A Nomogram for Calculation of Aerobic Capacity (Physical Fitness) From Pulse Rate During Submaximal Work

P.-O. ÅSTRAND AND IRMA RYHMING. From the Department of Physiology, Gymnastiska Centralinstitutet, Stockholm, Sweden

MANY TIMES it is of interest to know the individual’s capacity for muscular work, e.g., when selecting people for special tasks in military service or in industrial work, or when controlling the physical condition of athletes. Furthermore, a reduction of this capacity is often the first sign of a disease.

The individual’s capacity (or fitness) for heavy prolonged muscular work will first of all be dependent on the supply of oxygen to the working muscles. In types of work which engage large groups of muscles the limiting factor for the maximal oxygen intake (aerobic capacity) will probably be the capacity and regulation of the oxygen-transporting system.

A direct measurement of the maximal oxygen intake can be made (1), but the method is intricate and can only be applied in a well-equipped laboratory. Furthermore, maximal tests are not advisable with older individuals or people with heart or respiratory diseases. It would be of value to work out a simple test method giving information about the subject’s aerobic capacity. The work load used for the test should be a submaximal one. With this aim Ryhming (2) has suggested a step test. The result of this and other investigations (see below) will here be summarized in a nomogram for calculation of aerobic capacity.

When undertaking muscular activity of such severity that the demand for oxygen intake was 50% of the individual’s maximal oxygen intake, the heart rate after about 6 minutes’ work for a group of healthy male subjects averaged 128. The corresponding heart rate for female subjects was 138 (1). When the subjects worked with a heavier load, thus demanding an oxygen intake of 70% of their aerobic capacity, the average heart rate was 154 for males and 164 for females. The standard deviation (δ) was 8–9 beats/min. These results are illustrated in figure 1.

Based on figure 1 the nomogram1 shown in figure 2 has been worked out. With information about the heart rate and oxygen intake during a submaximal work the subject’s aerobic capacity could be calculated.

Wahlund (4) in his investigation of men of various physical fitness (athletes, normal healthy men, people with heart or respiratory troubles) found a fairly constant mechanical efficiency when his subjects were working on a bicycle ergometer. Thus the oxygen intake could be indirectly estimated from work load within a range of ±8% in two-thirds of the cases. The results reported by Åstrand (1) and Ryhming (2) obtained on healthy, well-trained subjects (50 men and 62 women) show that the oxygen intake during work could be calculated from work level within a range of ±6% in two-thirds of the subjects. Identical values for mechanical efficiency were obtained for men and women. These facts are illustrated in figure 3, giving the mechanical efficiency plotted against the work metabolism in percentages of the individually determined aerobic capacity.

According to Ryhming (2) a similar range of 6%
was found when the oxygen intake was calculated from the work done when the subjects performed a modified step test (bench height was 40 cm for men, 33 cm for women; 22.5 steps were done per minute). Performed work was calculated from body weight, bench height and a constant mechanical efficiency.

Based on the findings in the experiments mentioned, scales have been included in the nomogram giving work levels (cycle test) and body weights (step test). By reading horizontally from those scales to the scale with 'O$_2$ intake' a conception of the actual energy output can be obtained. E.g., work on the bicycle ergometer with a severity of 800 kg m/min or a step test for a male subject with a body weight of 62.0 kg (female subject 76.0 kg) corresponds to an oxygen intake of about 1.91 l/min. With a heart rate of 138 (for a female subject 148) attained during the work, the calculated 'maximal oxygen intake' of the subject should be 3.5 l/min.

In figure 4 the 'aerobic capacity' calculated from the nomogram is plotted against the actually determined 'aerobic capacity.' The figure includes values obtained on 27 male and 31 female well-trained subjects 20–30 years of age, whose maximal oxygen intake was determined in maximal tests on the treadmill or bicycle ergometer (1). The nomogram is mainly based on these results. The submaximal test was a cycle test (900 kg m/min...
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for women, 1200 for men) where the O₂ intake was determined. A statistical analysis of the values in figure 4 gives a mean difference of 0.023 ± 0.059 (females 0.010 ± 0.051) liters O₂ per minute be-

tween the determined and the calculated maximal O₂ intake. For two thirds of the cases the difference (standard deviation) will be less than 6.7% for men and 9.4% for women (table 1). With a lower rate of work, 600 and 900 kg/m/min for women and men respectively, the standard deviation was higher, 14.4% for women and 10.4% for men.

