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Section III – Sports Training

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Indirect Methods of Assessing Maximal Oxygen Uptake in Rowers: Practical Implications for Evaluating Physical Fitness in a Training Cycle

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The aim of the study was to evaluate the usefulness of indirect methods of assessment of VO2max for estimation of physical capacity of trained male and female rowers during a training cycle. A group of 8 female and 14 male rowers performed the maximal intensity test simulating the regatta distance (a 2 km test) and a submaximal incremental exercise test on a rowing ergometer. The suitability of the indirect methods of predicting VO2max during the training cycle was evaluated by performing the tests twice: in females at an interval of five months and in males at an interval of seven months. To indirectly estimate VO2max, regression formulas obtained for the linear relationship between the examined effort indices were utilized based on 1) mean power obtained in the 2 km test, and 2) submaximal exercises after the estimation of PWC170. Although the suitability of the two indirect methods of assessment of VO2max was statisticaly confirmed, their usefulness for estimation of changes in physical fitness of trained rowers during the training cycle was rather low. Such an opinion stems from the fact that the total error of these methods (range between 4.2-7.7% in female and 5.1-7.4% in male rowers) was higher than the real differences in VO2max values determined in direct measurements (between the first and the second examination maximal oxygen uptake rose by 3.0% in female rowers and decreased by 4.3% in male rowers).

Key words: *rowing ergometer, indirect methods, VO2max, training cycle.*

Introduction

It is noteworthy that estimation of both physical fitness and progress in trained athletes based on the value of peak oxygen uptake requires professional equipment, qualified laboratory staff, and a possibility to perform relatively few tests for estimation of oxygen uptake within one day, all of which raise the costs of such studies. Hence, indirect methods of predicting exercise intensity (Martins et al., 2012) and maximal oxygen uptake are still popular and various submaximal (Lambrick et al., 2009; Klusiewicz et al., 2011) and maximal (Andersen et al., 2008; Klusiewicz et al., 2011) exercise protocols and even self-reported non-exercise predictor variables (George et al., 1997) are used for its determination.

As demonstrated by the results of Klusiewicz and Faff (2003), VO2max can be relatively precisely (with a total error of approx. 5%) predicted based on submaximal and maximal exercises performed on a rowing ergometer.

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Earlier, Lakomy and Lakomy (1993) proposed an indirect method of assessing maximal oxygen uptake based on a submaximal exercise test performed on a rowing ergometer. On the other hand, limited usefulness of such indirect methods as the Astrand-Ryhming test on a cycle ergometer, the Rockport Walk Test, the George-Fischer Jog Test, or the 2.4 km run for estimation of training-induced changes has been noted (Carey, 1997). This concerns mostly elite athletes in whom the magnitude of changes induced by several weeks of training may be lower than the prediction error (Mejuto at al., 2012).

To our knowledge, no attempts have been made to assess the usability of specific indirect methods of assessing VO2max in rowers during their training cycle for estimation of the athletes' physical capacity. Hence, the primary goal of the present study was to evaluate the diagnostic value of the indirect method of estimating VO2max in male and female rowers over an annual training cycle.

Material and Methods

Eight female and 14 male rowers were selected for the study. The basic characteristics of the subjects are presented in Table 1. Approval from the Research Ethics Committee of the Institute of Sport-National Research Institute in Warsaw had been granted before the onset of the tests and informed written consent to participate in the study was obtained from all subjects.

All the subjects performed two exercise tests on the Concept II rowing ergometer (Morrisville, USA). On the first day, a test simulation of the 2000 m distance with maximal individual intensity (a 2 km test) was performed. The exercises were preceded by an 8 min warm-up consisting of constant rowing with two 1 min accelerations (in the 3rd and 5th minutes of the warm-up). The rest period between the warm-up and the maximal exercise protocol lasted 2 min. In the first phase of the research highest values of oxygen uptake recorded in the maximal test which simulated the rowing distance of 2000 m were regarded as VO_{2max}. This test had for years been used as the most popular method of estimation of aerobic capacity in oarsmen. As indicated by Mahler et al. (1984) and Pipstein et al. (1999), no significant difference can be detected between peak oxygen uptake determined in the 2km test on a rowing ergometer and maximal oxygen uptake registered in the incremental exercise until exhaustion.

