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Physiological determinants of speciality of elite middle- and long-distance runners

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Abstract

The aim of this study was to determine which physiological variables predict excellence in middle- and long-distance runners. Forty middle-distance runners (age 23 $\pm$ 4 years, body mass 67.2 $\pm$ 5.9 kg, stature 1.80 $\pm$ 0.05 m, $\dot{V}O_{2max}$ 65.9 $\pm$ 4.5 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}) and 32 long-distance runners (age 25 $\pm$ 4 years, body mass 59.8 $\pm$ 5.1 kg, stature 1.73 $\pm$ 0.06 m, $\dot{V}O_{2max}$ 71.6 $\pm$ 5.0 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}) competing at international standard performed an incremental running test to exhaustion. Expired gas analysis was performed breath-by-breath and maximum oxygen uptake ($\dot{V}O_{2max}$) and two ventilatory thresholds (VT_1 and VT_2) were calculated. Long-distance runners presented a higher $\dot{V}O_{2max}$ than middle-distance runners when expressed relative to body mass ($P < 0.001$, $d = 1.18$, 95% CI [0.68, 1.68]). At the intensities corresponding to VT_1 and VT_2, long-distance runners showed higher values for $\dot{V}O_2$ expressed relative to body mass or $\%\dot{V}O_{2max}$, speed and oxygen cost of running ($P < 0.05$). When oxygen uptake was adjusted for body mass, differences between groups were consistent. Logistic binary regression analysis showed that $\dot{V}O_{2max}$ (expressed as l $\cdot$ min^{-1} and ml $\cdot$ kg^{-1} $\cdot$ min^{-1}), $\dot{V}O_{2VT2}$ (expressed as ml $\cdot$ kg$^{-0.94}$ $\cdot$ min^{-1}), and speed at VT_2 (v_{VT2}) categorized long-distance runners. In addition, the multivariate model correctly classified 84.7% of the athletes. Thus, $\dot{V}O_{2max}$, $\dot{V}O_{2VT2}$, and v_{VT2} discriminate between elite middle-distance and long-distance runners.

Keywords: *Discriminant, ventilatory threshold, athletes, maximum oxygen uptake*

Introduction

Performance in middle- and long-distance running is influenced by a variety of physiological factors (Coyle, 1999; Joyner & Coyle, 2008). In addition to a high maximal oxygen uptake ($\dot{V}O_{2max}$), endurance performance is related to peripheral muscle factors (Green & Patla, 1992; Noakes, 1988; Paavolainen, Nummela, & Rusko, 2000), the oxygen cost of running, or fractional use of $\dot{V}O_{2max}$ (Bassett & Howley, 2000; Brandon, 1995). As a result, Billat and co-workers (Billat, Demarle, Slawinski, Paiva, & Koralsztein, 2001) suggested that top-class and highly trained marathon runners are different in terms of $\dot{V}O_{2max}$, but they did not develop a discriminant model.

Middle- and long-distance runners use different training methods (Costill, 1986; Noakes, 1991) that lead to different adaptations in aspects of aerobic fitness (Jones & Carter, 2000; Laursen & Jenkins, 2002). Anthropometric and physiological characteristics can discriminate between endurance athletes according to the distances over which they compete (Bret et al., 2003; Bunc, Heller, Sprynarova, & Zdanowicz, 1986; Maffulli, Capasso, & Lancia, 1991; Millet, Dreano, & Bentley, 2003). Identification of the variables that characterize different specialties in highly trained runners is important, and could be used for talent identification and training purposes.

Thus the aim of this study was to identify, using binary logistic regression, physiological variables that predict the probability of being either a middle- or long-distance runner. Also, we developed a multivariate model to identify specialty in highly trained runners.

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Materials and methods

Participants

Between 2000 and 2008, a total of 72 male elite Spanish athletes participated in the study. They were classified as middle-distance runners ($n = 40$), who competed at 800 and 1500 m, and long-distance runners ($n = 32$), who competed at 5000 and 10,000 m (Table I). All athletes competed at international standard, including European and World Championships finals and Olympic finals. It was possible to assess so many elite athletes because, since 1980, all Spanish athletes who compete at this standard are required by law to undergo medical and physiological testing in our centre.

The study received approval from the local ethics committee. All athletes provided written informed consent to participate in the study.

Procedures

At the beginning of the season, as part of their pre-participation screening, the athletes underwent an incremental treadmill running test (H/P/COSMOS Venus 4.0®, H/P/Cosmos Sports & Medical, Nussdorf-Traunstein, Germany) at a constant 1% slope (Jones & Doust, 1996). After a 2-min warm-up at a speed of 6 $km \cdot h^{-1}$, the speed was increased to 8 $km \cdot h^{-1}$, and then by 0.25 $km \cdot h^{-1}$ every 15 s until exhaustion. All tests were considered as maximum, and fulfilled at least two of the following criteria (Basset & Boulay, 2000): respiratory exchange ratio (RER) higher than 1.10, a plateau in $\dot{V}O_2$ (variation of less than 100 $ml \cdot min^{-1}$) despite increases in the intensity of exercise, and maximum heart rate calculated as 220 – age (at least 98% of maximum).

Gas analysis was performed using the Jaeger Oxycon Pro gas analyser (Erich Jaeger, Viasys Healthcare, Germany), the validity and reliability of which have been established previously (Carter & Jeukendrup, 2002; Foss & Hallen, 2005).

