The relationship between carbon dioxide sensitivity and sprint or endurance performance in young swimmers

S. P. McGurk MEd, B. A. Blanksby PhD and M. J. Anderson MEd

Department of Human Movement, University of Western Australia, Nedlands WA 6009, Australia

There has been some evidence that extremes of CO₂ sensitivity can indicate an individual's potential for sprint or endurance athletic performance. This study examined the responses to CO₂ rebreathing, and previously validated sprint and endurance tests by subjects who were involved in regular, but not intensive, swimming training. The aim was to determine whether subjects with low CO₂ sensitivity might perform better on endurance tests, whilst those subjects with high CO₂ sensitivity would be more successful in the sprint tests.

Initially, 168 young ($\bar{X}$ mean(s.d.) age = 12.4(2.1) years) swimmers were measured using a modified version of the Read¹ CO₂ rebreathing technique. From this sample, 17 high ($\bar{X}$ mean(s.d.) = 2.24(0.39) 1 min⁻¹ mmHg⁻¹) CO₂ responders were matched by gender, age, height, weight and FVC with 17 low ($\bar{X}$ mean(s.d.) = 0.57(0.19) 1 min⁻¹ mmHg⁻¹) responders. Each of these 17 pairs underwent two sprint tests (10 s Tri-level alactic power, 50 m run) and two endurance tests (PWC₁₇₀, 1.6 km run) in order to determine whether any differences existed between the two groups and the sprint and endurance parameters. The subjects remained unaware of their results of the rebreathing test throughout testing. A dependent *t* test was then used to compare the results collected from each group.

The low CO₂ responders recorded a significantly faster 1.6 km run time, but were not superior on the PWC₁₇₀ ergometer test, than the high CO₂ responders. The high CO₂ responding group recorded significantly higher results on the 10 s alactic power test, but not the 50 m sprint run, than the low responders. Hence, further study is required to ascertain underlying causes as to why significant differences occurred with CO₂ rebreathing, the 1.6 km run and the 10 s alactic power test, but not with the PWC₁₇₀ and the 50 m sprint run.

Keywords: CO₂ rebreathing, talent identification, young swimmers, sprint/endurance performance

As it takes many years of regular training to excel in most sports, athletes need to take up the activity well before the age at which it is generally expected that their best performances occur. Early recognition of any attribute which would benefit an athlete in developing through these formative years would assist in choosing those events to which an individual is best suited.

Some research has demonstrated that athletes in general tend to possess a reduced sensitivity to CO₂^{2–7}, while others have found no significant difference between athletes and non-athletes^{8–12}. Others have noted significant differences between endurance (aerobic) athletes who have exhibited a low ventilatory response and sprint (anaerobic) athletes who have possessed a high response^{13,14}. Another study found no changes occurred after a 5 month training period¹⁵.

The association between athleticism and ventilatory response to CO₂ is not well understood. Perhaps a decreased ventilatory response may produce dyspnoea and thus an enhanced exercise tolerance¹⁶. Furthermore, if low respiratory drives give a functional advantage during aerobic exercise then an increase in respiratory drive may decrease exercise performance over time. Such persons may be best suited to the shorter, anaerobic events where a higher ventilatory rate is needed. If blunted chemosensitivity to CO₂ is evident in successful endurance athletes it would be valuable to determine whether this attribute is an acquired or an inherited trait.

To examine whether the chemical drive to ventilation is controlled by genetic factors, 20 pairs of young monozygotic twins ($\bar{X}$ age = 16.4 yr) and 11 pairs of dizygotic twins were used in an age, body size and gender ratio matched study¹⁷. Results indicated that, in adolescent twins, sensitivity to hypercapnia involved genetically determined factors. It was postulated that these results may be explained by the large numbers of twins examined or by the fact that their relative youth made their CO₂ responses less susceptible to the influence of environmental factors¹⁸.

Other studies have attempted to ascertain the role of the environment in altering an individual's CO₂ hypercapnia response. The results have been inconclusive because some have concluded that environmental influence is strong^{12,19,20}; some have found both genetic and environmental factors are important^{17,21}; and others have considered that the genetic role is predominant^{13,15,16,22}.

This study examined whether there was any significant relationship between the sprint and endurance capabilities of a group of young people who have either a high or low ventilatory response to CO₂ and who were not heavily trained.

Subjects and methods

One hundred and eighty healthy school children aged between 8 and 15 years volunteered as subjects for the study (118 males; 62 females). Each subject was involved in a swimming programme in the Department of Human Movement at the University of Western Australia. The subjects were involved in regular swimming training, attending two or three training sessions each week of 1–1½ h duration for each session, but were not heavily trained.

