2021, ***Retos***, *41*, 695-700
© Copyright: Federación Española de Asociaciones de Docentes de Educación Física (FEADEF) ISSN: Edición impresa: 1579-1726. Edición Web: 1988-2041 (https://recyt.fecyt.es/index.php/retos/index)

Retrograde extrapolation of VO2max from recovery values recorded breath by breath

Extrapolación retrógrada del VO2max a partir de valores de recuperación recogidos respiración a respiración

Jose Naranjo Orellana, Sergio Muela Galán
Universidad Pablo de Olavide. Sevilla (Spain)

Abstract. The aim of this study was to assess the validity of VO2max prediction using retrograde extrapolation in a breath-by-breath (BxB) gas measurement system. A retrospective study was performed, analysing 31 incremental and maximal stress tests carried out in our laboratory, corresponding to male subjects who practised different sporting activities (age: 29.9 ± 14.45 years; height: 174.4 ± 6.5 cm; weight: 71.4 ± 7.2 kg). A linear regression of the first minute of recovery was used to obtain extrapolated VO2max data and, subsequently, a correction equation was applied that provided predicted VO2max values. Given the variability of data in BxB measurement systems, extrapolated values can be expected to vary significantly from those actually measured, but differences disappeared in the predicted values, which were almost identical to those measured. This method enables stress tests to be performed without having to record gas measurements until the end. It could be useful for the validation of specific field tests, measuring VO2 trackside after the test, during recovery.
Key Words: VO2max, Extrapolation, Retrograde, Breath by breath, Recovery.

Resumen. El objetivo de este estudio fue evaluar la validez de la predicción del VO2máx mediante la extrapolación retrógrada en un sistema de medición de gases respiración a respiración (BxB). Se realizó un estudio retrospectivo, analizando 31 pruebas de esfuerzo incrementales y máximas realizadas en nuestro laboratorio, correspondientes a sujetos masculinos que practicaban diferentes actividades deportivas (edad: 29,9 ± 14,45 años; talla: 174,4 ± 6,5 cm; peso: 71,4 ± 7,2 kg). Se utilizó una regresión lineal del primer minuto de recuperación para obtener datos de VO2max extrapolados y, posteriormente, se aplicó una ecuación de corrección que proporcionó valores de VO2max predichos. Dada la variabilidad de los datos en los sistemas de medición BxB, se puede esperar que los valores extrapolados varíen significativamente de los realmente medidos, pero las diferencias desaparecieron en los valores predichos, que eran casi idénticos a los medidos. Este método permite realizar pruebas de esfuerzo sin tener que registrar mediciones de gas hasta el final. Podría ser útil para la validación de pruebas de campo específicas, midiendo el VO2 a pie de campo después de la prueba, durante la recuperación.
Palabras clave: VO2max, Extrapolación, Retrógrada, Respiración a respiración, Recuperación.

Introduction

When maximal effort tests are performed in a laboratory incorporating the measurement of gases, there are frequently problems derived from the nuisance or discomfort endured by the athletes of wearing a facemask and the fact that, with some ergometers, the equipment makes it difficult to perform the technique correctly. Furthermore, there are some sports for which VO2max measurements cannot be taken in the laboratory since there are no adequate ergometers and they need (as the only option) reliable field tests. This is the case with swimming trials, for example.

For this reason, in the 1970s, different field tests were developed to estimate VO2max, validated by recording VO2 during recovery and then carrying out retrograde extrapolation using different techniques to estimate the maximum value.

Di Prampero et al. (Di Prampero, Cortili, Mognoni & Saibene, 1976) carried out the first estimation of oxygen cost in speed skating through retrograde extrapolation of the recovery curve for VO2 in a submaximal test, albeit it with only two subjects.

