J SPORTS MED PHYS FITNESS 2004;44:8-14

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

S. MALDONADO-MARTÍN, I. MUJIKA, S. PADILLA

Department of Research and Development
Medical Services
Athletic Club of Bilbao, Basque Country, Spain

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 ($\dot{V}O_{2max}$) and velocities corresponding to a blood lactate concentration of 4 mmol · l^{-1} (υ_{OBLA}) and to the lactate threshold (υ_{LT}). Cost of running (Cr) and maximal aerobic velocity ($\upsilon_{a\ max}$) were calculated from $\dot{V}O_2$ measurements.**

Results. **Males presented higher $\dot{V}O_{2max}$, $\upsilon_{a\ max}$, υ_{OBLA}, υ_{LT}, and $\dot{V}O_2$ @ υ_{OBLA} and υ_{LT} ($p<0.001$), but females had higher υ_{OBLA} and υ_{LT} ($p<0.01$) expressed as $\%\dot{V}O_{2max}$. $\upsilon_{a\ max}$ 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 υ_{LT} 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 $\%\dot{V}O_{2max}$ @ υ_{OBLA} and υ_{LT}, suggesting that both maximal and submaximal physiological variables should be considered when evaluating and comparing highly trained athletes of both genders. $\upsilon_{a\ max}$ 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.[1] Indeed, several aerobic physiological variables have been identified as determinants of distance running performance, including maximal oxygen uptake ($\dot{V}O_{2max}$), fractional utilization of $\dot{V}O_{2max}$ ($\%\dot{V}O_{2max}$), lactate threshold, and running economy.[2-9] 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 $\%\dot{V}O_{2max}$ for a prolonged period of time,[10, 11] 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 $\%\dot{V}O_{2max}$, can be associated with a high endurance capability (*i.e.* the capacity to sustain a high percentage of $\dot{V}O_{2max}$ for a prolonged period of time).[11] In line with this, previous studies have shown that the minimum velocity eliciting $\dot{V}O_{2max}$, known as the maximal aerobic velocity ($\upsilon_{a\ max}$), can be considered an important determinant of running performance,[3, 12-16] 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.[17]

Several researchers have reported on the existence of physical differences responsible for the physiological gender differences in variables like $\dot{V}O_{2max}$,[3, 16, 18-20]

Address reprint requests to: S. Maldonado-Martín, Ph.D., Mediplan Sport, Obdulio López de Uralde 4, 01008 Vitoria-Gasteiz, Basque Country, Spain. E-mail: s.maldonado@wanadoo.es

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)	50.1±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
1 500 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]

velocity at the lactate threshold (υ_{LT})[21] or $\upsilon_{a\,max}$,[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), $\dot{V}O_{2max}$ in comparative studies should be expressed relative to lean body mass (LBM), so that a part of the genetic factors contributing to $\dot{V}O_{2max}$ 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 1 500 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 (1 500 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 (υ) 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 $\dot{V}O_2$ 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_2 and OM_{11} analysers (Beckman Instruments Inc., Fullerton, CA, USA), calibrated with gas mixtures of compositions determined by the Scholander method.[23] The analyzers were connected to a computer which permitted to determine $\dot{V}O_2$ values from gas fractions. The $\dot{V}O_2$ measured during the last finished running stage of 4 minutes was considered to be maximal ($\dot{V}O_{2max}$), 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 workrate;