A second control of the validity of the nomogram is given by figure 5. For 18 well-trained male sub-
jects, 18–19 years of age, the maximal O₂ intake was determined (5). Additional tests were done, such as a step test on a 40-cm bench, frequency 22.5 steps/min, and running on a treadmill set at an angle of 5°. The speed was 10 km/hr. The values for O₂ intake and heart rate during these submaximal tests were used for calculations of the subject's aerobic capacity. The mean difference between the calculated and determined maximal O₂ intake was 0.006 ± 0.066 l/min in the step test, and 0.020 ±
0.058 l/min in the treadmill test. The standard deviation was less than 7% (table 1).

For 31 female and 28 male subjects 20–30 years

Table 1. Error of methods when maximal O₂ intake is calculated from nomogram as compared with directly determined maximum

<table>
<thead>
<tr>
<th>No., Sex</th>
<th>Max. O₂ Intake, l/min.</th>
<th>Deter. from nomo.</th>
<th>ε ± υ</th>
<th>δ</th>
<th>Error, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycling, 900 kg/min.</td>
<td>27, M</td>
<td>4.11</td>
<td>4.07</td>
<td>0.91 ± 0.083</td>
<td>0.43</td>
</tr>
<tr>
<td>Cycling, 1200 kg/min.*</td>
<td>24, M</td>
<td>4.14</td>
<td>4.17</td>
<td>0.23 ± 0.059</td>
<td>0.28</td>
</tr>
<tr>
<td>Cycling, 600 kg/min.</td>
<td>31, F</td>
<td>2.87</td>
<td>3.00</td>
<td>1.37 ± 0.077</td>
<td>0.42</td>
</tr>
<tr>
<td>Cycling, 900 kg/min.*</td>
<td>29, F</td>
<td>2.01</td>
<td>2.02</td>
<td>0.06 ± 0.051</td>
<td>0.27</td>
</tr>
<tr>
<td>Step test†</td>
<td>18, M</td>
<td>4.03</td>
<td>4.03</td>
<td>0.006 ± 0.066</td>
<td>0.28</td>
</tr>
<tr>
<td>Running, 10 km/hr., 5° uphill†</td>
<td>17, M</td>
<td>4.07</td>
<td>4.05</td>
<td>0.020 ± 0.058</td>
<td>0.23</td>
</tr>
</tbody>
</table>

* Fig. 4. † Fig. 5. † Fig. 6

Two experiments are included where the maximum was calculated from a step test or a cycle test. (δ = mean of difference, ε = standard error of the mean of differences, δ = standard deviation of the individual differences between variables.)

![Fig. 5.](http://jap.physiology.org/)

For text, see fig. 4. The tests were a step test and a treadmill test.

Fig. 6. Relationship between maximal oxygen intake calculated from the results obtained from a step test and those from a cycle test. For further details, see text, fig. 4.

Table 2. Body weight and height and maximal O₂ intake (aerobic capacity) of healthy, well-trained subjects 20–30 years old (1)

<table>
<thead>
<tr>
<th>No., Sex</th>
<th>Body Weight, kg</th>
<th>Height, cm</th>
<th>Maximal O₂ Intake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>l/min. ml/kg/min.</td>
</tr>
<tr>
<td>44, F</td>
<td>60.3 ± 0.9</td>
<td>165.8 ± 0.8</td>
<td>3.00 ± 0.04 (2.40±1.40)</td>
</tr>
<tr>
<td></td>
<td>(45.9-71.7)</td>
<td>(155.6-176.0)</td>
<td>(28.4 ± 0.5) (22.0-54.8)</td>
</tr>
<tr>
<td>42, M</td>
<td>70.4 ± 1.0</td>
<td>175.7 ± 1.0</td>
<td>4.11 ± 0.00 (3.17±1.86)</td>
</tr>
<tr>
<td></td>
<td>(58.8-82.8)</td>
<td>(164.7-188.7)</td>
<td>(26.6 ± 0.7) (10.4-66.8)</td>
</tr>
</tbody>
</table>

