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Prediction of vo_2 max in healthy non-athlete men based on ventilatory threshold

Predicción de vo_2 max en hombres sanos no atletas basado en umbral de ventilatorio

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Abstract. The VO2max measures provide efficiency in exercise prescription, due to a precise evaluation of one's physical conditioning level. The aim of the present study was to develop and validate a VO_2max prediction model based on ventilatory threshold indicators on maximal effort test in healthy non-athlete male. Accordingly, 3.147 healthy non-athlete male aged 20 and older volunteered to be tested on a cycle ergometer using a maximum incremental protocol. The subjects were randomly assigned into 2 groups: group A (estimation) and group B (validation). The independent variables were: weight in kilograms (weight), second workload threshold (WT2), and heart rate of the second threshold (HRT2). The cross-validation method was used in group B with group A serving as the basis for building the model and the validation dataset. The results presented a multiple linear regression model to predict VO_2max (VO_2max = 39.027 – 0.405 (weight) – 0.002 (HRT2) + 0.189 (WT2) in ml O_2/kg/min^{-1}; r = 0.995 and SEE = 0.96 mlO_2/Kg/ min^{-1}). The construction of this model allows to demonstrate that it is possible to predict VO2max with a minimum error (SEE = 1.00%) from ventilatory threshold indicators obtained in an incremental test, in healthy non-athlete male.
Keywords: Ventilatory threshold; VO2 max; submaximal test, exercise prescription, heart rate.

Resumen. Las medidas de VO2máx proporcionan eficiencia en la prescripción de ejercicio, debido a una evaluación precisa del nivel de acondicionamiento físico de un individuo. El objetivo del presente estudio fue desarrollar y validar un modelo de predicción de VO2máx basado en indicadores de umbral ventilatorio en la prueba de esfuerzo máximo en hombres sanos no atletas. En consecuencia, 3.147 hombres sanos, no atletas de 20 años o más se ofrecieron voluntariamente para hacerse la prueba en un cicloergómetro usando un protocolo incremental máximo. Los sujetos fueron asignados aleatoriamente en 2 grupos: grupo A (estimación) y grupo B (validación). Las variables independientes fueron: peso en kilogramos (peso), el segundo umbral de carga de trabajo (WT2) y la frecuencia cardíaca del segundo umbral (HRT2). El método de validación cruzada se utilizó en el grupo B y el grupo A sirvió para construir el modelo y el conjunto de datos de validación. Los resultados presentaron un modelo de regresión lineal múltiple para predecir VO2max (VO2max = 39.027 - 0.405 (peso) - 0.002 (HRT2) + 0.189 (WT2) en ml de O2 / kg / min-1; r = 0.995 y SEE = 0.96 mlO2 / Kg / min-1). La construcción de este modelo permite demostrar que es posible predecir el VO2max con un error mínimo (SEE = 1.00%) a partir de los indicadores de umbral ventilatorio obtenidos en una prueba incremental, en hombres sanos que no son atletas.
Palabras clave: umbral ventilatorio; VO2 max; prueba submáxima, prescripción de ejercicio, frecuencia cardíaca.

Introduction

The measure tests standardizations for physiological variables and their individual responses analysis during training activities allow establishing, within control pattern, the maximal oxygen consumption (VO2max). This variable may be presented as an important physical conditioning and physiological adaptation indicator for different types of training (Schnohr, O'Keefe, Marott, Lange & Jensen, 2015).

The VO2máx measures provide efficiency in exercise prescription, due to a precise evaluation of the physical conditioning level of an individual (Pires, Lima-Silva & Oliveira, 2005). However, the training ability also depends on submaximal intensities related to VO2max percentile applied to exercise (Lamberts, Swart, Noakes & Lambert, 2011). This relation may be influenced by hemodynamic, metabolic and pulmonary responses during exercises, which can be used as physical conditioning evaluation and physical training prescription (Raviv & Netz, 2007). The specificities in pulmonary and metabolic adjustments of the aerobic training may be represented by the ventilatory threshold (VT) variation (Nunes et al., 2009).

The ventilatory threshold consists on a particularly striking phenomena on metabolic response to exercise with a progressive higher intensity, which is the modification event, relatively abrupt, between the ventilatory increment and the oxygen consumption relation (Brown, 2012). In general, it is possible to identify 2 metabolic transition zones, called first and second ventilatory thresholds (VT1 and VT2) (Tanaka & Swensen, 1998). In this way, the oxygen consumption (VO2) in exercise peak and VT are the reference indicators for measuring pulmonary aptitude (Mourot, Perrey, Tordi & Rouillon, 2004).

