A longitudinal study on the ammonia threshold in junior cyclists

Y Yuan, K-M Chan

Methods: The cyclists performed tests at three time points (T1, T2, T3) during the year. Follow up tests were conducted every six months after the original test. Ammonia threshold was obtained from a graded exercise with four minute steps.

Results: The relatively non-specific one year training programme was effective in inducing an increase in peak VO₂ (60.6 (5.9), 65.9 (7.4), and 64.6 (6.5) ml/min/kg at T1, T2, and T3 respectively) and endurance time (18.3 (4.5), 20.1 (5.2), and 27.0 (6.1) minutes at T1, T2, and T3 respectively), but was not effective for the sprint related variables. Ammonia threshold, together with lactate threshold and ventilatory threshold, was not significantly different at the three test times. Only endurance time correlated significantly with ammonia threshold (r = 0.915, p = 0.001).

Conclusions: The findings suggest that a relatively non-specific one year training programme does not modify the ammonia threshold of junior cyclists. The significant correlation between ammonia threshold and endurance time further confirms that ammonia threshold is a measure of the ability to sustain exercise at submaximal intensities.

Exercise of various mode, intensity, and duration has been shown to induce an increase in blood ammonia concentration. The major sources of exercise ammonia are adenosine monophosphate (AMP) deaminase and catabolism of branched chain amino acids. During high intensity exercise, ammonia originates mainly from the deamination of AMP. However, during prolonged submaximal exercise, the oxidation of amino acids becomes an increasingly important source of ammonia production. Ammonia produced during exercise alters neuromuscular activity, may contribute to local muscle fatigue, and can also have detrimental effects on the central nervous system when it reaches the brain. As suggested by Mutch and Banister, a reduction in blood ammonia during exercise may increase a person’s capacity for exhaustive exercise.

Exercise ammonia concentration is also sensitive to training. Both sprint training and endurance training have been found to reduce the exercise induced increases in blood ammonia concentration. The effect of training on ammonia response has been widely studied in adults and for training programmes that lasted for six to eight weeks. The effect of long term training on ammonia production in adolescent athletes is currently inconclusive. Previous studies have compared ammonia response in trained and untrained children, and exercise ammonia was lower in the untrained children. However, there has been a lack of a direct comparison of ammonia response of children before and after training.

When the ammonia response of children was compared with that in adults, the increase in ammonia during maximal exercise in children was lower than that in adults. The lower ammonia response in children agrees with the reported lower anaerobic potential of skeletal muscles and the smaller oxygen deficit resulting from the faster rate of oxygen uptake at the onset of exercise in children. Nazar et al. also speculated that children may be able to remove ammonia in the bloodstream more effectively than adults. Together with other findings on the lower maximal anaerobic power and capacity of children, there is a need to investigate if training can change the ammonia response to exercise in children.

During progressive incremental exercise, blood ammonia concentration increases with exercise intensity in such a way that a threshold value exists. The ammonia threshold, obtained from a four minute step incremental exercise, was found to be sensitive to endurance training, but not sprint training. It was also found to correlate significantly with the lactate threshold, ventilatory threshold, and endurance time. It appears that the ammonia threshold may indicate the ability to sustain submaximal exercise.

We therefore investigated the effect of long term training (one year) on the ammonia threshold in a group of junior cyclists. Their physiological profiles, including the ammonia threshold obtained from a progressive incremental exercise, were followed over one year of systematic training consisting of not less than five days a week and averaging three hours a day. The correlation of ammonia threshold with other common physiological variables, including lactate threshold, ventilatory threshold, peak oxygen uptake, and sprinting capacity related variables, was also studied.

MATERIALS AND METHODS

Eight junior cyclists were recruited to the study. Table 1 summarises their physical characteristics. They had joined the Hong Kong Sports Development Board’s scholarship programme and had participated in organised training for less than 18 months. They had received a full explanation of the procedure and volunteered for the study. The Hong Kong Sports Development Board ethically approved all procedures.

