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original article

The highest velocity and the shortest duration permitting attainment of VO_2max during running

A maior velocidade e o menor tempo de exercício em que o VO_2max é alcançado na corrida

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Abstract – The severe-intensity domain has important applications for the prescription of running training and the elaboration of experimental designs. The objectives of this study were: 1) to investigate the validity of a previously proposed model to estimate the shortest exercise duration (T_{LOW}) and the highest velocity (V_{HIGH}) at which VO_2max is reached during running, and 2) to evaluate the effects of aerobic training status on these variables. Eight runners and eight physically active subjects performed several treadmill running exercise tests to exhaustion in order to mathematically estimate and to experimentally determine T_{LOW} and V_{HIGH}. The relationship between the time to achieve VO_2max and time to exhaustion (Tlim) was used to estimate T_{LOW}. V_{HIGH} was estimated using the critical velocity model. V_{HIGH} was assumed to be the highest velocity at which VO_2 was equal to or higher than the average VO_2max minus one standard deviation. T_{LOW} was defined as Tlim associated with V_{HIGH}. Runners presented better aerobic fitness and higher V_{HIGH} (22.2 ± 1.9 km.h^{-1}) than active subjects (20.0 ± 2.1 km.h^{-1}). However, T_{LOW} did not differ between groups (runners: 101 ± 39 s; active subjects: 100 ± 35 s). T_{LOW} and V_{HIGH} were not well estimated by the model proposed, with high coefficients of variation (> 6%) and a low correlation coefficient (r<0.70), a fact reducing the validity of the model. It was concluded that aerobic training status positively affected only V_{HIGH}. Furthermore, the model proposed presented low validity to estimate the upper boundary of the severe-intensity domain (i.e., V_{HIGH}), irrespective of the subjects' training status.

Key words: Oxygen uptake; Physical education and training; Physical fitness; Running; Exercise.

Resumo – *O domínio severo tem importantes aplicações para a prescrição do treinamento de corrida e elaboração de delineamentos experimentais. O estudo teve como objetivos: 1) investigar a validade de um modelo proposto previamente para estimativa do menor tempo de exercício (T_{INF}) e maior velocidade (V_{SUP}) em que o VO_2max é alcançado na corrida; e 2) comparar os efeitos do estado de treinamento nestes parâmetros. Oito corredores e oito indivíduos fisicamente ativos realizaram uma série de testes até a exaustão em esteira rolante para estimar matematicamente e determinar experimentalmente o T_{INF} e V_{SUP}. A relação entre tempo para atingir o VO_2max e tempo de exaustão (Tlim) foi usado para estimar o T_{INF}. A V_{SUP} foi estimada pelo modelo de Velocidade Crítica. V_{SUP} foi assumida como a maior velocidade em que o VO_2 foi igual ou maior que a média do VO_2max menos um desvio padrão. T_{INF} representou o Tlim associado a V_{SUP}. Corredores apresentaram melhor aptidão aeróbia e consequentemente, maior V_{SUP} (22,2 km.h^{-1}) do que sujeitos ativos (20,0 ± 2,1 km.h^{-1}). Entretanto, T_{INF} não foi diferente entre grupos (Corredores 101 ± 39; Ativos: 100 ± 35 s). V_{SUP} e T_{INF} não foram bem estimados pelo modelo proposto e apresentaram altos coeficientes de variação (> 6%) e baixa correlação (r < 0,70), o que diminuiu a sua validade. Pode-se concluir que o estado de treinamento aeróbio afetou positivamente apenas a V_{SUP}. Além disso, o modelo proposto apresentou baixa validade para predição do limite superior do domínio severo (V_{SUP}) independentemente do estado de treinamento dos indivíduos.*

Palavras-chave: *Aptidão física; Corrida; Educação física e treinamento; Exercício; Consumo de oxigênio.*

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INTRODUCTION

Exercise intensities are classified into four domains based on the oxygen uptake (VO_2) response: moderate, heavy, severe, and extreme[1,2]. The moderate domain comprises all exercise intensities that can be performed without a change in blood lactate in relation to resting values, i.e., below the lactate threshold. The heavy domain comprises all intensities between the lactate threshold and critical power, which corresponds to the highest constant intensity at which maximum oxygen uptake (VO_2max) is not reached[3]. Intensities just above critical power (i.e., 5 to 10%) permit VO_2max to be reached[4,5], thereby entering the severe domain which is characterized by all exercise intensities at which VO_2max is achieved. Finally, the extreme domain comprises even higher intensities when the individual reaches the point of exhaustion even before achieving VO_2max[1,2,6].

