The Wingate test

A good possibility to evaluate maximal power output in sports
Foreword
The purpose of this book is to describe the Wingate test using the original idea as starting point. The advantages and disadvantages of the original idea are discussed and a number of suggestions for improvements are given.

An important stage in development is the simplified operational use that Monark’s Wingate bicycle offers with its on-line results display via computer.

The design of the test using an ergometer bicycle does not mean that it is the perfect test for all sports.

The reasons for the choice of testing equipment can be compared to the development of the ergometer bicycle for assessment of endurance (the Åstrand test): simplicity in calculation and control of loading, and the fact that physical effort often involves the bone musculature.

The book contains experiences and results of measurements from various sports at different levels and can also be used as a reference book.
Introduction

Today there is a wide range of accepted methods for evaluating aerobic capacity or physiological qualities significant for the so-called long time endurance capacity. Concerning the anaerobic capacity, or the short-term performance capacity, there are limited options for evaluation. No measurement known of is fully accepted to quantify this capacity (Gastin, 1994). On the other hand there are several options giving a good picture of anaerobic power (Vandeville et al. 1987). The Wingate test (W-test), described by Ayalon, Inbar and Bar-Or 1974 and later developed at the Wingate Institute in Israel is one of them.

The test idea

The test was designed for simply handling by not specifically educated personnel. It is inexpensive and is performed on readily available equipment such as a Monark cycle or other mechanically braked bike ergometer. It is non-invasive, and measures muscular performance rather than indirect variables (biochemical or physiological). Furthermore the test is suitable for different groups of people including children and physically disabled. The measurements are applicable to both arms-and leg muscles. Finally the specifications included objectivity, reliability, validity and sensitivity for changes in anaerobic performances and specifically reflect anaerobic capacity in front of general performance capacity.
**Test description**

Normally the test is performed on a mechanically braked ergometer bike where the initial task is to accelerate the pedalling frequency without any load. At maximal pedal revolution the test leader will quickly load the flywheel with 7.5% of the athlete's body weight. Thereafter the highest possible pedalling frequency is performed throughout the 30 seconds. Power output is calculated as a mean each 5 s. The first 5 s is called peak power, mean power is calculated from 0 to 30 s and the final 5 s period is named end power. All these 3 values are significant for evaluation and comparisons. The values can either be expressed in absolute values (w) or related to body weight (w/kg). Peak power is regarded to mirror the alactic anaerobic processes and mean power the degree of anaerobic glycolysis in the working muscles. However there are studies showing that lactate is formed from the very beginning of a strenuous work (Hultman, 1983). The peak power reflects the muscle ability to produce a high mechanical power under a short period and the mean power the anaerobic short time endurance.

**Duration**

Originally 30 s of work is used as a suitable duration for taxing the anaerobic glycolysis. There have also been trials with longer duration's (45 and 60 s), but led frequently to tactical considerations by means of not maximal effort from the start to finish. This jeopardises the reproducibility of the test, especially when comparing peak power output from time to time. On the other hand a shortening of the test to for example 20 s could be used without similar problems.

**The Wingate test qualities**

The probability of achieving similar values in a test-retest situation (reliability) during similar conditions is very good. Eight investigations with different type of subjects shows a mean reliability of $r = 0.94 \pm 0.03$ SD. That covers both peak power and mean power output. There are also studies showing a good reproducibility between test performed at different temperatures and different levels of dehydration.

At different types of warm-ups (mean power) and motivation (peak power) reliability and reproducibility is more put into question. The recommendation will
therefore be to accomplish a standardised preparation and that the test leader will strongly motivate before and during the test procedure (see more below).

The reliability of the W-test, i.e. (measures according to intention), could be controlled by performing similar anaerobic glycolytic loading. It is highly interesting to establish good correlation's between a laboratory test like this and functional field tests from the specific sport. The most interesting is to find high correlation between the different Wingate values and the complete sport result.

