficit and maybe to the fact that they had not yet followed an intensive training program performed at speed higher than \( v \dot{V}O_2 \) max (2). Indeed, two months later, these middle-distance runners ran in official races over 800m. During this occasion, they were able to run 1 and 5\% faster for a 30\% longer exercise duration than on the 600m performed two months earlier. From that, we calculated that they would have improved their performance over 600m by 5 ±7 and 7±1 \% for males and females (\( P = 0.37 \)) which is in the range of the effectiveness of such training (5,6). This means that it might be possible to improve much more this prediction in middle-distance running by doing such a test after having performed some supra \( v \dot{V}O_2 \) max training.

*The adequacy of the energetic model to predict the performance.* We are aware that we cannot explain the performance based only on an energetic model which is supported by the theory that maximal exercise performance is determined by the rate of either oxygen use or ATP production in the exercising muscles. There are now alternative models using the concepts of central, neural governor which constrains the cardiac output by regulating the mass of skeletal
muscle that can be activated during maximal exercise in both acute and chronic hypoxia (20).

Fatigue as a sensation may occur as an activity process in the brain which has not yet been determined and involves many different areas of the brain (20). However, these two approaches to the energetics and neural conceptions of exercise fatigue are not incompatible as the latter considers that there is a regulation by the brain of the mass of skeletal muscle that can be activated during maximal exercise and this has direct consequences on $E_{\text{r}, \text{max}}$. This study shows that the energetics model proposed by di Prampero et al. (8) applied with individual data collected outside and on the track, and not on the treadmill and/or a cycle ergometer with standard values for the anaerobic capacity, fits with the metabolic power required over middle-distance running in junior elite male and females middle-distance runners. Then, the difference in $E_{\text{r}, \text{maxaero}}$ explains the difference in performance over 800m and 1500m between males and females which have no significantly different value of $E_{\text{r}, \text{maxanaero}}$. However, in addition with $E_{\text{r}, \text{maxaero}}$ for the female group $E_{\text{r}, \text{maxanaero}}$ allowed us to predict the performance over 1500m with $E_{\text{r}, \text{maxaero}}$ at the nearest 1.3s. For the whole group (including the both genders), the inclusion of the net energy cost of running improves the prediction of the performance over 800m which is possible at the nearest 1.4s which is a satisfactory level of accuracy from a physiological point of view (1.5%). The present study showed that $E_{\text{r}, \text{maxaero}}$ and $E_{\text{r}, \text{maxanaero}}$ provide additional information about the potential for performance and could help coaches in the orientation of training towards aerobic or anaerobic interval-training (2).
Conclusion

The aim of this study was to analyze the variance in performance by examining the partitioning of metabolic power into aerobic and anaerobic components in elite young middle-distance runners according to their gender. In elite junior athletes, the energetic model with individual data measured on an all-out 600m performed on track, allows the explanation of most of the variance in middle-distance performance between genders. The distinction of aerobic from anaerobic power allowed improved prediction of the middle-distance performance but for females and over 1500m only. $\hat{E}_r_{max_{aero}}$ explained most of the variance in the performance (the personal best performed 8 weeks later) between genders: 65% and 79% over 800m ($T_{800}$) and 1500m ($T_{1500}$). For females, $\hat{E}_r_{max_{aero}}$ explained most of the variance of $T_{1500}$ ($r^2=0.66$) while $\hat{E}_r_{max_{anaero}}$ improved this prediction ($r^2=0.84$). No energetic factor predicted the performance in males. In elite junior athletes, the energetic model with individual data measured over an all-out 600m performed on the track, provides an explanation for most of the variance in middle-distance performance between gender. The distinction between aerobic and anaerobic power allowed improvement in the prediction of the middle-distance performance.