Leger et al. (Leger, Seliger & Brassard, 1979) conducted a study to determine the specificity of VO2max response among hockey players and runners, on an ice rink and a treadmill. Shortly afterwards, they performed another study to assess the retrograde extrapolation of VO2max (Leger, Seliger & Brassard, 1980), in which they aimed to compare the value obtained through the retrograde extrapolation of VO2

Fecha recepción: 19-10-20. Fecha de aceptación: 06-02-21
José Naranjo Orellana
jnarore@upo.es

on the recovery curve at time zero of recovery with the value measured directly in a continuous multiple stage maximal test conducted in a laboratory. The method entailed connecting the subject, just after completing the test, to a Douglas bag to record VO2. This regression, extrapolated at time zero of recovery (coinciding with the end of the test), provided the estimated value for VO2max, related to the value obtained in the laboratory for a test of the same characteristics. The corresponding equations gave rise to validations of estimated consumptions using this type of field test. Hence, in 1982, Leger and Lambert validated the 20-m shuttle run test (Course Navette test) for the prediction of VO2max among adult men and women (Leger & Lambert, 1982).

Subsequently, other studies also used this type of estimation (Montpetit, Leger, Lavoie, & Cazorla, 1981; Costill, Kovaleski, Porter, Kirwan, Fielding, & King, 1985; Paliczka, Nichols, & Boreham, 1987; Leger, Mercier, Gadoury, & Lambert, 1988; Ramsbottom, Brewer, & Williams, 1988; Sleivert, & Mackinnon, 1991; Sproule, Kunalan, McNeill, & Wright, 1993; Carré, Dassonville, Beillot, & Prigent, 1994; Stickland, Petersen, & Bouffard, 2003; Bandyopadhyay, 2011;).

All these historic tests were carried out using a Douglas bag and, therefore, with averaged VO2 values usually obtained every minute (or in some cases every 20 or 30 seconds). This means that in order to obtain the regression, few points were used (usually 3 or 4) to avoid generating very long records.

However, no study has been done validating these regression measures with analyzers that use breath-by-breath (BxB) measurements. Since these measures involve clouds of points with large numbers of data in the same time unit, they could present differences in their predictability. Recently, studies have been carried out in swimmers with BxB equipment but estimating the VO2peak from recovery heart rate and with measurements of 20s (Chaverri, Iglesias, Schuller, Hoffmann & Rodríguez, 2016; Chaverri, Schuller, Iglesias, Hoffmann & Rodríguez, 2016; Rodríguez, Chaverri, Iglesias, Schuller & Hoffmann, 2017).

There has also been a work that extrapolates VO2max from second threshold data, although this does not resolve having to do the test with a face mask (Nunes, Silva, Machado, Menezes, Bocalini, Seixas et al, 1980).

The aim of this paper was to ascertain the validity of predicting VO2max by means of retrograde extrapolation in BxB gas measurement system.

Material and methods

Subjects

We performed a retrospective study analysing effort tests carried out in our laboratory along two years (2016 and 2017). A total of 31 incremental and maximal effort tests were exported from the laboratory's database. All the tests corresponded to male subjects who practised different sporting activities (age: 29.9 ± 14.45 years; height: 174.4 ± 6.5 cm; weight: 71.4 ± 7.2 kg).

The inclusion criteria for tests to be considered in this study were: a) they were carried out on the same treadmill (Ergo Run Medical 8, Daum Electronic; Fürth, Germany); b) they were carried out using a progressive protocol in 1 minute increments until exhaustion; c) during the tests, records had been kept of breathing and gases using the same analyser (Breezesuit CPX made by MedGraphics; St. Paul, Minnesota, USA) and with breath-by-breath (BxB) records; d) there was a record of VO2 for at least 2 minutes of recovery.

Procedures

For each of the subjects, the stress test was reviewed to check the VO2max value, and these values were compiled in a table under the heading 'measured VO2max'. Then, in each test, VO2 was analysed during recovery, verifying that the values all fit a linear regression for at least the first minute, although some of them, over a more prolonged period, presented an exponential fit. To standardise all the calculations, we chose to work with the first minute of recovery (certain to be during the rapid phase), obtaining the corresponding linear equation. Using this equation, in a graph where the Y axis represented VO2 in mL / min and the X axis represented time in minutes, the VO2max value was estimated, giving x the time value corresponding to the end of the test. This value was logged in the same table as above under the heading 'extrapolated VO2max'.

In tests performed using BxB methodology, greater variability can be expected between the extrapolated and measured values of VO2max for various reasons.

