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original article

Estimated VO_2max and its corresponding velocity predict performance of amateur runners

VO_2máx estimado e sua velocidade correspondente predizem o desempenho de corredores amadores

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Abstract – In recent years, there has been a substantial increase in the number of runners, with a proportional increase in their involvement in amateur street competition. Identification of the determinants of performance in this population appears necessary for optimization of time devoted to training. The objective of this study was to ascertain the association between estimated maximal oxygen uptake (VO_{2max}), critical velocity (CV) and VO_{2max} velocity (V_{VO2max}) and athletic performance in the 3.6 km (uphill) and 10 and 21.1 km (flatland) events. Twelve amateur runners (nine male), mean age 36 ± 5 years underwent five tests: 1 and 5 km race on level ground, 3.6 km race with slope (≈8%), and indirect VO_{2max} measurement. CV was determined from the linear relationship between distance and run time on the first two tests. The subjects then took part in two official 10 km and 21.1 km (half marathon) races. V_{VO2max} was calculated from the VO_{2max} through a metabolic equation. VO_{2max} showed the best association with running performance in the 10 and 21.1 km events. For the uphill race, V_{VO2max} showed a better association. Overall, the variable with the highest average association was VO_{2max} (0.91±0.07), followed by V_{VO2max} (0.90±0.04) and VC (0.87±0.06). This study showed strong associations between physiological variables established by low-cost, user-friendly indirect methods and running performance in the 10 and 21.1 km (flatland) and 3.6 km (uphill) running events.

Key words: Athletic performance; Running; Physical fitness.

Resumo – *Observa-se, nos últimos anos, um importante crescimento do número de praticantes de corrida com proporcional aumento da adesão destes às provas de rua. Nesta população, a identificação dos determinantes do desempenho parece ser necessária para otimização do tempo dedicado ao treinamento. O objetivo do estudo foi estabelecer a associação do consumo máximo de oxigênio ($VO_{2máx}$) estimado, da velocidade crítica (VC) e da velocidade do $VO_{2máx}$ ($V_{VO2máx}$), com os desempenhos nas provas de 3,6 km em subida e 10 e 21,1 km no plano. Doze corredores amadores (9 homens) com 36 ± 5 anos de idade foram submetidos a quatro testes: 1 e 5 km de corrida, no plano; 3,6 km de corrida, com inclinação (≈8%); e um teste para determinação indireta do $VO_{2máx}$. A VC foi determinada através da relação linear entre a distância e o tempo de corrida dos dois primeiros testes. Os sujeitos participaram de duas provas oficiais de 10 km e 21,1 km. A $V_{VO2máx}$ foi estimada a partir do $VO_{2máx}$, através de equações metabólicas. O $VO_{2máx}$ apresentou a melhor associação com o desempenho da corrida em 10 e 21,1 km no plano. Já na subida, a $V_{VO2máx}$ apresentou melhor associação. Considerando todas as provas, a variável com maior média associativa foi o $VO_{2máx}$ (0,91±0,07), seguido do $V_{VO2máx}$ (0,90±0,04) e VC (0,87±0,06), respectivamente. Este estudo demonstrou elevadas associações entre variáveis fisiológicas estabelecidas por métodos indiretos, de baixo investimento e alta praticidade, com o desempenho da corrida em 10 e 21,1 km, no plano, e 3,6 km, em subida.*

Palavras-chave: *Aptidão física; Corrida; Desempenho atlético.*

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INTRODUCTION

The rise in popularity of road running is evident by the increasing number of events, which has been mostly due to the greater involvement of recreational runners[1]. In view of the dedication of these practitioners to training and their search for better results based on their potential, it could be relevant—even for purely amateur runners—to identify the determining factors of running performance and related variables, with the purpose of optimizing time spent on training.

Among the several variables traditionally investigated in studies on this topic, VO_{2max} has long been used for prediction of aerobic performance[2] in events with distances ranging from three[3] to 90 km[4,5]. The evidence has shown a strong (0.70–0.91) and significant association between VO_{2max} and aerobic performance when the tested individuals have heterogeneous athletic skills[3,4,6]. In groups with more consistent athletic skills, weaker correlations are observed[7], and VO_{2max} is less useful for discrimination of athletic performance.

