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The relationships of selected physiological characteristics with performance on the historic Athens Marathon course

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ABSTRACT

Because of the special difficulty of the historic Athens Marathon course, any performance prediction based on previous research data is problematic. The purpose of this study was to investigate the relationships between selected physiological variables and final time in this particular race. Twenty-eight male volunteers were divided into two groups: elite and good runners (marathon times between 2:20:35 and 3:01:04) and slower runners (3:10:29 to 4:16:51). All subjects performed a standard laboratory treadmill test prior to participating in the race. The resulting data and the race times were analysed statistically. Ventilatory threshold (VT) and velocity at VO_2max (vVO_2max) correlated highly with performance. The authors conclude that knowledge of one's VT and vVO_2max are particularly meaningful for predicting optimal marathon pace. Using VO_2max, VT and $\%VO_2max@VT$, final marathon time can be predicted with fair accuracy (±5.4 min) and thus an optimal pace for runners with performance times <3:00:00 on this route can be prescribed.

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Introduction

Research has shown that performance in distance running is influenced by a number of factors including VO_2max[7, 13, 27, 4, 34], running economy[4, 34, 22, 12], muscle fibre composition[13, 8], substrate availability[7, 2], lactate threshold or ventilatory threshold (VT)[16, 20, 26, 31, 35] and the velocity associated with maximal oxygen consumption ($v\text{-}VO_2max$)[28, 24, 17]. Running velocity corresponded with VT and VO_2max has been found to be highly co-related with performance in distance races from 3km up to the marathon[16, 26, 28, 24, 17]. For the marathon race, the correlation coefficients concerning VT and marathon time ranged from 0.86-0.94[26, 24].

The Athens Marathon is an historic race and the course is regarded one of the most difficult in the world. In addition to the 2004 Olympic marathon, other international events, i.e. European Championships (1982), World Marathon Cup (1995) and the World Championships (1997), have been staged on the course. The athletes run on the same route followed almost 2500 years ago by Pheidippides, a war messenger who, according to legend, died from exhaustion after passing on the news of the Greek victory in the battle of Marathon. Because of its special difficulty (Figure 1) any prediction of running time based on previous research data[16, 26, 25, 32, 29] is problematic.

The purpose of this study was to investigate the relationships between selected physiological variables and performance time on the historic Athens Marathon course.

Methods

Subjects

Twenty-eight moderately to highly trained male runners volunteered for this study. Their height, weight and percent body fat estimated from skin fold thickness measurements[15] were (mean ± SD) 176.07 ± 4.94cm, 67.41 ± 7.71 kg and 13.58 ± 3.55% respectively. The means ±SD of the selected characteristics of the subjects are listed in Table 1. The subjects were well informed about the experimental purpose and possible risks, and each subject signed an informed consent form to participate. The selection of the subjects was such that they had each trained and competed in road races from 10km up to the marathon for more than four years.

Marathon performance

Marathon times were obtained during Athens Marathon, held in the first week of November. Environmental conditions for the race can be regarded as 'neutral' in terms of their impact on marathon performance[23]. Data on the weather conditions was obtained from Meteorological Bureau and included temperature (16°C) at 9:30 a.m. (when the front runners reached the approximate mid-point of the route) maximum temperature (19°C), relative humidity (55%), wind velocity (little or no wind) and direction (north east). Table 1 summarises the performances of the participants under study.

Testing

Laboratory tests were conducted two to three weeks before the race day. The exercise protocol involved a continuous horizontal treadmill (Technogym run race 1200) test with a starting velocity of 8-10 km/h^{-1}. The treadmill speed was calibrated in advance and while the subjects ran by counting the time taken for the completion for 30 treadmill revolutions. Subjects fasted for four hours prior to testing. Following a 5-min warm-up, the velocity was increased by 1 km/h^{-1} every two minutes until volitional fatigue and break-up. This protocol has been validated in other studies for the simultaneous determination of VO_2max, VT and vVO_2max in runners[28, 24, 17].

