

Gender effect on the relationship of time limit at 100% $\dot{V}O_{2max}$ with other bioenergetic characteristics

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ABSTRACT

BILLAT, V., J. BEILLOT, J. JAN, P. ROCHCONGAR, and F. CARRE. Gender effect on the relationship of time limit at 100% $\dot{V}O_{2max}$ with other bioenergetic characteristics. *Med. Sci. Sports Exerc.*, Vol. 28, No. 8, pp. 1049–1055, 1996. The aim of this study was to investigate the influence of gender on the possible contribution of t_{lim} at $v_{a\ max}$ (minimal speed that elicits $\dot{V}O_{2\ max}$) in performance speeds. The male and female elite middle-distance runners had similar performance (IAAF scores). Fourteen female and fifteen male (25.2 ± 3.6 and 25.1 ± 4.2 yr old; $\dot{V}O_{2max} = 63.2 \pm 4.2$ and 77.7 ± 6.4 ml·kg⁻¹·min⁻¹; $v_{a\ max} = 17.3 \pm 0.7$ and 20.8 ± 1.1 km·h⁻¹, respectively) performed three exercise tests on a treadmill (3° slope) within a 2-wk period: an incremental test to determine $\dot{V}O_{2max}$, $v_{a\ max}$ and the velocity at the onset of blood lactate accumulation (vOBLA); an exhaustive constant velocity test to determine t_{lim} at $v_{a\ max}$; and an exhaustive constant velocity test at 110% $v_{a\ max}$ to determine the accumulated oxygen deficit (AOD). There were no effects of gender, i.e., no significant differences were observed between female and male for t_{lim} at $v_{a\ max}$ (421 ± 129 vs 367 ± 118 s respectively; $P = 0.24$), vOBLA as % $v_{a\ max}$ (88.4 ± 2.7 vs $90.4 \pm 3\%$ of $v_{a\ max}$; $P = 0.07$), AOD (40.1 ± 14.9 vs 48.9 ± 21.3 ml·O₂·kg⁻¹; $P = 0.22$), running economy at the same absolute speed, i.e., 14 km·h⁻¹ (53.4 ± 2.6 vs 52.7 ± 4.1 ml·O₂·min⁻¹·kg⁻¹; $P = 0.64$) or for gross oxygen cost of running (CR) at the same relative velocity (75% $v_{a\ max}$) (0.214 ± 0.001 vs 0.214 ± 0.002 ml·O₂·kg⁻¹·m⁻¹; $P = 0.94$). However, an effect of gender was found on the relationship between the bioenergetic parameters and performance. For male, v1500 was predicted by $v_{a\ max}$, vOBLA, t_{lim} at 110% of $v_{a\ max}$, and CR ($R^2 = 0.96$). For female, no bioenergetic parameters were strongly correlated with v1500 m. The inverse relationship found between $v_{a\ max}$ and t_{lim} at $v_{a\ max}$ in previous literature was confirmed by the 29 runners in this study and for the subset of male only.

GENDER DIFFERENCES, ELITE MIDDLE-DISTANCE RUNNERS, PERFORMANCE, TIME TO EXHAUSTION AT $\dot{V}O_{2max}$, OXYGEN DEFICIT

Several recent reports suggest that the minimal speed that elicits $\dot{V}O_{2max}$, the so-called maximal aerobic running velocity ($v_{a\ max}$), may be an important determinant of middle-distance running performance (8,10,20,38). In addition, the maximal endurance

time (t_{lim}), according to Scherrer and Monod (32) at $v_{a\ max}$ is related to running performance (1). We have previously shown that t_{lim} at $v_{a\ max}$ is reproducible for a subject (1). However, it is associated with a greater coefficient of variation than other physiological variables, such as $\dot{V}O_{2max}$ (1).

Performance in long-distance running is related to several physiological variables, such as $\dot{V}O_{2max}$, the anaerobic threshold, running economy, and anaerobic capacity. Previous studies have delved into the gender differences in the relationships between long-distance performance and the anaerobic threshold (7,12,38) and between performance and running economy (8). Recently, Helgerud (13) evaluated performance-matched male and female marathon runners and reported that while men had higher $\dot{V}O_{2max}$ and anaerobic threshold, women had higher weekly training distance and demonstrated superior running economy (lower gross oxygen cost of running) and a higher exercise intensity expressed as a percent of $\dot{V}O_{2max}$ during the race. Medbø et al. (24–26) have described an approach to measuring the accumulated O₂ deficit (AOD) during heavy exercise. Maximal value of the AOD was observed at work loads causing exhaustion in 2–5 min. They have further demonstrated that the AOD is larger in sprint-trained athletes than in endurance-trained athletes or in the untrained. However, while anaerobic capacity is related to running performance (5) and is known to increase in women after training (25) the possibility of gender differences in the relationship between performance and anaerobic capacity has not been investigated.