The velocity at maximum oxygen uptake (V_{VO2max}), defined as the minimum velocity associated with VO_{2max} during an incremental exercise test[8], represents the association between running economy and VO_{2max}. V_{VO2max} has been noted as an important predictor of aerobic performance[6,9], particularly among subjects with similar VO_{2max} rates. Another variable that has been used to predict development is critical power, originally demonstrated in synergic muscular groups[10] and later adapted for cycle ergometer testing[11]. Critical power is defined as the highest exercise intensity that can be held for a prolonged period without leading to exhaustion[10]. In modalities that preclude quantification of power (running, swimming, etc.), critical velocity (CV) has been used instead[12]. This index has shown significant correlations with performance in 400 m swim events ($r = 0.86$)[12], 10k races ($r = 0.92$)[13] and marathon running ($r = -0{,}87$)[14].

The vast majority of the studies reviewed have focused on high-performing athletes and on the use of direct methods for determination of independent variables. Considering the rise in popularity of recreational running, there is a pressing need to investigate the power of VO_{2max}, V_{VO2max} and CV, measured on flat terrain, to predict the performance of amateur runners in flatland and uphill events, as these variables are highly applicable to optimization of training.

The objective of this study was to establish an association between estimated CV, V_{VO2max} and VO_{2max} and performance in the 3.6 km uphill, 10 km flatland, and 21.1 km flatland events. The research hypothesis is that all of these indices will be strongly and significantly associated with running performance in all three events.

METHODS

Study design

We analyzed the preparatory stages of a running team that took part in a 600 km relay race between the cities of São Paulo and Rio de Janeiro, Brazil, between 22 July and 15 August 2009. Subjects underwent four trials (1 km and 5 km flatland, 3.6 km uphill, and a test for VO_{2max} measurement) and took part in two official-distance events (10 km and 21.1 km). Trials and events took place at the same time of day, within a range of approximately 3 hours.

During the first visit (22 July 2009, temperature 17.2°C, 79% relative humidity), subjects underwent resting heart rate (HR) measurement with a Polar RS 400 monitor (Polar® Electro, Kempele, Finland) and a test for VO_{2max} measurement. The second visit (8 August 2009, temperature 21.7 °C, 79% relative humidity) consisted of a 5 km road race. The third visit (15 August 2009) consisted of a 3.6 km uphill trial, carried out on a graded track. The fourth visit (26 August 2009, temperature 18.8 °C, 85% relative humidity) consisted of a 1 km trial. Before all trials, participants were instructed to engage in free warm-up exercises for 15 min.

Subjects

The participants were members of the race team of a runners club in Rio de Janeiro. From a universe of 225 recreational runners, nine men and three women were selected to represent the club in a 600 km relay race. Race organizers set the maximum number of runners per team at 12. Table 1 presents the profile of the study participants.

Table 1. Subject characteristics and event times.

Variables	Male (n = 9)	Female (n = 3)	Overall (n = 12)
Demographic			
Age (years)	36.0 ± 5.0	36.0 ± 5.2	36.0 ± 4.8
Anthropometric			
Body mass (kg)	68.1 ± 11.2	50.3 ± 2.8	63.6 ± 12.6
Height (cm)	173.8 ± 10.5	159.3 ± 4.9	170.2 ± 11.3
Body fat (%)	10.2 ± 4.8	15.6 ± 2.0	11.5 ± 4.8
Aerobic			
VO_{2max} (mL.kg^{-1}.min^{-1})	62.4 ± 7.4	53.3 ± 4.7	60.1 ± 7.8
V_{VO2max} (km.h^{-1})	17.8 ± 2.1	15.0 ± 0.7	17.1 ± 2.2
CV (km.h^{-1})	15.7 ± 1.4	12.5 ± 0.9	14.9 ± 1.9
Event times (min)			
3.6 km (uphill)	22.1 ± 9.2	31.0 ± 2.6	24.3 ± 8.9
10 km	37.4 ± 5.2	45.0 ± 4.4	39.3 ± 5.9
21,1 km	89.7 ± 13.9	112.3 ± 4.0	95.3 ± 15.7

CV, critical velocity; SD, standard deviation; VO_{2max}, maximum oxygen uptake; V_{VO2max}, velocity at VO_{2max}. Data expressed as mean ± standard deviation.

The runners included in the sample were those who achieved the best performance in the 10 and 21.1 km flatland events. Subjects who developed any health issues during the test period were cut from the team. Subjects were instructed to avoid high-intensity exercise for 24 hours and avoid solid foods for at least three hours prior to each trial. Fluids were allowed ad libitum.

