Physiological variables to use in the gender comparison in highly trained runners

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Aim. The aims of this investigation were to compare physiological characteristics between highly trained middle-distance and marathon male (n=17) and female (n=11) runners; to determine the most suitable variables to use in the gender comparison in these subjects, considering physical difference between genders; and to indicate some of the best predictors of performance in running events in which oxidative metabolism prevails.

Methods. Subjects performed a progressive maximal exercise on the treadmill to determine maximal oxygen uptake (VO\(_{2\text{max}}\)) and velocities corresponding to a blood lactate concentration of 4 mmol·L\(^{-1}\) (\(\text{VO}_{2\text{BLA}}\)) and to the lactate threshold (\(v_{\text{T/L}}\)). Cost of running (Cr) and maximal aerobic velocity (\(v_{\text{a max}}\)) were calculated from VO\(_2\) measurements.

Results. Males presented higher VO\(_{2\text{max}}\), \(v_{\text{a max}}\), \(v_{\text{BLA}}\), \(v_{\text{T/L}}\), and VO\(_2\) @ \(v_{\text{BLA}}\) and \(v_{\text{T/L}}\) (p<0.001), but females had higher VO\(_{2\text{BLA}}\) and \(v_{\text{T/L}}\) (p<0.01) expressed as %VO\(_{2\text{max}}\), \(v_{\text{a max}}\) correlated with performance time relative to the world record in both, females (r=-0.77, p<0.01) and males (r=-0.58, p<0.05); and \(v_{\text{T/L}}\) with performance only in males (r=-0.59, p<0.05).

Conclusion. In conclusion, female athletes seemed to compensate partly their aerobic profile with higher %VO\(_{2\text{max}}\) @ \(v_{\text{BLA}}\) and \(v_{\text{T/L}}\), suggesting that both maximal and submaximal physiological variables should be considered when evaluating and comparing highly trained athletes of both genders. \(v_{\text{a max}}\) is one of the best predictors of performance in running events in which oxidative metabolism prevails.

Key Words: Performance - Oxygen consumption - Lactic acid - Running.

Current models of distance running performance do not attribute differences in performance to a single factor. Indeed, several aerobic physiological variables have been identified as determinants of distance running performance, including maximal oxygen uptake (VO\(_{2\text{max}}\)), fractional utilization of VO\(_{2\text{max}}\) (%VO\(_{2\text{max}}\)), lactate threshold, and running economy. As a matter of fact, the highest velocity that an athlete can maintain throughout a race depends on his ability to perform at the highest possible %VO\(_{2\text{max}}\) for a prolonged period of time, and this ability is related, to a great extent, with the rate of production-removal of lactate. This indicates that a high lactate threshold, in terms of %VO\(_{2\text{max}}\), can be associated with a high endurance capability (i.e. the capacity to sustain a high percentage of VO\(_{2\text{max}}\) for a prolonged period of time). In line with this, previous studies have shown that the minimum velocity eliciting VO\(_{2\text{max}}\), known as the maximal aerobic velocity (\(v_{\text{a max}}\)), can be considered an important determinant of running performance, because this parameter could identify aerobic differences between various runners or categories of runners, giving a practical assessment of aerobic demands and capability during running performance.

Several researchers have reported on the existence of physical differences responsible for the physiological gender differences in variables like VO\(_{2\text{max}}\).
velocity at the lactate threshold ($v_{lt}^{21}$) or $v_{lt}^{3}$ which suggests that these variables may not be the most suitable for a gender comparison among athletes of similar performance level. More to the point, studies by Tarnopolsky 20 indicate that because of the physical differences between males and females (e.g., size of the oxygen transport organs, muscle mass, adipose tissue), VO\(_{2}\max\) in comparative studies should be expressed relative to lean body mass (LBM), so that a part of the genetic factors contributing to VO\(_{2}\max\) can be accounted for by reporting them to the mass of metabolically active tissues.

Even though previous studies have compared several physiological variables contributing to running performance between males and females of similar performance level, both in middle-distance 3 and marathon, 21 there is still no consensus on the most suitable variables to perform these comparisons.

Therefore, the aims of the present investigation were: 1) to compare several physiological characteristics between female and male runners; 2) to determine the most suitable variables to use in the gender comparison in highly trained runners, taking into account physical differences between genders; and 3) to indicate some of the best predictors of performance in running events in which oxidative metabolism prevails.