— 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 $\dot{V}O_2$ measurements. In order to be valid, the computation of Cr must be based on $\dot{V}O_2$ measurements obtained under steady state submaximal metabolic conditions, during which $\dot{V}O_2$ 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 $\dot{V}O_2$ and υ.[25] In the present investigation Cr was computed as follows:[13, 15, 16, 26, 27]

$$Cr = (\dot{V}O_2 - 0.083) \cdot \upsilon^{-1}$$

in which $\dot{V}O_2$ is in ml · kg^{-1} · s^{-1} and υ in m · s^{-1}. The 0.083 ml O_2 · kg^{-1} · m^{-1} value is the $\dot{V}O_2$ value corresponding to the *y* intercept of the $\dot{V}O_{2max}/\upsilon$ 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 ($\upsilon_{a\,max}$) values were computed for all athletes, as follows:[3, 15, 16, 27]

$$\upsilon_{a\,max} = (\dot{V}O_{2max} - 0.083) \cdot Cr^{-1}$$

where $\upsilon_{a\,max}$ is in m · s^{-1} and $\dot{V}O_2$ 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} (υ_{OBLA}) was determined by straight line interpolation between the two closest measured values. In addition, the individual υ_{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 $\dot{V}O_{2max}$.[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 $\dot{V}O_{2max}$ 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 $\dot{V}O_{2max}$ values than females in the 2 computed units ($p<0.01$). $\upsilon_{a\,max}$, υ_{OBLA}, υ_{LT}, $\dot{V}O_2$ @ υ_{OBLA} and $\dot{V}O_{2max}$ @ υ_{LT} were also significantly higher ($p<0.05$) for males than for females. On the other hand, higher υ_{OBLA} and υ_{LT} values ($p<0.01$) expressed as %$\dot{V}O_{2max}$ 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 $\dot{V}O_2$ was similar for women and men at velocities 4.03, 4.45 and 4.87 m · s^{-1}.

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

Variables	Females	Males	p
$\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1})	60.7±4.7	69.3±3.5	0.0001
$\dot{V}O_{2max}$ (ml · LBkg^{-1} · min^{-1})	72.8±4.8	79.1±4.6	0.002
$v_{a\ max}$ (m · s^{-1})	5.11±0.19	5.87±0.21	0.0001
L_{max} (mmol · L^{-1})	10.4±3.2	11.7±3.0	0.31
HR_{max} (bpm)	192±8	186±7	0.05
RER_{max}	1.09±0.02	1.08±0.04	0.27
v_{OBLA} (m · s^{-1})	4.52±0.31	5.09±0.19	0.0001
v_{LT} (m · s^{-1})	4.29±0.25	4.87±0.20	0.0001
Cr (ml O_2 kg^{-1} · m^{-1})	0.183±0.015	0.183±0.010	0.89
$\dot{V}O_2$@v_{OBLA} (ml · kg^{-1} · min^{-1})	55.32±5.38	60.05±4.38	0.02
$\dot{V}O_2$@v_{LT} (ml · kg^{-1} · min^{-1})	52.40±5.24	56.76±4.05	0.02
%$\dot{V}O_{2max}$ @ v_{OBLA}	91.1±3.2	86.3±3.3	0.001
%$\dot{V}O_{2max}$ @ v_{LT}	86.4±4.6	81.7±3.9	0.01

$\dot{V}O_{2max}$: maximal oxygen uptake; $\dot{V}O_{2max}$ (ml · LBkg^{-1} · min^{-1}): maximal oxygen uptake per lean body mass; $v_{a\ max}$: aerobic running velocity; L_{max}: maximal blood lactate concentration; HR_{max}: maximal heart rate; RER_{max}: maximal respiratory exchange ratio; v_{OBLA}: velocity at the onset of blood lactate accumulation; v_{LT}: velocity at the lactate threshold; Cr: cost of running; $\dot{V}O_2$ @ v_{OBLA}: oxygen uptake at the v_{OBLA}; $\dot{V}O_2$ @ v_{LT}: oxygen uptake at the v_{LT}; % $\dot{V}O_{2max}$ @ v_{OBLA}: fractional utilization of $\dot{V}O_{2max}$ at the v_{OBLA}; % $\dot{V}O_{2max}$ @ v_{LT}: fractional utilization of $\dot{V}O_{2max}$ at the v_{LT}.

