Metabolic Responses to Exercise

The Precision Of Estimating The Total Energy Demand: Implications For The Determination Of The Accumulated Oxygen Deficit

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ABSTRACT

AARON RUSSELL, PETER LE ROSSIGNOL, and SING KAI LO. The Precision Of Estimating The Total Energy Demand: Implications For The Determination Of The Accumulated Oxygen Deficit. \textit{JEPonline}, 3(2):55-63, 2000. This study observed the precision of estimating the total energy demand required to calculate the AOD using three different VO\textsubscript{2}-power regressions which included, five VO\textsubscript{2}-power regression points and a forced y-intercept of 5.1 ml/kg/min (5+Y) (1), five VO\textsubscript{2}-power regression points without a forced y-intercept of 5.1 ml/kg/min (5-Y), Medbø's “procedure 3”(MED) (1). Fourteen well-trained schoolboy rowers completed a 2000-m performance test, VO\textsubscript{2} peak test, five submaximal tests, and an exhaustive 2-min test using rowing ergometry. There were no differences between the estimated total energy demand (ETED), AOD and slope of the regression lines when established from either of the three regression equations. The regressions developed from methods 5+Y and MED reduced the length of the 95% confidence interval (95% CI) (p<0.0167) compared to the method 5-Y. 2000-m rowing ergometer performance was significantly predicted by VO\textsubscript{2} peak and the AOD determined by either of methods 5+Y (p=0.047) and MED (p=0.042). The inclusion of a y-intercept value when estimating the total energy demand with a reduced number of regression points reduces the length of the 95% CI, increases the precision of the estimated value and therefore reduces the variability of the AOD measurement. It is suggested that the length of the 95% CI of the ETED be used as a criteria to measure the degree of precision in the estimated value. This approach has potential for improving the reproducibility of the AOD.

Key Words: rowing performance, 95% confidence interval, intense exercise.

INTRODUCTION

The accumulated oxygen deficit (AOD) is determined as the difference between the estimated total energy demand (ETED) and the actual measured oxygen uptake during the same exhaustive exercise bout (1). The total energy demand is estimated using a linear regression equation developed from the relationship between several regression points representing steady state oxygen uptake (VO\textsubscript{2}) and the corresponding work rate. The accuracy of the AOD method is dependent in part upon the precision of the ETED required to complete the exhaustive exercise bout.
Medbø, et al. (1) claimed that the AOD method provided a reasonable estimate of anaerobic capacity providing two key criteria were achieved. Firstly, establishing a linear relationship between submaximal VO\textsubscript{2} and power for the development of the regression equation and secondly, that the measured submaximal values used for the extrapolation are as close as possible to the ETED required for the AOD test. Medbø, et al. (1) established these criteria after having subjects perform approximately 20 submaximal tests representing VO\textsubscript{2} and power between 35–100% of VO\textsubscript{2max}. Medbø, et al. (1) also developed a more time efficient method, termed "procedure 3" which required only two measurements between 85 and 100% of VO\textsubscript{2max} as well as a common y-intercept value of 5.1 ml/kg/min. The AOD measurement from "procedure 3" was deemed to be satisfactory as it differed by only 2 ml/kg from Medbø’s original method and produced a high correlation between VO\textsubscript{2} and power (r=0.999). Several studies investigating the AOD have developed regression equations to estimate the total energy demand using Medbø’s “procedure 3” (1-4). However, many studies have used modifications of Medbø’s control method by using between 5 and 8 regression points representing steady state VO\textsubscript{2} and power output data points between 35 and 85% of VO\textsubscript{2max}, (5-7). With the exception of one investigation (8), all these studies have excluded the y-intercept value when using a reduced number of regression points (<10 regression points) to estimate the total energy demand. Presently, the effect of reducing the number of regression points without the inclusion of a y-intercept value on the precision of estimating the total energy demand and the subsequent influence on the calculation of AOD is not known.

