

## Research article

# PHYSIOLOGICAL RESPONSES TO 90 s ALL OUT ISOKINETIC SPRINT CYCLING IN BOYS AND MEN

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### ABSTRACT

The purpose of this study was to compare the VO<sub>2</sub> kinetic and mechanical power responses of boys and men to all out 90 s sprint cycle exercise. Eight boys (14.6 ± 0.3 y) and eight men (33.8 ± 6.5 y) volunteered to participate and completed a ramp test (to determine VO<sub>2peak</sub> and ventilatory threshold, VT) and then on subsequent days, two 90 s all out cycle sprints on an isokinetic cycle ergometer. During each test, breath-by-breath pulmonary gas exchange and power output were measured. Parameters from the power output profiles were derived from the average response of the two tests including peak power (PP, highest power output in 1 s), end power (EP<sub>60-90</sub>, power over the last 30 s), and mean power over the 90 s (MP<sub>90</sub>). Independent pairwise and dependent t-tests were used to compare the data from tests between adults and boys subject groups. Significant differences between adults and boys were found for absolute PP (881.4 ± 60.7 vs 533.6 ± 50.7 W), EP<sub>60-90</sub> (288.6 ± 25.7 vs 134.3 ± 17.6 W) and MP<sub>90</sub> (434.5 ± 27.4 vs 238.4 ± 17.3 W, p = 0.001) respectively. Relative to body mass significant differences between adults and boys were found for EP<sub>60-90</sub>, MP<sub>90</sub> and total work (p < 0.002). The boys attained 90 s VO<sub>2</sub> values that were closer to VO<sub>2peak</sub> than their adult counterparts (93.3 ± 2.6 vs 84.9 ± 2.3 %, p = 0.03). They also demonstrated faster VO<sub>2</sub> kinetics (10.8 ± 1.5 vs 17.6 ± 1.0 s, p < 0.01). In conclusion, during all out 90 s cycle sprinting boys were able to attain VO<sub>2</sub> values that were closer to VO<sub>2peak</sub> and a faster time constant than adult men. These findings provide insight into the contribution and speed of response of the aerobic system during an 'anaerobic' test.

**KEY WORDS:** VO<sub>2peak</sub>, anaerobic, kinetics, aerobic, ergometry.

### INTRODUCTION

In comparison to two of the most published physiological tests for aerobic and anaerobic tests, the maximal oxygen consumption (VO<sub>2max</sub>) and the Wingate test, there is surprisingly little published about tests, which attempt to integrate and measure the aerobic and anaerobic energy systems (Gastin, 2001). Whilst these two tests separately have shown to be reliable and valid, integration of both has proved a more difficult realisation (Greenhaff and Timmons, 1998). Although both of the above tests

are valid neither are without reproach as evidenced by continuing investigations into the concept of the plateau or non-plateau phenomenon in aerobic testing and the magnitude of the aerobic contribution to the Wingate test (WAnT). Tests, which combine both energy systems, are important to develop because the integrated metabolic response of all three energy pathways is simultaneous and its control is dependent on the regulated response of the whole system to a change in ATPase rate. Therefore, a test that combines these energy systems will be able to investigate responses to the whole system, which separate tests cannot accomplish.

Attempts have been made to measure the interaction of aerobic and anaerobic energy pathways in short term, exhaustive exercise (Chia et al., 1997; Kavanagh and Jacobs, 1988; Serresse et al., 1988). Although the accurate determination of anaerobic and aerobic generation of ATP during a single test is inherently more difficult and complex than separate tests of energy release, three broad methods have been attempted; 1) direct measures of intramuscular metabolites and substrates, 2) indirect measures such as the accumulated oxygen deficit or measures of  $\text{VO}_2$  and power output and 3) mathematical modelling to predict performance (Gastin, 2001). These studies have generally shown two common trends, firstly that equal contributions of the aerobic and anaerobic energy systems occur within 1 to 2 minutes ( $\sim 75$  s) and secondly, that the aerobic system responds much quicker than first appreciated (Bangsbo et al., 2000; Medbo and Tabata, 1989; Nummela and Ruseko, 1995; Serresse et al., 1998).

Studies measuring  $\text{VO}_2$  and power output during such tests have an advantage in profiling the entire test not only for peak power but also the decline in power as fatigue ensues. Also, because gas analyses are performed at the same time, it can be matched to the power profile (Carey and Richardson, 2003; Gastin, et al., 1991; Withers et al., 1991). Using these techniques, Williams et al. (2005) found that in a group of 16 adolescent children they were able to attain 93 % of  $\text{VO}_{2\text{peak}}$  during an all out 90 s sprint cycling test. Although there was some inter-individual variability the response from a same day test retest basis was acceptable. This observed high attainment of  $\text{VO}_2$  in what is typically considered an "anaerobic" test is supported by previous observations in children of significant contributions of oxidative pathways during the WAnT (Chia et al., 1997). A suggested explanation of this observation has been a greater aerobic ability of children in comparison to their anaerobic capability (Bar-Or, 1983). Although there is some tentative evidence, as demonstrated by differences in  $\text{VO}_2$  kinetics between children and adults for constant load sub maximal exercise (Williams et al., 2001), studies examining all out tests of durations  $> 30$  s are sparse.

Therefore, the purpose of this study was to compare the  $\text{VO}_2$  kinetic and mechanical power responses of boys and adult men to 90 s of all out sprint cycling. We hypothesised that the kinetics during all out sprinting in boys would be faster and therefore result in a higher attainment of  $\text{VO}_{2\text{peak}}$ . Also, we hypothesised that boys would attain a higher aerobic contribution during the 90 s all out sprints.