VO2max has been related to human performance and productivity (Davis, Storer, Caiozzo & Pham, 2002). However, the physical or psychological stress suffered by an individual during a maximal test, may be a determinant factor for inconsistent results, in addition, it may represent risk for sedentary, elderly and people with cardiovascular disease. In this way, the possibility to predict VO2max based on mathematical equations represents a safe and reliable option.

New submaximal protocols have been tested to predict VO2max based on ventilatory threshold identification. However, the studies found different results, some presented high correlation between estimated and observed (Storer, Davis & Caiozzo, 1990; Nunes et al., 2009; Lamberts et al., 2011), or low correlation (Akalan, Robergs & Kravitz, 2008), and even strong correlation using complex operational methodologies (Mauger & Sculthorpe, 2011). Studies with a small sample may have influence in those different results.

Thus, developing an equation model based on a submaximal protocol capable of presenting a high number of validations between estimated and predicted, with a simple methodology, for individuals with different ages, can be considered relevant and justifiable. The aim of the present study was to develop an equation model for VO2max prediction in healthy non-athlete men with different ages based on ventilatory threshold on cycle ergometer.

Material and Method

Subjects

The sample was composed of 3147 male individuals. To be included, candidates were required to undergo a clinical examination, performed by a sports medicine specialized doctor, consisting of the determination of risk factors and exclusion criteria; physical examination with cardiac evaluation, pulmonary examination, and the measure of resting HR; and measurement of resting blood pressure and analysis of resting electrocardiogram. The inclusion criteria were healthy, non athlete male, 20 years of age or older. The exclusion criteria were men with cardiovascular, pulmonary, or endocrine-metabolic diseases, those with muscular-skeletal anomalies, and those who used performance altering medication, or were unable to adapt to the ergometer. Thus, the subjects were apparently healthy and were familiar to exercise.

Prior to the test, each participant was informed verbally and in writing about the test´s procedures, risks and benefits. Next,

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anthropometric values of weight and height were recorded in accordance with the International Society for the Advancement of Kineanthropometry (ISAK) guidelines (Marfell-Jones, Stewart & Ridder, 2012). Each individual remained standing and barefoot on the digital scale (Welmy, Sta. Bárbara, Brazil), dressing only swimwear and keeping as motionless as possible. The scale cursor was moved manually until equilibrium was reached. Weight was recorded in kilograms (to the nearest 100 g). Height was measured during breath holding after a deep inspiration (to the nearest 0.1 cm), with the distance between the sole of the feet and the highest point on the head (vertex) observed.

Subjects were divided into the following age groups: 20 to 29, 30 to 39, 40 to 49, 50 to 59, 60 to 69, and over 70 years (table 1). The participants were randomly subdivided into two groups, group A (estimation) with n = 2360 (age: 36.84±11.12 years; height: 1.77±0.06 m; weight: 74.95±7.69 kg; BMI: 23.88±2.47) and group B (validation) with n = 787 (age: 33.21±11.22 years; height: 1.78±0.07 m; weight: 75.39±7.86 kg; BMI: 23.64±2.45).

Those who agreed to participate signed an informed consent form in accordance with the guidelines regarding human research delineated in the Helsinki Declaration. The local ethics committee of the university approved this study, which complied with international standards. The preparation guidelines for the effort test were then presented: on the day prior to testing, ensure to get a full night sleep and not to engage in any high intensity physical activities. On the day of evaluation subjects were told not to consume food or caffeine for 2 hours prior to testing.