The subjects fasted for at least 2 h before the appointment and avoided analgesics, caffeine and intensive exercise prior to the test. Female subjects who had undergone menarche were tested during the midfollicular phase of the cycle in an attempt to minimize the variations in ventilatory drive that had been attributed to the cyclical hormonal fluctuation of progesterone^{6, 23, 24}.

Height, weight and forced vital capacity were recorded. The ventilatory response to CO₂ was then assessed using the rebreathing method first established by Read¹ and later modified by Rebuck²⁵. This involved rebreathing a hyperoxic mixture of 93% oxygen and 7% CO₂ for a period of between 3 and 4 min. During this time both ventilation (V_e) and end tidal CO₂ were continuously monitored and recorded.

The linearity of the subsequent increase of end tidal PCO₂ and V_e with time, allowed a direct plot of V_e against end tidal CO₂. A regression line was fitted by the least squares method and the parameters of the regression equation used to define the response. Male and female groups were then separated and a matched pairs design was undertaken in order to compare high and low responders.

A low CO₂ sensitivity (S) score from one subject was paired with a high score from another subject of the same sex. In order to objectively enforce a selection criterion, a minimum of two standard deviations between the CO₂ sensitivity scores of each matched pair was maintained. This was to ensure that sufficient differentiation occurred with each couple on the rebreathing status. Furthermore, on the parameters of age, height, weight and forced vital capacity, only scores of less than one standard deviation were accepted as being analogous.

From the total of 168 subjects, 17 pairs were able to be matched as above. These included 12 pairs of males and five pairs of females, and represented 20% of the total sample. Physical performance testing was carried out via a 50 m dash, alactic peak power test, 1.6 km run and a PWC₁₇₀. The investigators involved with the performance testing were unaware of the CO₂ sensitivity status of each subject.

Statistics

The hypercapnic ventilatory drive was analysed by a least squares regression using the equation:

$$V_e = S(P_a\text{CO}_2 - B)$$

where V_e = minute ventilation; $P_a\text{CO}_2$ = alveolar CO₂ partial pressure; S = the slope of the line derived from plotting V_e against $P_a\text{CO}_2$. It is a measure of the

ventilatory responsiveness per unit change in $P_a\text{CO}_2$ ($V_e/P_a\text{CO}_2$); B = extrapolated intercept on the $P_a\text{CO}_2$ axis and represents an imaginary threshold of the CO₂ sensory system.

Measures of V_e and $P_a\text{CO}_2$ were obtained from the raw data and at least six points were used from each graph for analysis. Only a goodness of fit correlation greater than 0.90 was accepted.

Physical performance parameters were then measured in an attempt to determine the sprint and endurance ability between each of the 17 matched pairs. A dependent t test was adopted to establish whether any statistical difference existed between the sprint and endurance capabilities of each group.

Results

A summary of the means and the standard deviations from the 17 pairs of high and low responding subjects, including their physical parameters and physical performance results, are provided in Table 1. The endurance capabilities of subjects who revealed a low sensitivity to CO₂, performed significantly better on the previously validated 1.6 km run when compared to those subjects with a high CO₂ response ($P < 0.05$). These subjects also recorded better than average 1.6 km run times when compared to Australian norms of children of the same age and gender²⁶. Sprinting capabilities of the young swimmers with a high sensitivity to CO₂ performed significantly better on the 10 sec alactic test when compared to those subjects with a low CO₂ response ($P < 0.05$). No significant difference was evident from the high responding CO₂ sensitivity group when compared to the Australian norms for the 50 m run times.

However, no significant differences existed between CO₂ sensitivity of low and high responding groups when compared to the results of the PWC₁₇₀ bicycle ergometer test and 50 m run.

When the paired S responders were compared to

Table 1. Mean physical characteristics, ventilatory chemosensitivity and physical performance test results of paired low and high responding subjects

Variable	Low responses (n = 17)	High responders (n = 17)
Male	12	12
Female	5	5
Hypercapnic response		
S l min ⁻¹ mmHg	0.57(0.19)	2.24(0.39)
B mmHg ⁻¹	43.36(7.39)	51.78(3.63)
Average age (yrs, mths)	12.30(2.00)	12.80(2.10)
Height (cm)	152.70(12.10)	155.10(13.20)
Weight (kg)	43.60(11.60)	45.30(8.80)
Forced vital capacity (l)	2.96(1.01)	3.05(0.80)
Endurance tests		
1.6 km run (min, s)	6:59.0*(0:52.0)	7.45(1:10.0)
PWC ₁₇₀ (kgm kg ⁻¹ min ⁻¹)	15.52 ^{NS} (3.43)	15.11(3.57)
Sprint tests		
50 m run (s)	8.52 ^{NS} (0.75)	8.40(0.80)
10 s alactic power (w/kg)	11.02*(2.20)	11.91(2.79)

All values are mean(s.d.); ventilatory response to CO₂ was analysed by the equation $V = S(P_a\text{CO}_2 - B)$; * significance between high and low responders ($P < 0.05$); ns Not significant

the Australian norms for the 50 m and 1.6 km runs, there was no evidence to suggest that individuals with a low CO₂ sensitivity had reduced sprint capabilities. Conversely, those individuals with a high CO₂ sensitivity showed no signs of having reduced endurance capabilities.

