

**ASSESSMENT OF THE ACCURACY OF PREDICTION OF THE MAXIMAL OXYGEN UPTAKE BASED ON SUBMAXIMAL EXERCISES IN THE FORMER ELITE ROWERS AND PADDLERS**

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**Abstract.** The aim of the present study was to assess the usefulness of the Astrand-Rhyming and extrapolation methods as well as modifications thereof for prediction of the maximal oxygen uptake ( $VO_{2max}$ ) in the former elite rowers and paddlers, i.e. the representatives of sports requiring high endurance capacity and strength. For the assessment, results obtained in 52 former athletes aged between 30 and 67 years were used. The subjects performed the incremental exercise test on a cycle ergometer until volitional exhaustion.  $VO_{2max}$  was determined directly and its predicted values were also calculated based on the following parameters: the heart rate (HR) during a submaximal exercise at the given oxygen uptake (A-R1) or power output (A-R2) using the Astrand-Rhyming nomogram as well as modification of these methods (A-R3 and A-R4) in which the obtained results were multiplied by the additional age-related coefficient calculated from the linear regression of the subjects' age relative to the quotient of the measured and predicted  $VO_{2max}$  values; the relationship between the oxygen uptake and heart rate at a submaximal exercise extrapolated to the age-predicted values of  $HR_{max}$  calculated according to the formulas:  $HR_{max} = 220 - \text{age}$  (Extrp.1),  $HR_{max} = 220 - 0.9 \cdot \text{age}$  (Extrp.2), and  $HR_{max} = 197.4 - 0.435 \cdot \text{age}$  (Extrp.3); the latter formula was based on the linear regression of  $HR_{max}$  relative to the subjects' age in the examined group. Accuracy of the prediction of  $VO_{2max}$  was estimated based on the following indices: the difference between  $VO_{2max}$  determined directly and indirectly (MD), the correlation coefficient ( $r$ ) between these values, the standard estimation error (SEE), and the total error (TE). The results indicate that modifications of the A-R1, A-R2, and Extrp.1 methods significantly increased the accuracy of the  $VO_{2max}$  prediction with A-R3 and Extrp.2 being the most efficient. In the A-R3 compared to the A-R1 method significant decreases of MD (1.6% vs. 13.9%) and TE (6.5 vs. 8.2) were detected even though  $r$  (0.70 vs. 0.71) did not change and SEE rose insignificantly (6.4 vs. 5.7). In the Extrp.2 compared to the Extrp.1 method, decreases of MD (3.4% vs. 6.8%) and TE (4.5 vs. 5.2) were also detected, whereas  $r$  (0.84 vs. 0.83) and SEE (4.2 vs. 4.4) remained unchanged. Overall, our results demonstrate that  $VO_{2max}$  can be relatively precisely estimated

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in the former paddlers and rowers based on the heart rate at submaximal exercises. Apparently, a significant increase in the accuracy of the  $VO_{2max}$  prediction following modification of the widely used methods is partly due to the age-related slower decrease of  $HR_{max}$  in the former athletes compared to that found in people not engaged professionally in sports and/or in the former athletes from other sports. *(Biol.Sport 22:125-134, 2005)*

*Key words:* Prediction of the maximal oxygen uptake - Submaximal cycle ergometer test - the Astrand-Rhyming methods - extrapolation methods

## Introduction

Maximal oxygen uptake ( $VO_{2max}$ ) is generally viewed as the best index of the human body's cardio-pulmonary fitness. The most thorough method of estimation of  $VO_{2max}$  is a direct measurement of the oxygen uptake ( $VO_2$ ) at the maximal exercise test. This measurement, however, is troublesome due to the necessity of a) the strict adherence to the criteria of the maximal effort, b) meticulous evaluation of the health status of a subject prior to the test, and c) continuous supervision of the test by a physician trained in treatment of a circulatory failure. Particularly careful must be the direct measurement of  $VO_{2max}$  in the middle-aged and older subjects as well as in all the physically inactive people. In addition, appropriate equipment required for the measurements is rather expensive. Hence, numerous methods of prediction of  $VO_{2max}$  have been elaborated based on responses of the circulatory system during submaximal exercises. The most commonly employed methods to test subjects not professionally engaged in sports are the Astrand-Rhyming method along with its modifications, and the method of extrapolation of  $VO_2$  from the submaximal heart rate to the maximal age-predicted heart rate [2,4,7,20]. Indirect methods of estimation of  $VO_{2max}$  are less frequently used in athletes, especially from the endurance sports, when precise evaluation of the maximal oxygen uptake is required.

