A Prediction Equation for the Estimation of Cardiorespiratory Fitness Using an Elliptical Motion Trainer

GA Brown[1], RD Krueger[1], CM Cook[1], KA Heelan[1], BS Shaw[2], I Shaw[3]

ABSTRACT

Objective: *In the United States of America, 6.2 million individuals are using elliptical motion trainers in fitness centres. However, graded exercise test protocols to estimate peak oxygen consumption ($\dot{V}O_{2peak}$) using elliptical motion trainers have not been developed for the general population.*

Methods: *Fifty-nine subjects (mean age: 23.5 ± 4.1 years) were randomly divided into a validation (VAL: n = 39) or cross-validation (XVAL: n = 20) group. Peak oxygen consumption ($ml \cdot kg^{-1} \cdot min^{-1}$) was measured via indirect calorimetry on an elliptical motion trainer for both groups. Subjects exercised at 150 strides·min^{-1} against a resistance of four and a crossramp of 8%. The resistance was increased every two minutes by two units until exhaustion. For the VAL group, a stepwise regression analysis was used to predict VO_{2peak} from resistance, maximal heart rate (HR_{max}), body mass index (BMI), height and gender (female = 0, male = 1).*

Results: *The prediction equation derived from this study was $\dot{V}O_{2peak}$ ($ml \cdot kg^{-1}.min^{-1}$) = 187.39403 + 12.97271 (gender) - 1.45311 (height) - 1.21604 (BMI) - 0.19613 (HR_{max}) + 1.57093 (resistance) (R^2 = 0.76, SEE = 4.47, $p < 0.05$). Using this equation, the predicted VO_{2peak} of the XVAL group was 45.18 ± 6.42 $ml \cdot kg^{-1} \cdot min^{-1}$, while the measured VO_{2peak} was 43.55 ± 6.23 $ml \cdot kg^{-1} \cdot min^{-1}$*

Conclusion: *No significant difference was found between the measured and predicted $\dot{V}O_{2peak}$ in the XVAL group. Therefore, it appears this protocol and equation will allow individuals to accurately estimate their VO_{2peak} without using direct calorimetry. However, future studies should investigate the validity of this protocol with diverse populations.*

Keywords: Elliptical motion trainer, exercise, oxygen consumption, prediction equation

Una Ecuación de Predicción para la Evaluación de la Capacidad Cardiorespiratoria con un Entrenador de Movimiento Elíptico

GA Brown[1], RD Krueger[1], CM Cook[1], KA Heelan[1], BS Shaw[2], I Shaw[3]

RESUMEN

Objetivo: *En los Estados Unidos de América, 6.2 millones de personas están utilizando actualmente entrenadores de movimiento elíptico en los gimnasios. Sin embargo, no se han desarrollado protocolos de pruebas de ejercicios graduados para la población general, con el fin de calcular el consumo máximo de oxígeno ($VO_{2máx}$) usando entrenadores elípticos.*

Métodos: *Cincuenta y nueve sujetos (edad media: 23.5 ± 4.1 años) fueron divididos aleatoriamente en un grupo de validación (VAL: n = 39) y un grupo de validación cruzada (XVAL: n = 20) respectivamente. El consumo de oxígeno máximo ($ml \times kg^{-1} \times min^{-1}$) se midió mediante calorimetría indirecta en un entrenador de movimiento elíptico para ambos grupos. Los sujetos ejercitaron 150 pasos por minuto frente a una resistencia de cuatro y una rampa cruz de 8%. La resistencia fue aumentada cada dos minutos en dos unidades hasta la extenuación. Para el grupo VAL, se utilizó un análisis de regresión paso a paso para predecir el $VO_{2máx}$ de la resistencia, la frecuencia cardíaca máxima ($FC_{máx}$), el índice de masa corporal (IMC), la altura y el género (mujer = 0, hombre = 1).*

From: [1]University of Nebraska at Kearney, Human Performance Laboratory, HPERLS Department, Kearney, Nebraska, United States of America, [2]Department of Sport and Movement Studies, University of Johannesburg, Republic of South Africa and [3]Office of the Deputy Pro Vice-Chancellor: Research, Monash South Africa, Ruimsig, Republic of South Africa.