Even if the 600m run was comparable in terms of relative speed to $\dot{V}O_2_{max}$, it was probably too short for males to estimate their anaerobic work capacity. All the measurement were carried out on the field, which is an innovation when compared to previous studies which have examined predictor variables in the laboratory. The topic is important to understanding how human athletes produce power in middle-distance events, and if there are differences between men and women. Further studies are needed to explore the limiting factors of each component of the energetic model in the real conditions of track running.
ACKNOWLEDGEMENTS

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REFERENCES

Table 1 *Individual physical characteristics and performance of the males and females and metabolic power required to run the 800 and 1500m at their personal best.*

<table>
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<th>Time over 1500m (s)</th>
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Table 2. Aerobic and anaerobic capacities of the males and females. $\dot{V}O_2\text{max}$ is the maximal oxygen uptake achieved in the incremental test; $v\dot{V}O_2\text{max}$ is the velocity associated with $\dot{V}O_2\text{max}$ in the incremental test; $vLT$ is the velocity associated with the lactate threshold in the incremental test; Lactate max is the maximal blood lactate accumulation measured at the end of the incremental test. Free fat $\dot{V}O_2\text{max}$ is the $\dot{V}O_2$ expressed in mLO$_2$.kg$^{-1}$ of free fat mass.min$^{-1}$; $v600$ is the average velocity over the 600m run expressed in percentage of $v\dot{V}O_2\text{max}$, $AO_2$ deficit is the accumulated deficit measured in the all run over 600m (at 121.1% of $v\dot{V}O_2\text{max}$ in average).

<table>
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<th>$v\dot{V}O_2\text{max}$ km.h$^{-1}$</th>
<th>HRmax bpm</th>
<th>vLT % $\dot{V}O_2\text{max}$</th>
<th>Lactate max incr mM</th>
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<th>$v600$ % $v\dot{V}O_2\text{max}$</th>
<th>$AO_2$ deficit mL.kg$^{-1}$</th>
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Table 3. $\dot{E}_r$ is the metabolic power required in the 600m run for males and females; $\dot{E}_{r\text{max}}$ is the maximal metabolic power of the subjects during the 600m all-out run.; $\dot{E}_{r\text{max,aero}}$ and $\dot{E}_{r\text{max,anaero}}$ are the maximal aerobic and anaerobic powers calculated from the model of Wilkie (43); $Cr$ is the energy cost of running. Anaerobic contribution is the percentage of the energy spent over 600m yielded by the anaerobic metabolism. $\tau$ is the time constant of oxygen kinetics during the 600m run.

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<th>$Cr$ (J. kg$^{-1}$.m$^{-1}$)</th>
<th>$\tau$ (s)</th>
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Table 4. Step-by-Step regressions between the performance over 800 and 1500m among all the runners and gender group. \( \dot{E} \) is the metabolic power required in the 600m run and \( \dot{E}_{r_{\text{max}}} \) is the maximal metabolic power of the subjects in the 600m all-out run. \( \dot{E}_{\text{max}_{\text{aero}}} \) and \( \dot{E}_{\text{max}_{\text{anaero}}} \) are the maximal aerobic and anaerobic powers calculated from the model of Wilkie (43); \( Cr \) is the energy cost of running. Anaerobic contribution is the percentage of the energy spent over 600m yielded by the anaerobic metabolism. \( \tau \) is the time constant of oxygen kinetics during the 600m run.

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<th>Runners and racing distances</th>
<th>Variables</th>
<th>( r^2 )</th>
<th>Regression equation</th>
<th>Residual s</th>
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<td>All subjects over 800m (N = 15)</td>
<td>( \dot{E}<em>{r</em>{\text{max}}} )</td>
<td>0.58</td>
<td>( t_{800} = 146.46 - 15.35 \dot{E}<em>{r</em>{\text{max}}} )</td>
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<td>( \dot{E}<em>{\text{max}</em>{\text{aero}}} ) (watts.kg(^{-1})) + ( Cr ) (J.kg(^{-1}).m(^{-1}))</td>
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<td>All subjects over 1500m (N = 15)</td>
<td>( \dot{E}<em>{\text{max}</em>{\text{aero}}} ) (watts.kg(^{-1}))</td>
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<td>( t_{1500m} = 400.59 - 6.49 \dot{E}<em>{\text{max}</em>{\text{aero}}} )</td>
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<td>Female over 1500m (N = 7)</td>
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<td>( \dot{E}<em>{\text{max}</em>{\text{aero}}} ) (watts.kg(^{-1})) + ( \dot{E}<em>{\text{max}</em>{\text{anaero}}} ) (watts.kg(^{-1}))</td>
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Legends of the figure.

**Figure 1.** Relationship between the metabolic power (\(\dot{E}_r\)) required during the all-out 600m run and the maximal metabolic power (\(\dot{E}_{r_{\text{max}}}\)) produced over the all-out 600m run.
\[ y = 0.597x + 0.7164 \]
\[ R^2 = 0.7553 \]