VO_2max measurements

The open circuit Douglas Bag method was used to measure VO_2. Gas collection was made during the last 60-second period of each two-minute stage in order to allow the subject to attain steady state VO_2[20]. The subjects breathed through a low resistance 2-way Rudolph 2700 B valve. The expired gases passed through a 90cm length of 340mm diameter flexible tubing into a 150-litre capacity Douglas Bag. The concentration of CO_2 and O_2 in the expired air were measured by using the Hitech (GIR 250) combined Oxygen and Carbon Dioxide Analyzer. The gas analysers were calibrated continuously against standardised gases (15.88% O_2, 3.95% CO_2 and 100% N_2). Expired volume was measured by means of a dry gas meter (Harvard) previously calibrated against a standard airflow with a 3-litre syringe. Barometric pressure and gas temperature were recorded and respiratory gas exchange data for each workload (i.e. VO_2, VCO_2, VE and R) were determined on a locally developed computer program based on the computations described by MCARDLE, KATCH and KATCH[21] when VEatps, $FECO_2$ and FEO_2 are known. The highest VO_2 value obtained during an incremental exercise test was recorded as the subject's VO_2max, which also elicited a heart rate within ±10bpm of age predicted HRmax, a respiratory exchange ratio (RER) greater than 1.05, and finally a score on the completion of the test equal to or greater than 19 on the 15 grade Borg scale[5].

Ventilatory threshold assessment

Criteria described by others were used for the VT detection[26, 25, 14, 36]. The VT was primarily determined as the VO_2 or workload at which VE began to increase non-linearly. To check for the onset of hyperventilation subsidiary criteria were used: 1) a systematic increase of VE/VO_2, 2) a non-linear increase of VCO_2 and 3) a systematic decrease of $FECO_2$. The highest test-retest reproducibility (r=0.93) and the closest correlation (r=0.96) with LT have been reported by SUCEC[33] and CAIOZZO ET AL[6] when ventilatory transients such as FEO_2, VE/VO_2 and $FECO_2$, VE/VCO_2 are used for the VT detection. The workload before systematic increase of either VE/VO_2, or VE/VCO_2 with a concomitant decrease of $FECO_2$, when a two-minute incremental protocol has been employed can be easily defined (Figure 2). YOSHIDA ET AL[38] examined the use of the Douglas Bag technique for VT assessment and found it a valid non-invasive measure of onset of metabolic acidosis (OMA). Heart rates were continuously recorded throughout the test by a heart rate monitor (Polar S 710).

Velocity at VO_2max (vVO_2max)

The lowest running speed that elicits a VO_2 equivalent with VO_2max during the VO_2max test was defined as vVO_2max[3].

Statistical Analysis

Univariate relationships between VO_2max, VT, %VO_2max@VT, VO_2@VT and vVO_2max and marathon time were evaluated using a simple linear regression. A stepwise multiple regression analysis was performed using VO_2max, VT, %VO_2max@VT, VO_2@VT and vVO2max as predictor variables. The 95% level of confidence was chosen in all statistical analyses.