The effects of long term training were assessed by repeating the same test battery three times (T1, T2, and T3) within the year. The training programme during the test period emphasised the general development of the cyclists, and there were no major competitions to peak for. The
all peak VO2 tests were completed in five minutes of seated rest. The lactate threshold was defined as the intersection between these two lines. A similar threshold was defined as ammonia threshold from data in the graph of log [ammonia] against log (% VO2peak). All the threshold values were expressed in terms of % VO2peak.

**Sprint test**
After the warm up, the participant was asked to work maximally on the Monark 829E for a predetermined time (30 seconds and one minute). During the test, verbal encouragement was continuously provided to ensure maximal effort. Resistance of the ergometer was set to 0.882 N/kg body weight and 0.784 N/kg body weight for the 30 second and one minute sprint test respectively. All participants performed the 30 second test first and then rested for 15 minutes before performing the one minute test.

Power output was recorded every second during the 30 second and one minute test. The rotation average of three consecutive power output readings was used for further analysis of the data. The maximum power output is defined as the highest power output obtained during the test. The average power output is the average of all the power outputs obtained during the test. The fatigue index, modified from a previous study, is defined as the difference between the power output at the end of the test and the power output at the start of the test, expressed as a percentage of the power output at the start of the test.

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### Table 1: Physical characteristics of the subjects at the three test time points

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>% body fat</th>
<th>Lean mass (kg)</th>
<th>Peak VO2 (ml/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>16.6 (1.0)</td>
<td>170.6 (5.5)</td>
<td>59.1 (4.9)</td>
<td>5.8 (2.1)</td>
<td>56.1 (3.5)</td>
</tr>
<tr>
<td>T2</td>
<td>16.6 (1.0)</td>
<td>172.0 (5.2)</td>
<td>59.4 (5.2)</td>
<td>6.0 (1.6)</td>
<td>55.8 (4.1)</td>
</tr>
<tr>
<td>T3</td>
<td>17.1 (1.0)</td>
<td>172.8 (5.5)</td>
<td>60.8 (4.8)</td>
<td>5.7 (1.8)</td>
<td>57.3 (4.0)</td>
</tr>
</tbody>
</table>

Values are mean (SD). Percentage body fat was estimated from age and sum of chest, abdomen, and thigh skinfolds.

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**Figure 1** Illustration of the method of identifying the ammonia threshold and the lactate threshold.
maximum power and the minimum power divided by maximum power.

**Endurance test**
The ventilatory threshold as obtained from the peak VO₂ test is used as the workload in the endurance test. The ventilatory threshold was identified by three independent testers when at least two of the following criteria were satisfied: (a) a systematic increase in the ventilatory equivalent for oxygen (Vo₂) without a corresponding increase in ventilatory equivalent for carbon dioxide (VeCO₂); (b) when the rate of carbon dioxide production (VeCO₂) is larger than the rate of oxygen consumption (Vo₂); (c) non-linear increase in ventilation. The κ coefficient of agreement for the ventilatory threshold was 0.724 (p = 0.05).

After the warm up, the participant exercised at the ventilatory threshold as obtained from the peak VO₂ test. The test was terminated when the participant could not maintain the workload. The endurance time is defined as the duration of the test in minutes.

**Statistical analysis**
All data are presented as mean (SD). Test scores were analysed by multivariate repeated measures analysis of variance with n set at 0.05. In the event of finding significant differences, univariate repeated measures analysis of variance was conducted for each dependent variable. Bonferroni correction was considered in these tests, and n was set at 0.005. The Pearson correlation coefficient between ammonia threshold and various physiological measurements, including lactate threshold, ventilatory threshold, peak VO₂, and sprinting capacity related variables, was also calculated. Again Bonferroni correction was considered, and the significant concentration was set at p < 0.005.

The intraclass correlation coefficients were calculated to represent the intertester agreements in the identification of the thresholds (ammonia, lactate, and ventilatory).

**RESULTS**
Table 2 lists the measured ammonia threshold and other physiological variables at the three test points. Peak VO₂ and endurance time were significantly different at the different test times. Ammonia threshold, lactate threshold, ventilatory threshold, and all sprint related measurements were not significantly changed across the three tests. The intraclass correlation coefficients were 0.781 (p = 0.007), 0.802 (p = 0.006), and 0.845 (p = 0.006) for ammonia threshold, lactate threshold, and ventilatory threshold respectively.