Since the severe domain is the only intensity domain in which VO_2max is achieved during constant-load exercise, it represents an important physiological range for the prescription of high-intensity interval training[7], which is necessary to provoke additional adaptations in aerobic parameters of trained athletes[8]. Furthermore, an inverse relationship between exercise intensity and the time to achieve VO_2max (TAVO_2max) exists in this domain. In other words, the higher the exercise intensity, the lower TAVO_2max[1,9-11]. If the exercise intensity continues to be high, at a certain point, the constant intensity exercise will be so high that the individual reaches exhaustion even before VO_2max is achieved[12].

On the basis of this relationship, Hill et al.[1], using cycle ergometer exercise, proposed a mathematical model that would supposedly estimate the highest intensity at which VO_2max is achieved (I_{HIGH}). This model estimates a single time point at which the time to exhaustion (Tlim) corresponds to the exact time when VO_2max is achieved (i.e., Tlim = TAVO_2max). This time point corresponds to the shortest time necessary to achieve VO_2max during constant exercise (i.e., shortest exercise duration to achieve VO_2max, T_{LOW}). Finally, the intensity corresponding to T_{LOW} (i.e., I_{HIGH}) is estimated by the hyperbolic model of critical power[3]. Caputo and Denadai[12] subsequently demonstrated that I_{HIGH} is sensitive to aerobic training status. The authors observed that cyclists exhibited higher I_{HIGH} values in absolute terms (451 ± 33 vs. 269 ± 73 W) and relative to maximum aerobic power (130 ± 10 vs. 117 ± 6%), as well as lower T_{LOW} (117 ± 29 vs. 209 ± 29 s), when compared to untrained subjects. However, regardless of the training status of the subjects, the mathematical model proposed by Hill et al.[1] was not valid to predict T_{LOW} in the two groups. Furthermore, the validity of I_{HIGH} estimated with the model decreased with increasing aerobic training status of the subjects.

As a consequence, the mathematical model proposed by Hill et al.[1] showed poor validity in estimating the upper boundary of the severe-intensity domain during cycling[12]. The authors attributed this result to factors such as occurrence of the slow component of VO_2. Additionally, in the case of some subjects, the exercise intensities were so high and the exercise duration so short that $TAVO_2max$ estimated by VO_2 kinetics (tau x 4.6) was higher than Tlim[12]. On the other hand, some studies have shown a lower magnitude of the slow component of VO_2 in running exercise compared to cycling[13-15]. Moreover, in severe-domain exercise $TAVO_2max$ seems to be lower in running than in cycling[16]. Therefore, application of this mathematical model to running in subjects with different training levels may improve the validity of the model, since the factors that affected the validity of the model in cycling (i.e., slow component of VO_2 and $TAVO_2max$) would be minimized. Additionally, since runners and active subjects differ in terms of $TAVO_2max$ and VO_2 slow component amplitudes[2], the use of these two groups may demonstrate the importance of these factors for the capacity of the proposed model to predict V_{HIGH}. Also, the higher intensity and shorter exercise duration at which VO_2max is reached and the corresponding effects of training status on these variables have not been studied in running. This evaluation can be useful for runners who aim to improve VO_2max, since the highest velocity at which VO_2max is achieved (V_{HIGH}) would correspond to the VO_2max reached within the shortest duration of constant-load exercise. This would represent a good physiological index for training prescription designed to increase maintenance times spent close to or at VO_2max. Finally, although the determination of V_{HIGH} requires a large number of tests, consequently impairing its use during training, the value that this intensity represents of the main aerobic parameters (e.g., vVO_2max, critical velocity) can be easily used for training prescription in subjects with different levels of aerobic fitness.

Therefore, the objectives of the present study were: 1) to investigate the validity of the linear regression model of the relationship between time to exhaustion and $TAVO_2max$ in estimating T_{LOW} during running, and 2) to compare V_{HIGH} and T_{LOW} during running between runners and active subjects. On the basis of the lower magnitude of the VO_2 slow component and faster response of $TAVO_2max$ during running, the model proposed by Hill et al.[1] could be valid to predict T_{LOW} in running. Furthermore, in view of the shorter response times of VO_2 to aerobic training[2], a lower T_{LOW} and higher V_{HIGH} are expected in runners when compared to active subjects.