Maximum oxygen uptake and ventilatory thresholds

Maximum oxygen uptake ($\dot{V}O_{2max}$) was determined as the mean of the two highest values recorded at the maximum treadmill speed reached by each runner (Hawley & Noakes, 1992), and the first and second ventilatory thresholds (VT_1 and VT_2 respectively) were set at the point of maximum agreement of the most common methods of assessment. Briefly, VT_1 was calculated: (1) according to the V-slope method of Beaver and co-workers (Beaver, Wasserman, & Whipp, 1986), whereby VT_1 is the break point of the $\dot{V}CO_2$–$\dot{V}O_2$ relationship ($\dot{V}CO_2$ is carbon dioxide production); (2) as the first exponential increment in ventilation (V_E) (Skinner & McLellan, 1980); and (3) as the first rise in the $V_E/\dot{V}O_2$ relationship without increments in the $V_E/\dot{V}CO_2$ relationship (Davis, Whipp, & Wasserman, 1980). VT_2 was determined as the second rise in ventilation (Skinner & McLellan, 1980) and as the intensity that accompanied a second rise in the $V_E/\dot{V}O_2$ relationship with a concurrent rise in the $V_E/\dot{V}CO_2$ relationship (Davis et al., 1980).

To avoid a possible bias by the investigator determining the ventilatory thresholds and test the reproducibility of the measures, all tests were evaluated by two researchers in a double-blind fashion. In addition, to ensure the veracity of the two observers' measurements, the coefficient of variation between their assessments and those of a highly experienced expert was calculated. This was 1.2%.

Oxygen cost of running

The oxygen cost of running (Cr) was calculated at the intensity corresponding to $\dot{V}O_{2max}$, VT_1, and VT_2 using di Prampero's equation (di Prampero, 1986):

$$Cr(ml\,O_2 \cdot kg^{-1} \cdot km^{-1}) = \dot{V}O_2(ml \cdot kg^{-1} \cdot h^{-1}) \times 60 / speed\,(km \cdot h^{-1})$$

Table I. Characteristics of the participants (mean ± *s*).

	Middle-distance runners			Long-distance runners		
	800 m ($n = 17$)	1500 m ($n = 23$)	All	5000 m ($n = 20$)	10,000 m ($n = 12$)	All
Body mass (kg)	67.5 ± 5.1	67.0 ± 6.5	67.2 ± 5.9	60.5 ± 4.5[a,b]	58.6 ± 5.9[a,b]	59.8 ± 5.1*
Stature (cm)	180.6 ± 5.0	180.0 ± 5.6	180.3 ± 5.3	173.0 ± 5.7[a,b]	173.3 ± 5.3[a,b]	173.1 ± 5.5*
Age (years)	22 ± 4	24 ± 5	23 ± 4	25 ± 5	26 ± 4	25 ± 4*
Years of training	8.4 ± 4.0	7.8 ± 4.4	8.1 ± 4.2	8.4 ± 4.0	7.2 ± 3.2	7.9 ± 3.7

*Significant difference between middle- and long-distance runners. [a]Significant difference from 800-m runners, [b]Significant difference from 1500-m runners.

Statistical analysis

Groups (middle-distance runners vs. long-distance runners) were compared by means of unpaired Student's *t*-tests, while Cohen's *d* (Cohen, 1988) was calculated to indicate effect sizes and practical meaningfulness. Effect sizes were judged using Lipsey's criteria and considered medium when *d* was between 0.45 and 0.89, and large when *d* was higher than 0.90 (Lipsey, 1990). Differences between specialties (800, 1500, 5000, and 10,000 m) were evaluated by means of between-groups one-way analysis of variance (ANOVA). Identified differences between groups were specified by Bonferroni pair-wise comparisons. Since body mass was markedly different between groups, $\dot{V}O_{2max}$ and $\dot{V}O_2$ corresponding to the first and second ventilatory thresholds ($\dot{V}O_{2VT1}$ and $\dot{V}O_{2VT2}$, respectively) were adjusted for differences in body mass using a log-transformed allometric analysis of covariance (ANCOVA) (Winter & Nevill, 2009). Additionally, $\dot{V}O_{2max}$, $\dot{V}O_{2VT1}$, and $\dot{V}O_{2VT2}$ were expressed as power function ratios where body mass was raised to the power 0.67 (Nevill, Ramsbottom, & Williams, 1992), 0.75 (McMahon, 1973), and 0.94 (Nevill et al., 2003).

Subsequently, binary logistic regressions (conditional feedforward method) were constructed to determine which variables (Table II) had most influence on the probability of being a middle-distance or a long-distance runner. We built one model including all the variables presented in Table II (Model 1) and a second model including only variables expressed as standard ratio (Model 2). Both models were built with a randomized sample of 48 participants (two-thirds of the sample) and the remaining 24 athletes were used to validate the model. Goodness-of-fit tests included model chi-squares to determine model appropriateness and Wald statistics to evaluate the contributions of predictor variables.

Finally, using the same variables derived from the binary logistic regressions, several discriminant analyses were performed to seek a function that would predict the specialty to which an athlete might be best suited. All calculations were performed using SPSS v.15 software for Windows (SPSS, Chicago, IL). Statistical significance was set at $P < 0.05$.

Results

Differences between groups

Tables I and II show the differences between the two groups of athletes. Long-distance runners exhibited higher $\dot{V}O_{2max}$ than middle-distance runners when values were expressed relative to body mass ($P < 0.001$, $d = 1.18$, 95% CI [0.68, 1.68]). $\dot{V}O_{2VT1}$ and $\dot{V}O_{2VT2}$, expressed relative to body mass, were also greater in the long-distance runners ($P < 0.001$, $d = 1.35$, 95% CI [0.83, 1.87] and $P < 0.001$, $d = 1.36$, 95% CI [0.84, 1.87] for $\dot{V}O_{2VT1}$ and $\dot{V}O_{2VT2}$ respectively). The speed corresponding to $\dot{V}O_{2max}$, VT_1, and VT_2 (v_{max}, v_{VT1}, and v_{VT2} respectively) was always less in middle-distance runners (v_{max}: $P < 0.01$, $d = 0.67$, 95% CI [0.19, 1.14]; v_{VT1}: $P < 0.01$, $d = 0.74$, 95% CI [0.26, 1.22]; v_{VT2}: $P = 0.001$, $d = 0.82$, 95% CI [0.33, 1.3]). Finally, as a result of the combination of these variables, the oxygen cost of running was higher in long-distance runners at $\dot{V}O_{2max}$ ($P < 0.001$, $d = 0.89$, 95% CI [0.4, 1.37]), VT_1 ($P = 0.01$, $d = 0.63$, 95% CI [0.15, 1.1]), and VT_2 ($P = 0.001$, $d = 0.86$, 95% CI [0.37, 1.34]).