Discussion

The 17 low S responders recorded significantly ($P < 0.05$) faster 1.6 km (6 min 59 s) run times than their physically matched counterparts (7 min 45 s). Thus, the findings agreed with previous research which specifically examined endurance runners and revealed a significantly lower S response when results were compared to non-athletes, or athletes of a non-endurance nature^{2, 4, 6, 13, 27}. However, no significant difference was detected between the paired subjects undertaking the PWC₁₇₀ bicycle ergometer test. It was expected that the low S group would register a significantly increased score ($\text{kgmkg}^{-1} \text{min}^{-1}$) but, although they recorded a slightly higher mean response, it was not significantly different from that of the high responders. The PWC₁₇₀ is considered a valid test for determining the cardiorespiratory endurance of children aged between 8 and 14 years²⁸ but there is a chance of a $\pm 15\%$ error factor²⁹. Otherwise there is no obvious explanation as to why the 1.6 km run and PWC₁₇₀ were not more compatible.

No previous study has discriminated each test group on extreme S values rather than on athletic performance. Previous research studies have examined proven endurance capabilities of their subjects which were already established. In this study the subjects were relatively untrained and the minimal training they had done was similar for all 168 subjects. What was determined before performance testing was that the S values for each pair were different ($> 2 \text{ s.d.}$); while their physical parameters of gender, age, height, weight and vital capacity were more closely matched ($< 1 \text{ s.d.}$). The high responders tended to be slightly older and, consequently, tended to be taller, heavier and had larger lung capacities (Table 1).

This enabled the performance of each paired subject to be measured without having any prior knowledge of his/her endurance sprint capabilities.

It was hypothesized that the 17 high responders would run faster than the 17 low responders in a 50 m sprint run and perform better on the 10 s alactic

power test. Although this occurred in both activities, it was only in the 10 s alactic power test that a significant difference was revealed between the two groups ($P < 0.05$) (See Tables 1 and 2).

Other studies have revealed that a high level of CO₂ sensitivity is linked to sprint performance and lower than normal CO₂ sensitivity levels have been observed in exceptional sprint performers when compared to a non-athletic population¹⁴. However, when these S values were compared to endurance performers involved in the same study, the values of the sprinters were somewhat higher. One difficulty is that non-athletic populations can frequently reveal superior physical characteristics which are genetically based but have never been tested because they have never tried athletic participation. They could be potential Olympians were they to participate.

If there is a functional advantage from having a low respiratory drive to exercise, then any individuals who have an increased respiratory drive may have limited endurance performance. Reports indicate that subjects with a higher sensitivity to CO₂ had a higher resting respiratory frequency. Under prolonged stressful exercise this may inhibit endurance capabilities³⁰.

There is evidence in the present study to suggest that a high ventilatory response to CO₂ may be a prerequisite to successful sprint performance as indicated by the significant relationship with the 10 s alactic power test ($P < 0.05$). However, no significance was found between a high S score and the 50 m run, and no explanation can be found for such a discrepancy. It is confusing that one bicycle test (10 s alactic power – sprint) was significant but not the other (PWC₁₇₀ – endurance). Also, one run (1.6 km – endurance) was significant but not the other (50 m – sprint). Again, no conclusive reason can be offered for this.

The Australian Health and Fitness Survey²⁶ provided an opportunity to compare physical performance results of the sprint and endurance runs of our subjects to norms provided for other boys and girls of the same sex and age. Tables 3 and 4 summarize these results after raw scores have been converted to percentile rankings. Even though the subjects were in the early stages of a swimming season and had no long-term background of training, they would probably have some fitness advantage over average youngsters included in a national survey. However, it does provide a yardstick for substantiating, or otherwise, subjects' performances.