METHODS

Participants

Sixteen men volunteered to participate in the study and were divided into two groups: eight runners (27 ± 6 years, 67 ± 9 kg, 175 ± 8 cm) and eight active subjects (20 ± 2 years, 71 ± 3 kg, 175 ± 5 cm). The runners were 5- and 10-km specialists with a minimum experience of 2 years. The group of active subjects consisted of physical education students performing physical activity (soccer, indoor soccer, swimming, weight training) for at least 6 months, two times per week. Subjects undergoing systematic training for competitive purposes were excluded from this group. All participants were apparently healthy, non-smokers, and had no injuries. The volunteers were informed about the methodology of the study and signed a free informed consent form. The study was approved by the Ethics Committed of the State University of Santa Catarina (Universidade do Estado de Santa Catarina - Protocol No. 100/2010).

Experimental design

All subjects came to the laboratory in six to eight visits divided into three phases (Figure 1). In the first phase, body weight and height were measured, followed by an incremental test. In the second phase, three running tests until exhaustion were performed at 95%, 100% and 110% of vVO_2max for the determination of $TAVO_2max$ and critical velocity (CV). The latter corresponds to the y-axis intercept of the line derived from the linear regression of velocity on the inverse of time to exhaustion. In the third phase, 2 to 4 running tests until exhaustion were performed to determine V_{HIGH} and T_{LOW}. In all tests of the second and third phase, the test was preceded by warming up for 10 min at 50% of the velocity corresponding to the lactate threshold, followed by 5 min of rest in the sitting position prior to the test. The tests were performed on a motorized treadmill (INBRAMED Millenium Super Atl, Inbrasport, Porto Alegre, Brazil) maintained at 1% inclination.

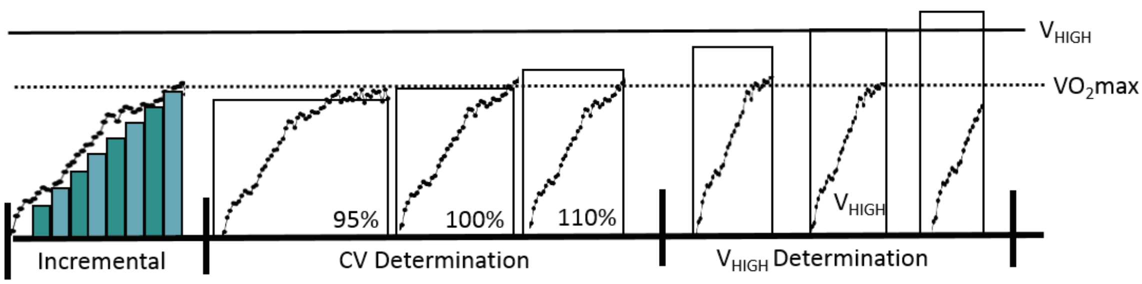

Figure 1. Schematic representation of the experimental protocol. The curves of oxygen uptake are merely illustrative. VO_2max, maximal oxygen uptake (dotted line); V_{HIGH}, highest constant velocity at which VO_2max is reached (solid line). For further details, see the Methods section.

The subjects were asked not to train exhaustively on the day prior to evaluation and to arrive at the laboratory in a fully fed and hydrated state. All procedures were carried out at the same time of day (±2 h), with an interval of 1 to 3 days between tests.

Incremental test

The initial load of the incremental test was 8 $km.h^{-1}$ for active subjects and 12 $km.h^{-1}$ for runners, with increments of 1 $km.h^{-1}$ every 3 min until voluntary exhaustion. At the end of each stage, the subjects interrupted the run for 30 seconds by holding onto the side bars of the treadmill and positioning their feet on the lateral borders to collect a 25-µl blood sample from the ear lobe for the determination of blood lactate concentrations. VO_2 was measured breath-by-breath throughout the test using a gas analyzer

(Quark PFTergo, Cosmed, Rome, Italy), previously calibrated according to manufacturer instructions. The data were reduced to means of 15 seconds and the highest value was defined as the VO_2max of the incremental test (VO_2INC), which was used to determine the subject's VO_2max. The lowest velocity at which VO_2max was achieved was defined as vVO_2max. The intensity prior to the increase of 1 $mmol.L^{-1}$ in blood lactate concentrations in relation to resting values was considered the velocity at lactate threshold[17]. Blood lactate concentrations were determined in heparinized capillary blood analyzed immediately in an electrochemical analyzer (YSI 1500 Sport, Yellow Springs, OH, USA).