The precision of the ETED and therefore the measured AOD is generally based on the Pearson correlation coefficient of the VO\textsubscript{2}- power relationship (r ≥0.99) and/or the standard error of the estimate (0.2-0.7 ml/kg/min) (9,10). Recently, Buck and McNaughton (1999) investigated the impact of using less than 10 regression points on the Pearson correlation coefficient of the VO\textsubscript{2}- power relationship and the standard error of the estimate. In this study a standard regression based on 10 x 10 min submaximal intensities between 30 and 90% of VO\textsubscript{2max} was developed. Following this the lowest intensity was removed from the regression and a new VO\textsubscript{2}-power regression was developed using 9 points. This process was repeated until only two points remained. An identical process was again used however, with the initial removal of the highest regression points first. The same process was used for a third time but with the most central points removed until only the highest and lowest points remained. The results from this study indicated that decreasing the number of regression points still produced Pearson correlation coefficient's of 0.99 or greater however, the regressions resulted in differences in the AOD that were much greater than the standard error of the estimate (11). These observations question the use of the Pearson correlation coefficient as the main indicator of the precision of the ETED and therefore an alternative criterion may be required. The 95% confidence interval (95% CI) of the ETED offers an additional criterion which can be used for measuring the precision at a point on the regression line. The precision of an estimated value in a regression can be found by calculating the variance, and hence the standard error of the estimate (12). The standard error can also be used to compute a confidence interval (13). Confidence intervals (CIs) can therefore be used as alternate measures of precision. The use of CIs is more general than that of SEs, for the latter are readily interpreted only when the quantity to which they are attached is approximately normal in distribution (14). Therefore a shorter CI indicates a more precise estimate.

The present study was therefore designed to examine the precision of estimating the required total energy demand and AOD when using a reduced number of regression points combined with and without the y-intercept value. This was achieved using three different methodological approaches. Precision was quantified by the length of the 95% CIs. Additionally, the AOD values calculated using the three different regression methods were combined with individual VO\textsubscript{2peak} values to observe whether the precision of the ETED and therefore the individually calculated AOD’s, affected the prediction of 2000-m rowing ergometer performance. An understanding of the
influence of the y-intercept value when reducing the number of regression points as well as the use of the 95% CI as an indicator of precision will assist in improving the AOD methodology by allowing the selection of regression equations which more precisely estimate the total energy demand.

METHODS

The subjects consisted of 14 elite male schoolboy rowers from three different coxed eight rowing crews. Their mean (±SD) age, height, weight and VO\(_2\)peak were 17.1±0.5 years, 186.1±4.7 cm, 85.2±8.7 kg, 53.8±6.5 ml/kg/min respectively. The subjects were asked not to participate in any physical activity 24 hours prior to testing and to abstain from eating for three hours. The subjects were familiar with the Concept II\(^\circledast\) rowing ergometer used in the study. Informed consent was obtained from each subject, and the University Ethics Committee approved the experiment.

2000-m performance

A 2000-m rowing ergometer test was undertaken (Concept II\(^\circledast\), Morrisville, Vermont, U.S.A) to assess rowing performance time and the average power required to row 2000-m.

Establishing individual regression equations

The various individual regression equations were determined by plotting different combinations of the VO\(_2\)-power co-ordinates. Firstly a VO\(_2\)-power relationship was established using the VO\(_2\) (ml/kg/min) values measured at 50, 60, 70, 80, and 90% of the average power measured during the 2000-m rowing ergometer test and the corresponding work rates (W) combined with a resting VO\(_2\) value of 5.1 ml/kg/min (5+Y) (1). Secondly, a VO\(_2\)-power relationship was determined using the above VO\(_2\) values and corresponding work rates without a resting VO\(_2\) value of 5.1 ml/kg/min (5-Y). Finally, a regression equation was developed based on Medbo’s “procedure 3” which included points at 80% and 90% of the average power measured during in the 2000-m row plus a common resting VO\(_2\) value of 5.1 ml/kg/min (MED) (1). These intensities respectively corresponded to between 75 and 82% and 85 and 92% of individual VO\(_2\)peak.