Correspondence: Professor BS Shaw, Department of Sport and Movement Studies, University of Johannesburg, PO Box 524, Auckland Park, 2006, Republic of South Africa. E-mail:shawbs@tut.ac.za

Resultados: *La ecuación de predicción derivada de este estudio fue $VO_{2máx}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) = 187.39403 + 12.97271 (sexo) – 1.45311 (altura) - 1.21604 (IMC) - 0.19613 ($FC_{máx}$) + 1.57093 (resistencia) [R2 = 0.76, SEE = 4.47,* $p < 0.05$*]. Usando esta ecuación, la predicción en $VO_{2máx}$ para el grupo XVAL fue 45.18 ± 6.42 $ml \cdot kg^{-1} \cdot min^{-1}$, mientras que la medición de $VO_{2máx}$ fue 43.55 ± 6.23 $ml \cdot kg^{-1} \times min^{-1}$.*
Conclusión: *No se hallaron diferencias significativas entre los valores de la medición y la predicción de $VO_{2máx}$ en el grupo XVAL. Por lo tanto, se evidencia que este protocolo y esta ecuación permitirán a las personas calcular con precisión su $\dot{V}O_{2máx}$ sin utilizar calorimetría directa. Sin embargo, los estudios futuros deben investigar la validez de este protocolo con distintas poblaciones.*

Palabras claves: Entrenador de movimiento elíptico, ejercicio, consumo de oxígeno, ecuación de predicción, consumo de oxígeno máximo

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INTRODUCTION

In clinical and research settings, cardiorespiratory fitness, peak oxygen consumption ($\dot{V}O_{2peak}$), is typically measured *via* indirect calorimetry with a graded exercise test protocol and is considered the single best indicator of cardiorespiratory fitness (1). An increase in $\dot{V}O_{2peak}$ and physical activity helps prevent the onset of coronary heart disease, stroke, hypertension and certain types of cancers (2). Due to the expense of equipment and the need for trained clinicians, the use of indirect calorimetry has been limited to the measurement of VO_{2peak} (1). The limitations of indirect calorimetry for cardiorespiratory fitness measurements have resulted in the development of sub-maximal and maximal graded exercise test protocols that utilize walking (3), running (4), and cycling (5), to estimate $\dot{V}O_{2peak}$ from prediction equations. In non-laboratory settings and in large groups, prediction equations are helpful in estimating VO_{2peak} for quantifying cardiorespiratory fitness and Astrand *et al (*1) have indicated that prediction equations are acceptable and valid predictors of $\dot{V}O_{2peak}$.

When quantifying $\dot{V}O_{2peak}$ for the purpose of designing an exercise prescription, the mode of the exercise test should be similar to the exercise-training mode and a maximal effort protocol should be selected for best results (6). The most commonly used protocols for maximal graded exercise testing in non-medical settings are the treadmill Bruce protocol (7) and the Astrand cycle ergometer protocol (8). However, 6.2 million individuals are using elliptical motion trainers in fitness centres all over the United States of America [USA] (9). Elliptical motion trainers have a fluid, low-impact motion, which is ideal for individuals with back, hip, knee, and joint problems and are less expensive than buying a treadmill (10, 11). However, graded exercise test protocols to estimate $\dot{V}O_{2peak}$ using an elliptical motion trainer have not been developed for the general population. Therefore, the purpose of the current study was to develop a maximal effort graded exercise test protocol and prediction equation to estimate using a Precor elliptical motion trainer (EFX 546, Precor, Woodinville, WA, USA) in order to develop an alternative and less expensive testing mode to reduce the impact associated with a treadmill. Further, the development of graded exercise test protocols to estimate VO_{2peak} using an elliptical motion trainer for the general population could assist in the design of exercise programmes for the many individuals exercising using elliptical motion trainers.

SUBJECTS AND METHODS

Fifty-nine subjects (males: n = 29, females: n = 30) aged 19–24 years participated in this study. Health histories were obtained for each subject prior to acceptance into the programme. Subjects with known metabolic or health condition(s) such as diabetes mellitus, heart complications, and orthopaedic limitations and injuries were excluded from participation. In addition, subjects taking medications or supplements that could affect physical performance or metabolism (*ie* cardiac drugs, thyroid drugs, thermogenics, *etc*), pregnant females and subjects that smoked or used tobacco products were excluded. The study was approved by the Institutional Review Board of the University of Nebraska at Kearney. All subjects read and signed an informed consent.

