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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 – age (Extrp.1), HR_{max} = 220 – 0.9·age (Extrp.2), and HR_{max} = 197.4 – 0.435·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 min^{-1}, respectively; these parameters were increased gradually by 50 W and 5 revolutions$\cdot min^{-1}$, 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 VO_{2max} was based included:

- plateaued VO_2 despite the increasing workload;
- post-exercise serum lactate concentration < 8 $mmol\cdot l^{-1}$;
- respiratory exchange ratio RQ >1.10;
- maximal age-related heart rate estimated according to the formula: $HR_{max} = 220 - 0.9\cdot age$.

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·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·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 – 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·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·age (in years);
- Additionally the formulas: HR_{max} = 220 – 0.85·age, and HR_{max} = 220 – 0.95·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·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±7.6 $ml \cdot kg^{-1} \cdot min^{-1}$) and predicted values of the maximal oxygen uptake. Presented are means ± SD, mean differences (MD), correlation coefficients (r), standard estimation errors (SEE), and total errors (TE). Percentages were calculated for the directly measured values

	Method						
Coefficient	A-R1	A-R2	A-R3	A-R4	Extrp.1	Extrp.2	Extrp.3
VO_{2max}±SD ($ml \cdot kg^{-1} \cdot min^{-1}$)	35.2±8.2	38.0±9.1	41.5±8.9	41.6±8.8	38.1±7.9	39.5±7.9	39.0±7.3
MD ±SD ($ml \cdot kg^{-1} \cdot min^{-1}$)	5.7±6.0***	2.9±6.7**	-0.6±6.5	-0.7±6.7	2.8±4.5***	1.4±4.3*	1.9±4.2**
MD ±SD (%)	13.9±14.7	7.1±16.4	1.6±15.9	1.7±16.4	6.8±11.0	3.4±10.5	4.6±10.3
r	0.71***	0.68***	0.70***	0.67***	0.83***	0.84***	0.84***
r^2	0.50	0.47	0.49	0.45	0.69	0.71	0.71
SEE ($ml \cdot kg^{-1} \cdot min^{-1}$)	5.7	6.6	6.4	6.5	4.4	4.2	4.1
TE ($ml \cdot kg^{-1} \cdot min^{-1}$)	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±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 Extrp.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 Extrp.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 – 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 – age [1,3,12,16,28,33]. Despite this, after replacement of the formula HR_{max} = 220 – age with HR_{max} = 220 – 0.9·age in the Extrp.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·age in the Extrp.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 Extrp.2 and Extrp.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 Extrp.2 and Extrp.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 Extrp.3 method. Clearly, compared to the Extrp.3 method the Extrp.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$\cdot$min^{-1} 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$\cdot$min^{-1} 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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