Blood Lactate Responses to Exercise in Children: Part 2. Lactate Threshold

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Part 2 reviews the literature concerning the lactate threshold in children. An analysis is presented comparing children to adults regarding responses to submaximal exercise, and the lactate threshold as a percentage of VO\(_2\)\text{max}. Possible explanations for lower blood lactate concentrations during submaximal exercise in children are considered.

Over the past 25 years, a number of studies have reported reduced lactate concentrations in children following maximal and submaximal exercise. In Part 1 (13) we reviewed the literature concerning blood lactate responses to maximal exercise in children. Here in Part 2 we will review the evidence regarding blood lactate responses to submaximal exercise in children and the lactate threshold.

Direct comparison of the results of different studies is complicated by the variability in terminology used to describe the lactate threshold. The following definitions are provided for clarification, and will be used throughout this review:

- **Inflection point of the lactate-intensity curve** describes the VO\(_2\)\(_\text{max}\) workload, or velocity at which blood lactate concentration increases nonlinearly as exercise intensity increases.
- **Fixed lactate concentrations** of 2.0, 2.5, or 4.0 mmol, and the corresponding exercise intensity, are convenient measures of the lactate threshold, and may represent specific metabolic events in the muscle.
- **1 mmol above baseline** describes the exercise intensity at which blood lactate concentration increases 1 mmol over resting levels.
- **Ventilatory threshold** (VT) describes the exercise intensity at which ventilation (VE) increases disproportionately versus oxygen consumption (VO\(_2\)). VT has been used as an alternative to lactate measurement in identifying the lactate threshold.

This paper considers blood lactate responses to submaximal exercise in children, and the evidence that the fixed concentration lactate threshold as a percentage of VO\(_2\)\text{max} is higher in children than in adults. To examine developmental patterns for submaximal exercise lactate responses, the associations between the
lactate threshold versus age/sexual maturation and other variables are also examined. Factors that may contribute to the differences observed in submaximal lactate responses across age in children or in comparison to adults are discussed.

**Lactate Threshold in Children**

The lactate threshold (LT) has been widely accepted as a predictor of endurance performance in adults. LT has been defined in a variety of ways by various authors. Some studies use fixed blood lactate concentrations of 2.0 mmol, 2.5 mmol, or 4.0 mmol to represent LT; others use the inflection point of the lactate-intensity curve; and still others use 1 mmol above baseline to represent LT. VT has also been used as a noninvasive alternative for estimating LT. Although the results of studies using different terms to represent the lactate threshold have sometimes been directly compared, these criteria for LT may not be equivalent physiologically. For example, in comparing two studies that used the inflection point and the 4-mmol concentration to represent LT, one cannot assume that both measures have the same physiological significance. That is, the 4-mmol lactate concentration is likely higher than the inflection point of the lactate-intensity curve in a given individual, and each index may represent a different metabolic event in the muscle.

Numerous studies have investigated the associations between the lactate threshold in children and age/sexual maturation, exercise training, and different exercise protocols, as well as the appropriate criteria to define LT in children. The results of several of these studies are presented chronologically in Table 1.

**Effects of Exercise Protocol and Threshold Criteria**

Measurement of LT is specific to the exercise protocol used, the criteria selected to represent lactate threshold, and the lactate assay methodology used (20). For example, Williams and Armstrong (20) used whole-blood analysis of blood lactate, whereas other studies have used cellular and plasma lactate. Given that LT has been defined and measured with a variety of methods, comparisons of the results of studies from different laboratories, or using different protocols (18) should be made with caution. Macek and Vavra (10) found conflicting results for LT in 52 girls between the ages of 6 and 14, depending on whether the ventilatory equivalent for oxygen or the lactate-intensity curve was used to estimate LT. The difficulty in determining LT in the girls underscores the importance of establishing common protocols in testing LT in children. Apparent differences between studies may be due to differences in measurement protocols.