Body mass and height were measured using a digital platform scale (PS6600, Befour Inc, Saukville, WI) to the nearest 0.05 kilograms and a standard height stadiometer (Model 115, Seca, Hamburg, Germany) to the nearest 1.27 centimetres (0.5 inches). Measures were obtained with the subjects dressed in minimal clothing and without shoes. Body mass index (BMI) was calculated by dividing the students' body weight in kilograms by height in metres squared (12). Cardiorespiratory fitness ($\dot{V}O_{2peak}$) was assessed for all subjects on the elliptical runner using a protocol developed by the investigators. After familiarization with the elliptical motion trainer, subjects were asked to run on the elliptical motion trainer sustaining 150 strides per minute ($strides \cdot min^{-1}$) with an 8% crossramp and with the resistance set at four units. Resistance was increased by two units every two minutes throughout the graded exercise test until maximal exhaustion occurred and exercise continuation was not possible. This elliptical motion trainer graded exercise test protocol was previously validated against a traditional treadmill graded exercise test protocol among

eighteen male (n = 9) and female (n = 9) subjects aged 19 to 24 years. Results of this study suggested that the elliptical motion trainer protocol was a valid protocol in assessing VO_{2peak} in this age group (r = 0.90, $p < 0.05$).

During the elliptical motion trainer graded exercise test protocol, the amount of oxygen and carbon dioxide in the expired air was analysed at 20-second intervals using a Sensor Medics 2900 metabolic cart (2900, Sensor Medics, Yorba Linda, California), calibrated before each test. A portable Polar heart rate monitor (E600, Polar Electro Inc., Woodbury, NY) was used to collect heart rate measurements in two-minute increments. A 15-point (6–20) Borg rating of perceived exertion (RPE) scale was administered every two minutes (13). Workload was increased every two minutes until maximal exhaustion, as determined by the subject. Three of four physiological markers were required: (i) maximal heart rate (HR_{max}) had to be within 10 beats per minute of age predicted maximum heart rate, calculated as 220-age; (ii) maximal respiratory exchange ratio of equal to or greater than 1.10; (iii) maximal oxygen consumption plateau within 200 millilitres (ml) in the last minute of exercise and (iv) RPE was equal to or greater than 18. If three out of the four above criteria were not met, the subject was asked to repeat the test on a separate day.

All data analysis was conducted using Statistical Analysis Software (SAS version 8.2, Cary, NC). Descriptive characteristics were computed using means and standard deviations. A stepwise regression analysis was used to predict $\dot{V}O_{2peak}$ for the validation (VAL) group from resistance, HR_{max}, BMI, height and gender (female = 0, male = 1). This equation was then cross-validated to determine differences between measured $\dot{V}O_{2peak}$ and $\dot{V}O_{2peak}$ using data obtained from the cross-validation (XVAL) group. The level of statistical significance was set at $p < 0.05$ for the regression coefficients of each of the independent variables.

RESULTS

Descriptive characteristics for all subjects in the VAL and XVAL groups are presented in Table 1 and indicates that the VAL and XVAL groups were homogenous at the baseline tests with regards to age, weight, BMI, HR_{max} and $\dot{V}O_{2peak}$.

A stepwise regression analysis of the VAL group yielded the following relative $\dot{V}O_{2peak}$ prediction equation: $\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) = 187.39403 + 12.97271 (female = 0, male = 1) – 1.45311 (height in inches) – 1.21604 (BMI) – 0.19613 (HR_{max}) + 1.57093 (resistance). Gender, height, BMI, HR_{max} and resistance from the graded exercise test all significantly contributed to the regression model ($p < 0.05$). Combined, these variables account for 76% of the variance ($R^2 = 0.76$, $p < 0.05$) in predicting $\dot{V}O_{2peak}$. The standard error of estimation (SEE) was 4.47 $ml \cdot kg^{-1} \cdot min^{-1}$. There was no significant ($p > 0.05$) difference between $\dot{V}O_{2peak}$ estimated from the prediction equation and the actual measured VO_{2peak}. The results of the cross-validation are presented in Table 2.