The ANCOVA model produced a sample-specific exponent of 0.87 for body mass by which to scale $\dot{V}O_{2max}$ (i.e. express $\dot{V}O_{2max}$ in $ml \cdot kg^{-0.87} \cdot min^{-1}$). When $\dot{V}O_{2max}$, $\dot{V}O_{2VT1}$, and $\dot{V}O_{2VT2}$ were expressed as power function ratios, differences between groups were consistent (Table II).

Probability to belong a group and classification of the athletes

Table III shows the results of binary logistic regressions. Model 1 (i.e. all variables presented in Table II were included) showed that $\dot{V}O_{2max}$ expressed as a standard ratio ($ml \cdot kg^{-1} \cdot min^{-1}$) and $\dot{V}O_{2VT2}$ expressed as a power function ratio ($ml \cdot kg^{-0.94} \cdot min^{-1}$) correctly classified middle- and long-distance runners in their specialties ($\chi^2 = 29.570$; $P < 0.001$). Altogether, 89.6% of the selected athletes used to build the model and 76.9% of the remaining participants used to validate the model were correctly categorized in their groups.

When only variables expressed as a standard ratio were included in the logistic regression (model 2), three variables ($\dot{V}O_{2max}$ expressed both as $l \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$, and v_{VT2}) determined the probability of being categorized as a middle- or long-distance runner (Table III). Odds ratios >1 are interpreted as increasing the probability of being categorized as a long-distance runner. Model fit statistics ($\chi^2 = 33.302$; $P < 0.001$) indicated that the predictive value of the final model was better than that of the null model. From the data of the 48 athletes entered in the model, 83.3% were classified correctly. In addition, 76.9% of the 24 participants used to validate the model were correctly classified.

Using the variables included by logistic binary regression, three discriminant analyses were performed to determine whether these variables were sufficient to produce a function that would predict the

Table II. Mean and standard deviation (*s*) for all the variables studied in middle- and long- distance runners.