Peak VO₂ increased by 8.8% and 6.6%, from the first test (60.56 (5.9) ml/min/kg), to the second (65.91 (7.4) ml/min/kg) and the third test (64.55 (6.5) ml/min/kg) respectively. Endurance time increased by 9.3% and 47.2%, from the first test (18.34 (4.53) min), to the second (20.05 (5.23) min) and the third test (27.00 (6.06) min) respectively.

Resting lactate and ammonia concentrations obtained before the step test at the three time points were: T1, 1.4 (0.3) mM; T2, 1.3 (0.3) mM; 34.6 (6.4) µM; T3, 1.1 (0.3) mM, 42.6 (8.2) µM respectively. Maximum lactate and ammonia concentrations obtained at the last stage of the step test at the three time points were: T1, 8.3 (1.8) mM, 98.6 (25.5) µM; T2, 9.2 (2.4) mM, 130.6 (17.0) µM; T3, 6.3 (1.7) mM, 101.6 (31.6) µM respectively.

Table 3 lists the Pearson correlation coefficients between ammonia threshold and the various physiological measurements. When n is set at 0.005, significant correlation is found between the ammonia threshold and endurance time (r = 0.915, p = 0.001) only.

**DISCUSSION**
This is the first study on the effect of long term training (one year) on ammonia threshold. The subjects were adolescents whose ammonia response to training may differ from that of adults. Previous studies have found that children have a lower ammonia response during maximal exercise. This year training programme emphasised the general development of the cyclists, and there were no major competitions to peak for. It consisted of a balance between aerobic, anaerobic, and musculoskeletal training. This training programme induced a significant increase in both peak VO₂ and endurance time at ventilatory threshold. However, the sprint related measurements showed no significant differences across the three tests. Neither were the ammonia, lactate, and ventilatory thresholds modified significantly by

<table>
<thead>
<tr>
<th>Physiological measurement</th>
<th>r Value</th>
<th>p Value</th>
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<tbody>
<tr>
<td>Peak oxygen uptake (ml/kg/min)</td>
<td>–0.404</td>
<td>0.320</td>
</tr>
<tr>
<td>Lactate threshold (% peak VO₂)</td>
<td>0.674</td>
<td>0.067</td>
</tr>
<tr>
<td>Maximum power of 30 s (W/kg)</td>
<td>–0.202</td>
<td>0.631</td>
</tr>
<tr>
<td>Average power of 30 s (W/kg)</td>
<td>–0.276</td>
<td>0.508</td>
</tr>
<tr>
<td>Fatigue index of 30 s test</td>
<td>–0.656</td>
<td>0.078</td>
</tr>
<tr>
<td>Maximum power of 1 min (W/kg)</td>
<td>–0.286</td>
<td>0.492</td>
</tr>
<tr>
<td>Average power of 1 min (W/kg)</td>
<td>–0.708</td>
<td>0.049</td>
</tr>
<tr>
<td>Fatigue index of 1 min test</td>
<td>–0.027</td>
<td>0.930</td>
</tr>
<tr>
<td>Ventilatory threshold (% peak VO₂)</td>
<td>0.572</td>
<td>0.139</td>
</tr>
<tr>
<td>Endurance time (min)</td>
<td>0.915</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*Significant correlation with ammonia threshold (p < 0.005).
Ammonia threshold is a measure of the ability to sustain submaximal exercise. However, it is not sensitive enough to pick up the improvement in exercise ability that is expected from a non-specific one year training programme.

The training programme is therefore able to improve aerobic capacity and endurance at the submaximal workload of the cyclists. It did not improve sprinting ability and the thresholds. It should be noted that the effect of this one year programme is very different from that of a relatively short endurance training programme. For instance, a 20 week endurance training programme induced a significant increase in peak \( V_{\text{O2}} \) and anaerobic threshold, but our long lasting and relatively non-specific programme only improved peak \( V_{\text{O2}} \) and not the thresholds.