Events were administered by the team's technical staff. Data used in the study were obtained from official event results and from the databases of the team responsible for data collection, which authorized their use for the purposes of this experiment. All participants were volunteers and provided written informed consent for the use of their personal information for research purposes. The study was approved by the Universidade Gama Filho Research Ethics Committee (protocol #098.2010).

Procedures

- **Anthropometry**

Height and body mass were measured with a Tanita BC553 body composition monitor (Tanita, USA) and body fat percentage[15,16], with a Sanny® brand skinfold caliper (American Medical do Brasil Ltda., São Bernardo do Campo, São Paulo). The measured skinfold thicknesses were chest, thigh, and abdominal in men and triceps, supra-iliac, and thigh in women, as proposed by Jackson and Pollock[15,16].

- **VO_{2max} measurement**

Maximum oxygen uptake was measured on 22 July 2009, between 0800h and 1000h. The measurement protocol was adapted from Swain et al.[17]. The trial took place on a flat asphalt track designed, specifically for road running, with a perimeter of 252.5 m (Garmin Edge® 305 GPS, Garmin Ltd., Olathe, KS, USA).

After 10 min in the supine position for measurement of resting HR (Polar RS 400, Polar® Electro, Kempele, Finland), subjects were instructed to perform at least two running stimuli, for at least 6 minutes per run, so that the test ended at the starting line with a rune time of over 6 minutes. The first run was performed at constant velocity and at an intensity defined as “very light/light” on the Rated of Perceived Exertion (RPE) scale[18]. After the first run, subjects were immediately instructed to run again at constant velocity, but with “moderate” perceived exertion. Preliminary tests done by our group showed the need for multiple running stimuli for adjustment of intensity at steady state, due to the natural tendency of subjects to overestimate initial test speed and, consequently, steady state velocity. Subjects ran while under continuous HR monitoring (Polar RS 400, Polar® Electro, Kempele, Finland) and were asked to report RPE and HR at the end of each lap. Lap times were also recorded for monitoring of steady state velocity. Subjects were asked to correct their velocity as required. The purpose of the test was to establish an association between HR and steady state velocity between 70% and 85% of HR reserve (HRR). If this intensity could not be achieved, more intense 6-minute runs were administered. The distance covered, equivalent time elapsed and intensity of exertion using the reserve method were used for estimation of VO_{2max} (Eq. 1). V_{VO2max} was estimated by means of the American College of Sports Medicine equation[19].

$$VO_{2max} = (\text{distance} / \text{time} \times 0.2) / [(HR_{load} - HR_{rest}) / (HR_{max} - HR_{rest})] + 3.5$$

where VO_{2max} = maximal oxygen uptake, in $mL \times kg^{-1} \times min^{-1}$; distance = total distance covered as multiple of 252.5 m during last run, in m; time = total time required to cover the total distance, in min; HR_{load} = mean HR while crossing the finish line during last two laps, in bpm; HR_{rest} = resting HR after 10 min in the supine position, in bpm; HR_{max} = maximum HR during 1 km run.

- **Critical velocity**

Determination of critical velocity was based on 1-km and 5-km flatland running performance. Test runs took place on different days and in the aforementioned order. Subjects were instructed to run the set distances, alone, in the shortest time possible. CV was calculated in a Microsoft® Excel for Windows 2007 (Microsoft Corporation, Redmond, WA, USA) spreadsheet as the linear relation between distance and race time, corresponding to the slope of the linear regression line[13].

- **Uphill trial**

Assessment of performance in uphill running events was carried out on a graded road within the city of Rio de Janeiro (Vista Chinesa). Participants began together at the starting line and the finish line was at the Vista Chinesa belvedere. The total distance was 3.6 km, with a 300-m change in altitude (Garmin Edge® 305 GPS, Garmin Ltd., Olathe, KS, USA), and an average grade of 8.3%.

- **Flatland trials**

For the selection of runners who would make up the race team, subjects took part in two official events in the city of Rio de Janeiro. The 10 km run took place on 26 July 2009 (temperature 18.8° C, 85% relative humidity) and the half-marathon (21.1 km), on 6 September 2009 (temperature 23.2 °C, 70% relative humidity). Performance was determined on the basis of official race times as provided by event organizers.