Measuring submaximal VO\(_2\) and VO\(_2\)peak

Five submaximal tests were performed on the Concept II\(^\circledast\) rowing ergometer at intensities of 50, 60, 70, 80 and 90% of the average power measured during the 2000-m rowing ergometer test and were set using a 2000-m chart with 500-m split times (15). As the intensity of the submaximal tests increased, 500-m split times were decreased by either 5 or 6 s depending on the required intensity (15). Test duration for each submaximal test was 5-7 min with a 10-min recovery between each work rate. The submaximal VO\(_2\) was measured when a steady state heart rate was achieved. Steady state was deemed to be reached when heart rate did not vary by any more than 5 beats over a 2-min period. Power output during the submaximal tests was obtained as the average power as indicated on the monitor of the Concept II rowing ergometer at the end of each test. Heart rates were measured using a Polar heart rate monitor (Polar Electro, Hakamaantie, Kemple, Finland). When steady state was reached expired gases were collected in Douglas bags for a further minute. VO\(_2\)peak was established by increasing the work rate after the 90% trial was completed. To measure VO\(_2\)peak the 500m split time was decreased by 4 s each minute until it could not be held for three consecutive stokes. Expired gas was collected in Douglas bags for each 60 s work rate during the maximal test, with the bags analyzed to determine VO\(_2\)peak. VO\(_2\)peak was determined as the highest VO\(_2\) value obtained from the bags. VO\(_2\) was analyzed by evacuating 21 L of the expired gas from the Douglas bags and pushing it into the Gould 2900 metabolic cart using a Hans Rudolph 7 L syringe attached to a 2 way valve. The fraction of expired oxygen (F\(_{\text{E}}\)O\(_2\)) and the fraction of expired carbon dioxide (F\(_{\text{E}}\)CO\(_2\)) were established approximately 90-s after the expired sample had been pushed into the oxygen and carbon dioxide analyzers of the metabolic cart. Ninety seconds allowed for the replacement of the previous gases with the gases from the Douglas Bag. Ventilation (VE) was determined by evacuating the rest of the contents of each bag using the 7 L Hans Rudolph syringe and adding the 21 L of gas that had all ready been evacuated. The syringe was calibrated against a 120 L Tissot spirometer by withdrawing 70 L of air from the spirometer on 10 occasions. The coefficient of variation for the syringe was 0.15 % with a systematic error of ±0.89% (4). VO\(_2\) was then
Table 1. Results for the estimated total energy demand (ETED), the length of the 95% confidence interval (95% CI), the accumulated oxygen deficit (AOD), the slope of the regression line, the VO₂-power correlation coefficient (r) and the standard error of the predicted value (SEP) when using the methods 5+Y, 5-Y and MED.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>5+Y</th>
<th>5-Y</th>
<th>MED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETED (ml/kg/min)</td>
<td>71.28±9.49</td>
<td>74.26±6.20</td>
<td>70.23±7.93</td>
</tr>
<tr>
<td>AOD (ml/kg/min)</td>
<td>27.84±9.48</td>
<td>30.82±6.20</td>
<td>26.79±7.93</td>
</tr>
<tr>
<td>Slope (ml/kg/min/W)</td>
<td>0.15±0.02</td>
<td>0.15±0.04</td>
<td>0.15±0.01</td>
</tr>
<tr>
<td>SEP (ml/kg/min)</td>
<td>1.58±0.41</td>
<td>4.12±2.25 *</td>
<td>1.31±0.69</td>
</tr>
<tr>
<td>r</td>
<td>0.991±0.009</td>
<td>0.966±0.041</td>
<td>0.998±0.000 *</td>
</tr>
<tr>
<td>95% CI (ml/kg/min)</td>
<td>12.88±2.93</td>
<td>27.63±14.47</td>
<td>16.89±10.07</td>
</tr>
</tbody>
</table>

All values are mean±SD; * = significantly different compared to the other methods (p<0.0167) # = significantly different from each other (p<0.0167)

calculated from the $F_{O_2}$, $F_{CO_2}$ and V E measurements which were representative of each bag.