On the second day, a submaximal test consisting of five 3 min exercises separated by 30 s rest intervals was performed. In the females the initial workload of 120 W was increased by 40 W in each consecutive bout, whereas in male rowers the initial workload of 170 W increased by 50 W (Klusiewicz et al., 2014). The recorded changes in the heart rate (HR) during the incremental exercise test were used to assess physical work capacity at HR=170 beat per minute (PWC_{170}) (Klusiewicz et al., 1999). The PWC_{170} index was calculated using the following formula:

$$PWC_{170}\ (W) = M_1 + (M_2 - M_1) \times (170 - HR_1) / (HR_2 - HR_1)$$

where: HR_1, M_1 – heart rate below 170 beat per minute and respective power (W),
HR_2, M_2 – heart rate above 170 beat per minute and respective power (W).

The tests were performed twice during the annual training cycle: in November and April (assuming improvement of results at the end of the preparatory period of the annual cycle) in female rowers, and in April and November (assuming worsening of the results in the transition period of the annual cycle) in males.

For the indirect estimation of VO_{2max} the following regression formulas based on a linear relationship between the examined indices determined in previous studies (Klusiewicz and Faff, 2003) were used:

A. based on mean power (WM) attained in the 2 km test, expressed in watts:

VO_{2max} (l/min) in females = 1.631 + 0.0088 WM,

VO_{2max} (l/min) in males = 1.682 + 0.0097 WM.

B. based on submaximal exercises after the estimation of PWC_{170}:

VO_{2max} (l/min) in females = 2.4138 + 0.0071 (PWC_{170}),

VO_{2max} (l/min) in males = 3.2131 + 0.0076 (PWC_{170}).

During the exercise tests, the HR was continuously monitored by using a Polar S610i recorder (Polar Electro Oy, Finland). The 2 km test was performed and respiratory exchange indices were measured by a breath-by-breath method (BxB) with the Vmax 29 (SensorMedics, Yorba Linda, CA, USA) or MetaLyser 3B (Cortex

Biophysik GmbH, Germany) devices in female and male rowers, respectively. Three minutes after completion of the 2 km test blood samples were collected for determination of lactate concentration using the LP 400 (Dr Lange, Germany).

Maximal oxygen uptake (VO_{2max}) was defined as the highest amount of oxygen consumed by the athlete during 1 min of the test. The maximal intensity exercise necessary for estimation of VO_{2max} was defined by the following criteria: the VO_2 plateauing with an increasing workload, the post-exercise blood lactate concentration >8 mmol/l, the Respiratory Exchange Ratio (RER) >1.1, and the attainment of the age-adjusted maximal heart rate expressed as HR_{max} = 220 – age of the subject. If at least two of the above criteria were met during the exercise, the attained effort and oxygen uptake were regarded as maximal.

For statistical analysis of the results means (x) and standard deviations (SD) of the examined parameters (x) as well as the Pearson linear correlation coefficients (r) and the total error (TE) were calculated. TE was calculated according to the formula:

$$TE = \sqrt{\frac{\sum (y - Y)^2}{n}}$$

where: y – VO_{2max} calculated with an indirect method, Y – VO_{2max} measured for each subject, n – number of the subjects.

Additionally, percentage of TE (TE%) was calculated according to the formula:

$$TE\% = \frac{TE}{Y} \cdot 100$$

where: Y – measured VO_{2max}.

The Shapiro-Wilk test was used to check if the distributions of examined variables were normal, whereas to compare the obtained results, the one-way analysis of variance (ANOVA) and the two-way analysis of variance for repeated measurements (3 x 2 ANOVA; groups x term) was used. The significance of differences between means was assessed using the Tukey's post hoc test. For statistical tests $p<0.05$ was considered significant.

For all the calculations and statistical analyses of the results Statistica v.8 (StatSoft) and Excel 2007 (Microsoft Office) software was used.

Results

Of the two indirect methods used for determination of maximal oxygen uptake during the two examination months only the values measured in male rowers in November were markedly lower than those measured in April (Tables 2 and 3).