Statistical analyses

Variables were expressed as mean ± standard deviation. The Shapiro-Wilk test was used to test for normality of distribution. Stepwise linear regression was performed to ascertain whether associations existed between CV, VO_{2max}, V_{VO2max}, and performance in the 3.6 km uphill and 10 km and 21.1 km flatland events. The standard error of estimate was calculated for each established association. Due to the sample size, 95% confidence intervals were presented. Correlation coefficients were interpreted according to the magnitude scale proposed by Hopkins (www.sportsci.org): < 0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; >0.9, nearly perfect. Analyses were performed in the SPSS 17.0 software environment (SPSS Inc., Chicago, IL, USA), with the significance level set at $P < 0.05$.

RESULTS

In addition to subject profiles, mean race times for each event are described in Table 1. The results of the investigated associations and their mean errors are reported in Table 2.

The variable with the greatest predictive power was VO_{2max} for the 10 km and 21.1 km events. This variable was also strongly and significantly associated with performance on the 3.6 km uphill event. V_{VO2max} correlated significantly with all events, but was most strongly associated with time to completion of the 3.6 km uphill event. Correlations detected for the CV variable were slightly weaker.

Table 2. Association between aerobic variables and running performance in the 3.6 km, 10 km, and 21.1 km events (n = 12)

Variable		Performance		
		$T_{Vista\ Chinesa}$ (3.6 km uphill)	$T_{10\ km}$	$T_{21.1\ km}$
VO_{2max}	r	-0.83**	-0.95**	-0.96**
	95%CI	(-0.95 to -0.48)	(-0.98 to -0.83)	(-0.99 to -0.88)
	SEE (min)	5	1.7	3.9
V_{VO2max}	r	-0.93**	-0.86**	-0.92**
	95%CI	(-0.98 to -0.78)	(-0.96 to -0.56)	(-0.97 to -0.74)
	SEE (min)	3.2	3	6.3
CV	R	-0.82*	-0.86**	-0.93**
	95%CI	(-0.94 to -0.47)	(-0.96 to -0.57)	(-0.98 to -0.76)
	SEE (min)	5.4	2.9	5.9

T = time; SEE = standard error of estimate; VO_{2max} = maximal oxygen uptake; V_{VO2max} = velocity at VO_{2max}; CV = critical velocity; CI = confidence interval.
* $P < 0.01$; ** $P < 0.001$.

DISCUSSION

The main finding of this study was that indirectly estimated VO_{2max} was the variable most strongly associated with running performance for the two flatland events assessed. V_{VO2max} had a stronger association with uphill running performance. The heterogeneous level of physical fitness in the sample may have contributed to the very high correlation coefficients, as observed in previous studies[3,4]. One limitation of this study is that independent variables were determined by an indirect method. Although this is not as reliable as direct measurement, it is a more user-friendly, low-cost method and thus more applicable to settings in which there is limited access to testing equipment. Therefore, the use of an indirect method increases the external validity of the study and supports the use of this approach in recreational runners.

Although previous studies have shown a weak association between VO_{2max} and performance on time limit at V_{VO2max} tests[20], the associations detected in the present study support other evidence that has indicated the importance of this variable in determining aerobic performance in 10 km to 42 km running events [4, 21]. Costill et al.[21] reported a strong, significant inverse correlation (r = -0,91) between VO_{2max} and time to completion of a 16 km event in runners. McLaughlin et al.[22] found an association of -0.90 between VO_{2max} and time to completion of a 16 km race in well-trained runners. Also in runners, a significant correlation has been reported between VO_{2max} and performance time in a 5 km race ($r = -0.86$; $P < 0.001$)[23]; this is consistent with the findings of Farrel et al. [4], who reported a significant association ($P < 0.05$) in various events: 3.2 km ($r = -0.83$), 9.7 km ($r = -0.86$), 15 km ($r = -0.89$), 19.3 km ($r = -0.91$) and 42.2 km ($r = -0.91$).

Finally, Grant et al.[6], in a sample of well-trained runners (r = -0.70), and Slattery et al.[3], in a sample of triathletes (r = -0.80), reported significant associations between 3-km race performance and VO_{2max}.