**The evolution of the test**

During the years there has been a certain development regarding equipment, protocol and evaluation of the test. Originally the test was performed on a mechanically pendulum braked Monark ergometer bike with manual timing and counting the pedal rate. The mechanical break with weights in a basket is the most controllable and secure to handle which is available on the new Monark Wingate bike. Through the years institutions of physiology have made their own "power output models" out of normal exercise bikes.

**The Monark Wingate bike**

The new Monark Ergomedic 834 E and its software have made the original W-test much more effective concerning time and accuracy. The new bike has a sport saddle with several adjustment possibilities, handlebars and toeclips. A manually operated leaver simultaneously lets the weight basket load the flywheel and start the registration of time and revolutions at the beginning of the test. For more stability during the strong medio lateral forces during the tests, the bike also has wider base bars. Before the test the athletes' personal data is entered to the computer (test- or personal number, name, mass and height). The program calculates the percentual load based on 7.5% of body mass or any other chosen percentage. There is also an option in the set up program to include or not the energy stored in the wheel from the acceleration phase before the measurement starts. This choice will especially effect the power output reported during first 5 s. It is possible to read RPM at the time zero and then RPM and power each 5 s during the measurement.
After the test is completed the results are displayed in a graph (w/kg each 5 s). The result table shows RPM every 5 s and maximal- mean- and end power output in w or w/kg. Power reduction in w/second and w/s/kg is also displayed.

**Experiences from Bosön Institute of Sport**

At our institute we have frequently used the W-test since the mid 1980's. Especially ice hockey, ice skating and other sports with explosive characteristics such as soccer, cycling and figure skating have been measured (see table 2a and b).

Our first bikes were connected to a simple printer that displayed each test with 5 s bouts in 6 rows of data. Tests with an ice hockey team consisting of 25 players demanded a lot of work including calculations of maximal- mean- and end power output. From these simple printouts, the data had to be input into a graphics program, to get an easier overview. During periods of 2-3 weeks we could test 4-5 teams, each wanting their results and analysis promptly. Under these circumstances we entered into a co-operation with Monark to develop a Wingate bike with a computer connection for immediate print out of results in figure- and graphic forms. The new device has led to a great saving in analysis time and furthermore increased the pedagogic value, as delay from test to presentation is as good as eliminated.

**Is 7.5% an optimal loading?**

In the original description of the test 7.5% of the subject's mass is used as a load. This may be questioned as optimal for well-trained and adult persons, as the original investigations were performed on a small group of untrained children.

At our Sport Institute we predominantly measure elite athletes and our experiences show that 7.5% is too low a loading, especially for male athletes. This is especially revealed during the first 5-10 s of the test. The power output is not optimal as the subject can not pedal faster than up to a certain rate. Normally most subjects will loose the neuro muscular controlled pedal frequency at approximately 200 RPM. This may occasionally be seen in an uneven frequency where for a short time the fluent pedalling is interrupted. Powerful and quick athletes will, with 7.5%, not reach the maximal power output in the beginning and experience that they are pedalling without resistance.
Four male national level speed skaters were tested with 7.5 and 10% loading of their body mass. RPM at the time 0 and from 0-5 s and power output during the first 5 s are shown as mean values ± SD in the table below.

At the time 0, when the maximal pedalling frequency should be reached and when the weight basket is loading the wheel, the RPM is 200. After the first 5 s RPM is still 194 with the lower loading. With 10% body mass loading RPM is reduced by approximately 30 revolutions but power output is significantly higher (p<0.001). It is therefore reasonable to assume that athletes of this calibre will be underestimated in peak power using 7.5%.

Table 1.