Determination of critical velocity

The subjects performed three time-to-exhaustion tests at 95%, 100% or 110%vVO_2max on three different days. These intensities were selected to induce a time to exhaustion between 2 and 15 min[3]. The tests were performed in a random order, with only one test per day. In all tests, the subject was encouraged verbally to maintain effort until voluntary exhaustion. VO_2 data were obtained in each test and reduced to means of 15 seconds. The highest VO_2 of each test was determined and considered for the calculation of the subject's VO_2max (i.e., $VO_2$95%, $VO_2$100% and $VO_2$110%). For each intensity, Tlim was defined as the total exercise time. For the estimation of CV and D', the individual values of velocity and Tlim obtained were adjusted using a linear model of velocity versus the inverse of time (1/time) as follows[18]:

$$V = D' \cdot 1/Tlim + CV \qquad \text{(Equation 1)}$$

where *V* is the constant exercise velocity ($km.h^{-1}$); *Tlim* is the time to exhaustion at the respective velocity (s); *D'* is the anaerobic distance capacity (m), and *CV* is the critical velocity ($km.h^{-1}$). Two parameters were derived from the equation: CV, which corresponds to the y-axis intercept of the line, and D', which corresponds to the slope of the line in relation to the x-axis.

Predicted V_{HIGH} and T_{LOW}

Linear regression was used to individually describe the relationship between $TAVO_2max$ and Tlim. With $TAVO_2max$ expressed as a function of Tlim, it was possible to identify the single Tlim at which VO_2max could hypothetically be achieved at the time of exhaustion (predicted T_{LOW}), i.e., when $TAVO_2max$ = Tlim. V_{HIGH} was estimated with Equation 1, replacing Tlim with predicted T_{LOW} (Figure 2).

Determination of V_{HIGH} and T_{LOW}

Predicted V_{HIGH} was selected as the velocity of the first test for the determination of true V_{HIGH}. For this purpose, the subjects performed two to four constant velocity tests until exhaustion to determine V_{HIGH}. When VO_2max was achieved during the first test, the following tests were performed at a velocity that was 5% higher until VO_2max had not been achieved (as shown in Figure 1). Otherwise, if VO_2max was not reached during the first test, the following tests were performed at a 5% lower velocity[12] until VO_2max had been reached. VO_2 was measured throughout the protocol. As a criterion to achieve VO_2max, breath-by-breath data obtained in the V_{HIGH} test were analyzed as averages of 5 seconds. The mean of the three highest consecutive values (i.e., 15 s) of VO_2 in the V_{HIGH} test were defined as VO_2max of the V_{HIGH} test. This value had to be equal to or higher than VO_2max (mean of VO_2INC, $VO_295\%$, $VO_2100\%$ and $VO_2110\%$) minus 1 intrasubject standard deviation (i.e., VO_2max – 1 SD) to considered the attainment of VO_2max[12]. V_{HIGH} was considered the highest constant velocity at which VO_2max was achieved. T_{LOW} was defined as Tlim associated with V_{HIGH}.