	Middle-distance runners			Long-distance runners		
	800 m (*n*=17)	1500 m (*n*=23)	All	5000 m (*n*=20)	10,000 m (*n*=12)	All
$\dot{V}O_{2max}$ ($l \cdot min^{-1}$)	4.3 ± 0.3	4.5 ± 0.5	4.4 ± 0.4	4.3 ± 0.5	4.2 ± 0.4	4.2 ± 0.5
$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	63.9 ± 3.4	67.4 ± 4.7	65.9 ± 4.5	71.4 ± 3.9[a,b]	71.8 ± 6.7[a,b]	71.6 ± 5.0*
$\dot{V}O_{2max}$ ($ml \cdot kg^{-0.87} \cdot min^{-1}$)	111 ± 6	116 ± 8	114 ± 8	120 ± 10[a]	122 ± 11[a]	121 ± 10*
$\dot{V}O_{2max}$ ($ml \cdot kg^{-0.67} \cdot min^{-1}$)	256 ± 13	270 ± 19	264 ± 18	273 ± 25	274 ± 23	273 ± 24
$\dot{V}O_{2max}$ ($ml \cdot kg^{-0.75} \cdot min^{-1}$)	183 ± 9	193 ± 13	189 ± 13	197 ± 18[a]	198 ± 17[a]	197 ± 17*
$\dot{V}O_{2max}$ ($ml \cdot kg^{-0.94} \cdot min^{-1}$)	82 ± 4	87 ± 6	85 ± 6	90 ± 7[a]	92 ± 8[a]	91 ± 8*
$\dot{V}CO_{2max}$ ($l \cdot min^{-1}$)	5.1 ± 0.5	5.3 ± 0.6	5.2 ± 0.6	5.0 ± 0.8	4.9 ± 0.5	4.9 ± 0.7*
V_{Emax} ($l \cdot min^{-1}$)	163.5 ± 19.1	167.1 ± 17.8	165.6 ± 18.2	161.1 ± 16.7	162.2 ± 28.6	161.5 ± 21.5
HR_{max} ($beats \cdot min^{-1}$)	192 ± 6	190 ± 7	191 ± 7	190 ± 7	191 ± 9	191 ± 8
$\dot{V}O_{2max} \cdot {HR_{max}}^{-1}$ ($ml \cdot beat^{-1}$)	22.4 ± 1.9	23.8 ± 2.9	23.2 ± 2.6	22.5 ± 2.7	22.0 ± 2.7	22.3 ± 2.7
RER_{max}	1.18 ± 0.06	1.18 ± 0.06	1.18 ± 0.06	1.16 ± 0.06	1.17 ± 0.06	1.16 ± 0.06
v_{max} ($km \cdot h^{-1}$)	21.4 ± 1.1	21.9 ± 0.6	21.7 ± 0.9	22.0 ± 0.6	22.5 ± 0.6[a]	22.2 ± 0.7*
Cr_{max} ($ml \cdot min^{-1} \cdot km^{-1}$)	179.9 ± 10.1	184.6 ± 12.1	182.6 ± 11.4	194.8 ± 10.5[a]	191.4 ± 17.0	193.5 ± 13.2*
$\dot{V}O_{2VT1}$ ($l \cdot min^{-1}$)	3.1 ± 0.3	3.1 ± 0.4	3.1 ± 0.4	3.3 ± 0.3	3.1 ± 0.3	3.2 ± 0.3
$\dot{V}O_{2VT1}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	45.8 ± 3.3	46.4 ± 6.0	46.1 ± 5.0	54.4 ± 6.5[ab]	54.0 ± 8.1[ab]	54.2 ± 7.0*
$\dot{V}O_{2VT1}$ ($ml \cdot kg^{-0.87} \cdot min^{-1}$)	79 ± 6	80 ± 10	80 ± 8	93 ± 11[ab]	92 ± 13[ab]	92 ± 11*
$\dot{V}O_{2VT1}$ ($ml \cdot kg^{-0.67} \cdot min^{-1}$)	184 ± 14	186 ± 22	185 ± 19	210 ± 23[ab]	206 ± 25[ab]	209 ± 24*
$\dot{V}O_{2VT1}$ ($ml \cdot kg^{-0.75} \cdot min^{-1}$)	131 ± 9	133 ± 16	132 ± 14	151 ± 17[ab]	149 ± 19[ab]	151 ± 18*
$\dot{V}O_{2VT1}$ ($ml \cdot kg^{-0.94} \cdot min^{-1}$)	59 ± 4	60 ± 8	59 ± 6	70 ± 8[ab]	69 ± 10[ab]	70 ± 9*
$\dot{V}O_{2VT1}$ ($\%\dot{V}O_{2max}$)	71.7 ± 5.8	67.8 ± 8.7	69.5 ± 7.7	74.0 ± 7.9	75.6 ± 11.0	74.6 ± 9.1*
V_{EVT1} ($l \cdot min^{-1}$)	71.2 ± 10.0	77.1 ± 10.7	74.6 ± 10.7	72.4 ± 9.9	76.2 ± 15.0	73.8 ± 12.0
v_{VT1} ($km \cdot h^{-1}$)	13.9 ± 1.3	14.7 ± 1.3	14.4 ± 1.3	15.0 ± 1.5	16.0 ± 1.1[ab]	15.4 ± 1.4*
Cr_{VT1} ($ml \cdot min^{-1} \cdot km^{-1}$)	198.8 ± 14.9	190.7 ± 31.7	194.2 ± 26.0	219.7 ± 37.9[b]	203.1 ± 31.5	213.5 ± 36.1*
HR_{VT1} ($beats \cdot min^{-1}$)	153 ± 9	154 ± 12	153 ± 11	154 ± 12	158 ± 13	156 ± 12
$\dot{V}O_{2VT2}$ ($l \cdot min^{-1}$)	3.9 ± 0.3	4.0 ± 0.3	3.9 ± 0.3	4.0 ± 0.4	3.9 ± 0.4	4.0 ± 0.4
$\dot{V}O_{2VT2}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	58.0 ± 3.1	59.3 ± 5.6	58.7 ± 4.7	67.0 ± 6.3[ab]	66.4 ± 8.7[ab]	66.8 ± 7.2*
$\dot{V}O_{2VT2}$ ($ml \cdot kg^{-0.87} \cdot min^{-1}$)	100 ± 5	102 ± 9	101 ± 8	114 ± 10[ab]	113 ± 14[ab]	114 ± 11*
$\dot{V}O_{2VT2}$ ($ml \cdot kg^{-0.67} \cdot min^{-1}$)	233 ± 12	237 ± 19	235 ± 16	259 ± 22[ab]	253 ± 28[a]	257 ± 24*
$\dot{V}O_{2VT2}$ ($ml \cdot kg^{-0.75} \cdot min^{-1}$)	166 ± 8	169 ± 14	168 ± 12	187 ± 16[ab]	183 ± 21[a]	185 ± 18*
$\dot{V}O_{2VT2}$ ($ml \cdot kg^{-0.94} \cdot min^{-1}$)	75 ± 4	76 ± 7	76 ± 6	86 ± 8[ab]	85 ± 11[ab]	85 ± 9*
$\dot{V}O_{2VT2}$ ($\%\dot{V}O_{2max}$)	90.8 ± 3.0	86.0 ± 7.6	88.2 ± 6.4	89.2 ± 6.7	86.5 ± 5.0	88.3 ± 6.2*
V_{EVT2} ($l \cdot min^{-1}$)	108.6 ± 11.0	114.4 ± 14.0	111.9 ± 13.0	107.9 ± 12.9	110.6 ± 22.0	108.9 ± 16.6
v_{VT2} ($km \cdot h^{-1}$)	18.1 ± 1.2	18.6 ± 0.8	18.4 ± 1.0	18.9 ± 0.8	19.7 ± 0.8[ab]	19.2 ± 0.9*
Cr_{VT2} ($ml \cdot min^{-1} \cdot km^{-1}$)	193.1 ± 12.1	191.1 ± 19.1	191.9 ± 16.3	213.7 ± 23.9	201.8 ± 23.8	209.3 ± 24.2*
HR_{VT2} ($beats \cdot min^{-1}$)	176 ± 6	175 ± 8	176 ± 7	175 ± 9	179 ± 9	176 ± 9

Note: Oxygen uptake ($\dot{V}O_2$), ventilation (V_E), heart rate (HR), CO_2 production ($\dot{V}CO_2$), respiratory exchange ratio (RER), speed (*v*), oxygen cost of running (Cr).
*Significant difference between middle- and long-distance runners. [a]Significant difference from 800-m runners, [b]Significant difference from 1500-m runners.

Table III. Results of binary logistic regressions to predict the probability of belonging to the long-distance or middle-distance group.