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

Sex	Running speed (m · s^{-1})	$\dot{V}O_2$ (ml · kg^{-1} · min^{-1})	%$\dot{V}O_{2max}$
Female	4.03	44.8±3.9	79.8±5.9*
(n=11)	4.45	50.7±3.6	88.7±5.6*
	4.87	55.3±4.3	96.7±3.4*
Male	4.03	45.6±3.8	65.9±4.9
(n=17)	4.45	51.2±3.3	74.0±4.0
	4.87	56.5±3.2	81.6±4.4
	5.28	62.8±3.2	90.7±3.8

p<0.001. $\dot{V}O_2$: oxygen uptake. %$\dot{V}O_{2max}$: fractional utilization of maximal oxygen uptake.

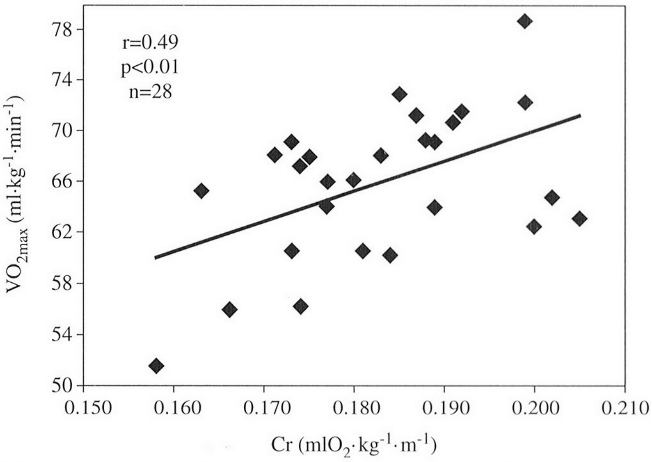

Figure 1.—Relationship between Cr and $\dot{V}O_{2max}$ for female and male runners.

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

Variables	Females		Males	
	r	P	r	P
Cr (mlO$_2$ · kg^{-1} · m^{-1})	–0.30	0.37	0.11	0.67
$\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1})	–0.06	0.86	–0.27	0.29
$v_{a\ max}$ (m · s^{-1})	–0.77	0.006	–0.58	0.02
v_{OBLA} (m · s^{-1})	–0.51	0.11	–0.46	0.07
v_{LT} (m · s^{-1})	–0.23	0.50	–0.59	0.02
%$\dot{V}O_{2max}$ @ v_{OBLA}	–0.025	0.94	–0.027	0.92
%$\dot{V}O_{2max}$ @ v_{LT}	–0.54	0.09	–0.09	0.73

Cr: cost of running; $\dot{V}O_{2max}$: maximal oxygen uptake; $v_{a\ max}$: aerobic running velocity; v_{OBLA}: velocity at the onset of blood lactate accumulation; v_{LT}: velocity at the lactate threshold; % $\dot{V}O_{2max}$ @ v_{OBLA}: fractional utilization of $\dot{V}O_{2max}$ at the v_{OBLA}; % $\dot{V}O_{2max}$ @ v_{LT}: fractional utilization of $\dot{V}O_{2max}$ at the v_{LT}.

However, the women's %$\dot{V}O_{2max}$ was significantly higher (p<0.001) at every submaximal velocity.

Regression analysis

There were significant correlations between $\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1}) and Cr (mlO$_2$ ·kg^{-1} · m^{-1}) for both genders (r=0.49, p<0.01, Figure 1), so that the runners who had the highest $\dot{V}O_{2max}$ 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 $\upsilon_{a\ max}$ values and performance time relative to the world record, such that the higher the $\upsilon_{a\ max}$ 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 υ_{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 $\dot{V}O_{2max}$, $\upsilon_{a\ max}$, υ_{OBLA} and υ_{LT} values) in comparison to females of similar relative performance level; 2) the females had significantly higher %$\dot{V}O_{2max}$ values at υ_{OBLA}, υ_{LT} and submaximal velocities than the males; 3) in both, males and females, $\upsilon_{a\,max}$ correlated with performance, whereas υ_{LT} correlated only in the male group.