Establishing the accumulated oxygen deficit (AOD)

An exhaustive test was performed at a constant work rate between 120 and 130% of VO₂peak work rate to determine the AOD (1). The total energy demand required for the exhaustive test was estimated by extrapolation from the individual regression equations established from the submaximal tests (1). Exhaustion occurred when the subjects voluntarily stopped rowing or when the required split time was unable to be maintained for more than three strokes. Douglas bags were used to collect the expired gas for the entire duration of the AOD test. Exercise duration was between 1.75 and 2.5 min. The oxygen uptake during the AOD test was determined by analyzing the expired gas in the Douglas bags using the same procedure as for the submaximal tests. The AOD was established by subtracting the measured accumulated oxygen uptake from the estimated oxygen demand required to complete the exhaustive AOD tests (1).

Statistical analysis

Regression equations were developed for each subject’s VO₂-power relationship so that their total energy demand and AOD could be calculated. Three regression equations were developed for each subject using the methods 5+Y, 5-Y and MED. Along with each individual’s ETED and AOD, other statistics calculated for each of the three methods included the slope, the standard error of the predicted value (SEP), the Pearson correlation coefficient of the VO₂-power relationship and the 95% CI associated with the ETED. The SEP is provided as opposed to the commonly used standard error of the estimate (SEE). The SEP is more precise than the SEE as the SEE is a broad term and may refer to the SE of the intercept or SE of the slope (both a and b in the equation $y = a+bX$). Repeated measures ANOVA, followed by all pairwise linear contrasts, were performed to test for differences in the dependent variables derived from the three different regression equations. Multiple linear regression was also used to investigate the prediction of rowing performance when combining VO₂peak with the AOD values established using the different methods. The adjusted multiple $R$, as opposed to the sample multiple $R$, was used to assess the proportion of variance explained by the independent variables (16). All statistics were performed using SPSSX Inc. statistical software (17). The Bonferoni adjustment was made for the repeated measures ANOVA so that the significance level was set at 0.0167. For all other analysis the 0.05 level was used to determine statistical significance.

RESULTS

Table 1 indicates mean group data for the dependent variables measured using the regression methods 5+Y, 5-Y and MED.

There was no significant difference between the ETED, AOD and the slope of the regression line when using the 3 different methods. The inclusion of a constant y-intercept when developing the regression equation resulted in a lower SEP (p=0.002) as well as a reduction in the length of the 95% CI for the ETED (p=0.004) compared to using the method 5-Y. The SEP was lower...
Estimating Accumulated Oxygen Deficit (AOD)

Table 2. Multiple regression equations, adjusted R, standard error of the predicted value (SEP), independent P-values and significance for the prediction of 2000-m rowing ergometer performance using the AOD measured from the 3 different methods combined with VO2peak.

<table>
<thead>
<tr>
<th>Variable</th>
<th>5 +Y</th>
<th>5 -Y</th>
<th>MED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple regression equation</td>
<td>2000-m time (min) = 6.601 - 0.018 x (AOD) + 0.010 x (VO2peak)</td>
<td>2000-m time (min) = 7.258 - 0.021 x (AOD) - 0.00006 x (VO2peak)</td>
<td>2000-m time (min) = 6.603 - 0.022 x (AOD) + 0.012 x (VO2peak)</td>
</tr>
</tbody>
</table>

Adjusted R       | 0.323                     | 0.187                     | 0.335                     |
SEP              | 0.190                     | 0.208                     | 0.188                     |
p-value AOD      | 0.016                     | 0.049                     | 0.014                     |
p-value VO2peak  | 0.297                     | 0.943                     | 0.232                     |
p-value          | 0.047                     | 0.128                     | 0.042                     |

MED was higher than for the other two methods (p<0.0167). There was however no difference between the SEP (p=0.200) and the length of the 95% CI (p=0.173) when using the methods 5+Y or MED.