Table 1:
Sample characteristics divided by age group for estimation (A) and validation (B)

Age group (years)	Group	n	Age (years)	Weight (kg)	Height (m)	BMI (kg/m²)
20-29	A	676	27.72±2.41	70.20±6.88	1.78±0.06	22.46±1.68
	B	226	24.37±2.32	70.50±6.59	1.78±0.06	22.22±1.58
30-39	A	849	36.39±2.99	73.60±6.63	1.78±0.06	23.85±1.83
	B	282	32.17±1.73	74.50±7.32	1.78±0.06	23.57±1.69
40-49	A	519	45.50±3.00	74.40±7.90	1.80±0.10	24.70±2.20
	B	171	41.79±1.17	73.60±8.64	1.76±0.07	24.68±2.14
50-59	A	194	54.96±2.63	78.80±8.91	1.75±0.08	26.09±2.84
	B	66	52.81±1.15	82.65±7.96	1.69±0.08	27.04±2.96
60-69	A	85	66.05±2.94	80.50±8.66	1.72±0.08	26.93±3.38
	B	30	61.88±0.99	77.30±7.23	1.77±0.07	25.93±2.29
70-78	A	32	74.37±3.55	78.80±7.67	1.68±0.07	28.47±3.72
	B	12	72.98±2.87	75.05±8.75	1.75±0.05	24.38±2.70

*Values expressed as mean and standard deviation; n= sample size; BMI= body mass index.

Procedures

Subjects were evaluated at the ergometer cycle from january of 2012 until december of 2015. Electrocardiogram tracing (ELITE software, Micromed Biotechnology, Brasilia, Brazil) was used to determine heart rate at the second ventilatory threshold (HRT2) and maximum heart rate (HRmax) at the end of the ergometric test. At the point of greatest intensity, maximum load (Wmax) and VO2max were defined.

Reliability for the ergometric test was shown with the use of this protocol. Thirty subjects of the sample, selected randomly, were tested on two separate occasions, with 48 hours difference, and showed an intraclass coefficient of 0.92. A paired-samples t-test was performed and did not demonstrate any significant difference ($p < 0.05$)

For the ergometric test, a continuous incremental protocol on a cycle ergometer (Model EC -1600, Cateye Ergociser, Osaka, Japan) was applied, with a cadence of 60 rpm (Nunes et al., 2009). The subjects completed a 2-minutes warm-up. During the first minute they pedaled without a load so that they could adapt to the ergometer, during the second minute they pedaled with a 0.5 kg.m load. After the second minute, the test began with 1.0kg.m load and increased in 0.2 kg.m/min until voluntary exhaustion was reached. Therefore, initial load in the first minute was 48 W (60 rpm x 1.0kg.m), 12 W/min increments were continuously added until maximal effort.

Exhaled gases were measured continuously by an Aerosport VO2000 analyzer (Medgraphics, St. Paul, MN), in which the gas samples were collected and measured every 10 seconds during the test. The analysis was conducted using oxygen and carbon dioxide detectors. The respiratory exchange ratio, volume of oxygen consumed per minute (VO2), and volume of carbon dioxide produced per minute (VCO2) were standardized and calculated directly by the device. Prior to each evaluation, the calibration settings of the equipment were inspected. The V-slope method was used to determine the VT2 by visually inspecting the second break in linearity of the VE curve or the point of continuous rise of the curve after the linearity break in VE/VCO2 (Malek et al., 2004).

Statistical analysis

The data, presented as means and standard deviations, was analyzed using SPSS Statistics 20 for Windows. The Kolmogorov-Smirnov test was used to verify the normal distribution curve. Multiple linear regression was used to develop an equation model for VO2max prediction. A minimum coefficient of determination R2 of 0.80 was adopted as the cut-off criterion of the independent variables in the model construction. Pearson's correlation coefficient (r) was used to analyze the relationship between observed and predicted VO2max. The regression model reliability was measured by the standard error of estimate (SEE), expressed in mlO2/Kg/min-1.

The forward stepwise method was used to construct the mathematical prediction model in terms of selecting the predictor variables for the model. The cross-validation method was followed, using group A as the basis for constructing the model and group B as its validation dataset. The significance level was set at $p<0.05$.

Results

The significance levels of the identified variables of the test were examined using multiple linear regressions with the *forwardstepwise* method.

Table 2 presents the equation models for the variables selection criteria, for each of the three models, a determination coefficient (R2) higher than 0.80 was obtained.

Table 2:
Equation models selected in sample.

MODEL	R	R^2	R^2 Adjusted	SEE (ml.kg.min^{-1})
VO_2max = 7.778 + 0.194 (WT2)	0.938	0.88	0.88	± 3.21616
VO_2max = 38.445 - 0.4 (Weight) + 0.189 (WT2)	0.995	0.98	0.98	± 0.96553
VO_2max = 39.027 – 0.405 (Weight) – 0.002 (HRT2) + 0.189 (WT2)	0.995	0.98	0.98	± 0.96135

Variables, VO2max – Maximum oxygen consumption, HRT2 – heart rate second threshold, WT2 – weight at the second workload threshold

In choosing the equation model that best fit the data in this study, two rules were adopted: 1ª rule – higher adjusted R2 and; 2ª rule – lower standard error of estimate (SEE). Thus, the model that would best meet these requirements may be expressed in the following equation.