The $\dot{V}O_{2max}$ 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] $\dot{V}O_{2max}$ differences in favour of male runners depended on whether the value was reported to body mass or LBM. Studies by Tarnopolsky [20] indicated that trained females generally have 6-9% more body fat than males of similar training level, and that a gender comparison in which $\dot{V}O_{2max}$ 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 $\dot{V}O_{2max}$ were reduced when this variable was expressed relative to LBM, the differences between genders were still significant ($p<0.01$).

These $\dot{V}O_{2max}$ differences between genders were largely responsible for the observed differences in $\upsilon_{a\,max}$, υ_{OBLA} and υ_{LT}. 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 $\dot{V}O_{2max}$ 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 $\%\dot{V}O_{2max}$ 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 $mmol \cdot l^{-1}$, usually attained at 80-90% $\dot{V}O_{2max}$ in male runners, represents the optimum intensity for aerobic endurance.[39, 40] In our study, significant gender differences were observed in $\dot{V}O_2$ at υ_{OBLA} and υ_{LT}, as well as in $\%\dot{V}O_{2max}$ at these running velocities; whereas absolute $\dot{V}O_2$ values were higher in male runners, the

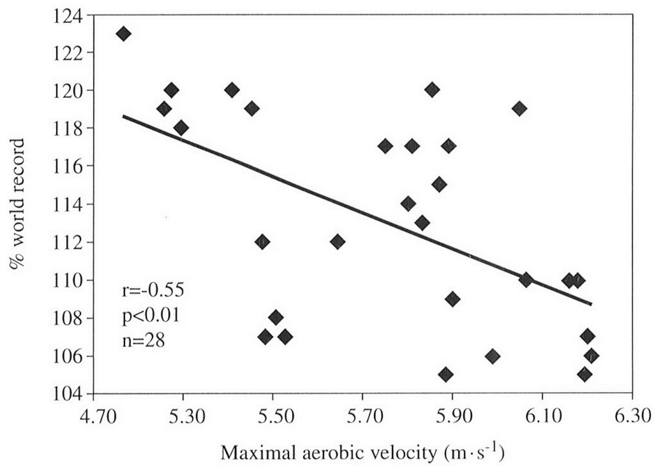

Figure 2.—Relationship between performance time relative to the world record (% world record) and maximal aerobic velocity for female and male runners.

female athletes presented with higher $\%\dot{V}O_{2max}$ values. Similarly, female runners also presented higher values of $\%\dot{V}O_{2max}$ 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.[11] In addition, these results suggest the validity of $\%\dot{V}O_{2max}$ at υ_{OBLA} and υ_{LT} to compare male and female athletes of similar relative performance level (%world record). We can also conclude that the lower $\dot{V}O_{2max}$ values attained by the females in the present study were partly compensated by their higher $\%\dot{V}O_{2max}$ 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 $mlO_2 \cdot kg^{-1} \cdot m^{-1}$ 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 $\dot{V}O_{2max}$.[15, 16, 31, 42] This was also true in the present investigation, in which highly significant correlations were found between Cr and $\dot{V}O_{2max}$ (Figure 1), in both females and males. Considering that the margin for improvement of $\dot{V}O_{2max}$ 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 $\%\dot{V}O_{2max}$ @ υ_{OBLA} and υ_{LT} 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 $\%\dot{V}O_{2max}$ but very high $\dot{V}O_{2max}$, however an outstanding $\%\dot{V}O_{2max}$ cannot fully compensate for a comparatively low $\dot{V}O_{2max}$.[11]

The regression analysis between physiological variables and performance revealed the relationship between $\upsilon_{a\,max}$ and performance time relative to the world record for males and females, whereas υ_{LT} 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] $\upsilon_{a\,max}$, a variable that integrates $\dot{V}O_{2max}$ 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 $\dot{V}O_{2max}$, $\upsilon_{a\,max}$, υ_{OBLA} and υ_{LT} values than the females. On the other hand, female athletes seemed to compensate partly their aerobic profile with higher $\%\dot{V}O_{2max}$ values at υ_{OBLA} and υ_{LT}, 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 $\upsilon_{a\,max}$ is one of the best predictors of performance in running events in which oxidative metabolism prevails.