## METHODS

### *Subjects*

Sixteen healthy volunteers (8 men, 8 boys) participated in the study. The adults (age:  $33.8 \pm 6.5$  y; stature:  $1.8 \pm 0.1$  m; body mass:  $71.0 \pm 12.1$  kg;  $\text{VO}_{2\text{max}}$ :  $3.7 \pm 0.7$  L $\cdot$ min $^{-1}$ ) and boys (age:  $14.6 \pm 0.3$  y; stature:  $1.7 \pm 0.1$  m; body mass:  $55.8 \pm 7.0$  kg;  $\text{VO}_{2\text{max}}$ :  $2.9 \pm 0.3$  L $\cdot$ min $^{-1}$ ) were pair matched according to  $\text{VO}_{2\text{peak}}$  relative to body mass ( $51.9 \pm 4.1$  vs  $52.1 \pm 3.3$  mL $\cdot$ kg $^{-1}\cdot$ min $^{-1}$  in the men and boys respectively). Participants and / or their parents were briefed as to the benefits and risks of participation and gave their written informed consent to participate in the study, which was approved by the University Ethics Committee. All were fully familiar with laboratory exercise testing procedures, having previously participated in other similar studies. Subjects were instructed to arrive at the laboratory in a rested and fully hydrated state, at least 3 h postprandial, and to avoid strenuous exercise in the 24 h preceding a test session. For each participant, tests took place at the same time of day ( $\pm 2$  h) to minimize the effects of diurnal biological variation on the results (Carter et al., 2002).

### *Experimental design*

The subjects were required to visit the laboratory for two stages of experimentation. Subjects first completed a ramp test to exhaustion to determine peak oxygen uptake ( $\text{VO}_{2\text{peak}}$ ), and the corresponding power output ( $P\text{-VO}_{2\text{peak}}$ ). The second stage involved the subjects performing two 90 s all-out efforts on an isokinetic cycling ergometer. All the tests were preceded by a 5 minutes baseline exercise at 50 W and strong verbal encouragement was provided. Subjects were instructed to remain seated during each test. The ramp tests and the 90 s all-out tests were separated by at least two days and were performed in random order. The study was completed within 2 weeks for all subjects.

### *Equipment*

All tests were performed on an electrically-braked cycle ergometer (Schoberer Rad Messtechnik, Germany), with seat and handlebar height kept constant over the sessions for each participant. Torque applied at the crank and the cadence was measured continuously at 200 Hz from the isokinetic cycle. Before each daily testing session the SRM Powermeter was calibrated according to the manufacturer's recommended procedure (Jones and Passfield, 1998).

During each test, pulmonary gas exchange was determined breath-by-breath using standard algorithms, allowing for the time delay between gas concentration and volume signals (Beaver et al.,

1973). Individuals breathed through a low dead space (90 mL), low resistance ( $0.65 \text{ mmH}_2\text{O}\cdot\text{L}^{-1}\cdot\text{s}^{-1}$  at  $8 \text{ L}\cdot\text{s}^{-1}$ ) mouthpiece and turbine assembly. Gases were drawn continuously from the mouthpiece through a 2 m capillary line of small bore (0.5 mm) at a rate of  $60 \text{ mL}\cdot\text{min}^{-1}$ , and analysed for  $\text{O}_2$ ,  $\text{CO}_2$  and  $\text{N}_2$  concentrations by a quadrupole mass spectrometer (CaSE EX670, Gillingham, Kent, UK), which was calibrated before each test using gases of known concentration. Expiratory volumes were determined using a turbine volume transducer (Interface Associates, CA). The volume and concentration signals were integrated by computer following analogue-to-digital conversion. Respiratory gas exchange variables ( $\text{VO}_2$ ,  $\text{VCO}_2$ ,  $\text{V}_E$ ) were calculated, displayed for every breath and then, subsequently interpolated to provide one value per second. Heart rate was monitored every second using a telemetric heart rate monitor (Sports Tester, Polar Electro Oy, Kempele, Finland).

### ***The ramp test***

The initial power output was 50 W which was then increased by 5 W every 12 seconds (equating to 25 W per minute). Volunteers were allowed to self-select pedal frequency (range  $70\text{--}90 \text{ rev}\cdot\text{min}^{-1}$ ) and mean self-selected cadence was recorded. The test ended at the point of volitional exhaustion. After three minutes a fingertip capillary blood sample ( $\sim 25 \mu\text{L}$ ) was collected and subsequently analysed for lactate concentration using an automated analyser (YSI 2300, Yellow Springs, Ohio). Attainment of  $\text{VO}_2\text{max}$  was confirmed by the incidence of a plateau phenomenon in  $\text{VO}_2$ , RER values above 1.10, and heart rates within  $5 \text{ b}\cdot\text{min}^{-1}$  of age-predicted maximum. In all subjects, at least 2 of the 3 criteria were met. Due to the difference in attainment of a plateau in children compared to adults, the term  $\text{VO}_{2\text{peak}}$  will be used (Armstrong and Welsman, 1997). The highest 30 s average of the second per second  $\text{VO}_2$  data was taken to be the  $\text{VO}_{2\text{peak}}$ . The ventilatory threshold (VT) was defined as the  $\text{VO}_2$  at which a non-linear increase in carbon dioxide production ( $\text{VCO}_2$ ) and an increase in minute ventilation (VE) and in  $\text{VE}/\text{VO}_2$  with no increase in  $\text{VE}/\text{VCO}_2$  were evident (Beaver et al., 1986; Serresse et al., 1988). Three independent investigators blindly reviewed the plots of each index and made individual determinations of VT. To calculate individually the power output corresponding to  $\text{VO}_2\text{max}$  ( $P\text{-VO}_2\text{max}$ ), regression analysis was carried out on the second by second data to determine the y-intercept ( $585 \pm 265$  and  $302 \pm 133 \text{ mL}\cdot\text{min}^{-1}$  in the men and boys respectively) and the slope ( $9.6 \pm 1.4$  vs  $10.6 \pm 1.9 \text{ mL}\cdot\text{min}^{-1}\cdot\text{W}^{-1}$ ) of the  $\text{VO}_2$ -power output relationship for exercise  $< \text{VT}$ .