Consistent with previous studies on the ammonia response to graded exercise, we observed a curvilinear relation between exercise intensity and blood ammonia. Blood ammonia remained near resting concentration during mild exercise and increased exponentially at workloads above the ammonia threshold. At low workloads, slow twitch oxidative fibres are mainly used, which are low in AMP deaminase. The rate of ammonia production is therefore limited. At higher workloads, more fast twitch fibres are recruited. Activation of the AMP deaminase in the fast twitch fibres results in large amounts of ammonia being produced.

A previous study reported that, after a short term endurance training programme (8–12 sessions, one hour per session at 60–90% \( V_{\text{O2MAX}} \)), the ammonia response after 45 minutes of exercise at 80% \( V_{\text{O2MAX}} \) was significantly reduced. However, the ammonia response, in relation to the \( %V_{\text{O2MAX}} \), during a progressive exercise protocol, did not change after training. In another study by Lo and Dudley, seven weeks of intensive training, which increased \( V_{\text{O2MAX}} \) by 32%, modified the ammonia response to graded exercise by lowering the blood ammonia concentration at the same absolute power and not for that at the similar relative intensity. However, neither study investigated the effect of the training programme on the ammonia threshold in graded exercise. In our long term training programme, the peak \( V_{\text{O2}} \) was increased by only 8.8% and 6.6%, from the first test, to the second and third tests respectively. Our results seem to be consistent with previous reports that training does not modify ammonia response, at the same relative intensity, during graded exercise. The ammonia threshold obtained from the four minute step graded exercise did not differ significantly at the three test times.

The subjects in our study were not fully grown adults; their mean (SD) age was 16.1 (1.0) at the start. Previous studies have shown that the maximal anaerobic power and capacity of children is less developed than that of adults. The rates of glycolgen utilisation and lactate production during maximal exercise in children are lower than those in adults. This is the only reported study to indirectly investigate the possible effect of training on ammonia response in children. The findings need confirmation from direct studies on the effect of training. Will the underdeveloped ammonia production system of children be responsive to training? In our study, the ammonia threshold, obtained from the four minute step graded exercise, was not significantly different across the time points. However, the training programme was only effective in modifying peak \( V_{\text{O2}} \) and endurance time, and the same results may not be obtained with a training programme that is more intense or more specifically designed to improve endurance or sprinting performance.

A significant correlation was found between ammonia threshold and endurance time. None of the other physiological variables investigated correlated significantly with ammonia threshold. This is similar to findings obtained with a group of relatively untrained adults. In that study, a significant correlation with ammonia threshold was found for both endurance time and lactate threshold. This discrepancy between the two groups of subjects seems to support the suggestion that the often observed correlation between ammonia and lactate concentration is phenomenological and not causative. However, there are studies that suggest that exercise ammonia and lactate concentrations are linked.

No significant correlation was found between ammonia threshold and the measurements related to anaerobic power and capacity (30 seconds and one minute maximum test). Similarly, no significant correlation was found between ammonia threshold and peak \( V_{\text{O2}} \). These findings suggest that ammonia threshold is not a measure of anaerobic power, anaerobic capacity, and aerobic capacity. As endurance time is a measure of the ability to sustain submaximal exercise, the consistent correlation between ammonia threshold and endurance time in both groups of subjects (our present and previous studies) further confirms that ammonia threshold is a measure of the ability to sustain submaximal exercise.

CONCLUSIONS

This study is noteworthy in three aspects. Firstly, it is the first investigation of the effect of one year of non-specific training on the ammonia response to exercise. Secondly, it is the first time that the effect of training on a group of children has been directly examined. Thirdly, the effect of training on ammonia threshold has not previously been thoroughly addressed. The one year training programme was found to be ineffective in inducing any significant change in the ammonia threshold in this group of junior cyclists. Correlation between ammonia threshold and endurance time was significant. This reconfirms that ammonia threshold is a measure of the ability to sustain submaximal exercise.

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REFERENCES

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