Values are means ± Σm; range, in parentheses. * X δ = 95% range.
of age, the maximal oxygen intake was calculated from a) the heart rate and \(O_2\) intake when doing a cycle test (600 and 900 kg m/min), and b) the heart rate and \(O_2\) intake when doing the mentioned step test (methods and subjects are described by Ryhming, ref. 2). These two values for maximal \(O_2\) intake were compared, and the mean difference between the means was 0.003 ± 0.052 l/min for the women and 0.025 ± 0.057 for the men. The standard deviation was 0.5 and 7.3% respectively. These results are illustrated by figure 6 and table 1.

**DISCUSSION**

When testing circulatory-respiratory fitness, a type of work must be chosen which engages large groups of muscles and the work level must be relatively high. The duration of work must be long enough to permit the adjustment of circulation and ventilation to the level of exercise. The above-mentioned results are derived from a single work test with the subject stepping up and down a bench, cycling on a bicycle ergometer, or running on a treadmill. The duration of work was 5-6 minutes and the determinations of oxygen intake, etc., were done during the last minute. It was found that a test with a submaximal work level could give good information about the subject’s aerobic capacity. The best results were obtained when the test work was of such a severity that the heart rate during steady state attained a level somewhere between 125 and 170. Within these limits there is normally an almost linear increase in metabolism with heart rate. For the examined subjects, the maximal heart rate reached during exhausting work was about 195 (\(\theta = 10\)). This means that the slope of a heart rate-oxygen intake curve is determined by the subject’s aerobic capacity. We do not know whether there is a linear relationship between the cardiac output and the oxygen intake, nor the variations of stroke volume and arteriovenous \(O_2\) difference as the stress on the circulation increases with heavier work load. Consequently, the physiological explanation of the findings of a high correlation between the heart rate when performing submaximal work and the maximal oxygen intake is far from obvious.

Table 2 gives values for maximal oxygen intake (l/min and ml/kg/min) for healthy, well-trained men and women. The maximal oxygen intake probably varies with the muscular mass, and the ratio of muscular mass to body weight should in many instances be an important factor in determining the individual’s capacity for hard work. Thus, the maximal oxygen per kilogram body weight will give a good conception of physical fitness. Athletes famous for their good results in events calling for endurance, e.g., running and skiing, are characterized by a very high figure for maximal oxygen intake/kg/min (1, 6, 7).

On the other hand, when testing a subject for a job of a fixed demand for oxygen intake, e.g., in industrial work, his aerobic capacity is decisive. It is suggested that the metabolism during a job involving large groups of muscles should not exceed 50% of the individual’s aerobic capacity (1, 8).

It should be emphasized that the nomogram is based on results from experiments with healthy subjects 18-30 years of age. We do not know its validity when testing younger or older people or patients with diseases in the oxygen-transporting system. Therefore, results obtained from tests with those categories must be evaluated with special criticism. Experience combined with further research should decide upon the application of the nomogram and interpretation of the results.

As stated above, in normal conditions the heart rate during work is determined by the metabolism. However, in a hot climate, when dehydrated, when exposed to hypoxia, the subject will attain a higher heart rate when performing work of a given intensity as compared with normalcy. Applying the nomogram would give a measure of the reduction in his aerobic capacity induced by the extra load on circulation.

**SUMMARY**

A nomogram is presented where an individual’s maximal attainable oxygen intake (aerobic capacity) can be calculated from heart rate and oxygen intake (or work level) reached during a test with a submaximal rate of work. As test work a step test, treadmill test or cycle test can be chosen. It is suggested that the individual’s aerobic capacity per kilogram body weight per minute will give a good measure of his physical fitness. Values for healthy, well trained men and women 20-30 years of age are presented.

**REFERENCES**