Can the Point of Deflection
From Linearity of Heart Rate
Determine Ventilatory Threshold in Children?

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Whether the point of deflection from linearity of heart rate (HRD) coincides with ventilatory threshold (VT) has not been extensively examined in children. The purpose of this study was to assess the relationship between the VO\textsubscript{2} measured at VT and the VO\textsubscript{2} measured at HRD. Twenty-two boys with a mean age of 10.7 years (±1.0) performed a graded exercise test to determine VT, HRD, and VO\textsubscript{2,max}. There was no significant difference between mean VO\textsubscript{2} (ml/kg/min) at VT and at HRD (33.5±3.5 vs. 34.1±4.4; \( p>0.05 \)). Linear regression analysis revealed a correlation of \( r=0.76 \) (\( p<0.01 \)) between the VO\textsubscript{2} measured at VT and the VO\textsubscript{2} measured at HRD. These results indicate that HRD may be an accurate predictor of VT in most but not all children, and caution should be used when interpreting the significance of HRD.

The ventilatory threshold (VT) has been defined as the point during incremental exercise when pulmonary ventilation begins to increase in a disproportionate manner with respect to the increase in VO\textsubscript{2}. It has been suggested that the onset of VT represents the point during exercise when anaerobic metabolism begins to contribute significantly to the production of ATP (15). The increased reliance on anaerobic metabolism is believed to promote an increase in blood lactate concentration (15). As a result, some researchers have used VT as a marker of the lactate threshold (LT) (4, 6, 15).

Whether these terms can be used interchangeably has not been fully resolved since the exact timing of these events and their biochemical origin is not entirely certain (3, 6). Despite this controversy, VT has been reported to be correlated to LT (4, 6) and has been shown to be a valid and reliable indicator of cardiorespiratory fitness in both children and adults (6, 9, 11, 14, 16). Furthermore, both VT and LT are highly related to endurance performance and are important components in establishing optimal training intensities (6).

Recently, Conconi et al. (5) reported that LT in adults could be determined...
by examining the relationship between increases in running speed and heart rate. They reported that during exercise the heart rate response eventually begins to plateau despite further increases in running speed. Conconi et al. (5) reported that the point of heart rate leveling corresponded to LT. Gaisl and Wiesspeiner (8) reported similar findings while studying children. Despite the high relationship between LT and HRD, the biochemical events that mediate HRD are unknown. Whether the point of deflection from linearity of heart rate (HRD) corresponds to VT has not been extensively examined in children. Quantifying either VT or LT by assessing only heart rate during graded exercise has considerable appeal in that the use of blood samples and sophisticated laboratory equipment to measure gas exchange would not be necessary. The purpose of this study was to further evaluate the use of HRD as an alternative method to assess VT in children. In order to do this, it was necessary to employ an exercise test that we have determined to be effective in eliciting VT in this subject population.

Methods

The purpose and procedures of this investigation were explained to 29 boys between the ages of 8 and 13 years. Of these 29 children, 4 were excluded from the final analysis because of failure to demonstrate HRD. In addition, 3 others were excluded from the final analysis because VT could not be identified. The results of this investigation were therefore based on data collected on 22 children. All of these boys were active but none were involved in any formal training programs at the time of testing. Parental consent was obtained for all subjects. This study was approved by the Institutional Human Subjects Review Board.

Upon entering the laboratory, the subject's age (yrs), height (cm), and weight (kg) were recorded. Mean age, height, and weight were 10.7 ± 1.0 years, 143 ± 8.3 cm, and 34.7 ± 5.8 kg, respectively. The subjects were then given a detailed explanation of the testing procedures, during which they were permitted to practice walking and running on a motor-driven treadmill (Quinton Instruments, Model 1860). During this practice period a comfortable running speed was determined for each child (range 5.0 to 7.0 mph). Following the practice period the subjects were given time to rest, during which a 2-lead ECG configuration was applied in order to assess heart rate.

An incremental exercise test was administered to measure VT, HRD, and VO₂max. During the incremental exercise test the subjects breathed through a low-resistance two-way Hans Rudolf breathing valve (deadspace, 67 ml) with a noseclip in place. The protocol began with all subjects walking 3.0 mph at 0% elevation for 1 minute. The speed was then increased by 0.5 mph per minute until the individual attained his predetermined running speed. From this point on, the speed remained constant but the elevation increased 2.5% every minute until VO₂max was achieved.

The criteria for achieving VO₂max included attainment of at least two of the following three criteria: failure of VO₂ to increase more than 2 ml/kg/min despite a further increase in workload; a heart rate greater than or equal to 195 bpm; or an $R$ value in excess of 1.00 (2). All children attained at least two of these criteria.

A Medical Graphics Corp. 2001 (MGC 2001) metabolic measuring cart was used to analyze expired air samples. Prior to each exercise test the MGC
2001 was calibrated according to standardized procedures (10). During the incremental exercise test, breath-by-breath data were collected and stored on an integrated computer system. The breath-by-breath data were then averaged over a 15-sec sampling period and recorded. This sampling period has previously been reported to yield a clear ventilatory deflection point (13). VT and HRD were then determined from 15-sec plots of VE/VO$_2$, VE/VCO$_2$, and heart rate plotted against time.