Variable	*B*	s_x	Wald	OR	95.0% CI for OR	*P*-value
Model 1						
$\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1})	0.30	0.11	8.17	1.346	1.10–1.65	0.004
$\dot{V}O_{2VT2}$ (ml · kg$^{-0.94}$ · min^{-1})	–0.16	0.07	5.23	0.851	0.74–0.98	0.022
Constant	–8.70	8.70	1.00	0.00	–	0.317
Model 2						
$\dot{V}O_{2max}$ (l · min^{-1})	–3.76	1.66	5.12	0.023	0.01–0.60	0.024
$\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1})	0.48	0.16	9.29	1.62	1.19–2.20	0.002
v_{VT2} (km · h^{-1})	1.43	0.73	3.87	4.166	1.00–17.23	0.049
Constant	–44.18	16.38	7.28	0.00	–	0.007

Note: Model 1 was built with all variables presented in Table II. Model 2 was built only with variables expressed as a standard ratio.

athletes' specialty (Table IV). Non-standardized coefficients gave the following discriminant functions:

Function 1:

Specialty = $-5.161 + 0.167\ \dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1}) – 0.78 $\dot{V}O_{2VT2}$ (ml · kg$^{-0.94}$ · min^{-1})

Function 2:

Specialty = –14.087 – 1.788 $\dot{V}O_{2max}$ (l · min^{-1}) + 0.192 $\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1}) + 0.465 v_{VT2} (km · h^{-1})

Function 3:

Specialty = 5.610 + 1.713 $\dot{V}O_{2max}$ (l · min^{-1}) – 0.180 $\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1}) + 0.66 $\dot{V}O_{2VT2}$ (ml · kg$^{-0.94}$ · min^{-1}) – 0.319 v_{VT2} (km · h^{-1})

With these equations, 79.2%, 81.9%, and 84.7% of the total cohort of 72 athletes were correctly classified (Table V, Figure 1), and clustered around different centroids: –0.676 vs. 0.845 in model 1, –0.788 vs. 0.985 in model 2, and 0.929 vs. –1.150 in model 3 for middle-distance and long-distance runners respectively.

Table IV. Standardised coefficients of the canonical discriminating function obtained. Model 1 was built with variables derived from logistic regression 1, model 2 with variables derived from logistic regression 2 and model 3 include all the variables.

Variable	Coefficient
Model 1	
$\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1})	0.793
$\dot{V}O_{2VT2}$ (ml · kg$^{-0.94}$ · min^{-1})	–0.628
Note: Wilks' $\lambda = 0.630$ ($\chi^2 = 31.870$; $P < 0.001$)	
Model 2	
$\dot{V}O_{2max}$ (l · min^{-1})	–0.815
$\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1})	0.912
v_{VT2} (km · h^{-1})	0.447
Note: Wilks' $\lambda = 0.556$ ($\chi^2 = 40.184$; $P < 0.001$)	
Model 3	
$\dot{V}O_{2max}$ (l · min^{-1})	0.781
v_{VT2} (km · h^{-1})	–0.307
$\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1})	–0.857
$\dot{V}O_{2VT2}$ (ml · kg$^{-0.94}$ · min^{-1})	0.448
Note: Wilks' $\lambda = 0.479$ ($\chi^2 = 50.068$; $P < 0.001$)	

Discussion

Despite the number of variables that differed between middle-distance and long-distance runners (Table II), few ($\dot{V}O_{2max}$, $\dot{V}O_{2VT2}$, and v_{VT2}) allowed the construction of a model that correctly classified 84.7% of highly trained runners in their chosen specialty. Although there is controversy over the use of ventilatory thresholds, VT_2 is reproducible (Amann et al., 2004; Dickhuth et al., 1999; Weston & Gabbett, 2001) and can predict endurance performance in athletes with similarly high $\dot{V}O_{2max}$ (Coyle, Coggan, Hopper, & Walters, 1988; Coyle et al., 1991). The question then arises why the probability of being a long-distance runner is determined by $\dot{V}O_{2max}$ (in absolute terms and relative to body mass), $\dot{V}O_{2VT2}$ expressed as a power function ration (ml · kg$^{-0.94}$ · min^{-1}), and v_{VT2}, and whether it is possible to discriminate between specialties using these three variables.

Success in high-standard middle-distance and long-distance running involves both aerobic and anaerobic metabolism (Brandon & Boileau, 1992; Lacour, Padilla-Magunacelaya, Barthelemy, & Dormois, 1990). However, middle-distance runners typically compete at a higher percentage of $\dot{V}O_{2max}$ than long-distance runners (Daniels, 1985; Morgan, Baldini, Martin, & Kohrt, 1989), a feature that suggests a different relationship with performance. In 112 endurance athletes (from 800- to 10,000-m events), Maffulli et al. (1991) assessed the relationships between the running speed at the different distances and the anaerobic threshold. While running speed at this threshold was closely correlated

Table V. Classification summary for discriminant analysis.

	Specialty	Predicted group membership: Middle-distance runners	Long-distance runners	Total
Model 1				
Count	MDR	32	8	40
	LDR	7	25	32
%	MDR	80.0	20.0	100.0
	LDR	21.9	78.1	100.0
Model 2				
Count	MDR	33	7	40
	LDR	6	26	32
%	MDR	82.5	17.5	100.0
	LDR	18.8	81.3	100.0
Model 3				
Count	MDR	33	7	40
	LDR	4	28	32
%	MDR	82.5	17.5	100.0
	LDR	12.5	87.5	100.0

Note: 79.2%, 81.9% and 84.7% of the subjects were correctly classified into their stated specialties with models 1, 2 and 3 respectively.

with running speed during longer distance races (5000 m and above), there was no relationship over shorter distances (e.g. 800 m). Therefore, the anaerobic threshold correlates well with running distance. In addition, heart rate during the cycling stage of an Ironman triathlon is well matched with VT_1, while the rate that corresponds to VT_2 could overestimate the intensity of races (Laursen & Rhodes, 2001; Laursen, Rhodes, Langill, McKenzie, & Taunton, 2002). As marathon runners and endurance athletes exercise at high percentages of their $\dot{V}O_{2max}$ during competition (Daniels, 1985; Joyner, 1991; Morgan et al., 1989), and this intensity is probably related to the maximal lactate steady state (Billat, 2005; Peinado et al., 2006), VT_2 probably better represents both the intensity and specialty in highly trained athletes. Both models built by logistic binary regression included variables representing maximum intensity ($\dot{V}O_{2max}$) and intensity corresponding to VT_2 ($\dot{V}O_{2VT2}$ or v_{VT2}).