The aims of the present study, which involved elite French male and female middle-distance runners with nearly the same competition level, were: (i) to investigate the gender effect on the bioenergetic characteristics as $\dot{V}O_{2max}$, anaerobic threshold, running economy, and particularly to study the t_{lim} at $v_{a\ max}$ and the anaerobic capacity, as reflected by the accumulated oxygen deficit (26), in these two groups; (ii) to study the relationships

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between t_{lim} at $v_{a\ max}$ and other bioenergetic characteristics; (iii) and, lastly, to study the relationship between t_{lim} at $v_{a\ max}$ and the other bioenergetic characteristics with 1500-m track performance.

METHODS

Subjects

This study was conducted with 29 elite middle-distance runners, 14 women and 15 men. All the subjects were volunteers and gave their written informed consent, according to the French Comité National de la Recherche Clinique. Their average weekly training distance ranged from 80 to 110 km for males and from 60 to 90 km for females. Based on their season's performance, 800 m, 1500 m, or 3000 m, all these athletes were ranked at the national or international level. International Amateur Athletics Federation (IAAF) tables were used to determine an IAAF score for each subject's best performance. Mean (\pm SD) scores for the men (984 ± 43 points) and women (1023 ± 105 points) did not differ ($P = 0.28$).

Body composition was estimated from skinfold thicknesses (11). Subjects' physical characteristics and the average velocity ($m \cdot s^{-1}$) sustained over their best performance are summarized in Table 1.

Experimental Procedures

All testing was performed during October and November. Three treadmill (Gymrol 2500, Saint-Etienne, France) tests were done in a 2-wk period at the same time of the day for each subject. During all the treadmill tests, a fixed constant slope of 3% was used. A brief rest period (3 d without strenuous exercise) separated each test session.

First test session. For the determination of individual $\dot{V}O_{2\ max}$ and onset of blood lactate accumulation (OBLA) (18), an intermittent graded exercise protocol was used. The durations of running and rest periods were 4 and 1 min, respectively, as it has been previously noted that a steady-state of gas exchange is obtained within 3.5 min (20). The initial speed was set at $12\ km \cdot h^{-1}$ for the men and $10\ km \cdot h^{-1}$ for the women, and speed was increased by $2\ km \cdot h^{-1}$ ($33.3\ m \cdot min^{-1}$) for each stage, except for the last one where the increment was only $1\ km \cdot h^{-1}$ ($16.7\ m \cdot min^{-1}$). The treadmill velocity was verified at each stage by stopwatch recording of 20 treadmill belt revolutions.

Oxygen consumption was continuously monitored during the initial resting period ($\dot{V}O_{2\ rest}$, measured with the subject standing on the treadmill) and throughout the tests until exhaustion. Expired gas was collected through a Hans-Rudolph valve in meteorological balloons during the last 30 s of each stage of the test. A three-way valve with a clock device was used to accurately measure the

duration of the gas collection. Volume of expired gas was measured with a Tissot 100-l spirometer, the O_2 and CO_2 concentrations were determined with a polarographic O_2 analyzer (Beckman OM 11, RFA) and an infrared CO_2 analyzer (Cosma Rubis 3000, RFA), which were calibrated against two different gases of known concentration before each test. The first one was nitrogen and the second was composed of 5% CO_2 and 12% O_2 .

During each 1-min rest period, a finger tip blood sample ($10\ \mu l$) was obtained for blood lactate measurement (YSI 27, Yellow Springs Instrument, Yellow Springs, OH) and diluted in $350\ \mu l$ of buffer solution under peroxide. Reactif was the enzyme L-lactate oxidase, which catalyzes the production of hydrogen peroxide and pyruvate from lactic acid and oxygen.

Heart rate was monitored throughout each test (Siemens electrocardiograph, RFA).

For attainment of $\dot{V}O_{2\ max}$ the following criteria were used: the exhaustion of the subject, the leveling-off of $\dot{V}O_2$, i.e., an increase in $\dot{V}O_2$ of less than $2.1\ ml \cdot min^{-1} \cdot kg^{-1}$ of the expected rise in oxygen uptake (36), the respiratory exchange ratio greater than 1.1, and the blood lactate concentration higher than $8.5\ mmol \cdot l^{-1}$ (33).