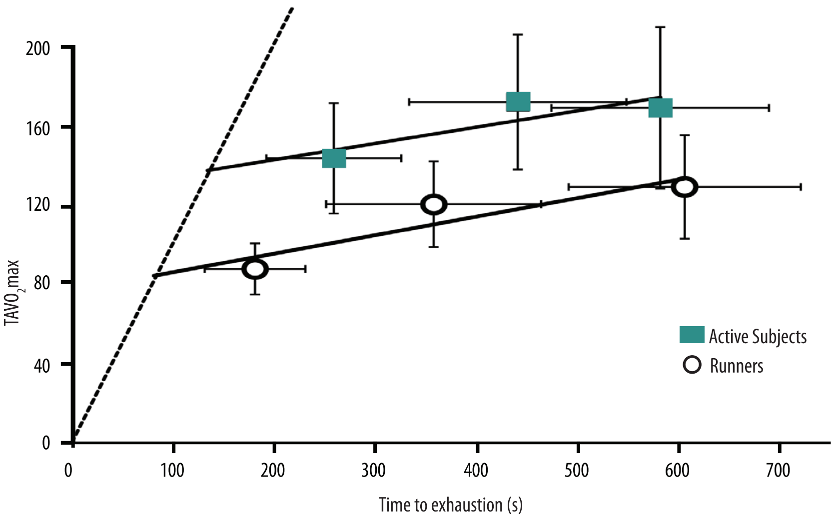

Figure 2. Relationship between time to achieve VO_2max ($TAVO_2max$) and time to exhaustion (Tlim) of tests performed at 95%, 100% and 110% vVO_2max in active subjects and runners. The estimate of the shortest duration when VO_2max is achieved (T_{LOW}) corresponds to the time when Tlim = $TAVO_2max$, i.e., the point of intersection of the trend line of regression between $TAVO_2max$ and Tlim and the identity line (dashed line).

VO_2 kinetics

For each exercise transition, breath-by breath VO_2 responses were fitted using the following equation:

$$VO_2(t) = VO_2b + A\,(1 - e^{-(t/\tau)}) \qquad \text{(Equation 2)}$$

where $VO_2(t)$ is the oxygen uptake at time t; VO_2b is the pre-exercise oxygen uptake; A is the asymptote of the amplitude, and τ is the constant time of oxygen uptake kinetics (defined as the time necessary to reach 63% of A). Occasional errant breaths were removed if they deviated more than four standard deviations from the local mean of 30 seconds[19]. For the tests at 95%, 100% and 110% vVO_2max, $TAVO_2max$ was calculated as 4.6 x τ.

Statistical analysis

The results are expressed as the mean ± standard deviation. Normality of the variables was verified by the Shapiro-Wilk test. Characterization variables were compared between groups by the Student t-test for independent samples. Two-way ANOVA with repeated measures for one factor (i.e., intensity for the analysis of $TAVO_2$max and Tlim, and method used for the analysis of V_{HIGH} and T_{LOW}) was used for all other analyses. When a significant F value was found, an appropriate Student t-test was used to detect possible differences between two variables. The validity of the proposed model was also analyzed using Pearson's correlation test and typical error expressed as the coefficient of variation[20]. Pearson's correlation test and multiple (stepwise) linear regression analysis, grouping all subjects in the same group, were used to analyze the relationship of V_{HIGH} and T_{LOW} with the variables studied. A level of significance of $P \leq 0.05$ was adopted in all analyses.

RESULTS

Incremental test and critical velocity

VO_2max, vVO_2max, CV (absolute and relative) and D' differed significantly ($P \leq 0.03$) between groups (Table 1). The mean coefficient of determination of the CV model was 0.981 ± 0.026 in the two groups.

Table 1. Characteristics of the group and critical velocity model.

	Active subjects	Runners
VO_2max (ml.min.kg^{-1})	56.2 ± 3.3	62.0 ± 5.2*
vVO_2max (km.h^{-1})	14.7 ± 0.9	18.3 ± 0.9*
CV (km.h^{-1})	12.2 ± 1.2	16.2 ± 1.1*
CV (%vVO_2max)	83 ± 5	89 ± 2*
D' (m)	301 ± 108	193 ± 57*

CV: critical velocity; D': anaerobic distance capacity. *Significant difference between groups ($P \leq 0.03$).

Responses in the constant-load tests

Analysis of variance of Tlim detected a significant F value in the factor intensity ($P < 0.001$) and in the interaction between the two factors ($P = 0.017$). Finally, pairwise comparison revealed no significant difference in Tlim at 95% vVO_2max (active: 585 ± 108 s; runners: 609 ± 115 s; $P = 0.43$) or 100% vVO_2max (active: 444 ± 108 s; runners: 360 ± 107 s; $P = 0.08$) between groups. However, Tlim at 110% vVO_2max was significantly higher ($P = 0.007$) in active subjects compared to runners (261 ± 67 versus 183 ± 50 s).