The first is that the regression is performed with a point cloud instead of 3 or 4 average values; the second is that the end of the stress test is very different if we consider the presence of VO2max (existence of a plateau) or a peak value, since the existence of a plateau also implies the average value of a point cloud.

Accepting that this variability will affect the prediction value of the directly extrapolated value, we explored the degree of fit between the extrapolated and measured values in 31 subjects, obtaining the equation that links these two variables, which enabled us to use it as a correction equation for each of the extrapolated values. This corrected value was included in the same table under the heading «predicted VO2max».

Both extrapolated and predicted VO2max were individually compared with measured VO2max to check whether both measurements could be considered superimposable. To do this, we assumed that no correlation measure (e.g. Pearson) is valid for comparing the matching of measurements made by two devices (Altman, & Bland, 1983) since what is measured is the association between the two measurements, not their agreement. In other words, two series can have a correlation of 1 with any line, but only a line matching the so-called identity line (which passes through the origin and whose slope is 1) shows a perfect agreement between both variables (Altman, & Bland, 1983).

For this reason, we followed the methodology proposed by Bland and Altman (Altman, & Bland, 1986) to specifically establish the degree of agreement between two measurements.

Statistical Analyses

First, a descriptive analysis was made reporting the mean and standard deviations (SD) of VO2max (measured, extrapolated and predicted). A 95% confidence level was established for all these analyses.

To obtain a visual reference of the possible adjustment between measures, the linear relationship obtained from the extrapolated vs measured VO2max and predicted vs measured VO2max, was represented on a graph and their adjustment to the identity line was examined.

Bland-Altman Methodology

For this analysis, the difference between each pair of measurements was calculated for each individual (both for extrapolated vs measured VO2max and predicted vs measured VO2max) and these values were represented on a chart and compared to the mean of each pair of measurements. The 95% confidence limits calculated as the mean of all differences + 1.96 SD (upper limit) and – 1.96 SD (lower limit) were added to this chart.

In order to include a conventional statistic, a Student's t-test for paired samples was applied to compare measured VO2max and predicted VO2max, accepting a value of $p<0.05$ as significant. Furthermore, a correlation study was performed (Pearson's coefficient) between these values and measured VO2max.

Results

Table 1 provides the data for all the subjects corresponding to measured, extrapolated, and predicted VO2max, including the individual extrapolation equations.

Table 1
Values for extrapolated and measured VO2max for each of the subjects

			VO_2max		
Subject	Equation	R^2	Extrapolated	Measured	Predicted
1	y = -43.123x + 26994	.964	2845	2900	2991.6
2	y = -42.302x + 12531	.803	2928	3259	3069.1
3	y = -30.526x + 13173	.980	2580	2786	2744.2
4	y = -24.674x + 12713	.977	2720	2847	2874.9
5	y = -27.215x + 10690	.975	2770	2792	2921.6
6	y = -59.092x + 27160	.988	3582	3564	3679.8
7	y = -47.019x + 26450	.992	3316	3329	3431.4
8	y = -715.9x + 12836	.992	2813	2724	2961.8
9	y = -389.34x + 14505	.952	2824	3176	2972.0
10	y = -40.403x + 20890	.967	3799	3816	3882.4
11	y = -36.958x + 15061	.968	3012	3275	3147.6
12	y = -20.854x + 10794	.971	2452	2443	2624.7
13	y = -32.623x + 16884	.944	3443	3458	3550.0
14	y = -9.0121x + 6593,3	.916	2582	2569	2746.1
15	y = -18.576x + 13633	.927	2896	3096	3039.3
16	y = -25.646x + 12868	.979	3712	3716	3801.2
17	y = -13.412x + 10012	.953	3064	3362	3196.1
18	y = -39.393x + 18210	.972	3713	3636	3802.1
19	y = -166.2x + 37487	.945	3416	3467	3524.8
20	y = -140.5x + 30662	.907	3124	3600	3252.1
21	y = -152.81x + 29253	.960	3733	3746	3820.8
22	y = -869.5x + 31189	.999	3365	3598	3477.2
23	y = -141.63x + 28631	.764	3420	3687	3528.5
24	y = -127.78x + 28166	.895	2993	3200	3129.8
25	y = -191.47x + 39716	.889	3719	4055	3807.7
26	y = -177.04x + 39643	.931	3703	3704	3792.8
27	y = -137.49x + 28693	.894	3807	4005	3889.9
28	y = -95.688x + 21301	.959	2928	2911	3069.1
29	y = -116.61x + 25027	.892	2637	2831	2797.4
30	y = -153.1x + 34174	.949	4166	4134	4225.1
31	y = -146.76x + 31601	.885	2836	3052	2983.2

Shown also is the equation obtained for each of the subjects to determine extrapolated VO2max along with the value for R2. The last column provides the values for VO2max once corrected using the corresponding equation (y = 0.94x + 335.26).