Several individual parameters were then calculated: (i) The accumulated oxygen deficit (26). For that, the linear relationship between $\dot{V}O_2$ and velocity was established by calculating the regression of the steady-state O_2 uptake on treadmill speed (during all stages except the last two) using the linear regression procedure on Statistica (Statsoft, OK). (ii) $v_{a\ max}$, i.e., the velocity associated with $\dot{V}O_{2\ max}$, was calculated according to the equation of di Prampero (10): $v_{a\ max} = (\dot{V}O_{2\ max} - \dot{V}O_{2\ rest}) \cdot CR^{-1}$, where CR ($ml\ O_2 \cdot kg^{-1} \cdot m^{-1}$) is the oxygen cost of running per unit of body mass at a given velocity (v) and was calculated by the formula: $CR = (\dot{V}O_{2v} - \dot{V}O_{2\ rest}) \cdot v^{-1}$ and CR was calculated for the velocity associated with 75% $\dot{V}O_{2\ max}$ under the OBLA velocity, to be sure that the subject is yet in aerobic condition, and that CR can be estimated with oxygen consumption (10). (iii) Running economy was determined by the $\dot{V}O_2$ values at the submaximal treadmill speed of $14\ km \cdot h^{-1}$ ($ml \cdot min^{-1} \cdot kg^{-1}$), referred to herein as running economy (RE) (6) were also determined. (iv) Onset of blood lactate accumulation. Lastly, individual OBLA was defined as the velocity at which blood lactate concentration reached a value of $4\ mM \cdot l^{-1}$ (18). OBLA velocity (v_{OBLA}) was expressed in $\%v_{a\ max}$.

Second test session. The purpose of the second session was to determine the individual t_{lim} at $v_{a\ max}$. After a 15-min warm-up at 60% $v_{a\ max}$, the treadmill speed was quickly increased (in less than 20 s) to the individual $v_{a\ max}$. The athlete was then verbally encouraged to run until exhaustion.

Third test session. The purpose of the last session was to determine the individual's accumulated oxygen deficit (AOD). According to Medbø et al. (26), an exhausting run at 110% of the individual $v_{a\ max}$ is appro-

TABLE 1. Physical characteristics and the race velocities of subjects.

	Male	Female
<i>N</i>	15	14
Age (yr)	25.1 ± 4.3	25.2 ± 3.6
Ht (cm)	177.3 ± 5.5	167.4 ± 3.9
Wt (kg)	65.3 ± 4.3	56 ± 5.5
% fat (%)	7.6 ± 1.7	14.9 ± 2.4
Race velocities (m·s ⁻¹)		
800 m	7.37 ± 0.11 (10)	6.26 ± 0.18 (8)
1500 m	6.64 ± 0.25 (9)	5.58 ± 0.11 (9)
3000 m	6.04 ± 0.20 (10)	5.20 ± 0.10 (2)
IAAF score	1023 ± 105	984 ± 82

Values are means ± SD. Figure within parentheses denotes the subject's number if it is not indicated above.

appropriate for use in the determination of AOD, which is defined as the difference between the estimated total accumulated oxygen demand and the measured accumulated oxygen uptake (26). In this study, the exhausting exercise was preceded by a warm-up period of 15 min at 60% of the individual $v_{a \max}$. Total accumulated O_2 uptake during all-out run was measured.

Statistics. Data are reported as means ± SD. Means were compared using the analysis of variance (ANOVA) technique at the 5% level of confidence. Correlations between bioenergetic parameters, i.e., $\dot{V}O_{2max}$, vOBLA, RE, AOD, and $v_{a \max}$, were determined using the Pearson product moment correlation coefficient, and their relationships with performance were evaluated using multiple regression. The bioenergetic parameters that produced the highest simple correlation with performance (race velocity) were then entered. A *P*-value lower than or equal to 0.05 was accepted as statistically significant.

RESULTS

Physical characteristics and the average race velocities for men and women are presented in Table 1.

The Gender Difference in $\dot{V}O_{2max}$, t_{lim} at $v_{a \max}$, and the Accumulated Oxygen Deficit

The data obtained in the present study are summarized in Table 2. No significant difference was noted between men and women, except for $\dot{V}O_{2max}$ ($F = 36$, $P = 0.0001$) and $v_{a \max}$ ($F = 96$, $P = 0.0001$). Women had twice as much fat as men ($14.7 \pm 2.4\%$ vs $7.8 \pm 1.8\%$). It remains a significant difference in $\dot{V}O_{2max}$ per lean body mass ($F = 11$, $P = 0.003$).

Each group of men and women was homogeneous with respect to their IAAF performance score and to their physiological parameters. There were three exceptions: for both men and women, there was considerable within-group variability in t_{lim} at $v_{a \max}$, and in the two measures of anaerobic capacity, namely t_{lim} at 110% $v_{a \max}$ and AOD; for these three variables, coefficient of variation was in excess of 25%.

The Relationship between t_{lim} at $v_{a \max}$ with Other Bioenergetic Parameters

Significant correlations among the variables are presented in Table 3 for all 29 runners, men and women. We can notice that: (i) t_{lim} at $v_{a \max}$ was inversely correlated with $v_{a \max}$ for all 29 runners and only for men, but not for women ($r = 0.08$); (ii) t_{lim} at $v_{a \max}$ was positively related to t_{lim} at 110% $v_{a \max}$ for all 29 runners and for men, but inversely and not significantly for women ($r = -0.38$); (iii) t_{lim} at $v_{a \max}$ was positively correlated with AOD for men but not for women ($r = 0.07$); (iv) t_{lim} at $v_{a \max}$ was positively correlated with $\dot{V}O_{2max}$ for women but not for men ($r = -0.16$); (v) t_{lim} at 110% of $v_{a \max}$ was positively correlated with AOD for all 29 runners and for men, but not for women ($r = 0.28$).

