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PREDICTION OF MAXIMAL OXYGEN UPTAKE FROM SUBMAXIMAL HEART RATE IN 13- TO 16-YEAR OLD BOYS AND GIRLS

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ABSTRACT

Values for oxygen uptake (VO_2) and heart rate (HR) at a submaximal running effort in boys and girls (aged 13-16) are used to study the best prediction of $\dot{V}O_2$max. The predictions were "validated" with (longitudinal) data from a (sub)maximal running test on a treadmill test measuring HR and $\dot{V}O_2$max in adolescent boys and girls from the Amsterdam Growth and Health Longitudinal Study (AGAHLS). For the prediction of $\dot{V}O_2$max, either absolute submaximal heart rate (HR_{submax}) was used or submaximal heart rate as a percentage of heart rate reserve (HR_{res}). The results indicated that HR_{res} was the most appropriate in predicting $\dot{V}O_2$max by submaximal test results. Furthermore, there was hardly any improvement in the estimated $\dot{V}O_2$max by using information from two running periods at 8 km/h on 0% and 2,5% slope instead of one running period (8 km/h on slope 0%). The best equation for $\dot{V}O_2$max, by stepwise regression analysis, uses body mass, body height, sex and HR_{res} after two minutes running (8km•hr^{-1}, slope 0%). The error made in this prediction does not exceed 18.5% in boys and 3.1% in girls.

The advantage of this submaximal running test is that it needs only a two minutes running period with a speed of 8 km/h at a horizontal slope with measurement of heart rate at rest and submaximal heart rate.

Key words: maximal oxygen uptake, teenage boys and girls, prediction from submaximal heart rate

Introduction

The direct measurement of the maximal oxygen uptake ($\dot{V}O_2$max) is considered to be the most accurate method to assess $\dot{V}O_2$max. This direct measurement however is expensive, requires sophisticated equipment, and takes much time. Large groups of teachers and trainers in physical fitness like to use more simple and inexpensive field-tests to predict $\dot{V}O_2$max of their pupils. The results of these (sub maximal) field-tests (6 or 12 minutes running, 1 mile or 2 km walking, 20 m shuttle run etc.) have different correlations with the real $\dot{V}O_2$max measurement in the different studies (0.4-0.9) (2, 3, 13, 10, 20-22). The variation in protocols of field-tests and the variation in protocols for the measurement of $\dot{V}O_2$max partially explains these different correlations. Furthermore, the differences in correlation may be explained by homogeneity in the population, the lack of motivation and/or the intra-individual variation of the maximal heart rate (14).

With the development of a simple running test for children to get an indication of their aerobic power a contribution can be made to the general conclusion of the

International proceedings and consensus statement in Physical activity, Fitness and Health: a consensus of current knowledge (1). ”Focus your attention in the near future on obtaining data of submaximal tests of moderate level. So we can develop simple but accurate feedback information for the population”. People use feedback-information to monitor themselves. It influences their self-efficacy on physical activity and this self-efficacy plays an important role to maintain or change activity behaviour (4, 5, 16, 17, 18).

From the linear relationship between the heart rate (HR) and the oxygen uptake (VO_2) during exercise, regardless of gender, fitness level or age (19, 24), it is possible to predict the maximal oxygen consumption using the results of a submaximal (field) test.

The present study was designed to answer the following research questions:

1. How accurate can we predict $\dot{V}O_2max$ by using submaximal heart rate and submaximal VO_2 values with different definitions of submaximal heart rate?
2. How accurate can we predict $\dot{V}O_2max$ by a simple submaximal field test?

Materials and methods

Subjects

The subjects of this study were boys and girls (13-16 years old) from the Amsterdam Growth and Health Longitudinal Study (AGAHLS). They were pupils from two high schools in Amsterdam and Purmerend (the Netherlands). Four annual measurements were available from a running test on a treadmill with measurements of heart rate and oxygen uptake (Table 1).