### ***The 90s all-out tests***

Prior to the 90 s tests familiarisation with the all-out test was undertaken, consisting of 2 – 3, 10-s sprints at the pre-set cadence. On the day of the test, participants were seated on the ergometer with handlebars and seat adjusted and toe clips used accordingly. Following a 2 minute period of baseline pedalling with no resistance, on the word “go”, the participant began sprinting all out in a seated position with the cadence imposed by the SRM system. The mean cadence for the isokinetic tests was  $101 \pm 11 \text{ rev}\cdot\text{min}^{-1}$  and was identical for each participant for both tests. Participants were instructed to reach their peak power as quickly as possible, and to maintain an all-out effort for the entire duration of the test thus avoiding pacing. To avoid day-to-day variations in  $\text{VO}_2$  and power output profiles, the second per second values obtained from the two 90 s all-out tests were time-aligned and averaged. On completion of each 90 s sprint a 3 minute post blood lactate sample was collected as described above. Test retest scores of the 90 s all out cycle sprints have produced excellent reproducibility (Dekerle et al., in press). Ratio limits of agreement for a repeated measurement were found to be in 95% of cases between 0.92 to 1.21 times the initial peak power measurement ( $1.06 \times/\div 1.15$ ) and 0.97 to 1.07 times the initial mean power measurement ( $1.02 \times/\div 1.05$ ).

### ***Data analysis***

As the aerobic contribution has shown to be an important factor within all out tests of 90 s we chose to pair match the boys and men for  $\text{VO}_{2\text{peak}}$ . Indices of the power profile were derived from the average response of the two tests including peak power (PP, accepted as the highest power output in 1 s), end power ( $\text{EP}_{60\text{--}90}$ , power over the last 30 s), and mean power over the 90 s ( $\text{MP}_{90}$ ). The fatigue index (FI) was calculated as peak power subtracted from end power divided by peak power multiplied by 100. The power output expected from the measured  $\text{VO}_2$  was determined second by second using the  $\text{VO}_2$ -power output relationship for exercise  $< \text{VT}$ . Its difference with the actual power output was calculated second by second and integrated with time to obtain an individual value of anaerobic work capacity (AWC). The anaerobic/aerobic contribution was calculated as the proportion of the total work done accounted for by the AWC.

The breath-by-breath data from the two, 90s tests were used to estimate and compare the  $\text{VO}_2$  kinetics in the two subject populations. The data from both tests were time aligned to the start of exercise and averaged in order to enhance the underlying response characteristics. Breaths deviating by more than 2 standard deviations from

the preceding 5 breaths were removed from the data sets. These values represented <1% of the total data collected. Following this process, the breath-by-breath data were interpolated to provide second-by-second values and modelled using a monoexponential fit.

$$VO_2(t) = VO_2(b) + A * (1 - e^{-(t-TD)/\tau}) \quad [1]$$

where  $VO_2(t)$  is the  $VO_2$  at time  $t$ ;  $VO_2(b)$  is the baseline  $VO_2$  measured in the 60 s before the transition in work rate;  $A$ ,  $TD$  and  $\tau$  are the amplitude, time delay and the time constant of the response, respectively. Since the purpose of the study is concerned with total  $VO_2$  and speed of the total  $VO_2$  kinetic response rather than the dynamics of muscular phosphorylation, the data were modelled from time 0 (i.e.  $TD = 0$ ).

A monoexponential function was chosen since: 1) the cardiodynamic component would be hard to interpret where high initial powers are produced; 2) a more complex model is not necessary during a response in which a slow component of  $VO_2$  does not become evident and 3) the exercise was not constant load in nature. In order for the latter issue to be explored, the  $VO_2$  response relative to the power output (the so called 'gain') was calculated.

### Statistics

Data are reported as mean values and SEM unless stated otherwise. Matched paired dependent t-tests were used to compare the data from the ramp test and the 90 s all out tests between the group of adults and boys. Independent t-tests were also used to evaluate the differences between values for the ramp and 90 s all out test. The 95 % confidence intervals for the time-based parameters were calculated using procedures outlined previously (Lamarra, 1987). Statistical significance was accepted at the  $p < 0.05$

level.