These data show that t_{lim} at $v_{a \max}$ depends on aerobic characteristics for women ($\dot{V}O_{2max}$) and on anaerobic ones for men (AOD). Moreover, there is a gender effect on the relationship between t_{lim} at $v_{a \max}$ and t_{lim} at 110%.

The Relationship among Physiological Variables and 1500-m Track Performance

Eighteen runners (9 men and 9 women) had performed a 1500-m run during the year the laboratory tests were performed. Table 4 provides data from a stepwise multiple regression analysis, which selects the best combination of predictors of velocity over 1500 m. For the 18 runners who competed over 1500 m, $v_{a \max}$ and t_{lim} at $v_{a \max}$ explained 95% of the variance in the average race velocity over 1500 m (v_{1500}). For the 9 men, the best combination of predictors was $v_{a \max}$, vOBLA, t_{lim} at 110% $v_{a \max}$, and ($\dot{V}O_{2max}$) ($R^2 = 0.96$). There was no significant predictor for women, $v_{a \max}$, t_{lim} at $v_{a \max}$, and CR having the partial coefficient of correlation of 0.40, 0.57, and 0.56, respectively ($F = 1.1, 2.8, 2.7$).

TABLE 2. Bioenergetics characteristics of subjects.

	Male	Female	<i>P</i>
<i>N</i>	15	14	
$\dot{V}O_{2max}$ (ml·min ⁻¹ ·kg ⁻¹)	77.7 ± 6.4	63.2 ± 4.2	*
$v_{a \max}$ (m·s ⁻¹)	5.8 ± 0.3	4.8 ± 0.2	*
$v_{a \max}$ (km·h ⁻¹)	20.88 ± 1.08	17.28 ± 0.7	
t_{lim} at $v_{a \max}$ (s)	367 ± 118	421 ± 129	NS
t_{lim} at 110% $v_{a \max}$ (s)	149 ± 45	147 ± 38	NS
AOD (ml·kg ⁻¹)	49.0 ± 21.3	40.1 ± 14.9	NS
CR (ml O_2 ·kg ⁻¹ ·m ⁻¹)	0.214 ± 0.02	0.214 ± 0.02	NS
vOBLA (% $v_{a \max}$)	90.4 ± 3.0	88.4 ± 2.7	NS
$\dot{V}O_2$ at 3.33 m·s ⁻¹ (12 km·h ⁻¹)	45.4 ± 3.4	46.1 ± 2.7	NS
$\dot{V}O_2$ at 3.88 m·s ⁻¹ (14 km·h ⁻¹)	52.7 ± 4.1	53.4 ± 2.6	NS
$\dot{V}O_2$ at 4.44 m·s ⁻¹ (16 km·h ⁻¹)	61.2 ± 4.9	59.6 ± 3.8	NS
$\dot{V}O_2$ at 5.00 m·s ⁻¹ (18 km·h ⁻¹)	67.2 ± 4.7	64.5 ± 3.9	NS

Values are means ± SD. Coefficient of variance (CV) is noted for each group. NS difference nonsignificant; a comparison between men and women has been realized. * = $P < 0.001$.

TABLE 3. Significant correlations for all 29 runners and for each gender among time to exhaustion at 100% $v_{a \max}$ ($t_{lim} v_{a \max}$) and $v_{a \max}$ (aerobic maximal velocity in $m \cdot s^{-1}$); time to exhaustion at 110% $v_{a \max}$ ($t_{lim} 110\%$), $\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$), and (vOBLA in % $v_{a \max}$).

Bioenergetic Characteristics	All 29 Runners	Women (N = 14)	Men (N = 15)
$t_{lim} v_{a \max}$	$t_{lim} 110\%$ ($r = 0.68, P < 0.01$)	$\dot{V}O_{2max}$ 0.602 ($P < 0.05$)	$t_{lim} 110\%$ ($r = 0.77, P < 0.01$) $v_{a \max}$ ($r = -0.85, p < 0.01$) AOD ($r = 0.69, p < 0.02$)
$\dot{V}O_{2max}$	$v_{a \max}$ ($r = 0.85, p < 0.001$) OBLA ($r = 0.59, p < 0.01$)	$t_{lim} 110\%$ ($r = -0.73, P < 0.01$) $v_{a \max}$ ($r = 0.62, P < 0.05$) OBLA ($r = 0.58, p < 0.05$)	$v_{a \max}$ ($r = 0.64, p < 0.02$) OBLA ($r = 0.57, p < 0.05$)
AOD ($ml \cdot kg^{-1}$)	$t_{lim} 110\%$ ($r = 0.68, p < 0.01$)		$t_{lim} 110\%$ ($r = 0.89, p < 0.001$)

TABLE 4. Multiple correlation coefficients of bioenergetic characteristics with running velocity over 1500 m (v_{1500}) among all the runners and gender group.