<table>
<thead>
<tr>
<th>Load</th>
<th>RPM t=0</th>
<th>RPM 0-5 s</th>
<th>Power (w) 0-5 s</th>
<th>Power (w/kg) 0-5 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5%</td>
<td>202</td>
<td>194</td>
<td>1167</td>
<td>14,5</td>
</tr>
<tr>
<td>SD</td>
<td>8</td>
<td>6</td>
<td>62</td>
<td>0,4</td>
</tr>
<tr>
<td>10%</td>
<td>203</td>
<td>175</td>
<td>1399</td>
<td>17,4</td>
</tr>
<tr>
<td>SD</td>
<td>9</td>
<td>6</td>
<td>72</td>
<td>0,5</td>
</tr>
</tbody>
</table>

One might eventually fear that 10% will force the athlete to interrupt before the 30 s are ended. This is not the case; 15 ice hockey players from the 1st league in Sweden produced as a mean 79 (±5) RPM during the final 5 s leading to 7,5 (±5) w/kg.

In a review article about the W-test Bar-Or (1987) also suggest that 10% of body mass is a more suitable load. We emphasise this, especially for well-trained men but eventually also for women, while 7.5% may be more suitable for younger, less massive and less trained women.

Who should be Wingate tested?

It is questionable whether a maximal test of this type is suitable for others than well-trained, healthy elite athletes. The W-test has like other tests with the character of maximal effort the disadvantage of strong motivation (Geron, Inbar, 1980). The test demands from the athlete a very tough attitude along with a physiological and mental readiness for total exhaustion. Athletes tested at our institute are rating the 30 s W-test to be the meanest of all tests. Occasionally subjects can feel sick. To reduce these effects it is important to let the athlete wind down directly after the test.
for some minutes on the test bike and then to continue on another ergometer bike for 5 additional minutes. The test leader must be prepared to support a totally exhausted athlete.

**Warm up and start**

We emphasise a 5 min warm up at approximately 1 to 2 kg and 50-60 cadence on an ergometer bike. After a careful adjustment of foot clips and saddle height (recorded for re-tests), two pre starts are carried out. This is to ensure that the subject know the feeling of maximal acceleration to top pedalling rate and the effect of the weight basket falling down to load the wheel. The pre starts take less than 5 s and are separated by a 2 min slow pedalling without loading. The pre start is also important for the test leader who can give additional instructions if he assumes that the athlete has not quite reached the maximal revolutions. These starts also serve as a final mental preparation for both subject and test leader.

The introduction is especially important for the result of the first 5 s ramp (maximal power output) as well as mean power output. The test leaders ability to enable the subject to reach absolute maximal pedalling frequency and to pull the lever in the right moment is decisive for the results. Experience and feeling is of greatest importance.

During tests with big and strong athletes the bike must remain steady until the end. Towards the end many tend to work extensive in the medio lateral direction with the upper body.

**Relations between Wingate results and ice hockey skating**

For many years a large number of 30 s tests have been performed on ice hockey players from top national and international levels. It was therefore of great interest to investigate the correlation between maximal sprint skating and Wingate results.

Ten players from the highest and second highest series were Wingate tested and skated 6 x 36 m (blue baseline) with full equipment and stick, back and forth in one sequence on an European size ice hockey pitch. Each 36 m- and final time was registered with an electronic watch. Each 36 m took approximately 5 s and corresponded to each 5 s bout in The W-test. Total time was as a mean 34.17 ± 1.65 sec.
In fig. 1 below the effect from each player (w/kg) each 5 s is related to the time for each 36 m lap. The correlation is $r = 0.82$ ($p < 0.01$) and show that the ice performance relates to power output each 5 s.

Ice hockey coaches are very positive about this correlation and the possibilities to evaluate that the test offers. The results also correspond highly to their opinion about explosive and slow players on the ice. Furthermore the results correspond to the different players’ “power endurance” in for example consecutive rushes on the ice. The relations between W-test, ice test and reality has made the W-test frequently used in most teams in Sweden and other prominent ice hockey nations. For further references about W-test on ice hockey players see Cox et al. (1995). However in their investigations loading was set to 8.0% of body mass and the duration was 45 s.
Correlation's between W-test results and shuttle run (soccer)

For analysis of soccer player's physical capacity Geese (1990) suggested a battery of measurements which was performed at that time on West German players, in different leagues. Among the tests a shuttle run of 150 m was described. After the start the athlete rounds a cone after 5 m and returns to the starting point, after which he continues to the next on the 10 m mark. So he goes on, till 5 cones with a 5 m distance in between are covered and the player is back on the starting point. The run is performed with maximal effort and timed. The total time is 32-35 s depending on level. This test reflects the anaerobic performance level but must be regarded as complex test including several qualities such as strength, quickness, co-ordination, lactate tolerance but not the least will power. These elements are included in soccer playing.