Atomi et al. (2) measured LT in 11 boys, ages 9 to 10 years, and defined LT as the inflection point of the lactate-intensity curve. LT was found to occur at 36.7 ml·kg⁻¹·min⁻¹, representing 71% of VO₂ max, at a mean lactate concentration of only 1.6 mmol. These findings for LT as a percentage of VO₂ max are lower than those found in most other studies with children. This difference could have resulted because identification of the inflection point of the lactate-intensity curve is somewhat subjective, and these investigators may interpret the inflection point as occurring earlier than some other investigators. Although children have been shown to have lower lactate levels than adults, it is possible that 1.6 mmol underestimated LT in this study. In comparison, Mocellin et al. (11), studying 11- and 12-year-old boys also defined LT as the inflection point of the lactate-intensity curve, but used
16-min stages on different days to identify LT. Their study found LT to occur at a lactate concentration of 2.6 mmol. It is unclear whether the differences in the lactate concentrations found at the inflection point are related to differences between subjects, differences in exercise protocols, differences in interpretation of the inflection point, or other factors.

Similarly, as seen in Table 1, the ventilatory threshold, as used by Weymans et al. (19), Paterson et al. (12), Washington (17), and Mocellin et al. (11), appears to identify (a) exercise intensities consistently lower than the fixed 4 mmol lactate concentration, and (b) similar, or slightly lower estimates than those found using the inflection point of the lactate-intensity curve as the definition of LT. In addition, under certain conditions, such as glycogen depletion, VT may be altered such that ventilatory indices are not reliable estimates of LT. Given the ethical considerations in collecting blood lactate in children, however, the use of a noninvasive method to estimate LT in children is attractive.

Fixed blood lactate concentrations can also be problematic when applied to children, particularly the 4.0 mmol concentration often used to define LT in adult athletes. Williams et al. (21) used 4-mmol blood lactate as the criterion for LT, and found LT to occur at 91 ± 6.8% in both boys and girls, which is similar to the findings of Fernhall et al. (6). In the Williams et al. study (21), 34% of the boys and 12% of the girls did not achieve a blood lactate concentration of 4.0 mmol at peak VO\(_{2}\). This suggests that 4 mmol is not an appropriate criterion for LT in children. Williams and Armstrong (20) commented that the 4-mmol lactate concentration represents a higher percentage of VO\(_{2}\)\(_{\text{max}}\) in children than in adults because the lactate concentration at the inflection point of the lactate–intensity curve appears to be substantially lower than 4 mmol in children. The 4-mmol level, therefore, may represent lactate threshold in adults (although this is certainly open to debate), but appears to be above lactate threshold in children. If an absolute value is used to represent LT in children, the 2.0- or 2.5-mmol level would be more appropriate than the 4.0-mmol level. However, any fixed concentration may be inappropriate because it appears likely that LT changes in the individual child over time, so any comparison of children at different ages or stages of sexual maturity using a fixed lactate concentration could be misleading.

The results presented in Table 1 support the use of the lactate inflection point rather than a fixed lactate concentration to represent the lactate threshold in children. The inflection point of the lactate–intensity curve, although more subjective than other LT criteria, has the advantage of representing the individual’s metabolic response to increasing workloads.

**Lactate Threshold and Chronological Age/Sexual Maturation**

Studies focusing on the relationship between the LT and chronological age or stage of sexual maturation include Atomi et al. (1), Beneke et al. (3), Weymans et al. (19), Paterson et al. (12), and Williams and Armstrong (20). The findings of these studies have generally been consistent, with the exception of the study by Paterson et al. (12).

Atomi et al. (1) measured LT, defined as the inflection point of the lactate–intensity curve, in two groups of boys ages 10.3 and 11.8 years. Seven of the boys were measured twice during treadmill running, 1.5 years apart. LT for the 10.3-year-old group was found to occur at 37.3 ml \(\cdot\) kg\(^{-1}\) \(\cdot\) min\(^{-1}\), representing 71.7 ± 1.7% of VO\(_{2}\)\(_{\text{max}}\), whereas LT for the 11.8-year-old group occurred at 33.2 ml \(\cdot\) kg\(^{-1}\) \(\cdot\) min\(^{-1}\),
Table 1  Lactate Threshold as a Percentage of Peak VO_{2} in Children

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Lactate threshold % VO_{2,max}</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rusko et al. (15)</td>
<td>15</td>
<td>85.7 ± 6.6%</td>
<td>LT as % of VO_{2,max} in endurance-trained girls similar to levels of elite endurance-trained adults. LT decreased with age both as a % of VO_{2,max} and in m·kg·min^{-1} in 10- to 13-year-old boys.</td>
</tr>
<tr>
<td>Atomi et al. (1)</td>
<td>13</td>
<td></td>
<td></td>
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<tr>
<td>Weymans et al. (19)</td>
<td>52</td>
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<tr>
<td>Rotstein et al. (14)</td>
<td>28</td>
<td></td>
<td></td>
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<tr>
<td>Atomi et al. (2)</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paterson et al. (12)</td>
<td>18</td>
<td></td>
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</tbody>
</table>