Runners	Variables	R ²	Regression equation	Residual ($m \cdot s^{-1}$)
All (N = 18)	$v_{a \max}$	0.84	$v_{1500} = 0.893 v_{a \max} + 1.453$	0.05
	$t_{lim} \text{ at } v_{a \max}$	0.95	$v_{1500} = 1.05 v_{a \max} + 0.001 t_{lim} \text{ at } v_{a \max} + 0.087$	0.02
Men (N = 9)	$v_{a \max}$	0.67	$v_{1500} = 0.47 v_{a \max} + 3.93$	0.02
	vOBLA	0.82	$v_{1500} = 0.43 v_{a \max} + 2.92$ vOBLA + 1.55	0.015
	$t_{lim} 110$	0.90	$v_{1500} = 0.56 v_{a \max} + 3.31$ vOBLA + 0.002 $t_{lim} 110$ + 0.19	0.004
	CR	0.96	$v_{1500} = 0.43 v_{a \max} + 5.22$ vOBLA + 0.003 $t_{lim} 110$ - 5.31 CR + 0.144	0.004

Regression equations for predicting running speed ($m \cdot s^{-1}$) are included when addition of a predictor variable significantly ($P < 0.05$) improves the prediction of performance. Residuals are the difference between the observed and the fitted Y_i .

$v_{a \max}$ = aerobic maximal velocity ($m \cdot s^{-1}$).

$t_{lim} v_{a \max}$ = time to exhaustion at 100% $v_{a \max}$ (s).

$t_{lim} 110$ = time to exhaustion at 110% $v_{a \max}$ (s).

CR = oxygen cost per unit of body mass transported at a velocity corresponding to 75%.

$\dot{V}O_{2max}$ = ($ml \cdot kg^{-1} \cdot min^{-1}$).

vOBLA = onset of blood lactate accumulation (% $v_{a \max}$).

The Relationship among ($\dot{V}O_{2max}$), AOD, and 1500-m Track Performance

From the point of view of energy, when ($\dot{V}O_{2max}$) and AOD only are entered in stepwise multiple regression analysis, ($\dot{V}O_{2max}$) ($ml \cdot min^{-1} \cdot kg^{-1}$) was the sole predictor of performance (v_{1500} in $m \cdot s^{-1}$) for all the runners ($r^2 = 0.69, F = 33.8$): $v_{1500} = 0.055 (\dot{V}O_{2max}) + 2.35$; and for the men ($r^2 = 0.536, F = 8.1$): $v_{1500} = 0.024 (\dot{V}O_{2max}) + 4.78$.

For women there was no predictor of performance, and we can notice that $\dot{V}O_{2max}$ lean body mass as $\dot{V}O_{2max}$ total mass was not correlated with performance ($r = 0.37$, and 0.47, respectively).

DISCUSSION

This study involved elite French male and female middle-distance runners. Each gender group was homo-

geneous with respect to their IAAF performance scores, and there were no differences between the sexes. The results of this investigation indicated that when the men and the women are studied separately, the relationships between the bioenergetic parameters studied and the 1500-m track performances, i.e., the average velocity over 1500 m, differ greatly. In fact, four parameters ($v_{a \max}$, vOBLA, $t_{lim} 110\% v_{a \max}$, and CR) predict 96% of the variance on 1500-m track performance in men. In contrast, for the women there were no significant predictors. Our study considered the velocity over 1500 m, a distance in which aerobic and anaerobic contributions are similar (24). However, for the same IAAF score, women spend a half-minute more than men to achieve a 1500 m event, which involves more aerobic contributions for women than for men. Moreover, Hill and Smith (14), showed that for the same all-out efforts of 30-s duration, women provided a relatively higher portion of the energy aerobically than men (25% vs 20%).

The fact that women have no significant aerobic predictors may seem to be surprising, since others have found that $\dot{V}O_{2max}$ and $v_{a\ max}$ were predictors of running performance in female long-distance runners (9,19,27,38). Our finding may be explained by the different training level of the different populations (no control in this study) and by the fact that some of the 1500-m women runners are more 800-1500-m runners (9 over 14) and the others are more 1500-m-3000/5000-m specialists. Moreover, from a statistical point of view, correlations are harder to obtain with a very low coefficient of variation, that is the case for the 1500-m track performance (<2%) of our female runner group (twice as high in the men: 4%). However, there is no specific energy profile for women to perform over 1500 m. In fact, there is little difference between the regression equation between bioenergetic characteristics and performance over 1500 m, calculated for "all" and for "men." Therefore, a coach could not use the regression equation calculated for "all" the runners. The vOBLA has also been proposed as a good 3000-m track performance predictor for 57 female distance runners (38). This was due to the large aerobic component of this race (20). Moreover, Yoshida et al. (37) demonstrated that the anaerobic component (peak power and mean power using the Wingate test performed on bicycle), was related only to 800-m running performance. Once more, a 1500-m race involves similar contributions of aerobic and anaerobic metabolism, but some runners can perform this event with different contributions of the various energy systems.