References

1. Bergh U, Ekblom B, Astrand P-O. Maximal oxygen uptake "classical" *versus* "contemporary" viewpoints. Med Sci Sports Exerc 2000;32: 85-8.
2. Bassett DR, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. Med Sci Sports Exerc 2000;32:70-84.
3. Billat VL, Beillot J, Jan J, Rochcongar P, Carre F. Gender effect on the relationship of time limit at 100% $\dot{V}O_{2max}$ with other bioenergetic characteristics. Med Sci Sports Exerc 1996;28:1049-55.
4. Bransford DR, Howley ET. Oxygen cost of running in trained and untrained men and women. Med Sci Sports 1977;9:41-4.
5. Conley DL, Krahenbuhl GS. Running economy and distance running performance of highly trained athletes. Med Sci Sports Exerc 1980; 12:357-60.
6. Costill DL, Thomason H, Roberts E. Fractional utilization of the aerobic capacity during distance running. Med Sci Sports 1973;5:248-52.
7. Farrell PA, Wilmore JH, Coyle EF, Billing JE, Costill DL. Plasma lactate accumulation and distance running performance. Med Sci Sports 1979;11:338-44.
8. Fay L, Londeree BR, Lafontaine TP, Volek MR. Physiological parameters related to distance running performance in female athletes. Med Sci Sports Exerc 1989;21:319-24.
9. Sparling PB. Physiological determinants of distance running performance. Phys Sports Med 1984;12:68-77.
10. di Prampero PE, Atchou G, Brückner JC, Moia C. The energetics of endurance running. Eur J Appl Physiol 1986;55:259-66.
11. Péronnet F, Thibault G, Rhodes EC, McKenzie C. Correlation between ventilatory threshold and endurance capability in marathon runners. Med Sci Sports Exerc 1987;19:610-5.
12. Abe D, Yanagawa K, Yamanobe K, Tamura K. Assessment of middle-distance running performance in sub-elite young runners using energy cost of running. Eur J Appl Physiol 1998;77:320-5.
13. di Prampero PE. The energy cost of human locomotion on land and in water. Int J Sports Med 1986;7:55-72.
14. Lacour JR, Padilla-Magunacelaya S, Chatard JC, Arsac L, Barthelemy JC. Assessment of running velocity at maximal oxygen uptake. Eur J Appl Physiol 1991;62:77-82.
15. Maldonado S, Mujika I, Padilla S. Influence of body mass and height on the energy cost of running in highly trained middle- and long-distance runners. Int J Sports Med 2002;23:268-72.
16. Padilla S, Bourdin M, Barthelemy JC, Lacour JR. Physiological correlates of middle-distance running performance. Eur J Appl Physiol 1992;65:561-6.
17. Billat VL, Koralsztein JP. Significance of the velocity at $\dot{V}O_{2max}$ and time to exhaustion at this velocity. Sports Med 1996;22:90-108.
18. Bunc V, Heller J. Energy cost of running in similarly trained men and women. Eur J Appl Physiol 1989;59:178-83.
19. Joyner MJ. Physiological limiting factors and distance running: influence of gender and age on record performances. In: Holloszy JO, editor. Exercise and sport sciences reviews. American College of Sports Medicine Series. Baltimore: Williams & Wilkins 1993;21: 103-33.
20. Tarnopolsky MA. Gender differences in substrate metabolism during endurance exercise. Can J Appl Physiol 2000;25:312-27.
21. Helgerud J. Maximal oxygen uptake, anaerobic threshold and running