### Materials and methods

#### Subjects

Twenty-eight highly trained female (FR, n=11) and male (MR, n=17) middle-distance and marathon runners took part in this investigation. All testing took place 2 months before the beginning of the track season. Subjects' physical characteristics and 1500 m and marathon performance times are presented in Table I. The athletes' performance times represented 113.0±5.6% of the world records in their respective events (1500 m or marathon) at the time of the study, with no statistical differences between males and females specialized in middle-distance and marathon events (Table I). Before giving their written consent to participate in the investigation, all subjects received thorough verbal and written information on the aims, procedures and potential risks of the study.

#### Treadmill protocol

The running protocol consisted of a progressive maximal exercise on the treadmill. The duration of the running stages was 4 minute and stages were interspersed with 1 minute rest intervals. The initial velocity ($v$) was set at 10 km · h\(^{-1}\) (2.78 m · s\(^{-1}\)) and it was increased by 1.5 km · h\(^{-1}\) (0.42 m · s\(^{-1}\)) at each subsequent stage. The first 3 stages were used as a warm-up, and testing continued until the subject could not longer maintain the required velocity.

#### Body fat

Percentage body fat was estimated from 4 skinfolds (biceps, triceps, subscapular, and suprailiac) performing every measurement 4 times, according to the method of Durnin and Rahaman. 22

#### Oxygen uptake

During the last minute of each submaximal running stage from 14.5 km · h\(^{-1}\) (4.03 m · s\(^{-1}\)), athletes breathed through a mouthpiece for VO\(_{2}\) determination. The expired gases were collected in Douglas bags during the last 30 seconds of each running period, through a low resistance Hans Rudolph 2700 valve (Hans Rudolph Inc., Kansas City, MO, USA). Subsequent volume determinations were carried out in a balanced Tissot spirometer. The O\(_2\) and CO\(_2\) fractions were determined using Beckman LB\(_3\) and OM\(_{11}\) analysers (Beckman Instruments Inc., Fullerton, CA, USA), calibrated with gas mixtures of compositions determined by the Scholander method. 23 The analysers were connected to a computer which permitted to determine VO\(_{2}\) values from gas fractions. The VO\(_{2}\) measured during the last finished running stage of 4

| Table I—Physical characteristics of female and male runners. Values are mean±SD. |
|---|---|---|---|
| Factors | Females | Males | p between genders |
| Age (y) | 24±4 | 28±5 | 0.06 |
| Height (cm) | 164±8 | 178±7 | 0.0001 |
| Mass (kg) | 50.5±7.1 | 64.3±7.0 | 0.0001 |
| Body fat (%) | 16.7±1.5 | 12.4±1.8 | 0.0001 |
| World record (%) | 115±5.9 | 111.8±5.1 | 0.14 |
| 1500 time (s) | 266±13.6 | 226±4.2 | 0.0001 |
| Marathon time (s) | 9820±658.2 | 8638±401.6 | 0.001 |

Percentage body fat estimated from 4 skinfolds according to the method of Durnin and Rahaman. 22

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minutes was considered to be maximal (VO2max), provided that at least 2 of the following criteria were met:24

- a plateau was reached (increase <2.1 ml · kg⁻¹ · min⁻¹ despite an increase in running speed);
- exhaustion of the athlete resulting in the inability to maintain exercise at the desired workload;
- the respiratory exchange ratio was equal or higher than 1.1;
- the heart rate was equal or greater than 90% of the predicted maximum for the subject’s age;
- the blood lactate concentration at the end of the stage was >10 mmol · L⁻¹.

Energy cost of running (Cr)

The Cr was calculated from VO2 measurements. In order to be valid, the computation of Cr must be based on VO2 measurements obtained under steady state submaximal metabolic conditions, during which VO2 is indicative of the energy expenditure per unit of time. In fact, when the protocol of the test is standardized, the mean values of Cr could be considered as steady. Cr represents the relationship between VO2 and v.25 In the present investigation Cr was computed as follows:13, 15, 16, 26, 27

\[ Cr = (\dot{VO}_2 - 0.083) \cdot v^{-1} \]

