A Short Cycle Ergometer Test to Predict Maximal Workload and Maximal Oxygen Uptake

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Abstract


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In order to develop a short cycle ergometer test for the prediction of maximal oxygen uptake (VO₂max) and maximal work load (Wmax) oxygen uptake, workload and heart rate data were collected in 22 subjects. In the first test the subjects cycled at two submaximal stages of 3 min each whereafter the workload was quickly (within 4 min) increased to a supramaximal level to attain the maximal heart rate. A second graded cycle test was used to compare observed Wmax and VO₂max with estimated Wmax and VO₂max. The means of the estimated Wmax and observed Wmax were 364.9 (SD ± 42.4) watts and 368.8 (SD ± 40.2) watts, respectively and the mean estimation error was 1.0% (range -7.1% to 4.4%). For 82% of the subjects the estimation error was within ±5%. The means of the estimated VO₂max and observed VO₂max were 4.49 (SD ± 0.45) l.min⁻¹ and 4.59 (SD ± 0.41) l.min⁻¹, respectively. The mean estimation error was -2.1% (range -13.8% to 5.1%). For 68% of the subjects the estimation error was within ±5%. It is concluded that for trained athletes the short test (8–10 min) is accurate for the estimation of Wmax and VO₂max by measuring two submaximal heart rates and maximal heart rate and making use of the linear relationship between heart rate, workload and oxygen uptake.

Key words

Cycle ergometry, maximal workload, maximal oxygen uptake, maximal heart rate, exercise testing.

Introduction

To assess the aerobic endurance capacity, maximal exercise tests under standardized conditions are frequently used. In general, the maximal oxygen uptake (VO₂max) is considered as the golden standard for aerobic endurance capacity (6,9). However, the VO₂max as indicator for endurance capacity has been discussed by some investigators (5,8,13,15). It has been found that endurance athletes with the same performance in competition may have considerable differences in VO₂max (8) on the one hand, while on the other hand athletes with the same VO₂max can achieve different workloads (15).

In the guidance of athletes changes in VO₂max are usually interpreted as changes in aerobic endurance performance. However, Kuipers et al. (13) reported that the day-to-day variation of VO₂max exceeded that of the maximal workload (Wmax) and suggested that Wmax might be a better parameter to detect changes in aerobic endurance capacity.

Direct measurement of VO₂max and Wmax can only be done in a well equipped laboratory. Therefore other techniques have been developed to predict VO₂max from submaximal as well as maximal tests (2,17). Most of the studies (1,2,11,17) concerning the prediction of VO₂max during submaximal exercise used a fixed percentage of the age predicted heart rate (220 - age) as a predetermined endpoint for the test. VO₂max was predicted by an extrapolation of this point to the age predicted maximal heart rate. Hawley and Noakes (12) found that VO₂max could be accurately predicted with the peak power output and consequently that the need to measure VO₂max may be questioned. A widely used method around the world is the prediction of VO₂max based on heart rate during submaximal exercise according to Astrand and Ryhming (2). However, the prediction based on Astrand test is not always accurate and some studies indicated that the correlation between predicted VO₂max and measured VO₂max was low (3,16). Differences of up to 30% can be found between actual and predicted VO₂max (16).

Because Wmax seems to be a valuable indicator for aerobic endurance capacity, we developed a short and time efficient test which can be used for the prediction of Wmax. However, in the experiment VO₂ was also measured to investigate differences in predictions between Wmax and VO₂max. The test was based on the linear relation between heart rate, workload, and oxygen uptake.

Therefore, the purpose of the present study was to compare actual Wmax and VO₂max, measured in a stepwise increasing exercise test until exhaustion with the estimated Wmax and VO₂max. For the estimation of Wmax and VO₂max a short and time efficient test was used consisting of 2 submaximal loads followed by a fast increase of the load to a supramaximal level to attain maximal heart rate.
Methods

Subjects

The group of subjects consisted of 22 male trained athletes. They were all competitive in endurance sports such as cycling, triathlon or marathon running. The mean age, height and weight of the subjects were 27.2 (SD ± 7.8) years, 1.83.3 (SD ± 7.0) cm and 73.7 (SD ± 7.8) kg.

Exercise tests

Each subject performed one maximal, stepwise increasing test and one short test on an electronically braked cycle ergometer (Lode Excalibur, Groningen, Holland). The time between the two tests was at least 24 hours and maximally one week. The maximal test consisted of the following protocol: 5 min warm up at a workload of 100 watt, the workload was then increased by 50 watt every 2.5 min until the heart rate exceeded 160 beats·min⁻¹. After this, workload was increased by 25 watt every 2.5 min until exhaustion.

The short test consisted of 2 submaximal workloads of 3 min each followed by an increase of 25 watts every 20 sec until exhaustion (Fig. 1). Each subject completed the test within 10 min. The submaximal stages were chosen so that the heart rate in the first stage exceeded 120 beats·min⁻¹ and that the difference between the first and second stages was at least 75 watt. In the submaximal stages the pedalling rate was held constant at 80±5 rpm (range) and during the supramaximal stage the pedalling rate was >90 rpm. Because there were large differences in exercise capacity, weight, and training status between the subjects, the lowest submaximal workloads varied between 150 and 270 watt, while the second submaximal workload varied from 250 to 350 watt.