Measurements

Heart rate (HR) and oxygen (uptake) were measured by a direct method using a (sub) maximal running test on a treadmill. The protocol of the submaximal running test was: 2 minutes at 8 km•hr^{-1} on slope 0 %, 2 minutes at 8 km•hr^{-1} on slope 2.5 %, 2 minutes at 8 km•hr^{-1} on slope 5 %. After a short recovery the running test was continued at the same speed (8 km•hr^{-1}) and slope was increased with 2.5 % or 5 % every 2 minutes, depending on the heart rate of the subject. The running test was continued until complete exhaustion. As confirmation of exhaustion (reaching $\dot{V}O_2max$), we applied three criteria: (1) a levelling-off in oxygen uptake, calculated as an increase of less than 150 ml during the last stage; (2) a HR_{max} more than 95% of the theoretical maximum in heart rate (i.e. 220-calendar age); (3) a mean Respiratory Exchange Ratio (RER) during the last minute of more than 1.04.

Running took place on a treadmill (Quinton, model 18-54, the Netherlands) in a Mobile Research Unit. The oxygen uptake of each subject was measured (in ml•min^{-1}) during the test with the Ergoanalyser (Jaeger, Breda, The Netherlands). Heart rate (in beats/min) was measured by telemetry (Telecust Siemens, Amsterdam, The Netherlands).

Body height (mm) was measured with a Harpenden digital readout, wall-mounted stadiometer (Holtain, UK; van Riet-

Table 1. *Total number of subjects (boys and girls separately) measured in each year group*

Age (yr)	13	14	15	16	Total
Boys (n)	80	96	109	70	355
Girls (n)	90	112	105	70	377
Total (n)	170	208	214	140	732

schoten & Houwens, the Netherlands) and body mass (0.1 kg) with a spring balance (Van Vught, the Netherlands).

Predictions

On the assumption of a linear relationship between HR and VO_2 it is possible to estimate the maximal oxygen consumption $\dot{V}O_2max$ by using submaximal values of VO_2 and heart rate. To predict $\dot{V}O_2max$ two definitions of submaximal heart rate were used: 1) «Absolute» submaximal heart rate (HR_{submax}). 2) Submaximal heart rate expressed as percentage of heart rate reserve (HR_{res}). Heart rate reserve is defined as the difference between maximal heart rate and heart rate at rest. Maximal heart rate is theoretically defined as 220 - calendar age.

Furthermore, the predictions were performed using only one submaximal test result (at slope 0%; fig. 1) and by using two submaximal test results (at slopes 0% and 2.5%; fig. 2).

Statistical analysis

To answer the first research question, first of all Pearson correlation coefficients (r) are used to evaluate the relation between predicted and measured $\dot{V}O_2max$. Secondly, differences and standard deviations

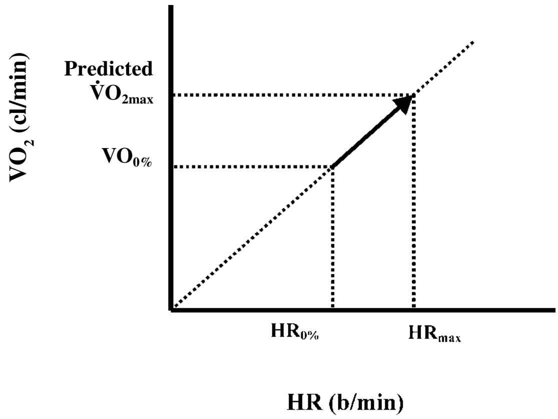

Figure 1. *Prediction of $\dot{V}O_2max$ on the assumption of a linear relationship between VO_2 and HR with a submaximal running speed of 8 km/h at a slope of 0 or 2,5% and HR_{max}*