## RESULTS

### The ramp test

The absolute  $VO_{2peak}$  was significantly higher in the adult men ( $3.69 \pm 0.31$  vs  $2.91 \pm 0.40$   $L \cdot min^{-1}$ ,  $p = 0.016$ ) and the power at  $VO_{2peak}$  was also significantly higher in the adult group ( $395 \pm 104$  vs  $235 \pm 34.2$  W,  $p = 0.001$ ). As the boys and men were pair matched according to  $VO_{2peak}$  relative to body mass there was no significant difference ( $52.1 \pm 3.3$   $mL \cdot kg \cdot min^{-1}$  vs  $51.9 \pm 4.1$ ,  $p > 0.05$ ) respectively. There was no significant difference in peak heart rate ( $189 \pm 9.5$  vs  $193 \pm 7.7$   $b \cdot min^{-1}$ ,  $p > 0.05$ ) or peak blood lactate ( $7.4 \pm 4.7$  vs  $6.6 \pm 1.7$  mM,  $p > 0.05$ ) in adults and boys respectively ( $p > 0.05$ ).

The adult group had a significantly higher VT than the boys when expressed as  $VO_2$  ( $2.17 \pm 0.36$  vs  $1.32 \pm 0.19$   $L \cdot min^{-1}$ ,  $p < 0.001$ ), power output at VT ( $160 \pm 33.3$  vs  $116 \pm 14.3$  W,  $p < 0.001$ ) and the % of  $VO_{2peak}$  at which VT occurred ( $59.1 \pm 4.3$  vs  $46 \pm 5.2$  %,  $p < 0.001$ ) respectively.

### All out 90 s cycle sprints

Table 1 shows the data measured and derived from the 90 s all out tests in the adult and child groups. The adult group achieved higher absolute peak, mean and end power and more total work during the 90 s test ( $p < 0.001$ ). Peak power relative to body mass was not significantly different between men and boys ( $p > 0.17$ ) but both mean and end power and total work relative to body mass were significantly different ( $p < 0.002$ ). A significantly higher  $VO_2$  and 3 minute post blood lactate was also found in men compared to boys ( $p < 0.05$ ).

### Comparison of $VO_{2peak}$ ramp test and 90 s all out test

Comparing the data collected in the  $VO_{2peak}$  ramp

**Table 1.** Descriptive power output and physiological parameters for the 90 s cycle sprint. Data are means ( $\pm$ SEM).

| Parameter                                 | Men          | Boys           |
|---|--------------|----------------|
| Peak Power (W)                            | 881.4 (60.7) | 533.6 (50.7) * |
| Relative Peak Power ( $W \cdot kg^{-1}$ ) | 11.7 (0.4)   | 10.1 (0.7)     |
| Mean Power (W)                            | 434.5 (27.4) | 238.4 (17.3) * |
| Relative Mean Power ( $W \cdot kg^{-1}$ ) | 5.9 (0.2)    | 4.5 (0.2) *    |
| End Power (W)                             | 288.6 (25.7) | 134.3 (17.6) * |
| Relative End Power ( $W \cdot kg^{-1}$ )  | 3.9 (0.2)    | 2.6 (0.3) *    |
| Fatigue Index (%)                         | 67.4 (2.0)   | 72.5 (3.3)     |
| Total work (J)                            | 38714 (2464) | 21171 (1554) * |
| Relative Total Work ( $J \cdot kg^{-1}$ ) | 521.5 (18.8) | 400.3 (2.4) *  |
| $VO_{2peak}$ ( $L \cdot min^{-1}$ )       | 3.41 (0.22)  | 2.70 (0.12) *  |
| Heart rate peak ( $b \cdot min^{-1}$ )    | 179 (5.2)    | 182 (5.6)      |
| Peak lactate (mM)                         | 10.5 (0.4)   | 7.3 (0.6) *    |

\* Significantly different to adult data ( $p < 0.05$ ).

**Table 2.** Modelling parameters

| Parameter                        | Absolute VO <sub>2</sub> |               | Gain       |               |
|----------------------------------|--------------------------|---------------|------------|---------------|
|                                  | Men                      | Boys          | Men        | Boys          |
| Baseline (L·min <sup>-1</sup> )  | 1.22 (0.04)              | 0.40 (0.04) * | N/A        | N/A           |
| Amplitude (L·min <sup>-1</sup> ) | 2.17 (0.21)              | 2.33 (0.08)   | 13.9 (1.4) | 35.7 (2.23) * |
| Time constant (s)                | 17.6 (1.0)               | 10.8 (1.5) *  | 39.0 (5.2) | 80.4 (5.4) *  |

\* Significantly different to adult data ( $p < 0.05$ ).

test with that from the 90 s all out sprints, the VO<sub>2peak</sub> was significantly higher in the ramp test for both the adult men ( $p < 0.001$ ) and boys ( $p < 0.05$ ). The boys attained values that were nearer to VO<sub>2peak</sub> than their adult counterparts ( $93.3 \pm 2.6$  vs  $84.9 \pm 2.3$  %,  $p < 0.05$ ). The peak blood lactate achieved after the 90 s tests was also significantly lower in the boys group ( $p < 0.05$ ) but this was not the case in the adult group ( $p > 0.05$ ). Peak heart rate was not significantly different across both exercise tests in both population groups ( $p > 0.05$ ) but tended to be lower after the 90 s all out effort (by  $\sim 10$  b·min<sup>-1</sup>).

Peak power in the 90 s test was considerably higher than the power at VO<sub>2peak</sub> in both the adult men ( $p < 0.001$ ) and boys ( $p < 0.001$ ), in the order of 210 to 230 %. In both groups, the mean power of the 90 s effort was not different to the power at VO<sub>2peak</sub> ( $p > 0.05$ ). The 90 s EP was significantly lower than the power at VO<sub>2peak</sub> in boys ( $p < 0.001$ ) and adults ( $p < 0.01$ ) yet the EP was higher than the power at VT, though this was only significant in the adult group ( $p < 0.01$ ).