Age 10.3 yrs: 71.7 ± 1.7%
Age 11.8 yrs: 63.7 ± 1.8%
Age 6: 72.3 ± 6.4%
Age 11: 67.4 ± 8.8
Age 14: 62.3 ± 8.0
Boys: 66.0 ± 10.5
Girls: 66.4 ± 7.5

4 mmol: Pretrain: 85.1 ± 6.8%
Posttrain: 80.6 ± 3.9%
Inflection: Pretrain: 82.2 ± 7.0%
Posttrain: 77.9 ± 5.5%

1.6 mmol inflection: 71 ± 2%
Age
11  56.0 ± 5.2%
12  58.8 ± 7.2
13  60.5 ± 6.0
14  60.5 ± 5.1
15  61.6 ± 4.3

Lower LT inflection point than most other studies. VT increased with increasing age. This conflicts with findings of other studies, but may be related to this sample of athletic boys, who became more highly trained over the 5-year period.
<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Size</th>
<th>Boys 75 ± 13%</th>
<th>Girls 71 ± 9%</th>
<th>Boys 91 ± 6.8%</th>
<th>Girls 91 ± 6.8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washington (17)</td>
<td>151</td>
<td></td>
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<tr>
<td>Williams et al. (21)</td>
<td>103</td>
<td></td>
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<tr>
<td>Williams &amp; Armstrong (20)</td>
<td>191</td>
<td>89/93%</td>
<td>NA</td>
<td>87/89</td>
<td>80/90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>84/90</td>
<td>79/91</td>
<td>81/91</td>
<td>73/88</td>
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<tr>
<td></td>
<td></td>
<td>80/92</td>
<td>71/87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mocellin et al. (11)</td>
<td>11</td>
<td>78 ± 3.6% (LT inflection point)</td>
<td>53 ± 8.8% (VT)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beneke et al. (3)</td>
<td>34</td>
<td>66.5 ± 7.7%</td>
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<tr>
<td>Fernhall et al. (6)</td>
<td>21</td>
<td>Boys 91 ± 5%</td>
<td>Girls 89 ± 5%</td>
<td></td>
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</tr>
</tbody>
</table>

Note. LT = lactate threshold. VT = ventilatory threshold. MLSS = maximal lactate steady state.

VT as % VO₂ max decreased with age in 7.5- to 12.5-year-old children.

Very high LT as % of VO₂ max. Four millimole may not be appropriate criterion for LT in children.

LT as 2.5 mmol declined with age, but LT at 4.0 mmol not related to age in 11- to 16-year-old boys and girls. No difference in 4.0 mmol LT as % of VO₂ max between boys and girls at each Tanner stage.

Blood lactate criterion substantially higher than VT as % of VO₂ max in 11- to 12-year-old boys.

No relationship between lactate concentration at MLSS and age, or between MLSS as % of VO₂ max and age.

4 mmol LT occurred at very high % of VO₂ max, LT VO₂ related to 3-mile (boys) and 2-mile (girls) race performance.
representing 63.7 ± 1.8% of VO\(_2\)\(_\text{max}\). LT, therefore, decreased with age both in m \(\cdot\) kg\(^{-1}\) \cdot min\(^{-1}\) and as a percentage of VO\(_2\)\(_\text{max}\). The authors hypothesize that the decrease in LT may be related to an observed increase in the area of the gastrocnemius muscle relative to the soleus muscle with age, which would increase the ratio of fast-twitch to slow-twitch muscle fibers in plantar flexion. This represents an increase in the mass of lactate-producing fast-twitch muscle fibers relative to slow-twitch muscle fibers, rather than a change in the metabolic profile of the muscles. A significant negative relationship was found between the gastrocnemius as a percentage of muscle mass in the plantar flexors and the percent of VO\(_2\)\(_\text{max}\) at LT.