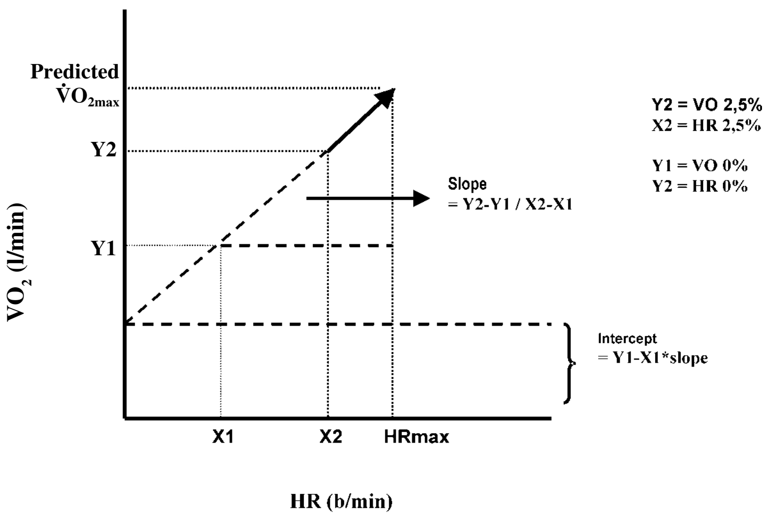

Figure 2. *Prediction of $\dot{V}O_2max$ using VO_2 and HR relationship between VO_2 and HR during two running periods with 8 km/h at a slope of 0% and 2.5% and HR_{max}*

are used to compare the prediction models. To answer the second research question a linear regression equation was made using stepwise regression analysis with parameters body height, body mass, sex, age and heart rate. For heart rate the most accurate «definition» (i.e. the smallest average difference combined with the smallest standard deviation) was used.

Results

Figure 3 and 4 show the mean values HR and VO_2 of boys and girls at the different age (13-16 years).

Correlations

Table 2 shows the correlation coefficients of the predictions separate for boys and girls and for each age group. Predictions with HR_{submax} have slightly higher correlations (.71-.81) than the predictions using HR_{res}. Not shown in this table is that none of the predictions using two running periods (series 2) have higher correlations than the one with only one running period (series 1).

Means and standard deviations of the difference between predicted and observed $\dot{V}O_2max$

Figure 5 shows mean and standard deviation of the difference between predicted and observed $\dot{V}O_2$max in males and females at age 13 and 16. The predictions using HR_{res} demonstrate the smallest average differences. The standard deviation of all $\dot{V}O_2$max predictions based on two running periods is higher. The smallest standard deviations are found in the prediction with HR_{submax}. However, the mean differences are far below zero, which means there

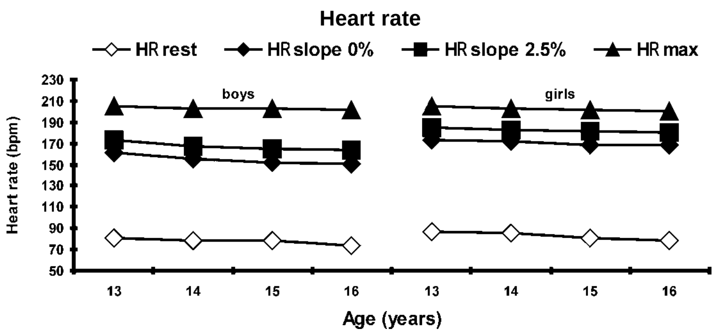

Fig. 3. *Mean heart rate for boys and girls; age 13-16 years*

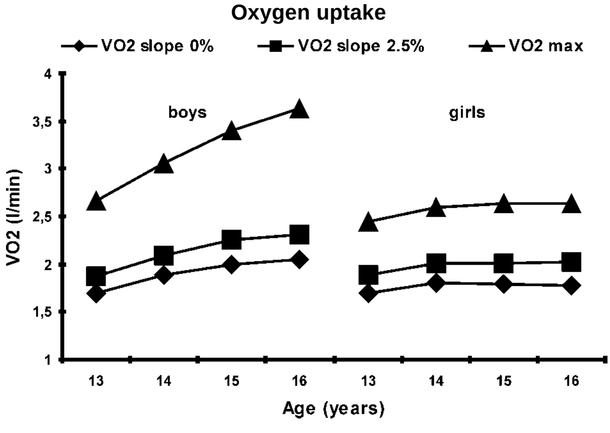

Fig. 4. *Mean oxygen uptake for boys and girls; age 13-16 years*

Table 2. *Pearson correlations of predicted $\dot{V}O_2max$ and observed $\dot{V}O_2max$ separate for girls and boys and for each of the four age groups*