VO2max = 39.027 – 0.405 (Weight) – 0.002 (HRT2) + 0.189 (WT2),
With an SEE ± 0.96135 ml.kg.min-1.

After choosing the model, the estimated VO2max was evaluated in both groups. The observed and estimated VO2max results in both the estimation (A) and validation (B) groups presented similar distribution with similar median value (figure 1).

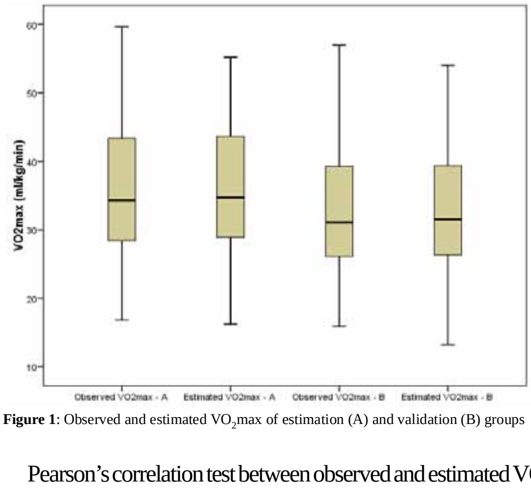

Figure 1: Observed and estimated VO_2max of estimation (A) and validation (B) groups

Pearson's correlation test between observed and estimated VO2max in the estimation (A) and validation (B) groups resulted in a high significant correlation coefficient ($p<0.001$) (table 3).

Table 3:
Cross validation of equation model for VO_2max estimation

Group	VO_2max Observed (ml/kg/min)	VO_2max Estimated (ml/kg/min)	Difference	R
A	32.52±9.28	32.56±9.23	-0.043±0.961	0.995
B	33.09±9.37	33.14±9.28	-0.050±0.980	0.994

A = estimation group; B = validation group; p<0.05.

The combination of the observed and estimated VO2max results in the validation group (B) showed symmetry between the average values. This result illustrates the magnitude of the collinear relationship between the two sample groups (figure 2).

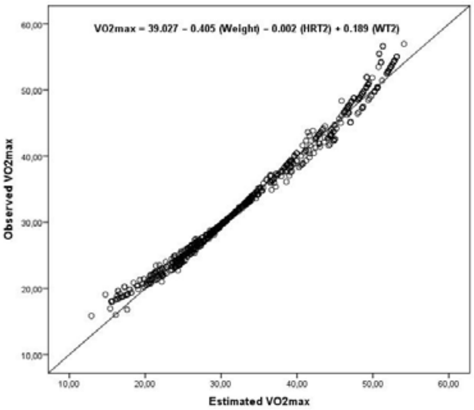

Figure 2: Linear regression between observed and estimated VO_2max in validation group (B)

Discussion

The idea of obtaining VO_2max from submaximal effort with the objective of preserving subject integrity and minimize any risk during the test is not new, however the presentation of the results in order to achieve possible solutions to this problem have been suffering transformations due to scientific and technological advances (Mauger and Sculthorpe, 2011). Between the used ergometers to develop VO_2max prediction models, the cycle ergometer is still the most used in number of models and protocols, and test and rest Heart Rate (HR), workload and time are the most used variables for developing submaximal protocol tests (Lamberts et al., 2011).

Kasch (1984) using HR variable, found a correlation between observed and estimated VO_2max of 0.63 (p<0.001). In another study, Fox (1973) developed a protocol for young males reaching an r = 0.83, SEE = 0.246 $l.min^{-1}$ (p<0.001), while Hartung, Blancq, Lally & Krock (1995), using a similar methodology to the present study, but for females ages between 19 and 47, found an r = 0.76, SEE = 0.295 $l.min^{-1}$ (p <0.001). In both mentioned studies the values were lower than the results of the present study.