Although there was no significant difference between the mean AOD values measured using the three different methods multiple regression analysis indicated that when combing the AOD values with VO2peak there was a different explanation or prediction of rowing performance (Table 2). The power of prediction was increased by approximately 45% when the y-intercept value was forced in the regression with five regression points. A similar level of prediction was observed for method MED.

The inclusion of a y-intercept value when reducing the number of regression points decreases the length of the 95% CI as can be seen for an individual subject in Figure 1. Figure 2
shows the group mean values of the length of the 95% CI. The length of the 95% CI from method 5+Y was 53% less than the 95% CI from method 5-Y.

DISCUSSION

The precision of the ETED was observed using three commonly used AOD methods calculated individually on 12 schoolboy rowers. The different regression methods resulted in similar mean ETED's and AOD values. However when using a reduced number of regression points, the method 5+Y significantly increased the precision of the ETED as indicated by a shorter 95% CI when compared to the method 5-Y. The length of the 95% CI was similar for the methods 5+Y and MED.

Collectively, these results demonstrate that estimating the total energy demand with a reduced number of regression points requires a y-intercept. As one of the main limitations of the AOD method surrounds the precision of estimating the total energy demand, the inclusion of the y-intercept and establishing the 95% CI provides a more precise estimation of the total energy demand.

Previously, the strength of the correlation coefficient of the regression equation as well as the standard error of the estimate (SEE) have been used to establish linearity between VO$_2$ and power at submaximal work rates. These criteria have been used to support the AOD method as an appropriate way of estimating the total energy demand for exhaustive exercise above VO$_2$peak intensity (1,918). As indicated by our results similar correlation coefficients can be obtained using different methods, however the variability in the estimated value can modulate significantly. The strength of the correlation coefficient and standard error of the estimate is dependent upon the number of points used to establish the VO$_2$-power relationship, as well as the spread of the points along the x-axis. Therefore a high correlation coefficient and low standard error of the regression may only be an artifact of the method used to develop the regression equation. As two regression points will always reveal a prefect correlation coefficient of 1.00, it is not surprising that three points will produce a relatively high correlation coefficient and low SEE. This has been demonstrated in several studies using Medbø’s “procedure 3” (2,4,19). This can be observed in our data as the method MED resulted in a higher correlation coefficient, a smaller standard error of the predicted value (SEP) and a smaller standard deviation for the estimated value compared to the method 5+Y. This observation is not surprising, as fewer regression points will artificially improve a point estimate. We have given the SEP instead of the SEE as the SEE is a broad term and may refer to the SE of the intercept or SE of the slope (both a and b in the equation y = a+bX). Our data suggest that the method MED produces a more linear relationship that could be misconstrued as producing a more precise estimation of the total energy demand and AOD. However, the 95% CI is longer for the ETED using method MED compared to method 5+Y. The shorter mean 95% CI for the total energy demand estimated from the method 5+Y indicates that the individually estimated total energy demands and therefore AOD produce less variability within individuals. This demonstrates an increased precision when estimating the total energy demand and hence a more precisely calculated AOD.