Regarding the comparison of $TAVO_2$max, ANOVA only detected a significant F value in the group ($P < 0.001$) and intensity ($P < 0.001$) factor. Pairwise comparison revealed no significant difference in $TAVO_2$max at 95% vVO_2max (active: 169 ± 41 s; runners: 129 ± 26 s) or 100 %vVO_2max (active: 173 ± 34 s; runners: 121 ± 22 s) between groups ($P > 0.2$). However, $TAVO_2$max at 110% vVO_2max was significantly lower in runners (active: 144 ± 28 s; runners: 88 ± 13 s) when compared to 95% and 100% vVO_2max ($P< 0.01$). Figure 3 illustrates the VO_2 kinetics of a representative subject of each group at each intensity.

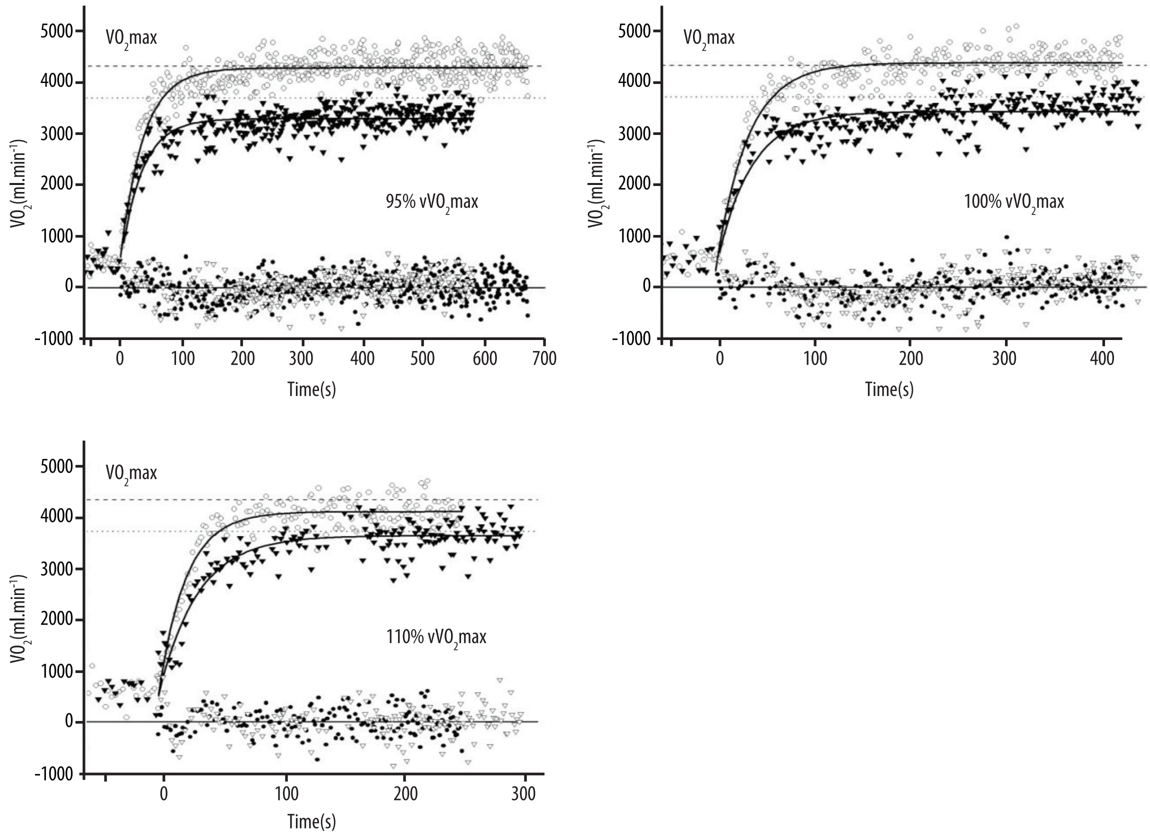

Figure 3. VO_2 responses at 95%, 100% and 110% vVO_2max obtained for a representative subjects of the group of runners (open circles) and active subjects (closed triangles). The graph includes residuals corresponding to runners (closed circles) and active subjects (open triangles) after adjusting the monoexponential function used. The dashed and dotted lines indicate the VO_2max of the active subject and runner, respectively.

Validity of the proposed model

Table 2 shows the predicted and observed (true) values of V_{HIGH} and T_{LOW} for the two groups, as well as the relative and absolute consistency of the model proposed. For absolute V_{HIGH}, ANOVA detected a significant F value in the group ($P < 0.05$) and prediction model ($P < 0.05$) factor. When V_{HIGH} was expressed as relative values, only the prediction model factor was significant ($P = 0.047$). Furthermore, the same analysis detected a significant F value in the group factor ($P \leq 0.01$) and in the interaction between factors ($P < 0.01$) for T_{LOW}.