economy in women and men with similar performance level in marathons. Eur J Appl Physiol 1994;68:155-61.
22. Durnin JVGA, Ramahan MM. The assessment of the amount of fat in the human body from measurements of skinfold thickness. Br J Nutr 1967;21:681-9.
23. Scholander RF. Analyzer for accurate estimation of respiratory gases in one-half cubic centimeter samples. J Biol Chem 1947;167:235-50.
24. Astrand PO, Rodahl K. Fisiología del Trabajo Físico. 2nd ed. Buenos Aires: Edit Panamérica; 1986.p.262-3.
25. Hausswirth C, Brisswalter J. Le coût énergétique de la course à pied de durée prolongée: étude des paramètres d'influence. Sci Sports 1999;14:59-70.
26. Bourdin M, Pastene J, Germain M, Lacour JR. Influence of training, sex, age and body mass on the energy cost of running. Eur J Appl Physiol 1993;66:439-44.
27. Lacour JR, Padilla-Magunacelaya S, Barthelemy JC, Dormois D. The energetics of middle-distance running. Eur J Appl Physiol 1990; 60:38-43.
28. Medbø JI, Mohn AC, Tabata I, Bahr R, Vaage O, Sejersted OM. Anaerobic capacity determined by accumulated O_2 deficit. J Appl Physiol 1988;64:50-60.
29. Geyssant A, Dormois D, Barthélémy JC, Lacour JR. Lactate determination with the lactate analyser L.A. 640: a critical study. Scand J Clin Lab Invest 1985;45:145-9.
30. Coyle EF. Integration of the physiological factors determining endurance performance ability. In: Holloszy JO, editor. Exercise and sport sciences reviews. American College of Sports Medicine Series. Baltimore: Williams & Wilkins; 1995.p.25-63.
31. Billat VL, Demarle A, Slawinski J, Paiva M, Koralsztein JP. Physical and training characteristics of top-class marathon runners. Med Sci Sports Exerc 2001;33:2089-97.
32. Billat VL, Renoux JC, Pinoteau J, Petit B, Koralsztein JP. Reproducibility of running time to exhaustion at $\dot{V}O_{2max}$ in subelite runners. Med Sci Sports Exerc 1994;26:254-7.
33. Spencer MR, Gastin PB. Energy system contribution during 200 to 1500 m running in highly trained athletes. Med Sci Sports Exerc 2001;33:157-62.
34. Jensen K, Johansen L, Secher NH. Influence of body mass on maximal oxygen uptake: effect of sample size. Eur J Appl Physiol 2001;84: 201-5.
35. Costill DL, Fox EL. Energetics of marathon running. Med Sci Sports 1969;1:81-6.
36. Londeree BR. The use of laboratory test results with long distance runners. Sports Med 1986;3:201-13.
37. Karlsson J, Jacobs I. Onset of blood lactate accumulation during muscular exercise as a threshold concept. Int J Sports Med 1982;3: 190-201.
38. Sparling PB, Nieman DC, O'Connor PJ. Selected scientific aspects of marathon racing. Sports Med 1993;15:116-32.
39. Billat VL. Use of blood lactate measurements for prediction of exercise performance and for control of training. Sports Med 1996;22: 157-75.
40. Sjödin B, Svedenhag J. Applied physiology of marathon running. Sports Med 1985;2:83-99.
41. Hagan RD, Strathman T, Gettman LR. Oxygen uptake and energy expenditure during horizontal treadmill running. J Appl Physiol 1980; 49:571-5.
42. Morgan DW, Daniels JT. Relationship between $\dot{V}O_{2max}$ and the aerobic demand of running in elite distance runners. Int J Sports Med 1994;15:426-9.
43. Hill DW, Rowell AL. Running velocity at $\dot{V}O_{2max}$. Med Sci Sports Exerc 1996;28:114-9.