Beneke et al. (3) investigated the relationship between the maximal lactate steady state (MLSS) and age in 11- to 20-year-old males. MLSS is the highest exercise intensity at which blood lactate concentration initially rises and then levels off over time. MLSS was observed to occur at 4.2 ± 0.7 mmol, and 66.5 ± 7.7% of VO\(_2\)\(_\text{max}\). This study found no relationship between lactate concentration at MLSS and age, or between MLSS as a percentage of VO\(_2\)\(_\text{max}\) and age. The authors assert that their findings suggest that neuromuscular development may have a greater role than changes in oxidative metabolism or glycolysis in determining age-related changes in exercise responses in children.

Weymans et al. (19) investigated the influence of age and gender on VT in 52 children aged 6, 11, and 14 years. VT was estimated from a graded exercise test on a treadmill defined as the exercise intensity at which VE/VO\(_2\) increased without an increase in VE/CO\(_2\). VT averaged 32.3 ml \(\cdot\) kg\(^{-1}\) \cdot min\(^{-1}\) in the boys, and 26.6 ml \(\cdot\) kg\(^{-1}\) \cdot min\(^{-1}\) in the girls. Despite the differences in VO\(_2\) at VT, there was essentially no difference when VT was expressed as a percentage of VO\(_2\)\(_\text{max}\) (boys 66.0%, girls 66.6%) because the boys had significantly higher VO\(_2\)\(_\text{max}\) values than the girls. These results suggest that similar biochemical factors may limit both boys and girls in maintaining a high percentage of VO\(_2\)\(_\text{max}\), despite the differences observed in VO\(_2\)\(_\text{max}\) between genders. VT, expressed both as the VO\(_2\) at VT, and as a percentage of VO\(_2\)\(_\text{max}\), was lower in the 14-year-olds than in the 6- or 11-year-olds, and the values were typical of those found in untrained adults. There was no significant difference in VT between the 6- and 11-year-olds. These results suggest that 14-year-olds may have metabolic profiles that are more similar to those of adults than those of younger children, and that decreases in VT with age may be related to sexual maturation.

Paterson et al. (12) assessed VT longitudinally in 18 boys from ages 11 to 15. Interestingly, the percentage of VO\(_2\)\(_\text{max}\) at VT was found to increase with age, which conflicts with several of the other studies in Table 1. This finding may be related to the sample of subjects in this study, which consisted of athletic boys, who became more seriously involved in competitive sports over the 5-year period. It is not possible, therefore, to separate the effects of age or sexual maturity from the effects of training in analyzing the observed increase in VT in these subjects.

The Williams and Armstrong (20) study measured lactate threshold as a percentage of VO\(_2\)\(_\text{max}\) at fixed lactates of 2.5 mmol and 4.0 mmol. No difference was found between the boys and girls in 4.0-mmol LT as a percentage of VO\(_2\)\(_\text{max}\) at each Tanner stage, but there was a trend for boys to be at a higher percent of VO\(_2\)\(_\text{max}\) at 2.5-mmol lactate concentration than girls. The percent of VO\(_2\)\(_\text{max}\) at 2.5 mmol, which may be closer to the inflection point in children than the 4.0 mmol level, was negatively related to stage of sexual maturation whereas the 4.0 mmol level was unrelated to stage of sexual maturation. The lack of a relationship with the 4.0 mmol concentration may be because 4.0 mmol represented a high
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percentage of VO2,max in all the subjects, and was likely above the inflection point of the lactate-intensity curve. These data support the importance of the specific criteria used to define LT in comparing the results of children of different ages, stages of sexual maturation, gender, and the like.

The results of the above studies, other than those of Paterson et al. (12), support the hypothesis that there is a negative relationship between LT as a percentage of VO2,max and age or stage of sexual maturation in children. This relationship may not be evident if the 4.0 mmol concentration is used to define LT. It is unclear whether there is an effect of age, independent of sexual maturation, on LT as a percentage of VO2,max. Possible causal mechanisms underlying these relationships are considered in the sections below.

Lactate Threshold and Exercise Training

In adults, LT as a percentage of VO2,max has been observed to increase with endurance training, and LT has been used as a predictor of endurance performance. This relationship has not been clearly established in children. Several studies have measured the lactate threshold in samples of trained children, and at least one training study examining how LT is affected by training has been conducted in children.