Moreover, direction of changes in VO2max obtained with indirect methods in female (an increase of the values from November to April) and male (a decrease of the values from April to November) rowers was the same as that detected by using direct methods (Tables 2 and 3). In contrast to females the change in male rowers was corroborated by statistically significant correlation coefficients calculated for the alterations of VO2max from April to November (ΔVO2max) (Table 4).

The total error for the indirect methods expressed in relative values for the two examination months ranged from 2.2 to 3.9 ml/kg/min for female rowers and from 3.2 to 4.4 ml/kg/min for male rowers (Tables 3 and 4). This error was higher than the real changes recorded in April versus November in female rowers (+1.5±2.5 ml/kg/min) and in November versus April in male rowers (-2.7±3.7 ml/kg/min) (Table 5).

Table 1

Basic characteristics of female (n=8) and male (n=14) rowers participating in the study

Group	Age (years)	Body mass (kg)	Body height (cm)	% fat	Training Experience (years)
Female rowers	18.1±1.3	73.4±4.4	181±5	24.1±4,5	4.4±1.2
Male rowers	20.2±0.8	90.7±4.4	192±5	13.2±2.4	6.4±1.6

Table 2

Measured (M) and calculated (C) values of maximal oxygen uptake (VO_{2max}), total error (TE) for VO_{2max} obtained in the 2 km test and PWC_{170} in the examined female rowers (n=8)

Variable	November	April
VO_{2max} (M) [ml/kg/min]	50.5±2.4	52.0±2.2
VO_{2max} (C) 2 km test [ml/kg/min]	53.1±3.0	53.3±3.7
VO_{2max} (C) PWC_{170} [ml/kg/min]	51.3±3.8	51.9±4.1
TE 2 km test [ml/kg/min]	3.9	2.2
TE 2 km test [%]	7.7	4.2
TE PWC_{170} [ml/kg/min]	3.8	2.7
TE PWC_{170} [%]	7.5	5.1

Table 3

Measured (M) and calculated (C) values of maximal oxygen uptake (VO_{2max}), total error (TE) for VO_{2max} obtained in the 2 km test and PWC_{170} in the examined male rowers (n=14)

Variable	April	November
VO_{2max} (M) [ml/kg/min]	62.6±4.2	59.9±4.5*
VO_{2max} (C) 2 km test [ml/kg/min]	63.4±2.3	61.1±4.1
VO_{2max} (C) PWC_{170} [ml/kg/min]	61.8±2.4	59.9±4.1
TE 2 km test [ml/kg/min]	3.2	3.9
TE 2 km test [%]	5.1	6.5
TE PWC_{170} [ml/kg/min]	4.1	4.4
TE PWC_{170} [%]	6.6	7.4

** - significant differences ($p<0.05$) between April vs November*

Table 4

Pearson correlation coefficients for changes in maximal oxygen uptake from one evaluation month to another (ΔVO_{2max}) between the values measured (M) and calculated (C) from the 2 km test and between the values measured (M) and calculated (C) from PWC_{170} in female (n=8) and male (n=14) rowers

	ΔVO_{2max}/kg (M)	
Variable	Females	Males
ΔVO_{2max}/kg (C) 2-km Test	0.49	0.67*
ΔVO_{2max}/kg (C) PWC_{170}	0.22	0.66*

** – statistically significant ($p<0.05$) value of the correlation coefficient*

Table 5

Changes in maximal oxygen uptake from one evaluation month to another (ΔVO_{2max}) for the values measured (M) and calculated (C) from the 2 km test and the values calculated (C) from PWC_{170} in female (n=8) and male (n=14) rowers

Variable	Females	Males
ΔVO_{2max} (M) [ml/kg/min]	1.5±2.5	-2.7±3.7
ΔVO_{2max} (C) 2-km Test [ml/kg/min]	0.2±2.0	-2.3±3.4
ΔVO_{2max} (C) PWC_{170} [ml/kg/min]	0.6±2.3	-1.8±2.8