Table 2. Dependent *t* test results from the 17 matched pairs of high and low CO₂ sensitivity (S) and results from the physical performance tests

Variable	N	Mean difference	S dev	t value	p value	Significance ($P < 0.05$)
Endurance tests						
1.6 km run	17	0.76	1.16	2.70	0.01	significant
PWC ₁₇₀	17	-0.46	1.82	-1.03	0.32	n.s.
Sprint tests						
50 m run	17	-0.19	0.71	-1.09	0.29	n.s.
10 s alactic power	17	0.89	1.69	2.17	0.04	significant

n.s. Not significant

After each paired individual was compared with percentile ranks, some trends were evident. Whilst there were minimal differences in the percentile rankings for the 50 m running times between the two groups, the low responders performed significantly better in the 1.6 km run and demonstrated less variation as determined by the standard deviations of their performance.

Table 3. Percentile ranks of height, weight, 50 m and 1.6 km run times of the 17 low S responders when compared to *Australian Health and Fitness Survey* norms for children of the same age and sex

Pair no.	S scores	Sex	Height	Weight	1.6 km run	50 m run
1	0.55	M	65	75	95	30
2	0.36	M	45	40	95	75
3	0.46	F	55	35	95	35
4	0.47	F	65	55	85	80
5	0.60	M	80	70	85	50
6	0.44	M	5	15	95	50
7	0.27	M	65	60	95	40
8	0.76	M	95	85	45	75
9	0.64	M	30	45	95	80
10	0.21	M	50	40	75	15
11	0.61	F	95	65	95	90
12	0.85	M	80	75	95	60
13	0.60	M	5	25	95	55
14	0.69	F	70	55	60	30
15	0.73	M	80	90	40	75
16	0.89	F	40	20	90	95
17	0.52	M	45	75	95	95
Mean(s.d.)	0.57(0.19)		57(27)	54(23)	84(18)	61(25)

Percentiles taken every 5%. Closest achieved percentile recorded. Lowest = 5% ile. Highest = 95% ile. S = 1 min⁻¹ mmHg⁻¹

Table 4. Percentile ranks of height, weight, 50 m and 1.6 km run times of the 17 high S responders when compared to *Australian Health and Fitness Survey* norms for children of the same age and sex

Pair no.	S scores	Sex	Height	Weight	1.6 km run	50 m run
1	1.80	M	65	75	65	40
2	2.11	M	25	20	85	90
3	2.44	F	85	85	90	95
4	2.00	F	70	90	20	25
5	1.87	M	85	85	45	50
6	1.87	M	5	30	60	10
7	1.82	M	80	70	35	65
8	1.94	M	80	50	95	40
9	2.26	M	85	75	75	50
10	2.57	M	40	30	85	75
11	2.42	F	45	50	90	90
12	3.00	M	40	40	85	70
13	2.46	M	45	50	55	60
14	2.55	F	90	50	60	75
15	2.92	M	95	65	80	75
16	2.39	F	10	40	85	70
17	1.69	M	65	40	30	95
Mean(s.d.)	2.24(0.39)		59(28)	56(21)	67(23)	63(25)

Percentiles taken every 5%. Closest achieved percentile recorded. Lowest = 5% ile; Highest = 95% ile. S = 1 min⁻¹ mmHg⁻¹

Additionally, 13 of the 17 low responders had 1.6 km run times which ranked them in the top 15% for their particular sex and age group. These subjects could have been individuals with above average athletic ability.

It is difficult to ascertain the extent of this influence, yet it is unlikely to fully account for the significant difference between the 1.6 km run times of the low responders when compared against the Australian norms. Comparisons between the high and low responding groups with the 10 s alactic power test, and the PWC₁₇₀, were not possible as the Australian Fitness Survey did not provide norms for these tests.

However, a high standard of performance was evident with the mean of the low responders in the 1.6 km run being at the 85th percentile. Furthermore, if the two low percentiles are excluded (subject 8 = 45th percentile and subject 15 = 40th percentile), then the mean(s.d.) percentile rank for the low S responders increases to 90(10.1). Hence, there was a strong relationship between those with a low S to CO₂, and performance on the 1.6 km run, when these subjects were compared to the general population of the same sex and age. It is suggested that the low ventilatory response to CO₂ is related to this enhanced performance.

On the basis of the 50 m run times, no such role could be associated with high ventilatory response to CO₂. Although the high S responders in this study ran slightly faster than children of the same age and sex in the national norms (61st percentile), their times were not differentiated as being significantly faster on the 50 m dash when compared to those recorded by the low S responders.

This study sought to prospectively examine relationships between CO₂ rebreathing responses and sprint/endurance performance. The results demonstrated a significant relationship between low CO₂ response and endurance via the 1.6 km run; and a high CO₂ response and sprinting via the 10 s alactic power test. However, the results are inconclusive because no significance was found for the PWC₁₇₀ and endurance; or the 50 m run and sprint performance. Further study is required to elucidate the matter further.

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