		boys 13 yr n=80	boys 14 yr n=96	boys 15 yr n=109	boys 16 yr n=70
$HR_{0\%}$ / $VO_{0\%}$	HR_{submax}	0.686	0.789	0.783	0.801
	HR_{res}	0.597	0.699	0.749	0.705
$HR_{0\%}$ / $VO_{0\%}$	HR_{submax}	0.532	0.552	0.567	0.431
$HR_{2.5\%}$ / $VO_{2.5\%}$	HR_{res}	0.532	0.552	0.567	0.431
		girls 13 yr n=90	girls 14 yr n=112	girls 15 yr n=105	girls 16 yr n=70
$HR_{0\%}$ / $VO_{0\%}$	HR_{submax}	0.734	0.800	0.770	0.764
	HR_{res}	0.664	0.726	0.697	0.683
$HR_{0\%}$ / $VO_{0\%}$	HR_{submax}	0.529	0.426	0.677	0.504
$HR_{2.5\%}$ / $VO_{2.5\%}$	HR_{res}	0.529	0.426	0.677	0.504

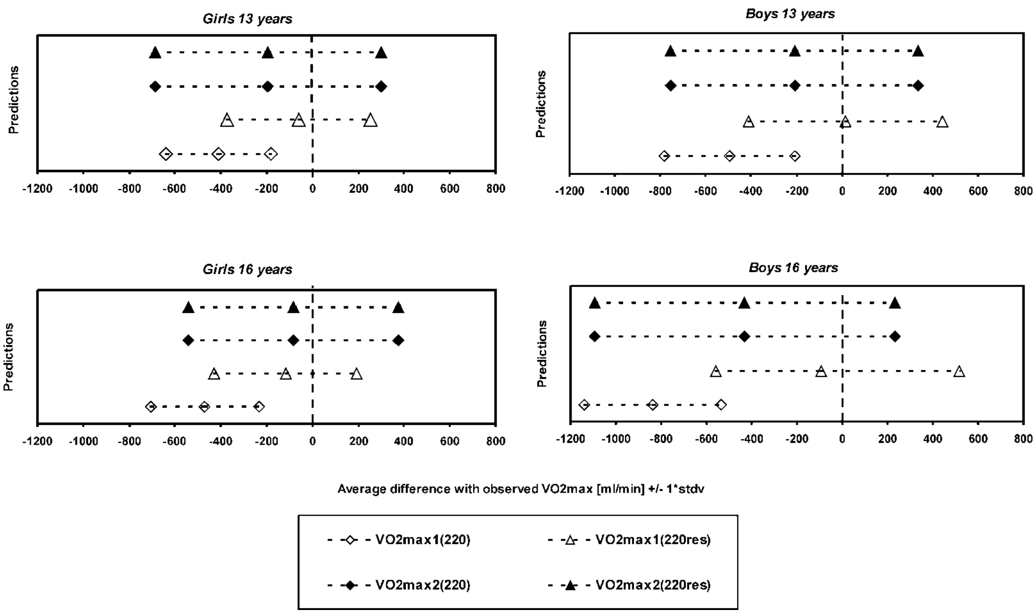

Fig. 5. *Mean difference (ml•min^{-1}) and standard deviation between $\dot{V}O_2max$-predictions and observed $\dot{V}O_2max$ in boys and girls at age 13 and at age 16 years*

is almost a complete underestimation of the $\dot{V}O_2$max. The predictions at age 14 and 15 show the same pattern as in the presented age groups (13 and 16 years).

Best overall regression equation

Based on the earlier analysis we decided to use submaximal heart rate as a percentage of heart rate reserve in the prediction model. For the determination of the best prediction model, stepwise regression analysis was used with body height (BH), body mass (BM), sex, age and HR_{res}.