The equation obtained relating the extrapolated and measured values in the 31 subjects, and which was used as the correction equation to obtain the predicted value, was y = .94x + 335.26 (Fig. 1). The relationship between the measured and extrapolated VO2max is linear but

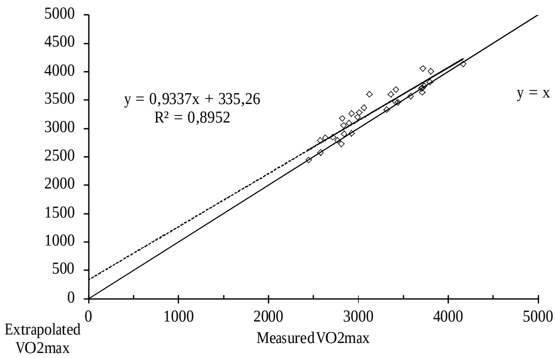

Figure 1. Relationship between measured VO2max and extrapolated VO2max in the total sample of subjects, with the equation used to correct and transform the extrapolated value into the predicted value.

separates from the line of identity in its lower section.

Table 2 shows the mean and standard deviation values for measured, extrapolated, and predicted VO2max. Extrapolated VO2max presents significant differences (p= .0001) from the measured value, but once the correction has been made, this difference disappears (p= .91). Both data (extrapolated and predicted) present a very good correlation with the measured values (r= .95; p< .001).

Table 2
Values for VO2max in the three situations studied

VO_2max (mL/min)	Mean	SD	p	r
Measured	3314.13	451.54		
Extrapolated	3190.26	457.55	.0001	.95
Predicted	3314.00	427.21	.91	.95

p values are given along with the Pearson correlation (r) for extrapolated and predicted VO2max in relation to the value measured in the test.

Figure 2 shows how when the predicted VO2 is represented against the measured one, the linear relationship overlaps with the line of identity.

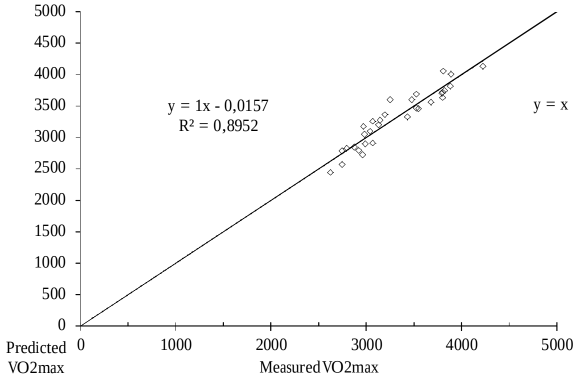

Figure 2.The linear relationship between predicted and measured VO2 is almost identical to the line of identity.

Figure 3 shows the Bland-Altman analysis with the differences between each pair of measurements, both for extrapolated vs measured VO2max and predicted vs measured VO2max, compared to the mean of each pair of measurements