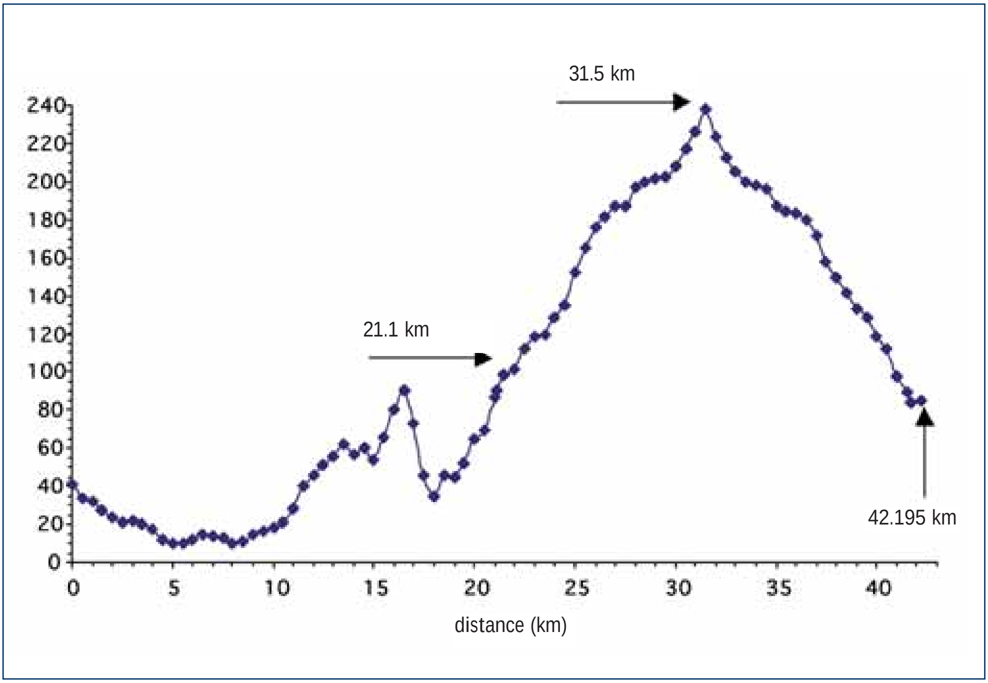

Figure 1. Altitude variations along the historic Athens Marathon route.

Statistical analysis was also extended in two subgroups applying the criteria suggested by SJODIN and SVEDENHAG[32]: the elite and good runners (EGR) range of marathon performance 2:20:35 to 3:01:04 (n=15) and the slower runners (SR) range of marathon performance 3:10:29 to 4:16:51 (n=13).

Results

Table 1 shows the runners' laboratory and marathon data (mean±SD). Mean marathon times for all subjects, EGR and SR were 3:08:40, 2:43:19 and 3:37:53 respectively. Mean % body fat, VO_2max (absolute and relative value), VT (km/h^{-1}), VO_2 @VT (ml/kgr^{-1}/min^{-1}) vVO_2max (km/h^{-1}), HRmax (bpm) and marathon performance were significantly different ($p<0.01$) between the EGR and SR (Table 1). Tables 2 and 3 present intercorrelations between selected physiological parameters and marathon time. VT (km/h^{-1}) is highly correlated with marathon time (r=-0.89, EGR; r=-0.90, SR, $p<0.01$). VO_2max (ml/kg^{-1}/min^{-1}), as referred to in Tables 2 and 3, correlated insignificantly with marathon time (r=-0.27, EGR; r=-0.38, SR, $p>0.05$). Marathon time was also highly ($p<0.01$) correlated (r=-0.85 and r=-0.82) with vVO_2max (km/h^{-1}) in