In the relationships between the physiological variables studied, it appears that for the 18 runners who had recent 1500-m performances, $v_{a\ max}$ and t_{lim} at $v_{a\ max}$ are the best predictors of 1500-m track performances. Many authors (7, 19, 20, 29) have previously reported a strong relationship between racing times and maximal oxygen consumption in male middle-distance runners. The importance of $v_{a\ max}$ is thus confirmed (20,29), while the importance of t_{lim} at $v_{a\ max}$ represents a new finding. It seems that time to exhaustion at $v_{a\ max}$ depends more on anaerobic aptitude for men than for women.

Despite the similarity between the men and women with respect to racing performance, there were some gender differences in bioenergetic parameters. Consistent with the findings of Joyner (17), Londeree (23) and Puhl (31), in this study there was a gender difference in $\dot{V}O_{2max}$ (relative to total or lean body mass). The average difference between the sexes in $\dot{V}O_{2max}$ was 18% ($\pm 3\%$) when expressed relative to body mass. This gender difference surely explains, in large part, the gender difference noted in $v_{a\ max}$ (17%). However, this difference of $\dot{V}O_{2max}$ was reduced to a mean of 11% ($\pm 2\%$) when $\dot{V}O_{2max}$ was expressed relative to lean body mass, since women had twice the mean percent of fat. The relative fat in women is in accordance with the values recommended by

Lohman (21) for cross-country runners (12% to 16% fat) even if there is no gold standard for women, since minimal levels of fatness are suggested by different investigators for women for health as well as performance (22). However, values of percent fat were obtained with the Durnin and Womersley formula (11). Since 1974, linear and quadratic polynomial equations have been generated (16). Lohman et al. (22) compared the Durnin-Womersley equations (sum of triceps and subscapular) and the Jackson-Pollock equations (triceps, abdomen, suprailiac, and thigh). Durnin-Womersley gave higher percent fat than Jackson-Pollock, and a higher standard error of estimate. Therefore, it seems that the Jackson-Pollock equation is more appropriate, even though it is for the general population, and especially useful for adults between 10% and 40% fat, long-distance male runners being under the lower threshold. However, Sinning et al. (34,35) showed that the Jackson-Pollock equation was more accurate and suitable for body composition screening of male and female athletes. Further studies are needed for female athletes (22).

However, although ($\dot{V}O_{2max}$) and $v_{a\ max}$ were higher in the male athletes, there was no gender difference in the lactate threshold, expressed as a percentage of $v_{a\ max}$. Relatively few data regarding the lactate threshold or OBLA in elite female athletes have been published (17). Our results are in agreement with those previous findings (12,15,38).

Oxygen cost of running (CR) at 75% $v_{a\ max}$ and RE were not significantly different between men and women, in agreement with the results of previous studies in which the type and level of conditioning were controlled (8,23,30). The range of variation of CR is nearly the same in men and women, but less than that noted by others (20). But the comparison is difficult, as in the present study we did not use a CR at a fixed velocity but a CR at an individual velocity ($v_{a\ max}$). No significant differences have been observed concerning the mean values of CR of the two groups.

In contrast, the individual t_{lim} at $v_{a\ max}$ varied greatly in the whole population of runners, and within the groups of men and women. t_{lim} at $v_{a\ max}$ was not significantly different for men and women, and similar values have been found in a group of male long-distance runners, although their method of determining $v_{a\ max}$ differed from that used in the present study (1,2). A recent study has shown that the great variability in t_{lim} at 90% $v_{a\ max}$ was positively related with the occurrence of hypoxemia during the all-out run at 90% $v_{a\ max}$, but not for the t_{lim} at $v_{a\ max}$ (4). The relationships between t_{lim} at $v_{a\ max}$ and the other classical physiological variables were evaluated. The t_{lim} at $v_{a\ max}$ was inversely correlated with $v_{a\ max}$ for the whole group of runners and for the group of male runners, in agreement with the results of a recent study performed with 38 elite long-distance runners (3). It is not clear why this relationship was not apparent in

the women athletes, despite their similarity to the men in many other aspects. This gender difference deserves further study.

AOD has been proposed as a measure of anaerobic capacity (26,28). In the present study, the mean AOD in male runners group was not significantly higher than that in the female group. However, here again, the individual values vary greatly. This fact, which has been noted previously (26), can be explained by the variation of individual anaerobic training sessions (intensity as % of $v_{a \max}$ and quantity in % of the total weekly kilometrage) which was not been quantified or controlled for this study. Medbø and Burgers (25) reported that the women's AOD was 17% less than the men's ($P = 0.03$), and that training increased the men's AOD more than the women's (+16% vs +5%). It is also possible that in the population studied here, which included some 3000-m specialists along with 18 1500-m track athletes, among them, some were 800-1500-m specialists, and some were 1500-3000-m specialists. To our knowledge, no data concerning the AOD % in well-trained female runners have been reported. In this study, men's values were relatively lower than those observed by others (26), which can be explained first by the different anaerobic training level of the population (28) and second by the treadmill slope chosen for the two protocols. It has been argued that AOD increases with the treadmill's slope (28) and our men's values are slightly higher than those obtained with a treadmill slope of 1% (28). In our study, t_{lim}

at 110% $v_{a \max}$ was well correlated with AOD for whole group, and for men, but not for women.