It is suggested that this observation of a larger variability for the ETED when using a small number of regression points with no y-intercept may also have occurred in previous studies (9,20,21). In the present study there was a mean 39-53% increase in the error or variability of the ETED established from the method 5-Y compared to the methods MED and 5+Y, respectively. Several studies investigating the difference in the AOD between athletes from different sporting events and the influence of training have estimated the total energy demand using a small number of regression points with no y-intercept (20,23). It is possible that using such a method may have reduced the precision of their measurements. It is suggested that both training changes and differences in AOD between sprint, middle distance and endurance athletes may be more precisely assessed if the variability in the energy demand due to the chosen regression points is reduced. High levels of precision for the calculation of AOD should be
Estimating Accumulated Oxygen Deficit (AOD) achieved before the method is tested for its repeatability. It is possible that only moderate levels ($r = 0.89$) of reliability for the AOD (24) and previous poor relationships between AOD and invasive indicators of anaerobic potential (21,25) may have been confounded by low precision in the measurement of the ETED and hence the AOD value. The above studies have not reported the variability in the individually ETED which may have been reduced with the inclusion of a wider spread of regression points and a y-intercept value. Another potential limitation influencing the precision of the ETED is the measurement of steady-state VO$_2$ during high intensity exercise. It has commonly been observed during cycling exercise that steady-state VO$_2$ may be delayed or not attained at high intensities above the lactate threshold due to the VO$_2$ slow component (SC) (26,27). The SC causes a non-linear rise in VO$_2$ at these high intensities that may effect the precise estimation of the total energy demand. The effect of the SC on the precision of the ETED is currently not known.

The relationship between performance and AOD has previously been investigated in sprint and middle distance events. Good examples are 4000-m individual pursuit track cycling (28) and 100-m, 200-m, 400-m and 800-m and 1500-m running events (6). Previously no study had observed the relationship between 2000-m rowing ergometer performance and AOD. Rowing is classed as a middle distance event of approximately six min duration and scientific opinion suggests that between 20-30% of the energy demand is from anaerobic sources (29,30). It can be hypothesized that the AOD will relate to 2000-m rowing performance. As the AOD values were determined using the same submaximal intensities a univariate correlation between AOD and rowing performance cannot be performed due to colinearity. However multiple linear regression analysis indicated that the combination of VO$_2$peak and the AOD values measured from the methods 5+Y and MED significantly predicted 2000-m rowing ergometer performance. Using the method 5-Y when establishing the AOD did not significantly predict performance when the AOD was combined with VO$_2$peak. Interestingly, a trend exists between the prediction of performance when using multiple linear regression, the p-value of the AOD in the multiple linear regression and the length of the 95% CI of the ETED. It appears that the prediction of performance and the P-value of the AOD within the prediction equation is improved when the AOD value is more precisely measured. More precision is indicated by a shorter 95% CI for the ETED. As only three data sets are available a Pearson product-moment correlation cannot be established to provide statistical significance of the relationship between the magnitude of the 95% CI and the correlation between AOD, VO$_2$peak and performance. It is reasonable to suggest that the stronger relationship between AOD and performance when the variability of the ETED and the calculated AOD is reduced, lends support for the more precise measure of AOD as being a more discerning measure of anaerobic capacity.

In summary, the variability of the ETED as indicated by the magnitude of the 95% CI is significantly decreased when using the method 5+Y. Additionally, the improved prediction of 2000-m rowing ergometer performance time when combining VO$_2$peak and the AOD measured using a y intercept and a wide spread of regression points may be related to the more precisely ETED. Using the method 5-Y greatly increases the variability associated with the ETED and reduces the precision of the AOD calculation. This less precise calculation of AOD may be too variable to correlate significantly to 2000m rowing performance time. This study demonstrates that the SEP and a high correlation coefficient of the regression line alone do not sufficiently indicate the more precise or confident measure of the ETED. Therefore the calculated AOD may be an artifact of the number and spread of regression points. It is suggested that the length of the 95% CI of the ETED be used as criteria to establish the precision of the estimated value. Additionally a wide spread of work rates including a y-intercept value should be instigated when only a small number of points are utilized in the regression. This approach is likely to improve the reliability of the AOD method.

REFERENCES


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