Discussion

The data obtained in the present study demonstrate that the two elaborated methods of estimation of maximal oxygen uptake yield more accurate results in male compared to female rowers. This observation is corroborated in former athletes by the lack of significant differences between the measured and calculated VO_{2max} as well as by the significant correlation coefficients obtained for the changes in the indexes between the two examination periods (Tables 3 and 4). The correlation between the changes in actual VO_{2max} values and the ones predicted based on mean power output for the 2 km test and PWC_{170} was statistically significant only for male rowers and equaled r = 0.67 and 0.66 ($p<0.05$), respectively. In the group of female rowers this correlation was smaller and statistically non-significant: the correlation coefficient for mean power output for the 2 km test and PWC_{170} estimation methods was r = 0.49 and r = 0.22, respectively, which was probably caused by the fact that female subjects were of the same age and the group was smaller than would be advisable to generalize the results of the study.

Similarly as in this study, Huntsman et al. (2011) observed a stronger correlation between actual and predicted values of VO_{2max} in male rowers than in female ones (r = 0.55 vs. r = −0.05). The authors stated that one of the reasons why the stress test used to design the method of estimating VO_{2max} was suitable only for male participants of the study and inappropriate for females was the design of the test protocol: an identical increase in the load (by 50 W) was applied both for men and women, which resulted in a more significant increase in relative intensity of the test in female participants, causing an excessive increase in the HR in the subsequent phases of the exercise. According to Huntsman et al. (2011), reducing these loads would make it possible to lower the increase in the HR and improve the predictive value of the test. In the current study protocol, the increase in the load for female subjects was smaller (40 W), however, when taking the subjects' body mass into consideration, it was the same for male and female subjects, and this might have been one of the factors, in addition to the ones mentioned above, which caused the validity of the methods used to predict changes in VO_{2max} values in the training cycle for female rowers, especially of the method based on PWC_{170} (r = 0.22), to be lower.

The total error (%) for the indirect methods used in the respective examination periods ranged from 4.2 to 7.7% in female and from 5.1 to 7.4% in male subjects. These data are compatible with earlier results (TE from 4.9 to 6.0%) obtained in a larger group of subjects (Klusiewicz and Faff, 2003). The validity of the methods used to predict VO_{2max} in male and female rowers assessed using the total error (TE) approach ranged from 4.2 to 7.7% and was within the range of intersubject variability for VO_2 values obtained in the measurement carried out for a given level of a submaximal workload, which, according to ACSM guidelines, can be as high as 7% when assessed using SEE (American College of Sports Medicine, 2006).

The validity of the equation used for estimating VO_{2max}, both in male and female rowers, based on the linear relationship between VO_{2max}-WM and VO_{2max}-PWC_{170} is much higher in the current study than that of the methods designed by Huntsman et al. (2011) based on the linear relationship between HR-VO_2. The VO_{2max} values estimated using the methods suggested by these authors amounted to only 77.4% and 75.3% of the VO_{2max} values measured in male and female rowers from university sports teams. It seems that one of the factors that contributed to such low accuracy of the methods used to predict VO_{2max} by Huntsman et al. (11) was the fact that they used 2 min intervals from the stress test protocol when calculating the linear regression HR-VO_2 and the peak for the HR from the submaximal phase of the test, instead of using a mean value for the HR from a given phase of the test. This modification seems to be necessary due to intrasubject variability in the HR, particularly with low-intensity submaximal effort, that affects the linearity of the HR-VO_2 relationship, which is a basic assumption for estimating VO_{2max} using HR values (Davies, 1968). According to Marsh (2012), all intrasubject variability in the HR during submaximal effort which is independent of VO_2 can cause errors in equations used to predict VO_{2max}, and, in our opinion, using peak HR values for this purpose can increase the probability of errors. Moreover, according to our observations, a steady-state HR, which is one of the conditions for accurately estimating VO_{2max} (American College of Sports Medicine, 2006) is not always achieved after 2 min of effort, particularly if there is a significant increase in the load, as was the case in the study conducted by Huntsman et al. (2011). The equation used to estimate VO_{2max} in the current study based on its relationship with PWC_{170}, calculated on the basis of the subjects' HR in the last 15 s of 3 min bouts of exercise that made it possible to achieve a steady-state HR, enabled us to avoid errors resulting from HR variability during submaximal efforts, considerably increasing the accuracy of the methods used. These methods were validated when tracking the changes in VO_{2max} in the training cycles of male and female rowers, although the validity of both methods was higher for male subjects. Huntsman et al. (2011) also claimed that the reason for the low validity of their method for predicting VO_{2max} in rowers was the 30 s breaks between the following phases of the test protocol. This can happen when duration of the bouts of exercise in stress tests is too short for a steady-state HR to be achieved. If the subjects exercise for at least 3 min, then 1 or even 3 min breaks do not reduce the validity of the equations used for predicting VO_{2max} (Klusiewicz et al., 2011; Morris et al., 2009).