in which \( \dot{VO}_2 \) is in ml · kg⁻¹ · s⁻¹ and \( v \) in m · s⁻¹. The 0.083 ml O₂ · kg⁻¹ · m⁻¹ value is the VO₂ value corresponding to the y intercept of the VO2max/v relationship calculated by Medbø et al.28 As suggested by these authors, the calculated value of Cr was the mean of the 2 values obtained during the last 2 stages sustained for 4 minutes by all runners (i.e. 4.45 and 4.87 m · s⁻¹ for females, 5.28 and 5.70 m · s⁻¹ for males). In addition, maximal aerobic velocity (\( v_{\text{a, max}} \)) values were computed for all athletes, as follows:3, 15, 16, 27

\[ v_{\text{a, max}} = (\dot{VO}_{2\text{max}} - 0.083) \cdot Cr^{-1} \]

where \( v_{\text{a, max}} \) is in m · s⁻¹ and \( \dot{VO}_{2\text{max}} \) is in ml · kg⁻¹ · s⁻¹.

Blood lactate

During the first 30 seconds of the pause after each stage of the protocol, blood samples were taken from a fingertip and lactate was measured by a Roche model 640 Kontron lactate analyzer (Roche Bio-electronics, Hoffman-La Roche, Basel, Switzerland) using the method described by Geyssant et al.29 The velocity corresponding to a blood lactate concentration of 4 mmol · L⁻¹ (\( v_{\text{OBLA}} \)) was determined by straight line interpolation between the two closest measured values. In addition, the individual \( v_{\text{LT}} \) was identified as the intensity of exercise at which blood lactate concentration was increased 1 mmol · L⁻¹ above baseline values measured during exercise at 40-60% of VO2max.30

Statistical analysis

Values are expressed as means±SD. After having checked the equality of variance, an independent "t"-test was used to compare physiological and physical characteristics between genders. Correlations between physiological variables and performance and between VO2max and Cr were evaluated using linear regression. Statistical significance was accepted at p<0.05.

Results

Data analysis

Middle-distance and marathon runners were pooled in a single group for each gender, given that a Mann-Whitney test indicated that there were no statistical differences between middle-distance and marathon specialists within each gender.

Gender difference in physical variables

As shown in Table I, men were heavier, taller, and had less body fat (p<0.001) than women.

Gender difference in physiological variables

Regarding physiological characteristics (Table II), males had significantly higher VO2max values than females in the 2 computed units (p<0.01). \( v_{\text{a, max}} \), \( v_{\text{OBLA}} \), \( v_{\text{LT}} \), \( \dot{VO}_2 @ v_{\text{OBLA}} \) and \( \dot{VO}_{2\text{max}} @ v_{\text{LT}} \) were also significantly higher (p<0.05) for males than for females. On the other hand, higher \( v_{\text{OBLA}} \) and \( v_{\text{LT}} \) values (p<0.01) expressed as %VO2max were found in females in comparison to males (91.1±3.2% vs 86.4±3.3% and 86.3±4.6% vs 81.7±3.9%, respectively).

The physiological responses during submaximal exercise (Table III) showed that VO2 was similar for women and men at velocities 4.03, 4.45 and 4.87 m · s⁻¹.
However, the women’s \%\text{VO}_{2\text{max}} was significantly higher (p<0.001) at every submaximal velocity.

**Regression analysis**

There were significant correlations between \(\text{VO}_{2\text{max}}\) (ml · kg \(^{-1}\) · min \(^{-1}\)) and Cr (mO₂ · kg \(^{-1}\) · m \(^{-1}\)) for both genders (r=0.49, p<0.01, Figure 1), so that the runners who had the highest \(\text{VO}_{2\text{max}}\) were also those who had the highest Cr (i.e., were the less economical). On the other hand, in both, females and males a significant correlation (Table IV) was observed between \(\nu_{\text{a,max}}\) values and performance time relative to the world record, such that the higher the \(\nu_{\text{a,max}}\) value, the closer the performance time to the world record (r=−0.55, p<0.01, Figure 2). In addition, a significant correlation was observed between \(\nu_{\text{LT}}\) and performance only in male athletes (r=-0.59, p<0.05).