The criteria used to determine VT was a systematic increase in VE/VO$_2$ without a corresponding increase in VE/VCO$_2$ (4, 6). HRD was identified as the point where the HR response to graded exercise began to deflect from linearity by flattening (5, 8). VT and HRD were assessed independently by two researchers familiar with the assessment of VT. When there were differences, VT and HRD were mutually agreed upon. Figure 1 presents the manner in which VT and HRD were determined.

A student t test for paired data was used to determine whether there was a significant difference between the mean VO$_2$ in ml/kg/min at VT and the mean VO$_2$ in ml/kg/min at HRD. Linear regression analysis was employed to determine the relationship of the VO$_2$ at VT with the VO$_2$ at HRD. A $p$ value of less than or equal to 0.05 was used to establish statistical significance in each analysis.

Results

Table 1 presents the mean maximal exercise data. These values, as well as those measured at VT and HRD (Table 2), are well within the range one would expect for children of this age (9, 11, 12, 14, 16). Figure 2 presents the mean VO$_2$ (relative to body weight) that was measured at VT and HRD. No significant differences were noted between these variables. Figure 3 presents the results of the linear regression analysis. A correlation of $r = 0.76$ ($p < 0.01$) was found between the VO$_2$ at VT and the VO$_2$ at HRD.
Conconi et al. (5) proposed the use of HRD as a noninvasive method to determine LT. In their study, the point of deflection from linearity of heart rate in response to increased running speed was highly correlated \((r=.99)\) to LT in 10 adult runners. The authors concluded that determination of the velocity–heart rate relationship was an adequate means of assessing LT. Examining children with a mean age of 11 years, Gaisl and Wiesspeiner (8) reported that HRD was also highly correlated with LT \((r=0.98)\). Although there is some debate regarding the biochemical origins that mediate both VT and LT, previous research has
Table 1
Maximal Exercise Data (n=22)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
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<tr>
<td>VO₂ (L/min)</td>
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<td>VO₂ (ml/kg/min)</td>
<td>44.2</td>
<td>5.8</td>
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<tr>
<td>HR (bpm)</td>
<td>205.3</td>
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</tr>
<tr>
<td>VE (L/min)</td>
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<td>12.1</td>
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<tr>
<td>R</td>
<td>1.17</td>
<td>0.07</td>
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Table 2
Cardiorespiratory Response at VT and HRD (n=22)

<table>
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<th>Variable</th>
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<th>HRD</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>VO₂ (L/min)</td>
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<td>VO₂ (ml/kg/min)</td>
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<tr>
<td>HR (bpm)</td>
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<td>181.4</td>
<td>10.1</td>
</tr>
<tr>
<td>% VO₂ max</td>
<td>75.5</td>
<td>6.5</td>
<td>77.9</td>
<td>7.1</td>
</tr>
<tr>
<td>VE (L/min)</td>
<td>39.5</td>
<td>5.4</td>
<td>43.1</td>
<td>6.6*</td>
</tr>
<tr>
<td>R</td>
<td>0.96</td>
<td>0.07</td>
<td>1.00</td>
<td>0.07*</td>
</tr>
</tbody>
</table>

*p<0.05.

shown a strong relationship between VT and LT (4, 6). With this in mind, we chose to examine whether HRD could be used as an alternative method to determine VT in children.

Examination of the data presented in Figure 2 shows that there was no significant difference between the mean VO₂ measured at VT and the mean VO₂ measured at HRD. Figure 3 demonstrates a moderately high relationship with regard to the VO₂ measured at both VT and HRD. These latter results are consistent with the findings of Baraldi et al. (1), who reported a correlation of \( r=0.80 \) between the power output at VT and the power output at HRD in a group of children between 7 and 14 years of age.

Further comparing the results of the present investigation to previous research is difficult since most of these studies have assessed HRD and LT. These studies have also employed a variety of exercise protocols. For example, Conconi et al. (5) used increasing running speed to determine HRD and LT.
Wiesspeiner (8) measured LT during graded exercise testing on a treadmill while HRD was assessed during a second test on a bicycle ergometer.

Gaisl and Hofmann (7) have proposed guidelines for determining HRD in children. They suggest that 12–16 one-minute exercise stages are necessary to accurately determine HRD. A protocol of increasing speed with increments of 0.5 kph per minute is recommended when using a treadmill (7). Our study used a protocol with progressive increases in speed only up to approximately 60–70% of the child’s VO$_2$ max. Thereafter, the workload was increased by increasing the elevation every minute. The duration of this test ranged from 8 to 12 minutes. This protocol differed from the recommendations of Gaisl and Hofmann (7) with
respect to increases in speed, the use of elevation, and the number of exercise stages. Nonetheless, we found this protocol to be effective in determining VT and HRD in the children examined in this study. This suggests that further research is necessary with regard to optimizing the exercise protocol to determine HRD in children.

In conclusion, we found no significant difference between the mean VO₂ at VT and the mean VO₂ at HRD. We also found that the correlation between these two variables was $r=0.76$. It appears that when used with caution, HRD may be an accurate predictor of VT in most but not all children. Future research is warranted with respect to elucidating the physiological and biochemical events that mediate HRD.

References