In the present study the usefulness of indirect methods of estimation of maximal oxygen uptake during the training cycle was evaluated in female and male rowers over five and seven months, respectively. As one could have expected the adaptive changes were observed in different periods of a training cycle. Indeed, the foreseen rise in maximal oxygen uptake, as estimated in direct measurements, equalled to 3.0% and the reduction to 4.3%. The results for the group of female rowers showed that the mean predicted VO_{2max} in November (the transitional period of the annual cycle), estimated based on mean power output for the 2 km test and on PWC_{170}, was overestimated compared to actual VO_{2max}, and the total error in the accuracy of predicting VO_{2max} was 7.7% and 7.5%, respectively. In April (at the end of the preparatory period of the annual cycle), when the aerobic capacity of the subjects had increased (mean VO_{2max} values increased from 50.5 to 52.0 ml/kg/min), the accuracy of predicting VO_{2max} using both methods improved as well, and the total error was 4.2% and 5.1%. The results for the group of male rowers showed that in April (at the end of the preparatory period) mean predicted VO_{2max} values estimated using mean power output for the 2 km test were overestimated compared to actual VO_{2max} values by 0.8 ml/kg/min, and the values calculated using PWC_{170} were underestimated by 0.8 ml/kg/min; the total error for the two methods was 5.1% and 6.6%, respectively. In November in the transitional period, when the aerobic capacity of male rowers declined (mean VO_{2max} significantly decreased from 62.6 to 59.9 ml/kg/min, $p < 0.05$), the accuracy of the estimation of VO_{2max} using both methods dropped as well, as indicated by an increase in total error rates, up to 6.5% and 7.4%, respectively. To conclude, the accuracy of predicting VO_{2max} using the two methods mentioned above was greater at the end of the preparatory period than in the transitional period, both for male and female rowers.

One of the reasons for the improvement of the accuracy of predicting VO_{2max} in April i.e. at the end of the preparatory period, both in male and female rowers, could have been the subjects' higher level of aerobic capacity at that time, which better corresponded with their physical capacity. A higher fitness level in this period of the annual training cycle, which was proved not only by the subjects' better physical capacity but also by better rowing technique, changed the economy of effort, increasing the accuracy of VO_{2max} estimation. This effect was noticed by Marsh (2012) who evaluated the predictive validity of the regression equation for estimating VO_{2max} recommended by the ACSM in a study involving runners of varying levels of fitness.

Previously, Carey (1997) evaluated the suitability of four indirect methods for estimating changes in physical fitness induced by a six-week training program and concluded that these methods were poorly applicable for such purposes, but also noted that the analyzed period of time was too short to detect significant alterations in VO_{2max}. Likewise, the present study demonstrates that despite the statistically confirmed applicability of indirect methods for estimation of maximal oxygen uptake, the usefulness of these methods for the assessment of changes in physical fitness of competitive rowers during the training cycle is rather low. This conclusion is based on the observation that the total error of indirect methods was higher than the actual differences in the directly measured VO_{2max} values. In spite of this, indirect methods are still regarded as very useful for evaluations of not only amateur but also professional athletes, especially during field or pre-selection tests aimed at estimation of their physical capacity.

Practical implications

1. The results of this study indicate that VO_{2max} can be assessed in a relatively accurate way in female and male rowers using a submaximal test with a gradual increase in power and a 2 km test carried out on a rowing ergometer, based on simple measurements, namely those of power and HR.
2. The accuracy of indirect methods is influenced by the phase of the training cycle. For the two methods used, based on mean power output for the 2 km test and PWC_{170}, the total error rate was smaller both for female and male subjects when their physical capacity was higher.

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