Training loads differ between middle-distance and long-distance runners. While the latter usually run 160–180 km per week during the preparatory period and aim to maintain the maximum aerobic speed, middle-distance runners run 130–140 km and focus their training on increasing their maximum aerobic power. Therefore, the fact that our cohort of athletes had 8 years of training experience at high standard (Table I) suggests that differences in volume, intensity, and training load during those years could have at least partially determined the ability of $\dot{V}O_{2max}$ and VT_2 to discriminate between specialties. This is in line with the work of Rusko (1992), who

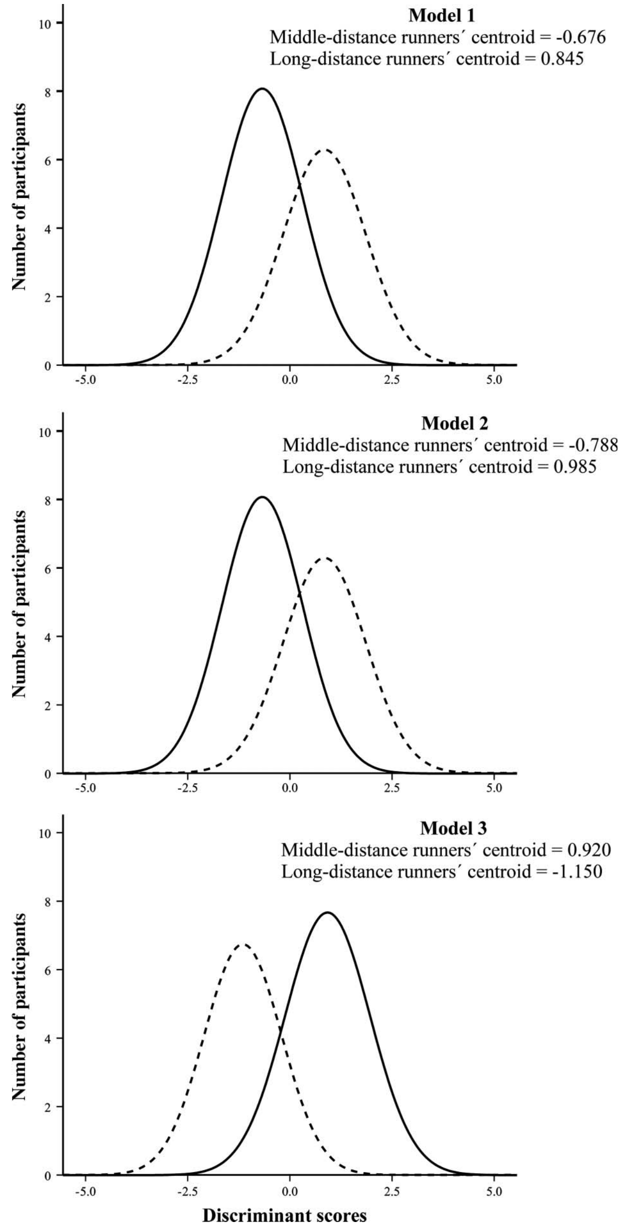

Figure 1. Distribution of athletes according to their discriminant scores in each model. The solid line represents middle-distance runners and the dashed line represents long-distance runners. 79.2%, 81.9%, and 84.7% of the runners were correctly classified into their stated specialties with model 1, 2, and 3 respectively.

tracked longitudinal changes in the aerobic power of cross-country skiers, and showed that the anaerobic threshold increased with training. Moreover, in a case study of an Olympic female runner, her lactate threshold improved throughout five seasons (Jones, 1998). Therefore, VT_2 seems to be a more sensitive indicator of training-induced changes, and could help to differentiate between long-distance and middle-distance runners. However, it is still unclear whether the model we propose allows differentiation between runners with less training experience.

Maximum oxygen uptake expressed both in absolute terms and relative to body mass contributed to the categorization of middle- and long-distance runners. Maximum oxygen uptake alone was shown not to be a good predictor of performance in a homogeneous sample (Bassett & Howley, 1997), but even in this group of elite runners, there was a wide range of $\dot{V}O_{2max}$ (see Table II), and this was included in the equations. Our results suggest that the combination of $\dot{V}O_{2max}$, $\dot{V}O_{2VT2}$, and v_{VT2} can predict the specialty (middle- or long-distance) in elite runners.

The oxygen cost of running did not classify athletes because it conveys the same information as $\dot{V}O_2$ and speed, but surprisingly it was higher in long-distance runners than their middle-distance counterparts (Table I). However, previous studies have reported a negative correlation between $\dot{V}O_{2max}$ and running economy in well-trained athletes (Morgan & Daniels, 1994; Pate, Macera, Bailey, Bartoli, & Powell, 1992). Moreover, it has been suggested that a higher submaximal $\dot{V}O_2$ is beneficial in long-distance runs because it is associated with greater use of fat as a substrate. Nevertheless, different concerns outlined when assessing the oxygen cost of running (Berg, 2003) prevent us reaching a definitive conclusion and these data should be interpreted with caution.