Pairwise comparison revealed significant differences between groups for V_{HIGH} expressed as absolute values ($P = 0.046$), but no significant difference for T_{LOW} ($P = 0.97$). Moreover, a significant difference between predicted and observed values of V_{HIGH} (relative and absolute) was only observed in runners ($P < 0.01$). Finally, comparison between predicted and observed T_{LOW} showed no significant difference in either group ($P > 0.09$).

Figure 2 shows the relationship between $TAVO_2max$ and Tlim in the tests at 95%, 100% and 110% vVO_2max for the two groups. The coefficient of determination of this relationship was low in runners ($r^2 = 0.79 \pm 0.26$) and active subjects ($r^2 = 0.68 \pm 0.39$). There was no significant correlation between the observed and predicted values of any of the parameters, despite the observation of a significant trend in the correlation for V_{HIGH} in runners ($P = 0.06$). The coefficient of variation to estimate V_{HIGH} was higher in active subjects (12.5%) than in runners (6.5%). The coefficient of variation for T_{LOW} was high in both groups (> 25%).

Table 2. Observed (true) and predicted values of highest velocity (V_{HIGH}) and shortest duration (T_{LOW}) at which VO_{2max} is achieved in active subjects and runners.

		Mean ± SD		Model validity	
Variable	Group	True	Predicted	Pearson	CV (%)
V_{HIGH} (km.h^{-1})	Active	20.0 ± 2.1*	20.9 ± 3.7	0.33	12.5
	Runners	22.2 ± 1.9#	25.0 ± 2.7	0.61	6.5
V_{HIGH} (%vVO_2max)	Active	136 ± 14	142 ± 25	0.33	12.6
	Runners	122 ± 13#	137 ± 17	0.69	6.6
T_{LOW} (s)	Active	100 ± 35	131 ± 18	-0.25	26.8
	Runners	101 ± 39	83 ± 16	-0.08	33.6

CV: coefficient of variation.*Significant difference between groups ($P < 0.05$).
#Significant difference between true and predicted values ($P < 0.05$).

Relationship between variables

V_{HIGH} was significantly correlated only with vVO_2max ($r = 0.49$; $P = 0.05$). The multiple linear regression model showed that the main variables predicting V_{HIGH} are, in order of importance, vVO_2max and D'. The multiple correlation coefficient adding each variable was 0.49-0.63 ($P = 0.03$) and the equation estimated from this correlation was $V_{HIGH} = 0.9 \times vVO_2max + 0.011 \times D' + 3.528$. T_{LOW} was not correlated with any of the variables studied.

DISCUSSION

To our knowledge, this is the first study determining the highest velocity and shortest exercise duration at which maximal oxygen uptake is achieved during running and the influence of training status on these variables. One of the main results of this study was that V_{HIGH} was sensitive to training status. However, in contrast to our initial hypothesis, T_{LOW} did not differ between groups. Furthermore, the capacity of the proposed model to estimate V_{HIGH} and T_{LOW} was poor.

Prediction model of V_{HIGH} and T_{LOW}

In the present study, V_{HIGH} corresponded to 136 ± 14% of vVO_2max in active subjects, the same relationship estimated by Hill et al.[1] with a mathematical model in active subjects during cycling (i.e., 136% of maximal aerobic power). However, this similarity must have occurred by chance considering the differences in the exercise mode used. In view of this difference, we applied the model proposed by Hill et al.[1] to estimate V_{HIGH} and T_{LOW}. This model is based on a strong linear relationship between TAVO_2max and Tlim, which was not strong in the present study, with a mean coefficient of determination of 0.68 ± 0.39 and 0.79 ± 0.26 for active subjects and runners, respectively. As a consequence, the model was also inefficient in estimating V_{HIGH}, probably because the estimate of V_{HIGH} obtained with the CV model depends on T_{LOW} estimated by the relationship between TAVO_2max and Tlim.