During the maximal test and the short test the heart rate was measured using a Sport-tester (PE 3000 Polar, Finland). Expiratory gases were analysed using a computerised on-line system (Sensormedics 2900, Sensormedics Corporation, USA) during the entire maximal test and during the submaximal stages of the short test.

Data processing and analysis

Maximal test

The workload, oxygen uptake, and heart rate were measured during the exercise tests. Wmax was calculated according to Kuipers et al. (13):

\[ W_{\text{max}} = W_{\text{com}} + (t/150 - W) \]

in which \( W_{\text{com}} \) is the last workload completed, \( t \) the number of sec the final, not completed load was sustained and \( W \) the final load increment.

The oxygen uptake was measured continuously and printed every 20 sec. The peak \( VO_2 \) measured was considered as maximal \( VO_2 \). The heart rate was measured continuously during exercise and the highest observed heart rate was considered as the maximal heart rate for the maximal test (MT-HRmax). The workload and oxygen uptake were plotted against the heart rate to check whether or not the relation between these parameters was linear (3).

Fig. 1. The protocol used of the short test and the prediction of \( W_{\text{max}} \) using two submaximal heart rates and maximal heart rate.

Short test

During the short test the heart rate was measured continuously and the mean of the last 20 sec of each submaximal stage was considered as the heart rate for this stage. The highest observed heart rate was considered as the maximal heart rate for the short test (ST-HRmax). The oxygen uptake was measured continuously during the submaximal stages of 3 min each and printed every 20 sec. The mean of the last 40 sec of each stage during the short test was considered as the \( VO_2 \) for this stage. \( W_{\text{max}} \) and \( VO_{2\text{max}} \) were determined by calculating the linear regression equations for the two submaximal stages and solving the equations with ST-HRmax. The regression equations were also solved at age predicted maximal heart rate (220 - age).

Statistics

For statistical comparison of observed and estimated \( W_{\text{max}} \) and \( VO_{2\text{max}} \), individual differences, the mean of the two tests, and the 95% limits of agreement were calculated as suggested by Bland and Altman (4).

Results

\( W_{\text{max}} \)

Using ST-HRmax, the mean of observed and estimated \( W_{\text{max}} \) was 368.8 (SD ± 40.2) and 364.9 (SD ± 42.4) watts, respectively. The mean estimation error of estimated \( W_{\text{max}} \) was -1.0% and the individual estimation error varied from -7.1% to 4.4% (Table 1). For 18 subjects the estimation error was within ±5%.

In Fig. 2 the mean difference and the 95% limits of agreement (± 2 SD) are represented. The mean difference in \( W_{\text{max}} \) between the observed and estimated values was 3.86 watts with 95% limits of agreement of -31.88 to 24.16 watts.

Using age predicted HRmax the mean of the estimated \( W_{\text{max}} \) was 387.6 (SD ± 54.0). The mean estimation error was 5.1% and the individual estimation error varied from -15.7% to 26%. For 10 subjects the estimation error was within ±5%.
The mean difference between observed and estimated Wmax using age predicted heart rate was 18.5 watts with 95% limits of agreement of -43.96 to 80.96 (Fig. 2).

**VO2max**

The mean of observed and estimated VO2max using ST-HRmax was 4.59 (SD ± 0.41) and 4.49 (SD ± 0.45) l·min⁻¹, respectively. The mean estimation error of VO2max was -2.1% and the individual estimation error varied from -13.8% to 5.1% (Table 1). For 15 subjects the estimation error was less than ±5%.

Fig. 3 shows the mean in VO2max of the two tests and the difference in VO2max between the two tests. The mean difference between observed and estimated VO2max using ST-HRmax was 0.09 l·min⁻¹ with 95% limits of agreement of -0.67 to 0.49 l·min⁻¹.

**Table 1** Results of Wmax, VO2max and HRmax.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>E.E. (%)</th>
<th>Range of E.E.</th>
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<td>MT-Wmax</td>
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<tr>
<td>ST-Wmax</td>
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<td>42.4</td>
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<td>Age-Wmax</td>
<td>387.6</td>
<td>54</td>
<td>5.1</td>
<td>-15.7/25</td>
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<tr>
<td>MT-VO2max</td>
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<td>0.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST-VO2max</td>
<td>4.49</td>
<td>0.45</td>
<td>-2.1</td>
<td>-13.8/5.1</td>
</tr>
<tr>
<td>Age-VO2max</td>
<td>4.73</td>
<td>0.51</td>
<td>3.1</td>
<td>-10.9/23</td>
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<tr>
<td>MT-HRmax</td>
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<td>8.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST-HRmax</td>
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<td>-3.0/ 3.3</td>
</tr>
<tr>
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<td>7.3</td>
<td>3.7</td>
<td>-6.7/ 11</td>
</tr>
</tbody>
</table>

At age predicted HRmax the mean of estimated VO2max was 4.73 (SD ± 0.51) l·min⁻¹. The mean estimation error of VO2max was 3.1% and the individual estimation error varied from -10.9 to 23%. For 6 subjects the estimation error was within ±5%.