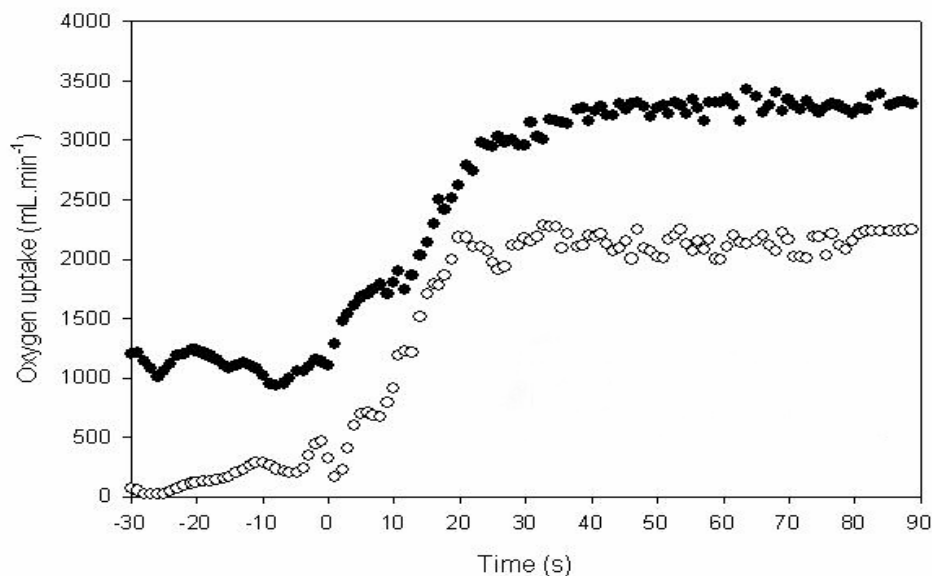
Table 2 represents the VO<sub>2</sub> kinetic response data. A significant difference was found in the baseline absolute VO<sub>2</sub> between boys and men. A significantly faster time constant was observed in boys for absolute VO<sub>2</sub>, as well as higher amplitude. The 95% confidence intervals for the time constants

were  $\pm 3.6$  and  $\pm 2.6$  s (adults and boys respectively).

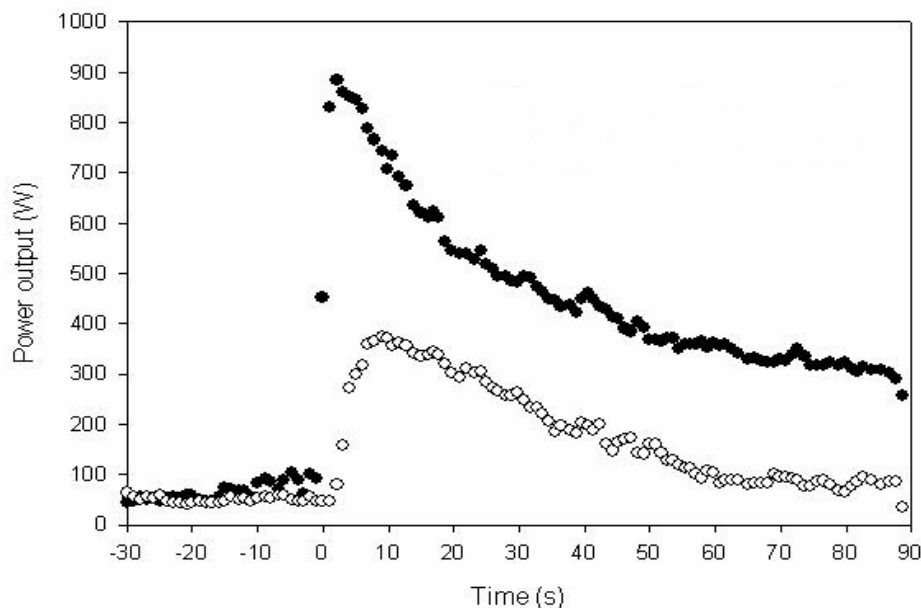
Figures 1 and 2 show typical profiles for the power output and oxygen uptake response during the 90 s test. From the estimations of the aerobic / anaerobic energy turnover adults had a higher anaerobic contribution to the work achieved during the 90 s test than the boys ( $46.5 \pm 3.4$  % vs  $40.2 \pm 1.4$  %) though this was not significantly different ( $p > 0.05$ ). Figure 3 represents the determination of AWC from the estimated power from VO<sub>2</sub> and power output data.

## DISCUSSION

This study compared the physiological responses attained in all out 90 s cycle sprints between adult men and boys. Specifically, we hypothesised that boys would possess a faster VO<sub>2</sub> kinetic response than adults and therefore attain a higher % of VO<sub>2peak</sub>. In addition, we expected the boys to attain a higher aerobic contribution to the 90 s sprint. Estimations have been reported for the % attainment of VO<sub>2max</sub> during all out (supra-maximal) exercise in adults (Astrand and Saltin, 1961; Gastin et al., 1991; Kavanagh and Jacobs, 1988) but to the best of our knowledge, this is the first study to compare boys and men. We found that there was a significantly higher attainment of VO<sub>2peak</sub> during the