$\dot{V}O_2max = 61.890 + 2.846 \cdot BM\ (kg) + 125.452 \cdot BH\ (m.) - 1.07 \cdot HR_{res} - 43.312 \cdot$ sex (male=1, female=2) (n=732). The predicted $\dot{V}O_2max$ has a correlation coefficient of r=0.87 with the observed $\dot{V}O_2max$ and a mean difference of 0.007 $ml \cdot min^{-1}$ and standard deviation of 273.7 $ml \cdot min^{-1}$. The error made in this prediction did not exceed 18.5% in boys and 3.1% in girls.

Discussion

In this study we compared predicted $\dot{V}O_2max$ with the observed $\dot{V}O_2max$. In the predictions of $\dot{V}O_2max$ we used the heart rate at submaximal level. Compared to $HR_{submax,}$ the use of HR_{res} brings the predicted values closer to the observed VO_2-values. However, by using two submaximal HR-values, there is no further improvement of the calculated values. The relationship between slope and intercept remains unchanged, because the proportion of the two submaximal values changes in the same way.

Probably the most important finding of the present study is that the predicted $\dot{V}O_2max$ values by using relatively simple low exercise levels are remarkably close to the observed values. So information from low exercise test can be used to predict $\dot{V}O_2max$. Besides the fact that low exercise test are much easier to implement on a large scale, these low exercise tests are less influenced by motivation, training status or fitness level and therefore more stable (7). However, in future this two minute running test on the treadmill at a speed of 8 $km \cdot h^{-1}$ and measurement of heart rate, to estimate $\dot{V}O_2max$ in teenagers, must be validated against direct measurement of $\dot{V}O_2max$ in a field situation. Another surprising finding was that although the prediction equation combined information from 13 to 16 year olds, age was not present in the regression equation that predicted $\dot{V}O_2max$ the best. Maybe age is already expressed in the formula by using maximal heart rate 220-minus age, body mass and body height.

Limitations

In this study longitudinal data are used to predict $\dot{V}O_2max$ at different ages. This is a limitation because the same subjects are measured at different ages. First of all, this creates the possibility of a so-called learning effect, which will lead to higher $\dot{V}O_2max$ values at higher ages due to the fact that the subjects are familiar with the test situation. However, Kemper showed (10) there was no learning effect observed, because there were no significant differences between longitudinal data, with repeated tests over the three year period and control groups with only one test over this three year period (10, 11). Secondly, one of the assumptions of linear regression analysis (i.e. independent observations) is violated because the same persons can be measured at different ages. In order to evaluate the importance of this violation, we reanalysed the data with generalised estimating equations (GEE), which is a regression technique that takes into account the dependency of observations. The results of the GEE-analysis were highly comparable to the results of the linear regression analysis reported in the present paper.

Another problem in these kind of studies is that there is always the question if the observed $\dot{V}O_2max$ value is the absolute highest value. The main criterion for $\dot{V}O_2max$ is reaching a VO_2 plateau during a progressive continuous treadmill exercise test. However many children never show a plateau (6, 15, 23). Therefore we used in this study two other criteria: a RER>1.04

and the HR_{peak} > 95% of the theoretical HR_{max} to replace the levelling off criteria.

Proposal for a field-test in the future

For most schools there is no possibility to use a running test with a slope more than 0% because no treadmills are available. Running during 2 minutes at a speed of 8 km•h^{-1} is very simple: for instance running 5 times around a volleyball pitch in 2 minutes, a distance is covered of 270m. This is equal to an average running speed of 8 km•h^{-1}. Heart rate can be monitored by HR monitors (Sports Tester of POLAR). The measurement of other parameters, body mass and body height, are also with in the competence of physical education teachers.

This field-test has to be validated in future research.

Conclusion

In this study the use of HR_{res} was more appropriate than HR_{submax} in the prediction of $\dot{V}O_2$max. The use of two submaximal values instead of one does not contribute to a more precise prediction. Furthermore it seems to be possible with one submaximal heart rate value (using HR_{res}) to make a accurate prediction of $\dot{V}O_2$max. The error of this prediction did not exceed 18.5% in boys and 3.1% in girls.

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