Other investigations realized experiments in which the respiratory equivalents were not considered (Kasch, 1989; Fox, 1973; Hartung et al., 1995; Hendriksen, Zuiderveld, Kemper & Bezemer, 2000; Mookerjee et al., 2005; George, Bradshaw, Hyde, Vehrs, Hager & Yanowitz, 2007; Vainionpää, Korpelainen, Kaikkonen, Knip, Leppäluoto & Jämsä, 2007). Those are important variables for a most precise VO2max prediction during submaximal effort.

However, the present study used ventilatory variables to compose a VO_2 max prediction model, achieving more significant and robust results than studies that were based only in the HR variable, as the ones from Nogueira and Pompeu (2006) with scaled protocol (25 W/min) in young males (r = 0.73 and R^2 = 0.54). Besides the indicated variables from ventilator threshold (HRT2 and WT2), the present study also used the weight variable, finding correlations of r = 0.99, R^2 = 0.98 and SEE = 0.96 $ml.kg.min^{-1}$. This may be corroborated by Nunes et al. (2009), that, using the same variables with a female sample (n= 4640), in a large age group (20 to 70 years old), obtained a correlation of r = 0.98, R^2 = 0.99 and SEE = 0.68 $ml.kg.min^{-1}$.

The influence of the weight variable in VO_2max prediction in cycle ergometer is applied to the simple task of moving pedals. However, the higher weight, mainly in lower limbs, higher is the efficiency for workload (W). Reducing the HR to the same load, consequently the absolute VO_2 max is overestimated (lO_2/min^{-1}) (Nunes et al., 2009).

Storer et al. (1990) study was the cycle ergometer ramp protocol precursor, using a gradual load protocol which benefits the found results. Authors accomplished tests in 115 male volunteers, using variables such as: maximal workload (Wmáx), weight (weight) and age (age) for a protocol with 15 W/min increase and obtained r = 0.939 and SEE = 212.0 for the equation: [(10.51 x W) + (6.35 x MC) – (10.49 x ID) + 519.3] / MC. These results corroborate with the present study findings that considered HRT2 in the adopted protocol model with a higher sample size and a lower SEE.

Akalan et al. (2008) used the reserve HR (HRr) and the effort load in cycle ergometer and obtained significant results (R^2 = 0.867 and SEE = 4.23 $ml.kg.mim^{-1}$), although still lower when compared to the present study results (R^2 = 0.98 and SEE = 0.96 $ml.kg.min^{-1}$). Another important consideration is the operational complexity of the test developed by Akalan et al. (2008), due to its methodology which requires the execution of 3 submaximal tests, making large scale application difficult. That hardness was not present in this investigation, which shows that the protocol and validated model present an easy application methodology.

Mauger and Sculthorpe (2011) proposed a new protocol, also considered of easy operational applicability, based on load self adjustment. The Self paced VO_2max test has five stages of two minutes using Borg scale (6 a 20) in a 10 minutes test. Although authors did not had significant results for justifying the protocol found low correlation for VO_2max prediction. On the opposite side, the present study findings demonstrate a high correlation between observed and estimated VO_2 max. Such different results may be justified by the fact that authors have used a protocol based on effort subjective analysis while the present study used a cycle ergometer and also verified threshold through ergospirometry. It is worth to reinforce that Mauger and Sculthorpe (2011) study used a 16 subject's sample size, far beyond the current study where 3.147 were evaluated.

Lamberts et al. (2011) verified the reliability and the predictive values of performance parameters, using a submaximal protocol. The sample presented significant results for both variables (r = 0.89 and r = 0.94), which reinforces the current study results, despite the limited age group composed only by well trained young cyclists, differently of the present investigation that used a large age group.

Siconolfi, Cullinane, Carleton & Thompson (1982) observed equation models for VO_2 max prediction, which produce higher correlation indexes with a higher operational practice, are those who apply load (W) and heart rate (HR) variables in rest and workload. The current study also selected both variables in the model, making the magnitude of the found results higher.

Conclusion

The current study proposition enables results with a significant correlation coefficient between observed and estimated VO2 max. That Indicates the equation model provide precise estimations of VO2 max, without taking individual to maximal effort. It is possible to asset the use of this protocol in cycle ergometers, with 12 W/min increments, allowing determine VO2max with lower risk and discomfort for the evaluated individuals. Another important factor is that this protocol may be used in any lower limbs cycle ergometer which allows to access pedals rotations per minute and braking load. This allows this protocol to be applied in large scale. In addition, the equation model enables higher protocol accuracy, making this procedure of easy operability and immediate application.

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