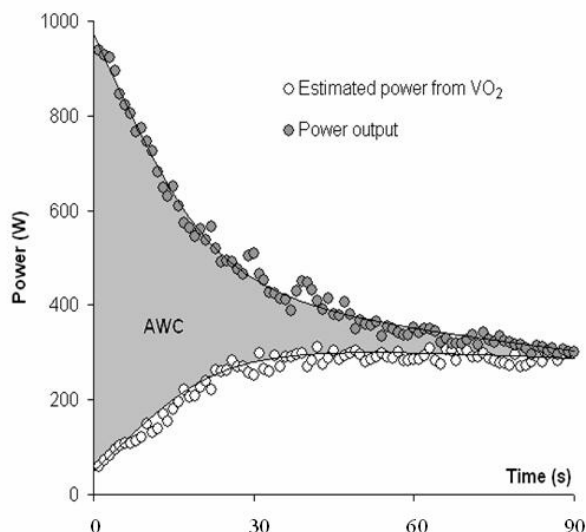


**Figure 1.** Oxygen uptake response during 90 s maximal isokinetic cycling for one man (filled circle) and boy (empty circle).



**Figure 2.** Power output response to 90 s maximal isokinetic cycling for one typical man (filled circle) and boy (empty circle).

90 s for boys compared to men,  $93.3 \pm 2.6$  vs  $84.9 \pm 2.3$  % respectively. A significantly faster  $\text{VO}_2$  kinetic response was also found in the boys compared to the men ( $10.8 \pm 1.5$  vs  $17.6 \pm 1.0$  s). The gain response, used to factor out differences in power output and which has seldom been investigated in the paediatric literature, was nearly three times higher for the boys.



**Figure 3.** Schematic showing the determination of AWC.

The findings of this study support previous work with boys (Williams et al., 2005) and adults (Craig et al., 1993; Davies and Sandstrom, 1989; Withers et al., 1991) that found  $\text{VO}_{2\text{peak}}$  measured in a 90 s all out sprint could approach those values obtained from a traditional aerobic test. Values for adults range from 84 % (Craig et al., 1993) to 94 %

(Wither et al., 1991), but values for children are sparse as there are only three cycling studies examining mechanical power with a test duration  $> 30$  s. In the studies of Gaul et al. (1995) and Mero (1988) the  $\text{VO}_2$  kinetic response during the  $>60$  s tests were not reported. In the only other study, Williams et al. (2005) reported values of  $\sim 92$  % attainment of  $\text{VO}_{2\text{peak}}$  during a 90 s cycle sprint. Using a protocol of cycling at 100 %  $\text{VO}_{2\text{max}}$  Macek and Vavra (1980) compared 20-22 year old men to 10-11 year old boys and found boys achieved  $56.4 \pm 7$  %  $\text{VO}_{2\text{max}}$  compared to the men  $35.5 \pm 7$  %. In a study of elite United States Federation adult cyclists, Carey and Richardson (2003) found during a 60 s and 75 s all out test that the %  $\text{VO}_{2\text{max}}$  at 60 s and 75 s was 90.7 and 91.0 % of that recorded in a ramp  $\text{VO}_{2\text{max}}$  test, but was still significantly lower than the aerobic  $\text{VO}_{2\text{max}}$  value. It is possible that a combination of different methods of gas collection and analyses, the differences in training status of the adult groups and a longer test duration used in the current study could be responsible for the differences between the two studies.

The mechanical 90 s power profiles clearly show that adult men attained significantly higher absolute peak, and absolute and relative mean and end powers as well as, higher total work and peak blood lactates than the boys ( $p < 0.05$ ). All these findings are well supported by previous literature, which has frequently investigated this concept using the 30 s WAnT or longer duration sprint cycling. For both men and boys the peak power was two fold greater than the power attained in the aerobic test, however the  $\text{MP}_{90}$  was not significantly different to the power at  $\text{VO}_{2\text{peak}}$ . Davies and Sandstrom (1989)

previously found a plateau or levelling out of the mechanical power during an 80 s cycle sprint and used this as evidence that their cyclists were maintaining a power output at the same rate as for their aerobic metabolism measured during a previous  $\text{VO}_2\text{max}$  test.

Oxygen uptake kinetics have typically been investigated under moderate, heavy or severe domains of exercise intensity in cycling (Carter et al., 2000; Fawcner and Armstrong, 2003). We modelled our  $\text{VO}_2$  response with a mono-exponential curve as the duration of the sprint was only 90 s. But it must be made clear that the  $\text{VO}_2$  response modelled in the present study comes from all-out exercise and not constant-load protocols. This further complicates the interpretation and comparison with previous works. However, a significant difference was found for the faster time constant in boys than men. This finding is generally supported in the paediatric literature of a faster  $\text{VO}_2$  kinetic response in children compared to adults, although all the evidence is within the moderate, heavy and severe domains (Fawcner and Armstrong, 2003). Hebestreit et al. (1998) compared 9-12 year old boys and 19-27 year old men for cycling at a constant cadence of  $80 \text{ rev}\cdot\text{min}^{-1}$  for at least 60 s at  $130\% \text{VO}_{2\text{peak}}$ . Hebestreit and colleagues found no significant differences for the time delay  $10.2 \pm 3.0$  vs  $10.8 \pm 1.7$  s, time constant  $19.8 \pm 4.1$  vs  $20.7 \pm 5.7$  or amplitude (expressed as a % of  $\text{VO}_{2\text{peak}}$ )  $97.3 \pm 1.4$  vs  $95.6 \pm 8.1$  between boys and men respectively. It is difficult to make intra-study comparisons as stated by Whipp (1997) because parameters related to the  $\text{VO}_2$  response are fraught with difficulties and comparing studies which have children and adults exercising at power output just above  $\text{VO}_{2\text{peak}}$  or  $\text{VO}_{2\text{max}}$  is significantly different to all out cycle sprinting.