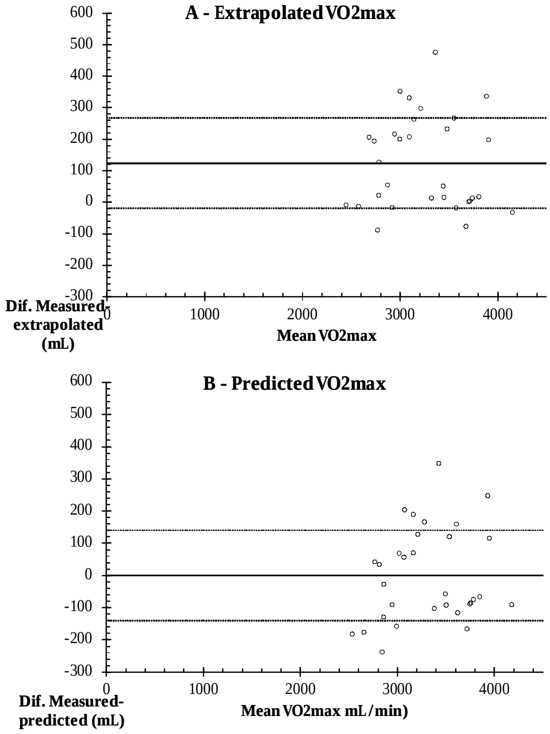

Figure 3. Bland-Altman analysis with the differences between each pair of measurements, both for extrapolated vs measured VO2max and predicted vs measured VO2max, compared to the mean of each pair of measurements

Discussion

The main contribution of this study is to provide data regarding the retrograde extrapolation of VO2max based on recovery values in measurements taken using BxB equipment.

Given that classic studies on this subject (Montpetit, et al, 1981; Costill, et al, 1985; Paliczka, et al, 1987; Leger, et al, 1988; Ramsbottom, et al, 1988; Sleivert, & Mackinnon, 1991; Sproule, et al, 1993; Carré, et al, 1994; Stickland, et al, 2003; Bandyopadhyay, 2011) were conducted using Douglas bags, this paper provides a validation of breath by breath measurements, since extrapolations made using averaged values measured using a Douglas bag mean that usually only three or four values are used to perform the regression, whereas in BxB measurements, even one minute of recovery provides a cloud of at least 20 or 30 points.

Although both linear regression and exponential regression are valid for the prediction of VO2max by means of retrograde extrapolation (Sleivert, & Mackinnon, 1991), this study has focused solely on performing a linear regression in the first minute of recovery, which has been possible thanks to the number of data provided by the BxB system, greatly simplifying the procedure as a result in order to maximise the number of possible applications.

The values for VO2max obtained directly by means of retrograde extrapolation of the first minute of recovery (3190.26 ± 457.55 mL/min) differed from the values measured during testing (3314.13 ± 451.54 mL/min), which would lead significant errors to be made. These differences confirm our initial idea that in BxB measurements, there is greater variability in the values for the reasons explained above. But if we apply by way of a correction the equation obtained from the linear relationship between the two values in the full group (Figure 1), we obtain almost an identical value (3314.00 ± 427.21 mL/min) to the one measured (Figure 2).

On the other hand, figures 1 and 3 confirm that the extrapolation from the first minute of recovery clearly overestimates the real value of VO2. In fact, figure 3A shows how all the differences between measured and extrapolated VO2 are positives. However, when the value is corrected (Figure 3B) the differences are positives and negatives with a value around 140 mL which means an error less than 5% for VO2max higher than three L/min.

Practical applications:

The possible applications for this estimation would be, among others:

a) The performance of stress tests without recording gas measurements (and therefore without having to use a facemask) until the end of the test. This application would be useful for athletes who feel that the facemask limits their real capacity, therefore making them unwilling to undergo such tests.

b) The measurement of VO2max by means of ergometers when it is somewhat tiresome having to keep a record of gas measurements throughout the entire test, for example a rowing or kayaking ergometer.

c) The validation of specific field tests, measuring VO2 trackside after the test, during recovery.

d) The measurement of VO2 immediately after swimming tasks.

For these applications we propose the following procedure: 1) to connect the subject to the gas analyzer just at the end of the test and collect recovery values; 2) to perform a linear regression using VO2 data from the first minute of recovery; 3) to obtain the VO2max extrapolated value in this equation giving x the time value corresponding to the end of the test; 4) to insert this value as x into the correction equation ($y = 0.94x + 335.26$). This equation could be substituted for any other equation obtained by each laboratory for specific populations.

Conclusions

It is possible to predict VO2max by means of retrograde extrapolation in BxB gas measurement system.

This extrapolation can be used in different circumstances, for which a specific procedure is proposed.

References

Altman, D.G. & Bland, J.M. (1983). Measurement in Medicine: The Analysis of Method Comparison Studies. *The Statistician*, *32*(3), 307–317.