In this context, the aim of the present study was to evaluate the usefulness of the indirect methods of determination of  $VO_{2max}$  in the former elite rowers and paddlers. Noteworthy, no reports have been published so far on the effects of the former professional engagement in the strength/endurance sports as well as of staying physically active after retirement on the age-induced changes in terms of the relation between the heart rate and oxygen uptake during submaximal exercises and the maximal oxygen uptake. In fact, this relation provides the basis for the most commonly used indirect methods of estimation of  $VO_{2max}$ .

## Material and Methods

Seventy seven former elite rowers and paddlers aged between 30 and 67 years volunteered to participate in the present study. Approval from the Research and Ethics Committee of the Institute of Sport had been granted prior to the beginning of testing and all the procedures and possible risks associated with exercising at maximal strength at the old age were explained to the subjects before obtaining their written informed consent. Preliminary medical tests including general examination, the 24-hour ECG (the Holter method), analysis of the heart rate variability, resting ECG before each test cycle, examination of the respiratory system, blood tests, and the serum levels of lipids, glucose, and the selected enzymes were performed. Based on the results of these examinations, 69 former athletes were selected for participation in the exercise tests.

The subjects performed an incremental exercise test on the Jeager ER 900 cycle ergometer. The initial workload and pedalling rhythm equalled to 50 W and 55 revolutions  $\text{min}^{-1}$ , respectively; these parameters were increased gradually by 50 W and 5 revolutions  $\cdot \text{min}^{-1}$ , respectively, during the consecutive four-minute exercises. At the fourth minute after completion of the test, arterial blood samples were collected from the finger pulp and the serum lactate concentration was determined using an enzymatic method (Boehringer-Mannheim, Germany). Heart rate was registered continuously at rest and during the exercise using the Medea Stress Test (Gliwice) or the Marquette Hellige computers, the latter operating in the MemoPort 4000 system.

The respiratory gasometric parameters, such as pulmonary ventilation, oxygen uptake, and carbon dioxide excretion in the open system, were estimated with the use of the MMC Beckman set. The printouts were obtained every 30 seconds. The criteria upon which the attainment of  $\text{VO}_{2\text{max}}$  was based included:

- plateaued  $\text{VO}_2$  despite the increasing workload;
- post-exercise serum lactate concentration  $< 8 \text{ mmol} \cdot \text{l}^{-1}$ ;
- respiratory exchange ratio  $\text{RQ} > 1.10$ ;
- maximal age-related heart rate estimated according to the formula:  $\text{HR}_{\text{max}} = 220 - 0.9 \cdot \text{age}$ .

If at least two of the above criteria were met during the exercise, the workload and oxygen uptake was regarded as maximal [13]. These criteria were satisfied by 52 of the tested subjects; five of the remaining subjects aborted the exercises before satisfying the above criteria, and twelve had to cease the exercising due to the appearance of such symptoms as depression of the ST segment (2 subjects), cardiac arrhythmia (2 subjects), bodily discomfort (1 subject), decrease of the systolic

blood pressure despite the rise in the workload (4 subjects), and excessive increase of the blood pressure (3 subjects).

For estimation of the maximal oxygen uptake with indirect methods the heart rate and oxygen uptake recorded at the last minute of the submaximal exercise preceding the maximal effort in the incremental exercise test were used. The  $VO_{2max}$  values were calculated using the following indirect methods:

- A-R1 - based on the heart rate at the given oxygen uptake with use of the Astrand-Rhyming nomogram corrected for the subject's age;
- A-R2 - based on the heart rate at the given power output with use of the Astrand-Rhyming nomogram corrected for the subject's age;
- A-R3 - as in A-R1 multiplied by the age-related coefficient equalled to  $0.897 + 0.006 \cdot \text{age}$  (in years), as calculated from the linear regression of age relative to  $VO_{2maxa}/VO_{2maxp}$  in the tested group, where  $VO_{2maxa} = VO_{2max}$  determined directly, and  $VO_{2maxp} = VO_{2max}$  calculated as in A-R1;
- A-R4 - as in A-R2 multiplied by the age-related coefficient equalled to  $0.7234 + 0.008 \cdot \text{age}$  (in years), as calculated from the linear regression of age relative to  $VO_{2maxa}/VO_{2maxp}$  in the tested group, where  $VO_{2maxa} = VO_{2max}$  determined directly, and  $VO_{2maxp} = VO_{2max}$  calculated as in A-R1;
- Extrp.1 - based on the relation between the oxygen uptake and heart rate at the submaximal exercises extrapolated to the age-related values of  $HR_{max}$  according to the formula:  $HR_{max} = 220 - \text{age}$  (in years);
- Extrp.2 - based on the relation between the oxygen uptake and heart rate at the submaximal exercises extrapolated to the age-related values of  $HR_{max}$  according to the formula:  $HR_{max} = 220 - 0.9 \cdot \text{age}$  (in years);
- Extrp.3 - based on the relation between the oxygen uptake and heart rate at the submaximal exercises extrapolated to the age-related values of  $HR_{max}$  calculated from the formula of the linear regression of  $HR_{max}$  relative to the age of the former athletes, where  $HR_{max} = 197.4 - 0.435 \cdot \text{age}$  (in years);
- Additionally the formulas:  $HR_{max} = 220 - 0.85 \cdot \text{age}$ , and  $HR_{max} = 220 - 0.95 \cdot \text{age}$  had also been used but the lowest MD at the insignificantly higher correlation coefficient and similar or insignificantly lower TE and SEE were obtained using the formula:  $HR_{max} = 220 - 0.9 \cdot \text{age}$ .

To assess the accuracy of the tested methods the following parameters were calculated:

- the difference between  $VO_{2max}$  determined directly and indirectly (MD) and the statistical significance of the difference;
- the coefficient of correlation between  $VO_{2max}$  determined directly and indirectly (r) and the statistical significance of this correlation;

- the standard estimation error (SEE) according to the formula

$$SEE = Sy \cdot \sqrt{1 - r^2},$$

where: Sy - standard deviation of the mean  $VO_{2max}$  determined with use of the given indirect method, r - coefficient of correlation between the measured and predicted  $VO_{2max}$ ;

- total error (TE) calculated with the formula  $TE = \sqrt{\frac{\sum (y - Y)^2}{n}}$ ,

i.e., square root of the sum of squares of the individual differences between  $VO_{2maxa}$  and  $VO_{2maxp}$  (y-Y) divided by the number of the subjects (n).

## Results

**Table 1**

Comparison of the directly measured (mean value  $40.9 \pm 7.6 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) and predicted values of the maximal oxygen uptake. Presented are means  $\pm$  SD, mean differences (MD), correlation coefficients (r), standard estimation errors (SEE), and total errors (TE). Percentages were calculated for the directly measured values

Coefficient	Method						
	A-R1	A-R2	A-R3	A-R4	Extrp.1	Extrp.2	Extrp.3
$VO_{2max} \pm SD$ ( $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ )	35.2 $\pm$ 8.2	38.0 $\pm$ 9.1	41.5 $\pm$ 8.9	41.6 $\pm$ 8.8	38.1 $\pm$ 7.9	39.5 $\pm$ 7.9	39.0 $\pm$ 7.3
MD $\pm$ SD ( $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ )	5.7 $\pm$ 6.0***	2.9 $\pm$ 6.7**	-0.6 $\pm$ 6.5	-0.7 $\pm$ 6.7	2.8 $\pm$ 4.5***	1.4 $\pm$ 4.3*	1.9 $\pm$ 4.2**
MD $\pm$ SD (%)	13.9 $\pm$ 14.7	7.1 $\pm$ 16.4	1.6 $\pm$ 15.9	1.7 $\pm$ 16.4	6.8 $\pm$ 11.0	3.4 $\pm$ 10.5	4.6 $\pm$ 10.3
r	0.71***	0.68***	0.70***	0.67***	0.83***	0.84***	0.84***
r <sup>2</sup>	0.50	0.47	0.49	0.45	0.69	0.71	0.71
SEE ( $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ )	5.7	6.6	6.4	6.5	4.4	4.2	4.1
TE ( $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ )	8.2	7.3	6.5	6.70	5.2	4.5	4.5
TE (%)	20.0	17.8	15.9	16.4	12.7	11.0	11.0