We performed on 18 players from one of Europe's most distinguished professional teams (Benfica, Portugal) a comparative study between the time for the shuttle run and the mean power output (0-30 s) from a W-test and found to have a significant relation ($p<0.01$) seen in fig. 2, page 10.
This may be interpreted as W-test being also valid in evaluating soccer players. In Geese’s investigation there was a significant differences in time between 1st, 2nd and 3rd leagues. The important correlation between field- and laboratory tests may also be regarded as established in soccer.

**Reference data from Bosön Institute of Sport**

In the table below data from various sports are displayed. A major part is from national teams or otherwise stated. Results are presented as mean values. (Monark = Mk, *=other make).

**Table 2a.**

<table>
<thead>
<tr>
<th>WOMEN</th>
<th>Number</th>
<th>Peak power (w/kg)</th>
<th>Mean power (w/kg)</th>
<th>Min. power (w/kg)</th>
<th>Weight (kg)</th>
<th>Bicycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycling (main roads)</td>
<td>5</td>
<td>10,7</td>
<td>8,4</td>
<td>7,2</td>
<td>64,0</td>
<td>Mk</td>
</tr>
<tr>
<td>Basketball</td>
<td>7</td>
<td>9,7</td>
<td>7,7</td>
<td>6,1</td>
<td>72,8</td>
<td>Mk</td>
</tr>
<tr>
<td>Figure skating</td>
<td>8</td>
<td>10,4</td>
<td>8,0</td>
<td>6,2</td>
<td>52,6</td>
<td>*</td>
</tr>
<tr>
<td>Squash</td>
<td>3</td>
<td>11,6</td>
<td>9,4</td>
<td>7,1</td>
<td>59,1</td>
<td>*</td>
</tr>
<tr>
<td>Ice hockey</td>
<td>28</td>
<td>10,0</td>
<td>7,4</td>
<td>5,6</td>
<td>65,7</td>
<td>Mk</td>
</tr>
<tr>
<td>Downhill skiing</td>
<td>3</td>
<td>10,0</td>
<td>8,2</td>
<td>6,5</td>
<td>64,9</td>
<td>Mk</td>
</tr>
</tbody>
</table>

**Fig. 2**

\[
Y = 24,1857 - 0,47194*X \\
N = 18 \\
r = 0,85 \\
p< 0,01
\]
### Table 2b.