Finally, the model proposed is simple and has clear practical applications. For example, take an athlete who had a $\dot{V}O_{2max}$ of 4.4 $l \cdot min^{-1}$ or 65.9 $ml \cdot kg^{-1} \cdot min^{-1}$ and reached a speed of 18.4 $km \cdot h^{-1}$ at VT_2. Using the proposed equation (for this example, Function 2), we obtain a final result of –0.7474. By locating this value on the x-axis of Figure 1, we find that the distance from the middle-distance runners' centroid (–0.788) is less than the distance from the long-distance runners' centroid (0.0406 vs. 0.2376 respectively). This indicates that our athlete is more suited to middle-distance running. Nonetheless, it is important to note that our study is limited due to the lack of cross-validation of the proposed equations on an independent sample of runners. Until such validation is carried out, the equations remain specific for our cohort, and the results derived from their application in other populations should be treated with caution.

In summary, we present a novel approach to differentiate between middle- and long-distance runners. A combination of $\dot{V}O_{2max}$ (expressed in $l \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$), $\dot{V}O_{2VT2}$ (expressed in $ml \cdot kg^{-0.94} \cdot min^{-1}$), and v_{VT2} classifies runners into their specialties. Although more research is needed to assess the extent to which the model is applicable to athletes with less training experience, the combination of these variables in the proposed equations is a good predictor of running specialty.

Note

*The authors wish to state that Manuel Rabadán and Víctor Díaz contributed equally to this article and share first authorship.

References

Amann, M., Subudhi, A. W., Walker, J., Eisenman, P., Shultz, B., & Foster, C. (2004). An evaluation of the predictive validity and reliability of ventilatory threshold. *Medicine and Science in Sports and Exercise*, *36*, 1716–1722.

Bassett, D. R., Jr., & Howley, E. T. (1997). Maximal oxygen uptake: "Classical" versus "contemporary" viewpoints. *Medicine and Science in Sports and Exercise*, *29*, 591–603.

Bassett, D. R., Jr., & Howley, E. T. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Medicine and Science in Sports and Exercise*, *32*, 70–84.

Basset, F. A., & Boulay, M. R. (2000). Specificity of treadmill and cycle ergometer tests in triathletes, runners and cyclists. *European Journal of Applied Physiology*, *81*, 214–221.

Beaver, W. L., Wasserman, K., & Whipp, B. J. (1986). A new method for detecting anaerobic threshold by gas exchange. *Journal of Applied Physiology*, *60*, 2020–2027.

Berg, K. (2003). Endurance training and performance in runners: Research limitations and unanswered questions. *Sports Medicine*, *33*, 59–73.

Billat, V. L. (2005). Marathon race is run around the maximal lactate steady state velocity (*v*MLSS). In N. Dikic, S. Zivanic, S. Ostojic, & Z. Tornjanski (Eds.), *Proceedings of the Xth Annual Congress of the European College of Sport Science* (pp. 10–11). Belgrade: Sport Medicine Association of Serbia.

Billat, V. L., Demarle, A., Slawinski, J., Paiva, M., & Koralsztein, J. P. (2001). Physical and training characteristics of top-class marathon runners. *Medicine and Science in Sports and Exercise*, *33*, 2089–2097.

Brandon, L. J. (1995). Physiological factors associated with middle distance running performance. *Sports Medicine*, *19*, 268–277.

Brandon, L. J., & Boileau, R. A. (1992). Influence of metabolic, mechanical and physique variables on middle distance running. *Journal of Sports Medicine and Physical Fitness*, *32*, 1–9.

Bret, C., Messonnier, L., Nouck Nouck, J. M., Freund, H., Dufour, A. B., & Lacour, J. R. (2003). Differences in lactate exchange and removal abilities in athletes specialised in different track running events (100 to 1500 m). *International Journal of Sports Medicine*, *24*, 108–113.

Bunc, V., Heller, J., Sprynarova, S., & Zdanowicz, R. (1986). Comparison of the anaerobic threshold and mechanical efficiency of running in young and adult athletes. *International Journal of Sports Medicine*, *7*, 156–160.

Carter, J., & Jeukendrup, A. E. (2002). Validity and reliability of three commercially available breath-by-breath respiratory systems. *European Journal of Applied Physiology*, *86*, 435–441.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Costill, D. L. (1986). *Inside running: Basics of sports physiology.* Indianapolis, IN: Benchmark Press.

Coyle, E. F. (1999). Physiological determinants of endurance exercise performance. *Journal of Science and Medicine in Sport*, *2*, 181–189.

Coyle, E. F., Coggan, A. R., Hopper, M. K., & Walters, T. J. (1988). Determinants of endurance in well-trained cyclists. *Journal of Applied Physiology*, *64*, 2622–2630.

Coyle, E. F., Feltner, M. E., Kautz, S. A., Hamilton, M. T., Montain, S. J., Baylor, A. M. et al. (1991). Physiological and biomechanical factors associated with elite endurance cycling performance. *Medicine and Science in Sports and Exercise*, *23*, 93–107.

Daniels, J. T. (1985). A physiologist's view of running economy. *Medicine and Science in Sports and Exercise*, *17*, 332–338.

Davis, J. A., Whipp, B. J., & Wasserman, K. (1980). The relation of ventilation to metabolic rate during moderate exercise in man. *European Journal of Applied Physiology and Occupational Physiology*, *44*, 97–108.

di Prampero, P. E. (1986). The energy cost of human locomotion on land and in water. *International Journal of Sports Medicine*, *7*, 55–72.

Dickhuth, H. H., Yin, L., Niess, A., Rocker, K., Mayer, F., Heitkamp, H. C. et al. (1999). Ventilatory, lactate-derived and catecholamine thresholds during incremental treadmill running: Relationship and reproducibility. *International Journal of Sports Medicine*, *20*, 122–127.