**Discussion**

The main findings of this investigation were that: 1) male runners showed a higher aerobic profile (i.e., significantly higher \(\text{VO}_{2\text{max}}\), \(\nu_{\text{a,max}}\), \(\text{VOBLA}^\text{max}\) and \(\nu_{\text{LT}}\) values) in comparison to females of similar relative performance level; 2) the females had significantly higher \%\text{VO}_{2\text{max}} values at \(\text{VOBLA}\), \(\nu_{\text{LT}}\) and submaxi-

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**Table II.**—Physiological characteristics of female and male runners. Values are mean±SD.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Females</th>
<th>Males</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{VO}_{2\text{max}}) (ml · kg (^{-1}) · min (^{-1}))</td>
<td>60.7±4.7</td>
<td>69.3±3.5</td>
<td>0.0001</td>
</tr>
<tr>
<td>(\text{VO}_{2\text{max}}) (ml · LB kg (^{-1}) · min (^{-1}))</td>
<td>72.8±4.8</td>
<td>79.1±4.6</td>
<td>0.002</td>
</tr>
<tr>
<td>(\nu_{\text{a,max}}) (m · s (^{-1}))</td>
<td>5.11±0.19</td>
<td>5.87±0.21</td>
<td>0.0001</td>
</tr>
<tr>
<td>(\text{Lmax}^\text{mmol} · \text{L}^{-1})</td>
<td>10.4±3.2</td>
<td>11.7±3.0</td>
<td>0.31</td>
</tr>
<tr>
<td>(\text{HRmax}) (bpm)</td>
<td>192±8</td>
<td>186±7</td>
<td>0.05</td>
</tr>
<tr>
<td>(\text{RERmax})</td>
<td>1.09±0.02</td>
<td>1.08±0.04</td>
<td>0.27</td>
</tr>
<tr>
<td>(\text{VOBLA}) (m · s (^{-1}))</td>
<td>4.52±0.31</td>
<td>5.09±0.19</td>
<td>0.0001</td>
</tr>
<tr>
<td>(\text{V}^\text{L}) (m · s (^{-1}))</td>
<td>4.29±0.25</td>
<td>4.87±0.20</td>
<td>0.0001</td>
</tr>
<tr>
<td>Cr (mO₂ · kg (^{-1}) · m (^{-1}))</td>
<td>0.183±0.015</td>
<td>0.183±0.010</td>
<td>0.89</td>
</tr>
<tr>
<td>(\text{VO}<em>{2\text{max}} \times \nu</em>{\text{LT}}) (ml · kg (^{-1}) · min (^{-1}))</td>
<td>55.3±5.38</td>
<td>60.05±4.38</td>
<td>0.02</td>
</tr>
<tr>
<td>(\text{VO}<em>{2\text{max}} \times \nu</em>{\text{LT}}) (ml · kg (^{-1}) · min (^{-1}))</td>
<td>52.40±5.24</td>
<td>56.76±4.05</td>
<td>0.02</td>
</tr>
<tr>
<td>%\text{VO}_{2\text{max}} \times \text{VOBLA}</td>
<td>91.1±3.2</td>
<td>86.3±3.3</td>
<td>0.001</td>
</tr>
<tr>
<td>%\text{VO}_{2\text{max}} \times \text{V}^\text{L}</td>
<td>86.4±4.6</td>
<td>81.7±2.9</td>
<td>0.01</td>
</tr>
</tbody>
</table>

\(\text{VO}_{2\text{max}}\): maximal oxygen uptake; \(\text{VO}_{2\text{max}}\): maximal oxygen uptake per lean body mass; \(\nu_{\text{a,max}}\): aerobic running velocity; \(\text{Lmax}\): maximal blood lactate concentration; \(\text{HRmax}\): maximal heart rate; \(\text{RERmax}\): maximal respiratory exchange ratio; \(\text{VOBLA}\): velocity at the onset of blood lactate accumulation; \(\nu_{\text{LT}}\): velocity at the lactate threshold; Cr: cost of running; \(\text{VO}_{2\text{max}} \times \nu_{\text{LT}}\): oxygen uptake at the \(\nu_{\text{LT}}\); \%\text{VO}_{2\text{max}} \times \text{VOBLA}: fractional utilization of \(\text{VO}_{2\text{max}}\) at the \(\text{VOBLA}\); \%\text{VO}_{2\text{max}} \times \text{V}^\text{L}: fractional utilization of \(\text{VO}_{2\text{max}}\) at the \(\text{V}^\text{L}\).