CONCLUSION

The times to exhaustion at velocities associated with $\dot{V}O_{2\max}$ (t_{lim} at $v_{a \max}$) and with 110% of $v_{a \max}$, did not differ between groups of elite male and female middle-distance runners. In addition, there was no gender difference in accumulated oxygen deficit. However, only in the male subjects was there a significant (inverse) relationship between t_{lim} at $v_{a \max}$ and $v_{a \max}$, and a significant positive relationship between t_{lim} at $v_{a \max}$ and oxygen deficit. These relationships have previously been reported (but only in samples of male subjects). It is not clear why these relationships are not evidenced in women athletes, and we believe that this question is worthy of further study. There were also differences between men and women with respect to the physiological variables that predicted middle-distance running performance. For men, multiple regression with four variables ($v_{a \max}$, t_{lim} at 110% $v_{a \max}$, $vOBLA$, and CR) explained 98% of the variance in 1500-m performance. In contrast, for women, no physiological variable was associated with 1500-m performance, perhaps because of the smaller variability among women's performances.

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REFERENCES

1. BILLAT, V., J. PINOTEAU, B. PETIT, J. C. RENOUX, and J. P. KORALSTEIN. Reproducibility of running time to exhaustion at $\dot{V}O_{2\max}$ in sub-elite runners. *Med. Sci. Sports Exerc.* 26:254-257, 1994.
2. BILLAT, V., J. PINOTEAU, B. PETIT, O. BERNARD, and J. P. KORALSTEIN. Time to exhaustion at $\dot{V}O_{2\max}$ and lactate steady-state velocity in sub-elite long-distance runners. *Arch. Intern. Physiol. Biochem.* 102:215-219, 1994.
3. BILLAT, V., J. PINOTEAU, B. PETIT, J. C. RENOUX, and J. P. KORALSTEIN. Time to exhaustion at 100% of velocity at $\dot{V}O_{2\max}$ and modelling of the relation time-limit/velocity in elite long distance runners. *Eur. J. Appl. Physiol.* 69:271-273, 1994.
4. BILLAT, V., J. PINOTEAU, B. PETIT, J. C. RENOUX, and J. P. KORALSTEIN. Hypoxémie et temps limite à la vitesse aérobie maximale chez des coureurs de fond. *Can. J. Appl. Physiol.* 20:102-111, 1995.
5. BULBULIAN, R., A. R. WILCOX, and B. L. DARABOS. Anaerobic contribution to distance running performance of trained cross-country athletes. *Med. Sci. Sports Exerc.* 18:107-113, 1986.
6. CONLEY, D. L. and G. S. KRAHENBUHL. Running economy and distance running performance of highly trained athletes. *Med. Sci. Sports Exerc.* 12:357-360, 1980.
7. COSTILL, D. L. The relation between selected physiological variables and distance running performance. *J. Sports Med. Phys. Fitness* 7:61-66, 1976.
8. DANIELS, J., G. KRAHENBUHL, C. FOSTER, J. GILBERT, and S. DANIELS. Aerobic responses of female distance runners to sub-maximal and maximal exercise. *Ann. N.Y. Acad. Sci.* 301:126-133, 1977.
9. DANIELS, J., N. SCARDINA, J. HAYES, and P. FOLEY. Elite and subelite female middle- and long-distance runners. In: *Sport and Elite Performers*, D. M. Landers (Ed.). Champaign, IL: Human Kinetics, 1986, pp. 57-72.
10. DI PRAMPERO, P. E. The energy cost of human locomotion on land and in water. *Int. J. Sports Med.* 7:55-72, 1986.
11. DURRIN, J. V. and J. WOMERSLEY. Body fat assessment from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged 16 to 76 years. *Br. J. Nutr.* 32:77-97, 1974.
12. FAY, L., B. R. LONDEREE, T. P. LAFONTAINE, and M. R. VOLEK. Physiological parameters related to distance running performance in female athletes. *Med. Sci. Sports Exerc.* 21:319-324, 1989.
13. HELGERUD, J. Maximal oxygen uptake, anaerobic threshold and running economy in women and men with similar performances level in marathons. *Eur. J. Appl. Physiol.* 68:155-161, 1994.
14. HILL, D. W. and J. C. SMITH. Gender difference in anaerobic capacity: role of aerobic contribution. *Br. J. Sports Med.* 27:45-48, 1993.
15. IWAOKA, K., H. HATTA, Y. ATOMI, and M. MIYASHITA. Lactate, respiratory compensation thresholds, and distance running performance in runners of both sexes. *Int. J. Sports Med.* 9:306-309, 1988.
16. JACKSON, A. S. and M. L. POLLOCK. Practical assessment of body composition. *Physician Sportsmed.* 13:77-90, 1985.
17. JOYNER, M. J. Physiological limiting factors and distance running: influence of gender and age on record performances. In: *Exercise and Sport Sciences Reviews*, Vol. 21, American College of Sports Medicine Series, J. O. Holloszy (Ed.). Baltimore: Williams & Wilkins, 1993, pp. 103-133.
18. KARLSSON, J. and I. JACOBS. Onset of blood lactate accumulation during muscular exercise as a threshold concept. 1. Theoretical consideration. *Int. J. Sports Med.* 4:190-201, 1982.