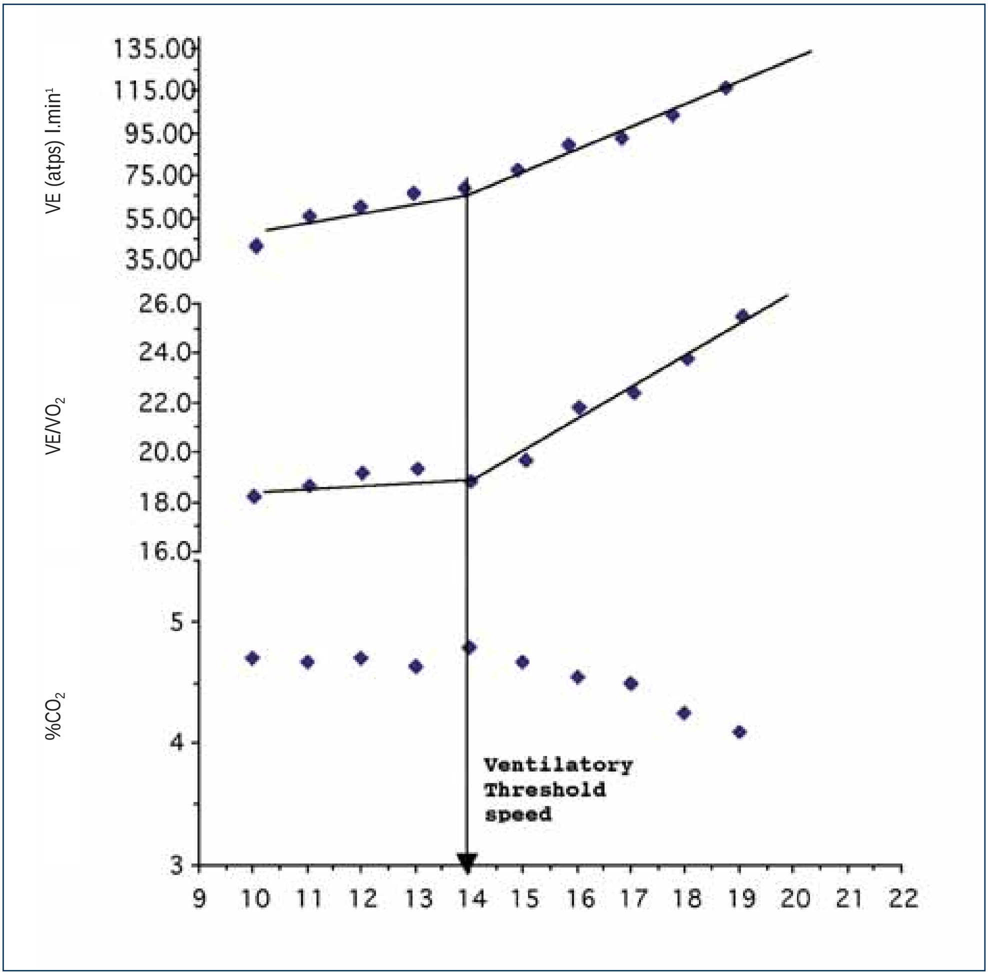

Figure 2. Diagrammatic representation of changes in minute ventilation (VEatps), ventilatory equivalent for O_2 and fractional expired CO_2 gas exchange parameters used for the detection of Ventilatory Threshold.

Table 1. Physiological and performance characteristics of subjects. Mean ± SD.

	All subjects (n=28)	EGR (n=15)	SR (n=13)
Age (years)	37.25±10.04	31.73±4.04	43.62±11.16 a
Weight (kg)	67.41±7.71	66.23±6.75	68.78±8.55
%Fat	13.58±3.55	11.67±2.7	15.79±3.08 a
Height (cm)	176.07±4.94	177.33+3.57	174.62±5.9 b
VO_2max ($ml/kgr^{-1}/min^{-1}$)	58.4±7.18	63.29±4.35	52.77±5.29 a
VO_2max (l/min^{-1})	3.92±0.53	4.19±0.47	3.6±0.39 a
*VT (km/h^{-1})	13.95±2.41	15.77±1.53	11.85±1.13 a
+%VO_2max @VT	79.19±2.28	79.8±1.96	78.48±2.43
#VO_2 @VT ($ml/kgr^{-1}/min^{-1}$)	45.66±6.19	50.07±3.59	40.60±4.22 a
**vVO_2max (km/h^{-1})	18.07±2.71	20.27±1.3	15.54±1.18 a
HRmax (bpm)	181.79±9.24	185.93±6.32	177±9.78 a
Marathon time (min:sec)	188:66±33.07	163.32±13.15	217.89±22.71 a
Marathon time (hours: min:sec)	3:08:40	2:43:19	3:37:53

ap<0.01, bp<0.05 unpaired, two-tailed t-test.
EGR Elite and good marathon runners, SR Slow runners
* Treadmill speed at Ventilatory threshold
+fractional utilization of VO_2 at ventilatory threshold
Oxygen consumption at ventilatory threshold
** treadmill speed at maximal oxygen consumption.

Table 2. Correlation coefficients between selected physiological parameters and marathon performance in EGR (n = 15).

	1	2	3	4	5	6	7	8
1 Marathon time (min:sec)	1							
2 %fat	0.72**	1						
3 VO_2max ($ml/kgr^{-1}/min^{-1}$)	-0.27	-0.06	1					
4 VO_2max (l/min^{-1})	0.01	-0.21	0.38	1				
5 VT (km/h^{-1})	-0.89**	-0.79**	0.35	-0.01	1			
6 %VO_2max @VT	-0.64**	-0.47	-0.24	-0.59*	0.55*	1		
7 VO_2 @VT ($ml/kgr^{-1}/min^{-1}$)	-0.35	-0.13	0.93**	0.25	0.46	-0.08	1	
8 vVO2max (km/h^{-1})	-0.85**	-0.81**	0.41	0.21	0.93**	0.40	0.52*	1

**p<0.01, *p<0.05

Table 3. Correlation coefficients between selected physiological parameters and marathon performance in SR (n = 13).

	1	2	3	4	5	6	7	8
1 Marathon time (min:sec)	1							
2 %fat	0.35	1						
3 VO_2max ($ml/kgr^{-1}/min^{-1}$)	-0.38	-0.36	1					
4 VO_2max (l/min^{-1})	0.17	0.00	0.27	1				
5 VT (km/h^{-1})	-0.90**	-0.51	0.42	-0.12	1			
6 %VO_2max @VT	-0.59*	0.18	0.05	-0.12	0.50	1		
7 VO_2 @VT ($ml/kgr^{-1}/min^{-1}$)	-0.52	-0.36	0.96**	0.20	0.54	0.26	1	
8 vVO_2max (km/h^{-1})	-0.82**	-0.47	0.41	-0.24	0.88**	0.64*	0.53	1

**p<0.01, *p<0.05

EGR and SR respectively. Stepwise multiple regression analysis between marathon time on the classic route (dependent variable) and selected physiological variables (independent variables) produced three predictive (Table 4) regression equations for all subjects (n=28), EGR (n=15) and SR (n=13). For the EGR group VT (km/h^{-1}) together with VO_2max (absolute value) and %VO_2max @VT explained 87% of the performance variability and produced the lowest standard error of the estimate (±5.4min). SR marathon time was predicted more accurately (Table 4) after the inclusion of %VO_2max @VT together with VT (km/h^{-1}).

Discussion

Significant correlation coefficients were observed between marathon time and the running speed that corresponds with VT (Tables 2 and 3). These findings further support the results reported by RHODES and MCKENZIE[26]. The slightly higher correlation coefficient (r=0.94) reported by that study may be explained by either the influence of the non-physiological factors on marathon performance (such as terrain, racing strategies and psychological features) or the different criteria used to assess VT. SELIG[29], in tests on 30 experienced

Table 4. Predictive multiple regression equations for selected physiological variables and marathon performance time on the classical route.

Subjects	Predictive equation
All (n=28)	Marathon time (min) =498.7-5.87VT[a]-1.55 %VO_2max @VTb-5.82vVO_2max[c]
EGR (n=15)	Marathon time (min) =512-7.03 VO_2max (l/min^{-1})-5.75VT[a]-2.86%VO_2max @VT[b]
SR (n=13)	Marathon time (min) =546.4-16.5VT[a]-1.69%VO_2max @VT[b]

a=Treadmill velocity (km.h-1) at ventilatory threshold, b=Fractional utilization of VO2max at ventilatory threshold, c=Treadmill velocity associated with VO2max, EGR=Elite and good marathon runners, SR=Slow marathon runners marathon runners, reported a high correlation coefficient (r=0.93) between respiratory compensation threshold (RCT) and mean marathon speed. Since RCT has been reported to occur at higher exercise intensities compared to VT[14, 36] this makes the direct comparison of the studies difficult. A more recent study by KAI ET AL[19] demonstrated that the velocity corresponding with individual anaerobic threshold (a geometric version of lactate threshold) correlated highly (r= -0.93) with marathon performance. The studies by FARRELL ET AL[16], SJODIN and JACOBS[31] and TANAKA and MATSURA ET AL[35] cannot be used for comparison since the research regarding VT and lactate threshold coincidence has not being conclusive as yet. Marathon time was also highly[30] correlated with critical velocity (r=0.87, $p<0.01$) while VT velocity presented lower correlation (r=-0.53, $p>0.05$). The lower correlation observed in that study maybe due to either differences in endurance capabilities of the subjects or possibly the course characteristics may influence the relationship.