<table>
<thead>
<tr>
<th>Sport</th>
<th>Number</th>
<th>Peak power (w/kg)</th>
<th>Mean power (w/kg)</th>
<th>Min. power (w/kg)</th>
<th>Weight (kg)</th>
<th>Bicycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor bandy (Floor ball)</td>
<td>11</td>
<td>12,2</td>
<td>9,3</td>
<td>6,8</td>
<td>74,9</td>
<td>*</td>
</tr>
<tr>
<td>Cycling (main roads)</td>
<td>8</td>
<td>12,3</td>
<td>9,9</td>
<td>7,6</td>
<td>79,7</td>
<td>M k</td>
</tr>
<tr>
<td>Bandy</td>
<td>7</td>
<td>12,7</td>
<td>9,8</td>
<td>7,8</td>
<td>77,8</td>
<td>M k</td>
</tr>
<tr>
<td>Basketball (junior n.t.)</td>
<td>7</td>
<td>11,1</td>
<td>9,0</td>
<td>7,0</td>
<td>78,7</td>
<td>M k</td>
</tr>
<tr>
<td>Soccer (foreign professional)</td>
<td>18</td>
<td>11,3</td>
<td>8,5</td>
<td>6,4</td>
<td>78,3</td>
<td>M k</td>
</tr>
<tr>
<td>Figure skating</td>
<td>4</td>
<td>12,5</td>
<td>9,3</td>
<td>6,9</td>
<td>72,4</td>
<td>*</td>
</tr>
<tr>
<td>Speed skating</td>
<td>4</td>
<td>14,5</td>
<td>10,6</td>
<td>7,6</td>
<td>80,2</td>
<td>*</td>
</tr>
<tr>
<td>Squash</td>
<td>11</td>
<td>12,2</td>
<td>9,4</td>
<td>7,1</td>
<td>75,6</td>
<td>*</td>
</tr>
<tr>
<td>Rugby</td>
<td>21</td>
<td>12,2</td>
<td>8,7</td>
<td>89,3</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>8</td>
<td>12,2</td>
<td>8,9</td>
<td>6,5</td>
<td>69,0</td>
<td>M k</td>
</tr>
<tr>
<td>Ice hockey (élite) May</td>
<td>20</td>
<td>12,7</td>
<td>9,6</td>
<td>7,1</td>
<td>82,5</td>
<td>*</td>
</tr>
<tr>
<td>Ice hockey (élite) August</td>
<td>20</td>
<td>13,1</td>
<td>9,8</td>
<td>7,1</td>
<td>83,0</td>
<td>*</td>
</tr>
<tr>
<td>Ice hockey (junior n.t.)</td>
<td>23</td>
<td>11,9</td>
<td>9,4</td>
<td>7,3</td>
<td>81,6</td>
<td>M k</td>
</tr>
<tr>
<td>Sports students</td>
<td>17</td>
<td>11,4</td>
<td>9,0</td>
<td>6,9</td>
<td>77,5</td>
<td>*</td>
</tr>
<tr>
<td>Running, middle-distance (élite)</td>
<td>6</td>
<td>12,1</td>
<td>9,5</td>
<td>7,6</td>
<td>61,7</td>
<td>M k</td>
</tr>
</tbody>
</table>

n.t. = national team

In the tables values from M k measurements are given with eliminated stored energy from the acceleration phase before time = 0 in the test, while values from older bikes are not corrected for pre-test energy. On the other hand the mass of the older bikes wheel is 4.5 kg compared to Monark's 22 kg. All groups in the table were loaded with 7.5% of actual body mass.

**W-test evaluations**

The most used numeric values origin from maximal- mean- and end power expressed in w/kg. These values are easy to compare from time to time. The new software provides the option to compare two graphs from different assessments by superimposing them. It is interesting to see how the different W-test values changes during for example a bandy season. Fig. 3, page 12, shows how mean values from 5 national team players develop during a period of two seasons. However, non of the visual changes in this material are significant. Heavy strength training was introduced in the beginning of the period and progressively increased over the time represented.
It is shown how various values (maximal-, mean- and end power) in all parts do not change simultaneously, which may be logical as they partly reflect different qualities in the performance capacity. Mostly an increased maximal value is accompanied by an unchanged or decreased end one (see measurement 3 and 6 for this). Uncommonly in measurement 7 all three values are high. A similar example can be seen in table 2 where the values from an ice hockey team are shown from the months May and August.

**The W-test and the future**

In our opinion this is in many ways a very valuable test, but can in some aspects be fine-tuned. In our institute one and the same test leader has through the years performed all tests on the national level. This gives a very important experience and test-retest situation. One of the major problems with the test is to pull the lever for starting the test in exactly the right time. That is, when the maximal pedalling frequency is assumed to have been reached.

To direct a W-test demands experience, endurance and engagement. A properly performed test takes place in a very tense situation, for both test leader and athlete.
This is especially the case on elite and national levels, where the results are expected to reflect important factors in the total performance capacity. Nothing may fail; one can hardly restart a test after 5 to 10 s maximal work.

With other words the test leader must be well educated, experienced and use a secure and exact device. If the W-test will continue to establish itself as a reflector of the maximal power output, accuracy is of greatest importance.

References:


