Heart Rate Determination of Anaerobic Threshold in Children

Georgine Gaisl and Peter Hofmann

Ethical and logistical limitations preclude the routine determination of anaerobic threshold in children by invasive measurement of blood lactate concentrations or ventilatory parameters. A noninvasive field test developed by Conconi can be used to determine anaerobic threshold through analysis of the heart rate curve during increased exercise workloads. Although this test was initially evaluated in adult athletes, recent data indicate that the Conconi test is applicable to children in both laboratory and field settings. Close correlation with lactate-derived anaerobic threshold appears to be possible when utilizing standard testing protocols.

The point of rapid acceleration in the rise of blood lactate level during progressive exercise, typically approximately 4 mmol/l, has been termed the anaerobic threshold (9, 38). Determination of this threshold may prove useful in evaluating aerobic fitness, providing training guidelines for athletes, and determining proper levels of exercise intensity in cardiac rehabilitation programs.

Blood sampling is not suitable during routine testing of pediatric subjects, and alternative means for estimating anaerobic threshold have been sought. Assessment of expiratory gases during exercise can provide such an estimate, but this technique involves expensive equipment in a laboratory setting. Conconi et al. developed a field test by which anaerobic threshold could be estimated noninvasively by means of heart rate curve analysis during increasing workload (7, 8). This test was initially only used on top athletes and could not be performed on children and adolescents.

The determination of anaerobic threshold in the pediatric age group has been the main topic of research in the Department of Exercise Physiology at the Institute of Sports Sciences of the University of Graz since 1977. Anaerobic threshold was initially determined invasively, first by measuring delta base excess (12, 13, 14, 15) and later through lactate measurement (11, 23, 26). Recently this group has attempted to modify Conconi’s test method to obtain reliable estimations of anaerobic threshold in young subjects in the laboratory (cycle ergometer, treadmill) as well as in the field. This review will examine testing protocols in children which have proven useful in heart rate determination of anaerobic threshold (20, 24, 25, 27, 30).

The authors are with the Department of Exercise Physiology, University Graz, Mozartgasse 14, A-8010 Graz, Austria.
General Testing Principle

The original Conconi test and subsequent modifications for children are based on the concept that with increasing workloads the heart rate increases linearly over a wide range (between approximately 120 and 170 bpm). Above and below these limits, heart rate deviates from linearity, resulting in a typical S-shaped curve (44). Conconi et al. reported that the upper deviation from linearity, or the heart rate threshold (HRT), correlates significantly with the invasively determined lactate threshold (7, 8). These authors showed that the running speed of adult athletes at the HRT was closely related to the speed at AT determined by lactate measurements ($r = .99$).

A number of other investigators have confirmed the value of heart rate analysis in determining anaerobic threshold (5, 10, 33, 39, 41). Others, however, have not been successful in duplicating these results (1, 6, 29, 35, 43, 46). Aigner and Muss (1), for instance, were unable to find an acceptable correlation between heart rate-derived anaerobic threshold and that obtained by blood lactate determinations in 32 cross-country skiers on the cycle ergometer and in the field. These authors deviated from the methodology prescribed by Conconi et al., however; this suggests that close attention to procedural detail is important if the Conconi test or its modifications are to prove useful.

We determined anaerobic threshold from the HRT in 72 11-year-old boys and girls and compared findings with the threshold established as a blood lactate level of 4 mm/l. A deflection of heart rate from linearity at high workloads was visible in all 64 subjects who cycled to this intensity. A high correlation was observed between the invasive and noninvasive methods ($r = 0.98$), supporting the validity of HRT in estimating anaerobic threshold in the pediatric age group. Others have reported a close relationship between HRT and anaerobic threshold estimated by ventilatory parameters in children as well (2, 3, 4).

Modified Testing Method for Children and Adolescents

As noted above, it may be crucial that standard testing protocols be utilized if the changes in heart rate with exercise are to be used for AT estimation. In the course of a 4-year research project, 59 pupils were tested in our laboratory and in the field for a total of six examinations. The results of these studies have been published elsewhere (24, 25, 27, 30). The following are procedures that have been used in these investigations.

**Cycle Ergometer.** Subjects were tested on an electrically braked cycle ergometer (Jaeger) while pedaling at a rate of 70 rpm. The test was started with a 3-min warm-up phase with zero watts in the first three examinations and 20 watts in the consecutive tests. The workload was then increased continuously by 10 watts every minute until exhaustion. Theoretical maximal heart rate ($HR_{max} = 220 - \text{age}$) was used as the criterion for maximal effort.

Initial workload was 10 watts in the first three tests, and in the consecutive examinations this was increased to 40 watts in the girls and 60 watts in the boys. Heart rate was recorded continuously with the System Sport Tester PE 3000 (Polar Electro, Finland) and stored in 5-sec intervals (34, 36, 42, 45). After the tests, the heart rate curve was analyzed visually and by computer (31, 37) and the HRT was determined (Figure 1).
Figure 1 — Typical heart rate curve with progressive cycle exercise. \( \text{HR}_d = \) heart rate deflection point (heart rate threshold), \( \text{P}_d = \) power deflection point.

**Treadmill.** After a 5-min warm-up period at 6 kph, testing was initiated at a treadmill rate of 8 kph (first examination), 7 kph (second test), and 6 kph in the third and fourth test. Speed was increased continually every 200 m (in the first and second examination) and every minute (third and fourth test) by 0.5 kph until voluntary exhaustion. The treadmill was maintained at a 5% grade. HRT was determined in the same manner as with cycle testing.
Field Test/Running. After a warm-up phase with a teacher, the test was started on a 200-m shuttle track with an initial speed of 7 kph (100 seconds per 200 meters). Running time was decreased continually every 200 meters by 2 seconds (first examination) and 4 seconds (consecutive tests) until the given tempo could no longer be sustained. The tempo was provided by the constant beeping of a pocket computer (Sharp PC 1260 pacer program) (28). Running distance was divided in 10 equal sections of 20 meters, which were clearly marked by adhesive tape or cones.

The pupils ran in groups of six. The first runner of the group (a teacher in the first examination and a well-trained pupil in subsequent tests) determined the tempo of the group with the pocket computer, adjusting the tempo such that a marker was passed whenever the computer beeped. The program automatically decreased running time for each consecutive 200-m distance by 2 seconds (first examination) and by 4 seconds (consecutive tests). The same method of HRT determination was used as on the cycle and treadmill.

Testing Guidelines

On the basis of the results obtained using these procedures (24, 25, 27, 30), general testing protocols for young subjects can be derived (16, 17, 18, 19, 21, 22). In order to obtain analyzable heart rate curves, the following testing criteria need to be observed.

Initial Workload. The heart rate curve is not linear below approximately 120 beats/min (44). The initial workload should therefore be such that a heart rate of approximately 120–130 beats/min results after the first stage. This heart rate marks the beginning of the linear relationship between heart rate and workload (32). The degree of initial workload for children is approximately 0–40 watts for the cycle ergometer, 6–8 kph on the treadmill, and 6–10 kph during field testing.

Number of Workload Stages. In order to ascertain reliable heart rate curves, many workload stages are necessary. Conconi et al. found 12–16 stages to be optimal in top athletes (7), and this number is appropriate for children and adolescents as well.

Total Testing Time. The total test duration for children should not be longer than approximately 15 minutes. Otherwise the influence of fatigue on heart rate could lead to falsification of test results (4). Heart rate increase due to fatigue adds to the load-adequate heart rate, making identification of the deflection point difficult.

Rate of Increments. To keep the total test duration at approximately 15 minutes with a given number of workload stages and defined initial workload, it is necessary to adapt the rate of increments to each person’s physical fitness. From the initial workload (which can be easily determined during the warm-up phase) and the maximal workload (Table 1), the rate of increments can be calculated:

\[
\text{rate of increment} = \frac{\text{maximal load} - \text{initial load}}{12 \text{ to } 16}
\]

Guidelines for workload stages for children are as follows: cycle ergometer 5–15 watts, treadmill 0.5 kph, and field test 2–5 seconds per 200 meters.
Anaerobic Threshold in Children

Table 1
Average Maximum Performance ($P_{\text{max}}, P_{\text{max}/\text{kg}}$) Related to Age and Accompanying Calculated Values for Oxygen Intake ($\dot{V}O_2\text{max}, \dot{V}O_2\text{max}/\text{kg}$) for Children