19. KENNEY, W. L. and J. L. HODGSON. Variables predictive of performance in elite middle-distance runners. *Br. J. Sports Med.* 19: 207-209, 1986.
20. LACOUR, J. R., S. PADILLA-MAGUNACELAYA, J. C. CHATARD, L. ARSAC, and J. C. BARTHELEMY. Assessment of running velocity at maximal oxygen uptake. *Eur. J. Appl. Physiol.* 62:77-82, 1991.
21. LOHMAN, T. G. *Advances in Body Composition Assessment. Current Issues in Exercise Science.* Champaign, IL: Human Kinetics, 1992, pp. 115-117.
22. LOHMAN, T. G., M. L. POLLOCK, M. H. SLAUGHTER, J. BRANDON, and R. A. BOILEAU. Methodological factors and the prediction of body fat in female athletes. *Med. Sci. Sports Exerc.* 16:182-187, 1984.
23. LONDEREE, B. R. Gender difference in cardiorespiratory and metabolic variables related to endurance performance. In: *The Athletic Female*, A. J. Pearl (Ed.). Champaign, IL: Human Kinetics Publishers, 1993, pp. 149-168.
24. MEDBØ, J. I. and I. TABATA. Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. *J. Appl. Physiol.* 67:1881-1886, 1990.
25. MEDBØ, J. I. and S. BURGERS. Effect of training on the anaerobic capacity. *Med. Sci. Sports Exerc.* 22:501-507, 1990.
26. MEDBØ, J. I., A. C. MOHN, I. TABATA, R. BAHR, O. VAAGE, and M. SEJERSTED. Anaerobic capacity determined by accumulated O_2 deficit. *J. Appl. Physiol.* 64:50-60, 1988.
27. NOAKES, T. D., K. H. MYBURGH, and R. SCHALL. Peak treadmill running velocity during the VO_{2max} test predicts running performance. *J. Sports Sci.* 8:35-45, 1990.
28. OLESEN, H. L. Accumulated oxygen deficit increases with inclination of uphill running. *J. Appl. Physiol.* 73:1130-1134, 1992.
29. PADILLA, S., M. BOURDIN, J. C. BARTHELEMY, and J. R. LACOUR. Physiological correlates of middle-distance running performance. *Eur. J. Appl. Physiol.* 65:561-566, 1992.
30. PATE, R. R., C. BARNES, and W. MILLER. A physiological comparison of performance-matched female and male distance runners. *Res. Q. Exerc. Sports* 56:240-250, 1985.
31. PUHL, J. L. Women and endurance: some factors influencing performance. In: *Female Endurance Athletes*, B. L. Drinkwater (Ed.). Champaign, IL: Human Kinetics Publishers, 1986, pp. 41-58.
32. SCHERRER, J. and H. MONOD. Le travail musculaire chez l'homme. *J. Physiol. (Paris)* 52:419-501, 1960.
33. SHEPHARD, R. J. Tests of maximum oxygen uptake: a critical review. *Sports Med.* 4:19-33, 1984.
34. SINNING, W. E. and J. R. WILSON. Validation of "generalized" equations for body composition analysis in women athletes. *Res. Q. Exerc. Sport* 55:153-160, 1984.
35. SINNING, W. E., D. G. DOLNY, K. D. LITTLE, et al. Validity of "generalized" equations for body composition analysis in male athletes. *Med. Sci. Sports Exerc.* 17:124-130, 1985.
36. TAYLOR, H. L., E. BUSKIRK, and A. HENSCHEL. Maximal oxygen uptake as an objective measure of cardiorespiratory performance. *J. Appl. Physiol.* 8:73-80, 1955.
37. YOSHIDA, T., M. UDO, K. IWAI, et al. The reproducibility of the 4 mmol/l lactate threshold in trained and untrained women. *Int. J. Sports Med.* 12:363-368, 1991.
38. YOSHIDA, T., M. UDO, K. IWAI, and T. YAMAGUCHI. Physiological characteristics related to endurance running performance in female distance runners. *J. Sports. Sci.* 11:57-62, 1993.