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**Table III.**—Physical parameters of female and male runners submaximal velocities. Values are mean±SD.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Running speed (m · s (^{-1}))</th>
<th>(\text{VO}_{2}) (ml · kg (^{-1}) · min (^{-1}))</th>
<th>%\text{VO}_{2\text{max}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>4.03</td>
<td>44.8±3.9</td>
<td>79.8±5.9*</td>
</tr>
<tr>
<td>(n=11)</td>
<td>4.45</td>
<td>50.7±3.6</td>
<td>88.7±4.6*</td>
</tr>
<tr>
<td>Male</td>
<td>4.03</td>
<td>55.3±4.3</td>
<td>96.7±3.4*</td>
</tr>
<tr>
<td>(n=17)</td>
<td>4.45</td>
<td>51.2±3.3</td>
<td>74.0±4.0</td>
</tr>
<tr>
<td></td>
<td>4.87</td>
<td>56.5±3.2</td>
<td>81.6±4.4</td>
</tr>
<tr>
<td></td>
<td>5.28</td>
<td>62.8±3.2</td>
<td>90.7±3.8</td>
</tr>
</tbody>
</table>

p<0.001. \(\text{VO}_{2}\) oxygen uptake. \%\text{VO}_{2\text{max}}: fractional utilization of maximal oxygen uptake.

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**Table IV.**—Correlation coefficients between physiological variables and performance relative to the world record in female and male runners.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Females</th>
<th>Males</th>
<th>r</th>
<th>P</th>
<th>r</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr (mO₂ · kg (^{-1}) · m (^{-1}))</td>
<td>−0.30</td>
<td>0.37</td>
<td>0.11</td>
<td>0.67</td>
<td>0.06</td>
<td>0.29</td>
</tr>
<tr>
<td>(\text{VO}_{2\text{max}}) (ml · kg (^{-1}) · min (^{-1}))</td>
<td>−0.06</td>
<td>0.86</td>
<td>−0.27</td>
<td>0.29</td>
<td>0.77</td>
<td>0.06</td>
</tr>
<tr>
<td>(\text{nu}_{\text{max}}) (m · s (^{-1}))</td>
<td>−0.51</td>
<td>0.11</td>
<td>−0.46</td>
<td>0.07</td>
<td>−0.23</td>
<td>0.50</td>
</tr>
<tr>
<td>(\text{VOBLA}) (m · s (^{-1}))</td>
<td>−0.025</td>
<td>0.94</td>
<td>−0.027</td>
<td>0.92</td>
<td>−0.54</td>
<td>0.09</td>
</tr>
<tr>
<td>(\nu_{\text{LT}}) (m · s (^{-1}))</td>
<td>−0.54</td>
<td>0.09</td>
<td>−0.09</td>
<td>0.73</td>
<td>0.70</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Cr: cost of running; \(\text{VO}_{2\text{max}}\): maximal oxygen uptake; \(\text{nu}_{\text{max}}\): aerobic running velocity; \(\text{VOBLA}\): velocity at the onset of blood lactate accumulation; \(\nu_{\text{LT}}\): velocity at the lactate threshold; \%\text{VO}_{2\text{max}} \times \text{VOBLA}: fractional utilization of \(\text{VO}_{2\text{max}}\) at the \(\text{VOBLA}\); \%\text{VO}_{2\text{max}} \times \text{V}^\text{L}: fractional utilization of \(\text{VO}_{2\text{max}}\) at the \(\text{V}^\text{L}\).
mal velocities than the males; 3) in both, males and females, \( \bar{V}_{\text{O}_{2}} \)max correlated with performance, whereas \( V_{L,T} \) correlated only in the male group.

The \( VO_{2}\max \) values of the present group of female and male runners were similar to those previously reported on highly trained athletes,4, 8, 18, 27, 31-33 Also in keeping with previous investigations,3, 16, 19, 31, 34 \( VO_{2}\max \) differences in favour of male runners depended on whether the value was reported to body mass or LBM. Studies by Tarnopolsky20 indicated that trained females generally have 6-9% more body fat than males of similar training level, and that a gender comparison in which \( VO_{2}\max \) is expressed relative to LBM would reduce to a great extent the differences in this variable between genders. In our study, differences in body fat between males and females amounted to only 3-4%; whereas the present female values were in close agreement with recommended values of 12-16%,3 males were well above values of 5-7% observed in elite athletes.35, 36 As a result, even though gender differences in \( VO_{2}\max \) were reduced when this variable was expressed relative to LBM, the differences between genders were still significant (p<0.01).