Some limitations of the present study regarding the estimation of V_{HIGH} and T_{LOW} should be taken into consideration. First, the model proposed is based on a strong linear relationship between $TAVO_2max$ and Tlim[1]. However, in each group, $TAVO_2max$ was significantly lower only at the intensity of 110% vVO_2max compared to the other intensities (95% and 100% vVO_2max). It is important to note that the extent of $TAVO_2max$ was probably affected by the use of only one transition at each intensity[24]. This fact impairs the comparison of small changes in VO_2 kinetics during running exercises across the severe-intensity domain, i.e., those that already exhibited rapid VO_2 kinetics[25]. Therefore, using only one transition, the relationship between $TAVO_2max$ and Tlim was compromised in the two groups studied and was apparently not linear, reducing the efficacy of the model to mathematically estimate T_{LOW}. However, only one transition was conducted for all evaluations due to the high requirements of the tests, large number of laboratory visits and low availability of the group of runners. Finally, the small number of subjects may reduce the power of the statistical test used by causing type II errors. However, despite the small number of subjects, the present study detected failures arising from this model and these failures would probably persist even if a larger number of subjects were included.

Effects of training status

The results of VO_2max, vVO_2max and CV obtained for the runners studied were similar to those reported in the literature for moderately trained athletes[21]. Furthermore, the aerobic fitness of active subjects was lower than that of runners, with the observation of lower aerobic indices and higher $TAVO_2max$ at all intensities tested. However, active subjects exhibited a higher D', i.e., the characteristic of withstanding intensities above CV for a longer period of time[22]. This fact was demonstrated by the higher Tlim at the intensity of 110% vVO_2max in active subjects compared to runners.

As observed for other aerobic indices evaluated in the present study, V_{HIGH} was higher in runners and was consequently found to be sensitive to training status. Additionally, this parameter was correlated with vVO_2max, indicating that V_{HIGH} is an important aerobic index. However, multiple regression analysis suggests that V_{HIGH} is influenced by both vVO_2max and D'. This suggestion is in accordance with the study of Billat et al.[10] in which only subjects possessing higher D' values achieved VO_2max at 140% vVO_2max. However, it should be noted that vVO_2max was the main variable in multiple regression analysis, a finding corroborated by studies in which this threshold responded positively to aerobic training[6,12].

In contrast to V_{HIGH}, T_{LOW} was similar in the runners and active subjects studied here. This result disagrees with Caputo and Denadai[12] who found a lower T_{LOW} in trained athletes due to aerobic adaptations that were responsible for a rapid VO_2 kinetic response[2]. In fact, a lower $TAVO_2max$ in athletes was also observed in the present study. This finding might be due to the fact that active subjects were able to withstand intensities above the CV (i.e., higher D') for a longer period of time, resulting in the same Tlim at different relative intensities in the two groups (i.e., active subjects at a higher relative intensity than athletes). As a consequence, it is likely that the two groups studied present a similar $TAVO_2$max for the same Tlim in supramaximal exercises, since an increase in relative intensity reduces $TAVO_2$max[1,9-11]. These factors may explain in part the lack of a difference in T_{LOW} between groups.

In addition to the lack of difference in T_{LOW} between groups (active subjects: 100 ± 35 s; runners: 101 ± 39 s), the T_{LOW} values obtained here are lower than those reported by Caputo and Denadai[12] for cycling exercise (active subjects: 209 ± 29 s; runners: 117 ± 29 s). VO_2 kinetic responses in the severe domain have been shown to be faster in running when compared to cycling[15, 23]. Furthermore, when the same relative intensities are compared, cyclists showed a higher Tlim during cycling than runners during running[16], which could explain the apparent differences in T_{LOW} between studies. Finally, despite lower aerobic fitness compared to runners, the active subjects studied here exhibited good aerobic conditioning, as demonstrated by the fact that their VO_2max (56.2 ± 3.3 $ml.min.kg^{-1}$) was similar to that of long-distance runners during cycling (54.6 ± 5.5 $ml.min.kg^{-1}$) and higher than that of untrained subjects (42.9 ± 3.5 $ml.min.kg^{-1}$) in the study of Caputo and Denadai[12]. Taken together, these factors seem to contribute to an apparent lower T_{LOW} in running compared to cycling.

CONCLUSION

The present study showed that the highest velocity at which VO_2max is achieved responds positively to aerobic training. However, on the basis of the multiple regression model used, training strategies designed to improve D' may also be important for improvement of V_{HIGH}. Finally, researchers and coaches should not rely on the mathematical estimation of V_{HIGH} and T_{LOW}, since the model proposed appeared not to be valid in running.

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