<table>
<thead>
<tr>
<th>Age (yrs)</th>
<th>$P_{\text{max}}$ W</th>
<th>$P_{\text{max}/\text{kg}}$ W/kg</th>
<th>$\dot{V}O_2\text{max}$ l/min</th>
<th>$\dot{V}O_2\text{max}/\text{kg}$ ml/kg • min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boys</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>89</td>
<td>4.4</td>
<td>0.93</td>
<td>51.8</td>
</tr>
<tr>
<td>11</td>
<td>124</td>
<td>4.4</td>
<td>1.34</td>
<td>50.9</td>
</tr>
<tr>
<td>12</td>
<td>163</td>
<td>4.4</td>
<td>1.81</td>
<td>50.1</td>
</tr>
<tr>
<td>13</td>
<td>197</td>
<td>4.3</td>
<td>2.23</td>
<td>49.5</td>
</tr>
<tr>
<td>14</td>
<td>225</td>
<td>4.3</td>
<td>2.58</td>
<td>48.8</td>
</tr>
<tr>
<td>15</td>
<td>246</td>
<td>4.2</td>
<td>2.83</td>
<td>48.2</td>
</tr>
<tr>
<td>16</td>
<td>261</td>
<td>4.2</td>
<td>3.01</td>
<td>47.6</td>
</tr>
<tr>
<td>17</td>
<td>271</td>
<td>4.1</td>
<td>3.13</td>
<td>47.1</td>
</tr>
<tr>
<td>18</td>
<td>278</td>
<td>4.1</td>
<td>3.20</td>
<td>46.5</td>
</tr>
<tr>
<td>Girls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>79</td>
<td>3.6</td>
<td>0.91</td>
<td>39.6</td>
</tr>
<tr>
<td>11</td>
<td>106</td>
<td>3.5</td>
<td>1.29</td>
<td>39.2</td>
</tr>
<tr>
<td>12</td>
<td>142</td>
<td>3.5</td>
<td>1.51</td>
<td>38.9</td>
</tr>
<tr>
<td>13</td>
<td>166</td>
<td>3.5</td>
<td>1.69</td>
<td>38.6</td>
</tr>
<tr>
<td>14</td>
<td>179</td>
<td>3.4</td>
<td>1.83</td>
<td>38.2</td>
</tr>
<tr>
<td>15</td>
<td>186</td>
<td>3.4</td>
<td>1.94</td>
<td>37.9</td>
</tr>
<tr>
<td>16</td>
<td>189</td>
<td>3.4</td>
<td>2.01</td>
<td>37.6</td>
</tr>
<tr>
<td>17</td>
<td>190</td>
<td>3.4</td>
<td>2.07</td>
<td>37.3</td>
</tr>
<tr>
<td>18</td>
<td>190</td>
<td>3.3</td>
<td>2.10</td>
<td>37.0</td>
</tr>
</tbody>
</table>

Duration of Workload Stages. The duration of the first workload stage should be 60 seconds (minimum) to reach a workload-adequate level of heart rate (40). A lower limit for the duration of the consecutive workload stages is approximately 30 seconds. Guidelines for children are as follows: cycle ergometer 1 minute, treadmill 1 minute, and field test 100–200 meters.

Conclusions

Reliable estimations of anaerobic threshold from the heart rate deflection can be obtained with the above modifications of the Conconi test. It is important, however, that the outlined testing procedures be strictly followed. The method is simple and inexpensive, and analysis can be objectively performed by computer programs.

In light of ethical and economic considerations, the modified Conconi test may be the optimal means of noninvasively determining anaerobic threshold in children. It has to be critically noted, however, that a sound theoretical base and causes for the phenomenon of the HRT remain to be determined.
References


15. Gaisl, G., and J. Buchberger. Changes in the aerobic-anaerobic transition in boys


**Acknowledgments**

This study was supported by Grant No. 6961 from the Austrian Research Fund (Fonds zur Förderung der wissenschaftlichen Forschung) and by the Austrian Ministry of Education, Art and Sports (Ministerium für Unterricht, Kunst und Sport).