The correlations reported in the present study were slightly stronger than those observed in previous studies, particularly for the 10 km and 21.1 km events. This may have been due to the difference in strategies used for determining VO_{2max}, as this study used an indirect approach based on estimation from a field test and the association between steady state velocity and exertion as established by the HRR method. Taking into account the collinearity between these two variables (r = 0.91; P = 0.01), VO_{2max} estimates in this study may have had a statistical benefit from the characteristic association between V_{VO2max} and running performance[3]. The fact that VO_{2max} estimation was based on a track test rather than a treadmill test may have contributed to a better association between the typically aerobic variables analyzed herein and running performance.

There was a strong and significant correlation between V_{VO2max} and time required to complete a 3.6 km uphill run. This variable was also strongly and significantly associated with performance in the 10 km and 21.1 km events. Significant association results were reported by Grant et al.[6], who found V_{VO2max} to correlate significantly with mean speed during a 3 km event (r = 0.86). In triathletes, 3 km performance has been reported as significantly associated with V_{VO2max} (r = -0.91; P < 0.05)[3]. Scott and Houmard[23] reported that V_{VO2max} was highly related to performance in a 5 km simulated time trial (r^2 = 0.94; P < 0.001) and an official 5 km race (r^2 = 0.89; P < 0.001). McLaughlin et al.[22] found that, in a sample of well-trained runners with heterogeneous VO_{2max} values, V_{VO2max} was the best predictor of 16 km performance (r = -0.97).

In a previous study[24], CV correlated with 1 km (r = -0.75), 10 km (r = -0.85), and 21.1 km performance (r = -0.79). The authors reported that CV would be a good predictor of performance, similar to maximum speed in an incremental test to exhaustion for the 10 km (r = -0.85 vs. 0.84) and 21.1 km (r = -0.79 vs. -0.78) distances. Another study[13] reported an association between CV and mean velocity during a 9.8 km race (r = 0.92). We found similar significant correlations between CV and run time for the 3.6 km uphill, 10 km flatland, and 21 km flatland events. Furthermore, CV was determined on the basis of aerobic performance, which may have at least partly helped to explain the correlations detected. The results of this study confirm prior data on the quality of this performance index.

The correlations found in this study between typically aerobic variables and run distances revealed that the association between VO_{2max} and CV improves with increasing distances, supporting the hypothesis that CV is the maximum velocity that can be sustained for prolonged periods. V_{VO2max} had its strongest association for the shortest event distance; however, one should bear in mind that the shortest event was run at an ≈8% grade. Uphill running is known to increase the metabolic and neuromuscular components of the activity[25]. A previous study[25] reported increased muscle activation and oxygen deficit for the same exercise intensity. The authors concluded that this increased oxygen deficit was due to increased muscle activity in the lower extremities. Paavolainen et al.[26], who investigated the prediction of athlete performance in an activity run at a ≈12% grade, found significant associations between peak velocity on flat ground (r = 0.85) and velocity during a maximal anaerobic run test (V_{MART}), (r = 0.49) for blood lactate levels during the same test and (r = 0.78) for peak 30 m velocity, but not for VO_{2max}. Peak uphill velocity was significantly correlated with VO_{2max} (r = 0.78), V_{MART} (r = 0.61) and peak 30 m velocity (r = 0.53). The authors concluded that variables related to muscular power factors were better associated with flatland performance, whereas VO_{2max} was more strongly associated with uphill performance. The results of the present study do not corroborate those of Paavolainen et al.[26], because V_{VO2max} was more strongly associated with uphill performance. The use of V_{VO2max} as an indicator of performance at 0% and ≈12% grades by these authors may have influenced their findings, as this variable is not considered a manifestation of performance, but rather a marker of performance. In our study, we used a manifestation of performance (3.6 km uphill run time) instead. V_{VO2max} has been reported as able to represent aerobic and anaerobic modes of energy production in an integrated manner[7,27], in addition to being associated with running economy[6,28,29]. This may partly explain its superior predictive power for a short, uphill event in this study.

CONCLUSION

This study showed strong associations between physiological variables established by an indirect, low-cost, user-friendly method and running performance in the 10 and 21.1 km (flatland) and 3.6 km (uphill) running events. Estimated VO_{2max} was the variable with the most associations, and is potentially the best predictor of flatland running performance. For uphill running performance, V_{VO2max} exhibited greater predictive power. This was the first study to establish an association between variables related with aerobic performance and uphill running performance. CV was high and significantly associated in all studied event distances, and proved to be an adequate predictor of aerobic performance. The aerobic testing approach used in this study was deemed practical enough for use by technical-level practitioners and individuals involved in recreational running activities.

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