Table 2: Cross-validation (XVAL) of regression equation

XVAL Group	Relative VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$)
Measured VO_{2peak}	43.55 ± 6.23
Predicted VO_{2peak}	45.18 ± 6.42
Difference	1.64 ± 5.62*

* Difference between measured and predicted $\dot{V}O_{2peak}$: $p > 0.05$

DISCUSSION

Elliptical motion trainers are an attractive mode of exercise for all ages since they are low-impact especially in comparison to the high impact characteristics of treadmill walking and running (10, 11). In a study by Sweitzer *et al (*14), the elliptical motion trainer was selected as the exercise mode of choice for coronary artery disease patients as it was considered a safer mode of exercise com-pared to treadmill walking. An elliptical motion trainer was also found to induce higher metabolic, cardiovascular and ventilatory responses than treadmill walking at an equivalent level of perceived exertion in coronary artery disease patients (14). However, results for non-coronary artery disease patients have not yet been published.

Performing graded exercise test protocols for the purpose of quantifying cardiorespiratory fitness has become standard for accurately prescribing safe and effective exer-

Table 1: Descriptive characteristics of subjects

Group	Age (Year)	Weight (kg)	BMI ($kg \cdot m^{-2}$)	HR_{max} (bpm)	VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$)
All subjects (n = 59)	23.5 ± 4.1	77.8 ± 16.2	25.7 ± 3.4	193.4 ± 8.4	43.6 ± 7.3
VAL (n = 39)	22.7 ± 3.4	79.2 ± 15.2	26.2 ± 3.9	195.7 ± 8.2	43.7 ± 7.8
XVAL (n = 20)	24.3 ± 4.8	76.3 ± 17.2	25.4 ± 2.8	191.1 ± 8.5	43.5 ± 6.1

Values are means ± standard deviation. BMI: body mass index, HR_{max}: maximal heart rate, VO_{2peak}: peak oxygen consumption, VAL: validation group, XVAL: cross-validation group

cise programmes. However, by the principle of specificity, assessment of $\dot{V}O_{2peak}$ should be completed using the same mode as the exercise training (6). The current investigation provides exercise specialists with an alternative method to reliably predict cardiorespiratory fitness in college-aged males and females using an elliptical motion trainer. This is essential since 41% of the members who join fitness centres each year are between the ages of 18 and 34 years (9). Hence, the current protocol and prediction equation may be beneficial for many fitness facility clients.

For fitness facility clients who prefer aerobic training on an elliptical motion trainer, the prediction equation established in this study will provide valid, reliable results that can aid fitness specialists in prescribing exercise, evaluating changes in aerobic fitness and quantifying. VO_{2peak}. The elliptical motion trainer graded exercise test that was developed for use in this study showed a predictive accuracy that is similar to other graded exercise prediction tests that involve walking (3) running (4, 15) and cycling (5). The standard error for most prediction equations estimating VO_{2peak} is between 3.0 and 5.0 $ml \cdot kg^{-1} \cdot min^{-1}$ (1, 3, 4) and the current prediction equation had a standard error of 4.7 $ml \cdot kg^{-1} \cdot min^{-1}$. However, it should be noted that the current prediction equation was developed specifically for college-aged males and females and should not be generalized to all age groups.

CONCLUSIONS

In conclusion, to accurately quantify cardiorespiratory fitness, for effective exercise prescription, $\dot{V}O_{2peak}$ needs to be determined based on the specificity principle. As such, we have developed and cross-validated a prediction equation for estimating $\dot{V}O_{2peak}$ using an elliptical motion trainer in a sample of 59 males and females. This protocol and prediction equation appears to provide valid results when estimating $\dot{V}O_{2peak}$ among individuals aged between 19 and 24 years and may be beneficial in non-medical facilities for quantifying cardiorespiratory fitness. Future studies with middle-aged and older individuals should be conducted to develop an age-specific graded exercise test protocol and prediction equation for the elliptical motion trainer.

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