These \( VO_{2}\max \) differences between genders were largely responsible for the observed differences in \( \bar{V}_{\text{O}_{2}} \)max, \( V_{OBLA} \) and \( V_{L,T} \). Thus, according to the present results, it can be stated that highly trained male runners have an aerobic advantage (i.e. a higher aerobic profile) over their female counterparts of similar performance level. The lower aerobic values presented by the females are the result of female physical characteristics.19, 37, 38 Female runners must therefore compensate their lower \( VO_{2}\max \) values with other physiological mechanisms that favour distance running ability.21

Given that middle- and long-distance races require a high energy flow from aerobic metabolic sources, and taking into account that women usually need a half-minute and half an hour more than men to perform a 1 500 m and a marathon event, respectively; an athlete’s ability to perform at high \% \( VO_{2}\max \) values is of paramount importance to racing performance.2 In this respect, it has been suggested that an exercise intensity corresponding to a blood lactate concentration of 4 mmol·L-1, usually attained at 80-90% \( VO_{2}\max \) in male runners, represents the optimum intensity for aerobic endurance.19, 40 In our study, significant gender differences were observed in \( VO_{2} \) at \( V_{OBLA} \) and \( V_{L,T} \), as well as in \% \( VO_{2}\max \) at these running velocities; whereas absolute \( VO_{2} \) values were higher in male runners, the female athletes presented with higher \% \( VO_{2}\max \) values. Similarly, female runners also presented higher values of \% \( VO_{2}\max \) in all submaximal velocities of the study.

These results indicated the high quality of the female participants, who showed a great capacity to maintain high power outputs under steady blood lactate levels, allowing them to maintain fast running velocities and a high rate of oxidative ATP production,2 thus delaying an increased participation of anaerobic metabolism.31 In addition, these results suggest the validity of \% \( VO_{2}\max \) at \( V_{OBLA} \) and \( V_{L,T} \) to compare male and female athletes of similar relative performance level (% world record). We can also conclude that the lower \( VO_{2}\max \) values attained by the females in the present study were partly compensated by their higher \% \( VO_{2}\max \) at competition running velocities, causing an increase of their “aerobic profile”, and resulting in the end in comparable performances relative to their respective world records.19, 21

In agreement with previously published reports,3, 16, 18, 21, 31, 41 the oxygen cost of running was not significantly different between males and females (Table II). Considering that values of \( Cr \) in our runners were much better than some findings in the literature in top-class runners (0.183 vs 0.196 and 0.183 vs 0.210 mO2·kg-1·m-1 for females and males, respectively),31 we can conclude that both female and male runners of our study were very economical. In line with this point, several authors have shown that the less economical runners tend to have higher maximal aerobic power values,
i.e. they exhibit counterbalancing profiles of running economy and VO₂max.10, 11 This was also true in the present investigation, in which highly significant correlations were found between Cr and VO₂max (Figure 1), in both females and males. Considering that the margin for improvement of VO₂max is quite limited within a population of highly trained athletes, running economy may be considered a key factor in determining performance variability. Therefore, a low energy cost of running along with a fairly high aerobic power contribute to success in distance running events.4 Indeed, males and females of this study presented good running economy, but whereas men showed high absolute aerobic values, women displayed much better %VO₂max @ uOBLA and uLT to compensate up to a point the lower aerobic values. This is the most likely explanation for the observed performance difference relative to the world record (115.0% for females, 111.8% for males). Therefore, a very good distance running performance can be achieved by runners having a comparatively low %VO₂max but very high VO₂max, however an outstanding %VO₂max cannot fully compensate for a comparatively low VO₂max.11

The regression analysis between physiological variables and performance revealed the relationship between u₄ max and performance time relative to the world record for males and females, whereas uLT correlated only in the male group. This confirms that in events beyond the 800 m, performance depends to a great extent on the athlete’s capacity to maintain high running velocities under aerobic conditions.15, 27 u₄ max, a variable that integrates VO₂max and Cr,10, 14, 16, 17, 27, 43 can help to identify differences in aerobic capacity and distance running performance that running economy or maximal aerobic power independently do not discern.

Conclusions

In conclusion, the results of this study showed that all participating athletes had a high aerobic capacity and power output. However, physical differences between genders contributed to the observed physiological differences between highly trained males and females of similar relative performance level, as the males had higher VO₂max, u₄ max, uOBLA and uLT values than the females. On the other hand, female athletes seemed to compensate partly their aerobic profile with higher %VO₂max values at uOBLA and uLT, which suggests that both maximal and submaximal physiological variables need to be taken into account when evaluating and comparing highly trained athletes of both genders. In addition, the present results indicate that u₄ max is one of the best predictors of performance in running events in which oxidative metabolism prevails.

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