Rusko et al. (15) studied elite female cross-country skiers using 4 mmol to define LT, and found a mean LT of 85.7 ± 6.6% of VO2,max. LT was found at a similar percentage of VO2,max as typically found in elite endurance-trained adults. These girls were among the best junior cross-country skiers in Finland, so the high LT could be related to training or genetics, or it could be related to the ages or stage of sexual maturity of the subjects. Given the lack of a control group, the influence of training, genetics, and age/sexual maturation on LT cannot be examined in this study. Similarly, Femhall et al. (6) investigated LT in relation to running performance in 15- to 18-year-old boys and girls. These investigators used 4 mmol as the criterion for LT because they believed 4 mmol would correlate more highly with race performance than other criteria. Femhall et al. found mean 4 mmol levels to be 91 ± 5% of VO2,max in the boys and 89 ± 5% of VO2,max in the girls. These levels are as high or higher than those found in elite adult endurance athletes, which is consistent with the hypothesis that the ratio of glycolytic to oxidative capacities may be lower in adolescents than in adults, so LT may not occur until a higher percentage of VO2,max is reached.

In a 1986 training study, Rotstein et al. (14) investigated the effects of 9 weeks of interval training on the lactate threshold of 10- to 11-year-old boys. The study found LT, defined as the inflection point of the lactate-intensity curve, as a percentage of VO2,max to decrease with training from 82.2% to 77.9%. The running speed at lactate threshold, however, increased by 0.51 km · hr⁻¹ because there was an increase in relative VO2,max of 8%, which was greater than the percentage decrease in LT as a percentage of VO2,max. These results suggest that VO2,max may respond more to interval training in children than the lactate threshold. These results are consistent with training studies in adults in which interval training at approximately 100% of VO2,max provides the greatest stimulus to increase VO2,max, whereas lower intensity training at approximately LT provides the greatest stimulus to increase LT.

Before the relationship between exercise training and LT in children can be understood, further investigation is needed to separate the effects of age, sexual maturation, training, and genetics on LT. The Rusko and Femhall studies did not include control groups, so it is not clear whether the high LT values were due to training or other factors. The evidence from the Rotstein study suggests that interval training
may lead to a decreased LT as a percentage of VO\textsubscript{max}, but an increase in the VO\textsubscript{2} at LT because this type of training may stimulate significant increases in VO\textsubscript{2}\textsuperscript{max}. An area for further investigation would be to conduct an endurance training study to determine the effects of lower intensity training on the lactate threshold in children.

**Explanations for an Altered Lactate Threshold**

A possible explanation for lower lactate concentrations during submaximal exercise in children compared to adults is altered enzyme profiles in skeletal muscles in children. There is evidence that children have somewhat reduced glycolytic enzyme activity, and lower ratios of glycolytic to oxidative enzymes compared to adults, and that skeletal enzyme profiles change during childhood (4, 5, 7, 8, 13). These differences are consistent with the higher percentage of VO\textsubscript{max} at fixed lactate concentrations observed in children compared to adults. A lower ratio of glycolytic to oxidative enzyme activity in children could be related to reduced production of lactic acid, increased oxidation of lactate, or both.

A number of other explanations have been proposed to explain why children may have lower lactate concentrations during submaximal exercise, including lower glycogen concentration and lower rate of glycogen utilization, particularly in pre-pubescent children (9, 22), and lower sympathetic activity in children (22).

**Conclusions**

Although a number of studies have found the exercise intensity at the lactate threshold to represent a higher percentage of VO\textsubscript{2}\textsuperscript{max} in children than in adults, most of those studies used a criterion for lactate threshold of 4 mmol, which may not be appropriate for children. Given that children achieve lower peak lactate concentrations than adults, with some children reaching peak lactate concentrations of less than 4 mmol, this concentration represents a relatively higher percentage of glycolytic capacity in children, and appears to be an inappropriate criterion for the lactate threshold in children. Using the inflection point of the lactate-intensity curve to define the lactate threshold, although somewhat subjective, has the advantage of representing the increase in lactate concentration with increased exercise intensity in the individual child, regardless of age, or stage of sexual maturation.

Glycolytic enzyme activity may be moderately reduced in children, and the activity of certain oxidative enzymes may be moderately enhanced. This reduction in the ratio of glycolytic to oxidative enzyme activity may lead to reduced lactate production and increased lactate clearance in children, both of which would result in lower blood lactate concentrations during submaximal exercise. Further investigation is warranted to determine (a) whether the lactate threshold, as determined by the inflection point of the lactate-intensity curve, is related to age and sexual maturation; (b) the causal factors for lower lactate levels during submaximal exercise in children; and (c) the effects of endurance training on the lactate threshold in children.

**References**

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