Foss, O., & Hallen, J. (2005). Validity and stability of a computerized metabolic system with mixing chamber. *International Journal of Sports Medicine*, *26*, 569–575.

Green, H. J., & Patla, A. E. (1992). Maximal aerobic power: Neuromuscular and metabolic considerations. *Medicine and Science in Sports and Exercise*, *24*, 38–46.

Hawley, J. A., & Noakes, T. D. (1992). Peak power output predicts maximal oxygen uptake and performance time in trained cyclists *European Journal of Applied Physiology and Occupational Physiology*, *65*, 79–83.

Jones, A. M. (1998). A five year physiological case study of an Olympic runner. *British Journal of Sports Medicine*, *32*, 39–43.

Jones, A. M., & Carter, H. (2000). The effect of endurance training on parameters of aerobic fitness. *Sports Medicine*, *29*, 373–386.

Jones, A. M., & Doust, J. H. (1996). A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *Journal of Sports Sciences*, *14*, 321–327.

Joyner, M. J. (1991). Modeling: optimal marathon performance on the basis of physiological factors. *Journal of Applied Physiology*, *70*, 683–687.

Joyner, M. J., & Coyle, E. F. (2008). Endurance exercise performance: the physiology of champions. *Journal of Physiology*, *586*, 35–44.

Lacour, J. R., Padilla-Magunacelaya, S., Barthelemy, J. C., & Dormois, D. (1990). The energetics of middle-distance running. *European Journal of Applied Physiology and Occupational Physiology*, *60*, 38–43.

Laursen, P. B., & Jenkins, D. G. (2002). The scientific basis for high-intensity interval training: Optimising training programmes and maximising performance in highly trained endurance athletes. *Sports Medicine*, *32*, 53–73.

Laursen, P. B., & Rhodes, E. C. (2001). Factors affecting performance in an ultraendurance triathlon. *Sports Medicine*, *31*, 195–209.

Laursen, P. B., Rhodes, E. C., Langill, R. H., McKenzie, D. C., & Taunton, J. E. (2002). Relationship of exercise test variables to cycling performance in an Ironman triathlon. *European Journal of Applied Physiology*, *87*, 433–440.

Lipsey, M. W. (1990). *Design sensitivity: Statistical power for experimental research*. Newbury Park, CA: Sage.

Maffulli, N., Capasso, G., & Lancia, A. (1991). Anaerobic threshold and performance in middle and long distance running. *Journal of Sports Medicine and Physical Fitness*, *31*, 332–338.

McMahon, T. (1973). Size and shape in biology. *Science*, *179*, 1201–1204.

Millet, G. P., Dreano, P., & Bentley, D. J. (2003). Physiological characteristics of elite short- and long-distance triathletes. *European Journal of Applied Physiology*, *88*, 427–430.

Morgan, D. W., Baldini, F. D., Martin, P. E., & Kohrt, W. M. (1989). Ten kilometer performance and predicted velocity at $\dot{V}O_{2max}$ among well-trained male runners. *Medicine and Science in Sports and Exercise*, *21*, 78–83.

Morgan, D. W., & Daniels, J. T. (1994). Relationship between $\dot{V}O_{2max}$ and the aerobic demand of running in elite distance runners. *International Journal of Sports Medicine*, *15*, 426–429.

Nevill, A. M., Brown, D., Godfrey, R., Johnson, P., Romer, L., Stewart, A. D. et al. (2003). Modeling maximum oxygen uptake of elite endurance athletes. *Medicine and Science in Sports and Exercise*, *35*, 488–494.

Nevill, A. M., Ramsbottom, R., & Williams, C. (1992). Scaling physiological measurements for individuals of different body size. *European Journal of Applied Physiology and Occupational Physiology*, *65*, 110–117.

Noakes, T. D. (1988). Implications of exercise testing for prediction of athletic performance: A contemporary perspective. *Medicine and Science in Sports and Exercise*, *20*, 319–330.

Noakes, T. D. (1991). *The lore of running*. Champaign, IL: Leisure Press.

Paavolainen, L., Nummela, A., & Rusko, H. (2000). Muscle power factors and $\dot{V}O_{2max}$ as determinants of horizontal and uphill running performance. *Scandinavian Journal of Medicine and Science in Sports*, *10*, 286–291.

Pate, R. R., Macera, C. A., Bailey, S. P., Bartoli, W. P., & Powell, K. E. (1992). Physiological, anthropometric, and training correlates of running economy. *Medicine and Science in Sports and Exercise*, *24*, 1128–1133.

Peinado, P. J., Di Salvo, V., Pigozzi, F., Bermudez, A. I., Peinado, A. B., Calderon, F. J. et al. (2006). Steady-state acid–base response at exercise levels close to maximum lactate steady state. *Clinical Journal of Sport Medicine*, *16*, 244–246.

Rusko, H. K. (1992). Development of aerobic power in relation to age and training in cross-country skiers. *Medicine and Science in Sports and Exercise*, *24*, 1040–1047.

Skinner, J. S., & McLellan, T. H. (1980). The transition from aerobic to anaerobic metabolism. *Research Quarterly for Exercise and Sport*, *51*, 234–248.

Weston, S. B., & Gabbett, T. J. (2001). Reproducibility of ventilation of thresholds in trained cyclists during ramp cycle exercise. *Journal of Science and Medicine in Sport*, *4*, 357–366.

Winter, E. M., & Nevill, A. M. (2009). Scaling: Adjusting for differences of body size. In R. Eston & T. Reilly (Eds.), *Kinanthropometry and exercise physiology laboratory manual: Vol.1: Anthropometry* (pp. 300–321). Abingdon: Routledge.