Significant correlation coefficient was also observed between vVO_2max and marathon performances (Table 2 and 3). This finding was in accordance with the correlation (r=-0.90) reported by NOAKES ET AL[24] between a similar parameter (the peak treadmill running velocity derived during the VO_2max test). Physiological determinants of vVO_2max or peak treadmill running velocity are still not well known and, given its exhausting nature, one may suggest that the parameter encompasses information for both aerobic and anaerobic energy systems. In addition, in the present study with the marathon time as the dependent variable a multiple correlation (R^2=0.87 for EGR and R^2=0.85 for SR) was obtained (Table 4) by combining several important factors (e.g. VT, VO_2max, %VO_2max@VT). This means that these factors can account for 85-87% of the variance in marathon time on the historic route.

R	R2	R2 adjusted	Std. Error of the estimate
0.95	0.91	0.90	10.1
0.94	0.87	0.84	5.4
0.92	0.85	0.82	9.5

In the present study, the mean marathon speed for the EGR and SR groups (excepting five runners of each group) was less than the speed at VT (mean 1.1%, and 1.3% respectively). It seems that experienced marathon runners instinctively choose to run at a speed close to their VT. However, it is a matter of terrain, environmental conditions and racing strategy as to how close an athlete can run to his threshold speed obtained in the laboratory in the absence of air resistance and course contour. It has been said that VT coincides with the onset of metabolic acidosis[37], therefore running speed at VT is the highest speed where anaerobic metabolites such as hydrogen protons (H^+) can be fully reoxidized and not accumulated into the cytoplasm and interfere with glycolytic enzyme activity[18]. By exceeding this speed for a long period of time, as during the marathon, the runner will gradually become fatigued.

The mean %VO_2max @VT values for EGR and SR (Table 1) were 79.8 and 78.4 ($p>0.05$). This means that the fractional utilisation of VO_2max was similar for the EGR and the SR groups during the race despite significant differences in performance times. Factors that determine the %VO_2max at marathon pace are age[7] and the training history (years of training and km/week)[32]. Fractional utilisation of VO_2max between elite (<2:30:00) and good (2:30:00-3:00:00) marathon runners[32] was similar (80% VO_2max) with comparable weekly training volume (130km) compared to slow runners (71% VO_2max) with significantly lower weekly training volume (57km). COSTILL and WINROW[10] noted that older runners (>40) could utilise 80-85% VO_2max when running the marathon. The subjects in the present study had identical training histories (>100km weekly) and the performance differences between EGR and SR could be mostly attributed to genetic factors (natural talent) and the performance decrements due to older age of SR group (Table 1). Therefore, similar fractional utilisation of VO_2max during the race for both groups was expected despite significant differences in performance times.

Another limiting factor to marathon performance is glycogen availability[2]. The stores of this energy substrate are not enough to support the energy needs exclusively for the entire race if not supported by fat metabolism. The results of a study by ASTORINO[1] confirm that running speed that corresponds with ventilatory threshold coincides with a maximal rate of fat oxidation. Thus, it seems reasonable to assume that VT may represent the optimal exercise intensity that can be sustained for 42km. Therefore, an athlete running at a pace close to his/her VT speed right from the start of the race avoids experiencing hypoglycemia with its adverse effects to performance early in the race, given that the glycogen reserves are to their highest level before the race.

Conclusion

In summary, the results of this investigation showed that VT and vVO_2max correlated highly with performance on the historic Athens Marathon route. Knowledge of one's VT and vVO_2max speed is particularly meaningful for the prediction of optimal marathon pace. VO_2max VT and $\%VO_2$max@VT can be used predict final marathon time with fair accuracy (±5.4 min) and to prescribe an optimal race pace for runners with performance times <3:00:00 on this route.

Practical Applications

Running speed that corresponds with ventilatory threshold and maximal oxygen consumption are physiological measures that explain a large amount of the variance associated with marathon performance. The improvement through running training of VT running velocity and vVO_2max will bring also significant changes in prolonged sub-maximal endurance performance. Trained runners, regardless of performance level, competing in the Athens Marathon on the historic course should maintain a mean speed slightly slower than their VT speed throughout the race.

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