The significant difference found in gain between the boys and adult men has been previously found but this was in submaximal treadmill running and therefore comparisons are difficult (Williams et al., 2001). Williams and colleagues interpreted the higher gain as being advantageous to children in dealing with the ensuing fatigue by responding with an increased aerobic energy provision. In the present study an increased gain was found throughout the duration of the test. Traditionally although the gain has been interpreted as reflecting a decreased efficiency, it must be presumed that due to the supra-maximal stimulus to the energy pathways at the onset of exercise, it would be unlikely to see  $\text{VO}_2$  decreasing with power output. Rather the 'additional'  $\text{VO}_2$  reflect a 'paying back' of the early oxygen debt. It is interesting to note that the EP60-90 finished lower than the power at  $\text{VO}_{2\text{peak}}$  even though the  $\text{VO}_2$  was near maximum.

Although the boys attained a higher aerobic contribution to the cycle sprints than the adults, this was not statistically significant. Previous speculations have postulated that the higher rate of exhaustion of the anaerobic capacity in boys might have resulted in an earlier onset of the aerobic energy system (Ratel et al., 2003). This mechanism has some support as a slightly higher fatigue index was found in boys compared to men (72.5 vs 67.4 %). However, there was a significantly higher total work done by men than boys and therefore comparisons between the two groups may not be equivalent. Adult men because of their larger anaerobic capacity stores might have been able to accomplish more of the work done anaerobically. Whereas, the declining rate of glycolysis of the boys might be as a response of the reduced energy demand, thereby increasing the relative contribution of the aerobic energy system.

Explanations as to why boys were able to attain near  $\text{VO}_{2\text{peak}}$  values can only at present be speculative. However, since invasive and therefore direct procedures of addressing this question in children are unacceptable and unethical i.e. muscle biopsy in children, the concurrent measurement of mechanical power output and  $\text{VO}_2$  kinetic responses remain as the sole method of investigation. The 90 s all out test is well suited to examine these issues. The test provides a more extensive power profile than shorter duration tests (< 30 s), it incorporates the aerobic system, is less time consuming than a  $\text{VO}_{2\text{peak}}$  test, it is well tolerated by healthy children and may prove to be more practical when testing athletes/patients for whom a longer test is not possible.

## CONCLUSIONS

In conclusion, boys attained higher  $\text{VO}_2$  values during all out sprints that were nearer to  $\text{VO}_{2\text{peak}}$  than adult men. Additionally,  $\text{VO}_2$  kinetic parameters were found to be significantly different for the time constant of the response and the gain amplitude between adult men and boys. Although statistically non-significant, boys attained a higher contribution of the aerobic energy system during all out 90 s cycle sprinting. Further research is needed to develop tests that integrate both energy systems, as well as determining the underlying mechanisms for adult-child differences.

## REFERENCES

- Armstrong, N. and Welsman, J.R. (1997) *Young People and Physical Activity*. Oxford University Press, Oxford.

