A longitudinal study on the ammonia threshold in junior cyclists

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**Objectives:** To identify the effect of a one year non-specific training programme on the ammonia threshold of a group of junior cyclists and to correlate ammonia threshold with other common physiological variables.

**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 time tests. 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.\(^1\)\(^-\)\(^3\) 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.\(^1\) However, during prolonged submaximal exercise, the oxidation of amino acids becomes an increasingly important source of ammonia production.\(^1\) 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.\(^1\) As suggested by Mutch and Banister,\(^3\) 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\(^6\) and endurance training\(^7\) 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.\(^7\)\(^-\)\(^9\) The effect of long term training on ammonia production in adolescent athletes is currently inconclusive. Previous studies\(^1\)\(^-\)\(^4\) 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.\(^1\)\(^-\)\(^4\) The lower ammonia response in children agrees with the reported lower anaerobic potential of skeletal muscles\(^1\)\(^-\)\(^4\) and the smaller oxygen deficit resulting from the faster rate of oxygen uptake at the onset of exercise in children.\(^1\)\(^-\)\(^4\) Nazar et al\(^10\) 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,\(^1\)\(^-\)\(^4\) 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.\(^1\)\(^-\)\(^4\) The ammonia threshold, obtained from a four minute step incremental exercise, was found to be sensitive to endurance training, but not sprint training.\(^1\)\(^-\)\(^4\) It was also found to correlate significantly with the lactate threshold, ventilatory threshold, and endurance time.\(^1\)\(^-\)\(^4\) It appears that the ammonia threshold may indicate the ability to sustain submaximal exercise.\(^1\)\(^-\)\(^4\)

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
cyclists spent not less than five days a week and an average of three hours a day in training. The three test times were evenly separated from each other by six months. The cyclists were instructed to consume a similar diet with high carbohydrate content on the day before testing. The test battery consisted of four tests: peak VO₂ test; four minute step graded exercise; sprint test; and endurance test. Each cyclist performed the tests in random order except the peak VO₂ test, which always preceded the endurance test. All four tests were completed within seven days, and at least one day of rest was allowed between tests.

**Test protocols**

All tests, except the sprint tests, were performed on the cyclists’ own bike mounted on a Cateye bike simulator (CS 1000; Cateye Co, Ltd, Osaka, Japan). Gear ratio and cadence were not predetermined, and the athletes were required to keep the power output as close as possible to the assigned value during all the tests. Before each test, participants underwent a 10 minute standard warm up followed by five minutes of seated rest.

**Peak VO₂ test**

All participants performed a peak VO₂ test with a metabolic cart (Vmax29; SensorMedics, Yorba Linda, California, USA), which had been calibrated according to the guidelines provided by the manufacturer. During the test, power output was increased by 20–25 W per minute. The initial workload and increment were chosen according to the subject’s exercise capacity as estimated by the coach, the initial workload for the graded exercise ranged from 100 to 125 W. The subsequent workload increased by 20–25 W every four minutes until it could not be maintained. Depending on the subject’s exercise capacity as estimated by the coach, the initial workload for the graded exercise ranged from 100 to 125 W. 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 of each step was recorded by the Sports Tester and was calculated as the heart rate for each exercise stage.

The ammonia threshold and lactate threshold were determined by the method of Beaver et al.31 On the graph of log [lactate] against log (% VO₂peak), the data points were divided into two segments by visually selecting the division point (three individuals performed this selection independently). The k coefficient of agreement for lactate threshold and ammonia threshold were 0.569 (p > 0.05) and 0.535 (p > 0.05) respectively. The division point was selected where the steep portion of the curve began and was assumed to belong to both segments. Using linear regression analysis, two straight lines were used to represent the data points of each segment. 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 average power output 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,19 is defined as the difference between the

![Illustration of the method of identifying the ammonia threshold and the lactate threshold](http://bjsm.bmj.com/brj.sportmed.2002.000158/23.3.2004.png)
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 (VE/VO2) without a corresponding increase in ventilatory equivalent for carbon dioxide (VE/CO2); (b) the rate of carbon dioxide production (VCO2) is larger than the rate of oxygen consumption (VO2); (c) non-linear increase in ventilation. The 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 the thresholds (ammonia, lactate, and ventilatory) as dependent variables set at 0.005. In the event of finding significant differences, univariate repeated measures analysis of variance was conducted for each dependent variable. Bonferroni correction was considered, and the significance was set at 0.005. In the event of finding significant differences, univariate repeated measures analysis of variance with the thresholds (ammonia, lactate, and ventilatory) as dependent variables set at 0.005. Significant changes across the three tests. Neither were the ammonia, lactate, and ventilatory thresholds modified significantly by the endurance test.

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.

Table 2 Changes in ammonia threshold and other physiological variables during the 12 month study

<table>
<thead>
<tr>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia threshold (% peak VO2)</td>
<td>66.3 (5.8)</td>
<td>60.3 (6.9)</td>
<td>64.7 (4.3)</td>
</tr>
<tr>
<td>Lactate threshold (% peak VO2)</td>
<td>62.2 (5.6)</td>
<td>56.9 (7.2)</td>
<td>63.5 (4.7)</td>
</tr>
<tr>
<td>Ventilatory threshold (% peak VO2)</td>
<td>76.0 (4.5)</td>
<td>76.0 (4.8)</td>
<td>78.6 (6.4)</td>
</tr>
<tr>
<td>Peak VO2 (ml/min/kg)</td>
<td>60.6 (5.9)</td>
<td>65.9 (7.4)</td>
<td>64.6 (6.5)</td>
</tr>
<tr>
<td>30 s sprint test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum power (W/kg)</td>
<td>12.1 (1.0)</td>
<td>12.2 (1.2)</td>
<td>12.6 (1.2)</td>
</tr>
<tr>
<td>Average power (W/kg)</td>
<td>10.5 (0.7)</td>
<td>10.4 (0.9)</td>
<td>10.7 (1.2)</td>
</tr>
<tr>
<td>Fatigue index</td>
<td>0.7 (0.1)</td>
<td>0.7 (0.1)</td>
<td>0.7 (0.0)</td>
</tr>
<tr>
<td>1 min sprint test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum power (W/kg)</td>
<td>10.6 (1.1)</td>
<td>10.6 (0.9)</td>
<td>10.2 (0.6)</td>
</tr>
<tr>
<td>Average power (W/kg)</td>
<td>7.7 (0.8)</td>
<td>8.0 (1.0)</td>
<td>8.02 (0.8)</td>
</tr>
<tr>
<td>Fatigue index</td>
<td>0.6 (0.1)</td>
<td>0.6 (0.1)</td>
<td>0.6 (0.1)</td>
</tr>
<tr>
<td>Endurance time (min)</td>
<td>18.3 (4.5)</td>
<td>20.1 (5.2)</td>
<td>27.0 (6.1)</td>
</tr>
</tbody>
</table>

Values are mean (SD). p Value was obtained by univariate repeated measures analysis of variance. *Significant difference in terms of time (p < 0.005).

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.12 This one year training programme emphasised the general development of the cyclists, and there were no major competitions for peak power. 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 the endurance test.
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 ammonia response during exercise is also less profound in children than in adults. Blood ammonia remained near resting concentration during mild exercise. In another study by Lo and Dudley, the peak VO_{2MAX}, during a progressive exercise protocol, did not change after training. In our long term training programme, the peak VO_{2MAX} was increased by only 8.8% and 6.6%, from the first test, to seven weeks of intensive training, which increased VO_{2MAX} 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 training on the ammonia response to exercise. Secondly, it is the first 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 under-developed 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 VO_{2} 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 VO_{2}. 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