\*p<0.05, \*\*p<0.01, \*\*\*p<0.001

Table 1 shows mean values of the maximal oxygen uptake in the group of the former athletes determined indirectly based on the indices obtained in the submaximal exercises ( $VO_{2maxp}$ ) compared to  $VO_{2max}$  determined directly in the maximal exercise ( $VO_{2maxa}$ ); the latter value equalled to  $40.9 \pm 7.6$  ml/kg. Interestingly, mean values of  $VO_{2maxp}$  determined with use of the most common indirect methods denoted in the tables as A-R1, A-R2, and Extrp.1 are significantly different from the  $VO_{2maxa}$  values. Precision of the prediction (e.g., lower SEE and TE, and an increased correlation coefficient) was higher using the extrapolation method (Extrp.1) than the Astrand-Rhyming methods (A-R1, A-R2). Modifications of the A-R1 and A-R2 methods (denoted as A-R3 and A-R4) significantly reduced the differences between the determined and predicted  $VO_{2max}$  (MD) and slightly decreased TE. Modifications of the Extrp.1 method (marked as Extrp.2 and Extrp.3) led to the decreased MD and TE without affecting the remaining indices.

### Discussion

An original result of the present study is the selection of methods useful for a precise prediction of  $VO_{2max}$  in the former rowers and paddlers, i.e., the representatives of sports requiring high endurance capacity and strength. The presented methods constitute a modification of the widely used methods of determination of the maximal oxygen uptake based on submaximal exercises. For the last 50 years, the selected by us Astrand-Rhyming method has been most frequently applied for indirect estimation of  $VO_{2max}$  [4]. Somewhat less frequently used method recommended by the WHO is based on extrapolation from the oxygen uptake at the submaximal heart rate to the maximal age-related heart rate [2].

The obtained results indicate that the commonly applied methods yield the markedly decreased values of  $VO_{2max}$  in the examined group. As indicated by the smallest difference between the measured and predicted  $VO_{2max}$  (6.8% vs. 13.9% and 7.1%), the highest value of the coefficient of correlation ( $r$ ) between these indices (0.83 vs. 0.71 and 0.68), as well as the lowest SEE (4.4 vs. 5.7 and 6.6) and TE (12.7% vs. 20% and 17.8%), the Extrp.1 method was somewhat more accurate than the A-R1 and A-R2 methods. Noteworthy, the accuracy of prediction of  $VO_{2max}$  with use of the A-R1, A-R2, and Extrp.1 methods was similar to that obtained by other authors. For instance, Louhevaara *et al.* [20] found that the differences between measured  $VO_{2max}$  values and those predicted by the Astrand-Rhyming method equalled to 2.9% and 8.1%, whereas the  $r$  values equalled to 0.39 and 0.73. In accord with the present study, these authors obtained more precise results using the extrapolation method: the respective differences between the

measured and predicted  $VO_{2max}$  equalled to 4.6% and 6.1%, while the  $r$  values equalled to 0.81 and 0.83. Using the Astrand-Rhyming methodology, the correlation coefficient values obtained by other investigators ranged from 0.53 to 0.8 and the SEE values from 4.57 to 8.05 [6,7,11,19,21,24]. Mean value of the coefficient of correlation between  $VO_{2maxa}$  and  $VO_{2maxp}$  calculated by Carey *et al.* [6] from the results of the reviewed 24 studies ( $r=0.69$ ) approximated that obtained by us with use of the A-R1 and A-R2 methods, but was lower than that obtained using the Extrap.1 method. On the other hand, the mean SEE value calculated by the cited authors (SEE = 4.36) was similar to the one obtained by us using the Extrap.1 method but lower than those obtained using the A-R1 and A-R2 methods. Interestingly, a few reports have suggested that a high conformity between  $VO_{2maxa}$  and  $VO_{2maxp}$  can be obtained when new methods of the measurements or modifications thereof are applied [17,19,25]. Thus far, however, no reports substantiating the usefulness of such modifications have been published.