- Astrand, P.O. and Saltin, B. (1961) Oxygen uptake in the first minutes of heavy muscular exercise. *Journal of Applied Physiology* **16**, 971-976.
- Bangsbo, J., Krustrup, P., Gonazalez-Alonso, J., Boushel, R. and Saltin, B. (2000) Muscle oxygen kinetics at the onset of intense dynamic exercise in humans. *American Journal of Physiology and Regulatory and Integrative Comparative Physiology* **279**, R899-906.
- Bar-Or, O. (1983) *Pediatric Sports Medicine for the practitioner. From physiologic principles to clinical applications*. Springer-Verlag, New York.
- Beaver, W.L., Wasserman, K. and Whipp, B.J. (1973) On-line computer analysis and breath-by-breath graphical display of exercise function tests. *Journal of Applied Physiology* **34**, 128-132.
- Beaver, W.L., Wasserman, K. and Whipp, B.J. (1986) A new method for detecting anaerobic threshold by gas exchange. *Journal of Applied Physiology* **60**, 2020-2027.
- Carey, D.G. and Richardson, M.T. (2003) Can aerobic and anaerobic power be measured in a 60-second maximal test? *Journal of Sports Science and Medicine* **2**, 151-157.
- Carter, H., Jones, A.M., Doust, J.H., Burnley, M., Williams, C.A. and Barstow, T.J. (2000) The comparison of VO<sub>2</sub> kinetics in treadmill running and cycling ergometry. *Journal of Applied Physiology* **89**, 899-907.
- Carter, H., Jones, A.M., Maxwell, N.S. and Doust, J.H. (2002) The effect of interdiurnal and diurnal variation on oxygen uptake kinetics during treadmill running. *Journal of Sports Science* **20**, 901-909.
- Chia, M., Armstrong, N. and Childs, D. (1997) The assessment of children's anaerobic performance using modifications of the Wingate anaerobic test. *Pediatric Exercise Science* **9**, 80-89.
- Craig, N.P., Norton, K.I., Bourdon, P.C., Woolford, S.M., Stanef, T., Squires, B., Olds, T.S., Conyers, R.A.J. and Walsh, C.B.V. (1993) Aerobic and anaerobic indices contributing to track endurance cycling performance. *European Journal of Applied Physiology* **66**, 150-158.
- Davies, C.T.M. and Sandstrom, E.R. (1989) Maximal mechanical power output and capacity of cyclists and young adults. *European Journal of Applied Physiology* **58**, 838-844.
- Dekerle, J., Hammond, A., Brickley, G. and Carter, H. (2005) Reproducibility of variables derived from a 90s all-out effort isokinetic cycling test. *Journal of Sports Medicine and Physical Fitness* in press.
- Fawkner, S.G. and Armstrong, N. (2003) Oxygen uptake kinetic response to exercise in children. *Sports Medicine* **33**, 651-669.
- Gastin, P.B. (2001) Energy system interaction and relative contribution during maximal exercise. *Sports Medicine* **31**, 725-741.
- Gastin, P., Lawson, D., Hargreaves, M., Carey, M. and Fairweather, I. (1991) Variable resistance loadings in anaerobic power testing. *International Journal of Sports Medicine* **12**, 513-518.
- Gastin, P.B. and Lawson, D.L. (1994) Variable resistance all-out test to generate accumulated oxygen deficit and predict anaerobic capacity. *European Journal of Applied Physiology* **69**, 331-336.
- Gaul, C.A., Docherty, D. and Cicchini, R. (1995) Differences in anaerobic performance between boys and men. *International Journal of Sports Medicine* **16**, 451-455.
- Greenhaff, P.L. and Timmons, J.A. (1998) Interaction between aerobic and anaerobic metabolism during intense muscle contraction. *Exercise and Sport Sciences Reviews* **26**, 1-30.
- Hebestreit, H., Kreimler, S., Hughson, R.L., and Bar-Or, O. (1998) Kinetics of oxygen uptake at the onset of exercise in boys and men. *Journal of Applied Physiology* **85**, 1833-1841.
- Jones, S.M. and Passfield, L. (1998) The dynamic calibration of bicycle power measuring cranks. In: *The Engineering of Sport*. Ed: Haake, S.J. Oxford, Blackwell Science. 265-274.
- Kavanagh, M.H. and Jacobs, I. (1988) Breath by breath oxygen consumption during performance of the Wingate test. *Canadian Journal of Applied Sport Science* **13**, 91-93.
- Lamarra, N., Whipp, B.J., Ward, S.A. and Wasserman, K. (1987) Effect of interbreath fluctuations on characterizing exercise gas exchange kinetics. *Journal of Applied Physiology* **62**, 2003-2012.
- Macek, M. and Vavra, J. (1980) The adjustment of oxygen uptake at the onset of exercise: a comparison between prepubertal boys and young adults. *International Journal of Sports Medicine* **1**, 70-72.
- Medbo, J.I. and Tabata, I. (1989) Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. *Journal of Applied Physiology* **67**, 1881-1886.
- Mero, A. (1988) Blood lactate production and recovery from anaerobic exercise in trained and untrained boys. *European Journal of Applied Physiology* **57**, 600-660.
- Nummela, A. and Rusko, H. (1995) Time course of anaerobic and aerobic energy expenditure during short-term exhaustive running in athletes. *International Journal of Sports Medicine* **16**, 522-527.
- Ratel, S., Lazaar, N., Williams, C.A., Bedu, M. and Duché, P. (2003) Age differences in human skeletal muscle fatigue during high-intensity intermittent exercise. *Acta Paediatrica* **92**, 1-7.
- Serresse, O., Lortie, G., Boucard, C. and Boulay, M. (1988) Estimation of the contribution of the various energy systems during maximal work of short duration. *International Journal of Sports Medicine* **9**, 456-460.
- Wasserman, K., Whipp, B.J., Koyal, S.N. and Beaver, W.L. (1973) Anaerobic threshold and respiratory gas exchange during exercise. *Journal of Applied Physiology* **35**, 236-243.
- Whipp, B.J. (1997) Developmental aspects of oxygen uptake kinetics in children. In: *Children and Exercise XIX*. Eds: Armstrong, N., Kirby, B.J. and Welsman, J.R. London: E&F.N. Spon. 233-247.
- Williams, C.A., Ratel, S. and Armstrong, N. (2005) Achievement of peak VO<sub>2</sub> during a 90-s maximal



intensity cycle sprint in adolescents. *Canadian Journal of Applied Physiology* **30**, 157-171.

Williams, C.A., Carter, H., Jones, A.M., and Doust, J. (2001) Oxygen uptake kinetics during treadmill running in children and adults. *Journal of Applied Physiology* **90**, 1700-1706.

Withers, R.T., Sherman, W.M., Clark, D.G., Esselbach, P.C., Nolan, S.R., Mackay, M.H. and Brinkman, M. (1991) Muscle metabolism during 30, 60, 90 s of maximal cycling on an air braked ergometer. *European Journal of Applied Physiology* **63**, 354-362.

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## KEY POINTS

- The results of this study confirm the significant contributions of the aerobic energy systems during so called 'anaerobic tests'.
- Boys were able to attain  $\text{VO}_2$  values from an all out 90 s sprint cycle that were closer to their aerobic  $\text{VO}_{2 \text{ peak}}$  test than adults. More detailed studies are required to investigate the limiting factors that prevent  $\text{VO}_{2 \text{ peak}}$  being reached in an all out sprint cycle.
- All out tests of a duration > 30 s and coupled with gas and power analyses offer paediatric physiologists considerable scope to examine the contributions of the anaerobic and aerobic energy systems until more ethically viable methods are found.

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