Bandyopadhyay, A. (2011). Validity of 20 meter multi-stage shuttle run test for estimation of maximum oxygen uptake in male university students. *Indian Journal of Physiology and Pharmacology*, *55*, 221.

Bland, J.M. & Altman, D.G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *The Lancet*, *327*, 307–310.

Carré, F., Dassonville, J., Beillot, J., & Prigent, J.Y. (1994). Use of oxygen uptake recovery curve to predict peak oxygen uptake in upper body exercise. *European Journal of Applied Physiology Occupational Physiology*, *69*, 258-61.

Chaverri, D., Iglesias, X., Schuller, T., Hoffmann, U. & Rodríguez, F.A. (2016). Estimating peak oxygen uptake based on postexercise measurements in swimming. *Applied Physiology, Nutrition and Metabolism*, *41*, 588–596.

Chaverri, D., Schuller, T., Iglesias, X., Hoffmann, U. & Rodríguez, F.A. (2016). A New Model for Estimating Peak Oxygen Uptake Based on Postexercise Measurements in Swimming. *International Journal of Sports Physiology &Performance*, *11*, 419 -424.

Costill, D.L., Kovaleski, J., Porter, D., Kirwan, J., Fielding, R. & King, D. (1985). Energy expenditure during front crawl swimming: predicting success in middle-distance events. *International Journal of Sports Medicine*, *6*, 266-270.

Di Prampero, P.E., Cortili, G., Mognoni, P. & Saibene, F. (1976). Energy cost of speed skating and efficiency of work against air resistance. *Journal of Applied Physiology*, *40*, 584-591.

Leger, L.A. & Lambert, J. (1982). A maximal multistage 20-m shuttle run test to predict VO2max. *European Journal of Applied Physiology & Occupational Physiology*, *49*, 1-12.

Leger, L.A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Science*, *6*, 93-101.

Leger, L.A., Seliger, V. & Brassard, L. (1979). Comparisons among VO2max values for hockey players and runners. *Canadian Journal of Applied Sport Sciences*. *4*, 18-21.

Leger, L.A., Seliger, V. & Brassard, L. (1980). Backward extrapolation of VO2max values from the O2 recovery curve. *Medicine &Science in Sports &Exercise*, *12*, 24-27.

Nunes, R., Silva, J., Machado, A., Menezes, L., Bocalini, D., Seixas I. et al (1980). Prediction of vo2 max in healthy non-athlete men based on ventilatory threshold. *Retos*, 35, 136-139.

Montpetit, R.R., Leger, L.A., Lavoie, J.M., & Cazorla, G. (1981). VO2 Peak During Free Swimming Using the Backward Extrapolation of the O2 Recovery Curve. *European Journal of Applied Physiology*, *47*, 385-391.

Paliczka, V.J., Nichols, A.K. & Boreham, C.A. (1987). A multi-stage shuttle run as a predictor of running performance and maximal oxygen uptake in adults. *British Journal of Sports Medicine*, *21*, 163-165.

Ramsbottom, R., Brewer, J. & Williams, C. (1988). A progressive shuttle run test to estimate maximal oxygen uptake. *British Journal of Sports Medicine*, *22*, 141-144.

Rodríguez, F.A., Chaverri, D., Iglesias, X., Schuller, T. & Hoffmann, U. (2017). Validity of Postexercise Measurements to Estimate Peak VO2 in 200-m and 400-m Maximal Swims. *International Journal of Sports Medicine*, *38*, 426–438.

Sleivert, G. & Mackinnon, L.T. (1991). The validation of backward extrapolation of submaximal oxygen consumption from the oxygen recovery curve. *European Journal of Applied Physiology & Occupational Physiology*, *63*, 135-139.

Sproule, J., Kunalan, C., McNeill, M., & Wright, H. (1993). Validity of 20-MST for predicting VO2max of adult Singaporean athletes. *British Journal of Sports Medicine*, *27*, 202-4.

Stickland, M.K., Petersen, S.R. & Bouffard, M. (2003). Prediction of maximal aerobic power from the 20-m multi-stage shuttle run test. *Canadian Journal of Applied Sport Sciences*, *28*, 272-282.