Application of the additional age-related index in the Astrand-Rhyming methodology significantly improved the accuracy of prediction of  $VO_{2max}$  using both the A-R1 and the A-R2 methods. Mean differences between  $VO_{2maxa}$  and  $VO_{2maxp}$ , which equalled to 1.6% and 1.7%, respectively, do not differ significantly from zero pointing to the extremely high reproducibility of the results. Modification of this method resulted also in a slight reduction of the total error value although no changes were noted in the correlation coefficient and SEE. Likewise, a significant rise in the accuracy of prediction of  $VO_{2max}$  was achieved in the extrapolation method following modification of the formula for calculating  $HR_{max}$ , i.e.  $220 - \text{age}$  (in years) [9,12,22]. This formula has been substantiated by numerous observations in which mean  $HR_{max}$  approximated in the age-related manner the value of  $220 - \text{age}$  [1,3,12,16,28,33]. Despite this, after replacement of the formula  $HR_{max} = 220 - \text{age}$  with  $HR_{max} = 220 - 0.9 \cdot \text{age}$  in the Extrap.2 method or the one obtained from the linear regression of  $HR_{max}$  relative to age (in the examined group), i.e.  $HR_{max} = 197.4 - 0.435 \cdot \text{age}$  in the Extrap.3 method, a significant decrease in the differences between  $VO_{2maxa}$  and  $VO_{2maxp}$ , increase in the correlation coefficient, and reduction of TE and SEE were obtained. Although two different formulas for calculating  $HR_{max}$  were used, the accuracy of prediction of  $VO_{2max}$  using the Extrap.2 and Extrap.3 methods was almost identical. Of some importance may be the fact that  $HR_{max}$  calculated for the mean age of the subjects (i.e., 48.2 years) was identical in the Extrap.2 and Extrap.3 methods (176.6 vs. 176.4), although the line of regression of  $HR_{max}$  relative to age in the formula used in the former method is steeper than that obtained in the formula used in the Extrap.3 method. Clearly, compared to the Extrap.3 method the Extrap.2 modification

appears to yield slightly lower MD values (3.4 vs. 4.6) at the same  $r$ , TE, and SEE values.

Comparison of the A-R3 (MD=1.6%,  $r=0.7$ , SEE=6.4, TE=6.5) method with the Extrp.2 (MD=3.4%,  $r=0.84$ , SEE=4.2, TE=4.5) method suggests that due to the lower MD the former modification is more accurate for obtaining average values in groups of subjects, whereas the latter method, which yields less diversified results, is more useful for testing individual people.

A significant increase in the accuracy of prediction of  $VO_{2max}$  resulting from some modifications of the widely used methods may be, to a certain extent, associated with the relatively slow decrease in the maximal heart rate (by 0.43 beats·min<sup>-1</sup> annually) detected in the former athletes. Most of the reports of other authors indicated faster reduction of  $HR_{max}$  (by 0.5 to 1.14 beats·min<sup>-1</sup> per year) in the physically inactive people as well as in the former athletes [11,14,15,16,22,26,27,30,32,34]. In fact, a slower decrease with age of the heart rate in the intensively training subjects was reported only by a few investigators [29,30].

The significant differences between the rapidity of the age-related reduction of  $HR_{max}$  in the former athletes from the endurance-strength sports and those reported by other authors from studies of the former athletes from other sports or of people not engaged professionally in sports can be related to the specificity of training and/or the inherited traits of the subjects tested in the present study enabling them to achieve excellent results in sports. As mentioned earlier, rowers and paddlers are characterised by a large mass and strength of the muscles as well as by a very high aerobic capacity, the features rare in athletes from other endurance or strengths sports, respectively [11,18]. Nonetheless, a large diversity of the present results with respect to the above discussed differences in the speed of the age-related decrease in the maximal heart rate (similar to the ones showed in all the cited reports concerning  $HR_{max}$ ), warrants further investigations.

In conclusion, the obtained results indicate that  $VO_{2max}$  can be relatively precisely estimated in the former rowers and paddlers based on submaximal exercises utilising the modified Astrand-Rhyming method and the extrapolation to the age-predicted  $HR_{max}$ . Apparently, a significant increase in the accuracy of prediction of this parameter following modification of the widely used methods is partly due to the slower age-related reduction of  $HR_{max}$  in the former rowers and paddlers compared to the average characteristic for either people not professionally engaged in sports or the former athletes from other sports.

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