The mean difference between observed and estimated VO2max was 0.14 l·min⁻¹ with 95% limits of agreement of -0.61 to 0.88 l·min⁻¹ (Fig. 3).

**HRmax**

The mean HRmax was 185.9 (SD ± 8.5) beats·min⁻¹ for the maximal test and 186.8 (SD ± 8.3) beats·min⁻¹ for the short test (Table 1). The mean estimation error of ST-HRmax in comparison with MT-HRmax was 0.5% and for all subjects the individual error was within ±5%.

The mean difference between ST-HRmax and MT-HRmax was 0.90 beats·min⁻¹ with 95% limits of agreement of -6.26 to 8.06 beats·min⁻¹ (Fig. 4).

The mean age predicted HRmax was 192.8 (SD ± 7.3) beats·min⁻¹. The mean estimation error of age predicted HRmax was 3.7% and the individual estimation error varied from -6.7% to 11% (Table 1). For 14 subjects the estimation error was within ±5%.

The mean difference between age predicted HRmax and MT-HRmax was 6.95 beats·min⁻¹ with limits of agreement of -8.23 to 22.13 beats·min⁻¹ (Fig. 4).
Discussion

A simple, time efficient test was developed to predict $W_{\text{max}}$ and $V_{\text{O}2}\text{max}$. In agreement with Åstrand and Rodahl (3) during the graded exercise test the relation between the heart rate on the one hand and workload and oxygen uptake on the other hand was linear. We failed to observe a levelling off of oxygen uptake at the point of exhaustion. This is in agreement with some (7,10,12,13,14) but in contrast with other (19) investigations. Levelling off of oxygen uptake is usually seen in tests in which the highest workload is aborted, resulting in an incomplete adaptation of the cardiorespiratory system.

$W_{\text{max}}$ and $V_{\text{O}2}\text{max}$ were estimated using the maximal heart rate attained with the short test (ST-HRmax) and the maximal heart rate predicted for age (200 - age). Fig. 4 shows good agreement between the ST-HRmax and the MT-HRmax. This means that the short test is accurate in its determination of maximal heart rate. Between the age predicted HRmax and MT-HRmax poor agreement was found. The mean age predicted heart rate was over-predicted by almost 7 beats·min$^{-1}$ with 95% limits of agreement of -8.23 to 22.13 beats·min$^{-1}$. This implicates that using the estimated heart rate from the age HR-formula seems to be justified on group level but on individual level considerable deviations may occur (1,3,20). Since in sport guidance one tries to follow an individual approach, the use of this formula is not justified and HRmax has to be measured (20).

In addition, the data demonstrate that an over-prediction of 18.5 watts with wide limits of agreement (-43.96 to 80.96) was found by the estimation of $W_{\text{max}}$ using age predicted heart rate. The age predicted heart rate can be actually maximal for some, submaximal for others, and supramaximal for the rest (20). In the present study the age predicted heart rate was overestimated and had a negative effect on the accuracy of the test result. This implies that the use of the age predicted HRmax is limited and can not be used to estimate $W_{\text{max}}$ reliably, which is in agreement with the findings of Whaley et al. (20).

Using the ST-HRmax a good agreement was found between the estimated and observed $V_{\text{O}2}\text{max}$, the mean difference was 0.091·min$^{-1}$ with 95% limits of agreement of -0.67 to 0.49·min$^{-1}$. For 68% the estimation error was within ±5% and the individual estimation error varied from -13.8% to 5.1%.

A poor agreement was found between observed and estimated $V_{\text{O}2}\text{max}$ using age predicted heart rate, with a mean difference between observed and estimated values of 0.14 l·min$^{-1}$ with limits of agreement of -0.61 to 0.88 l·min$^{-1}$. For only 23% of the subjects the estimation error was within ±5% and the estimation error varied from -10.9% to 23%. Because of the poor agreement and this wide variability in estimation error of predicted $V_{\text{O}2}\text{max}$ we conclude that the age predicted heart rate should not be used to predict $V_{\text{O}2}\text{max}$ in individuals.

Using two submaximal heart rates and ST-HRmax the agreement between observed and estimated $W_{\text{max}}$ was good. The mean difference between observed and estimated $W_{\text{max}}$ was -3.86 watts with limits of agreement of -31.88 to 24.16 watts. The data demonstrate that for 82% of the subjects the estimation error of $W_{\text{max}}$ was within ±5%.

In conclusion, with the short test $W_{\text{max}}$ as well as $V_{\text{O}2}\text{max}$ can be estimated accurately by measuring two submaximal heart rates and the maximal heart rate and making use of the linear relationship between heart rate, workload and oxygen uptake. However, the estimation of $W_{\text{max}}$ is more accurate than the estimation of $V_{\text{O}2}\text{max}$. It is advised not to use the age predicted heart rate for the prediction of $W_{\text{max}}$ and $V_{\text{O}2}\text{max}$.

References


