

# Aerobic Energy Contribution during High Intensity Exercise

## 最大強度運動中的有氧供能

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### Abstract

The review focuses on the aerobic energy contribution during high intensity cycling exercise. It is erroneous to assume that the energy demands of an exercise task can be met exclusively by either aerobic or anaerobic sources. During peak oxygen uptake determination, especially during the latter portions of the incremental exercise test, the anaerobic energy stores are also taxed. Not surprising, during maximal exercise of a short duration, there is also energy supplementation from aerobic energy sources. However, for a test to be considered predominantly anaerobic, the aerobic contribution to the test must be kept minimal. The quantification of aerobic contribution to a maximal exercise performance is difficult because the mechanical efficiency (ME) during a non-steady state exercise task remains speculative. Nevertheless extreme ME values for cycling have been proposed to provide a general scope of the estimated values. In adults, assumptions about oxygen uptake lag time, the size and role of the stored oxygen stores, which are taken into account also affect the magnitude to the aerobic contribution. Equivalent data on young people are insecure and greater research attention in this area is advised.

Keywords: Oxidative metabolism, high intensity exercise

### 摘要

本文著重介紹了大強度自行車運動中的有氧供能。如果認為運動中機體所需能量僅以某一能源系統，有氧系統或無氧系統供能是不正確的。在逐級遞增負荷測定最大攝氧量的運動中，尤其在測試的後階段，無氧系統參與供能。而在短時間的最大強度運動中，有氧供能也佔有一定的比例。即使進行無氧運動，在測試中仍能發現有低比例有氧供能。很難確定有氧系統在最大強度運動中的供能量為多少，因為不穩定狀態下的運動其供能效率仍不十分明確。但對於踏車運動中最高供能效率有一估計值範圍。對於成年人，攝氧量的延遲時間以及氧的儲存量的多少將影響最大有氧供能的比例。而在青少年中，有關這方面的資料較為缺乏，有待進一步的研究。

### Introduction

During maximal exercise of a short duration such as in the Wingate Anaerobic Test (WAnT), there is energy supplementation from oxidative metabolism (Vandewalle et al, 1987; Inbar et al, 1996). Exercise bouts are best described as predominantly anaerobic or predominantly aerobic, rather

than exclusively anaerobic or aerobic, because in either of the exercise bouts, there is always some energy supplementation from the other energy pathway. The extent of the supplementation is largely dependent on a number of factors such as the intensity and duration of the exercise. Other determining factors include the age and maturation of the subjects and their fitness and nutritional status (Newsholme, 1997). Thomson and Garvie

(1981) reported that oxygen consumption increases linearly over a maximal intensity sprint during the first 45 seconds. This linear increase in oxygen uptake with time during the exercise bout indicates that oxidative energy production starts at the onset of the exercise performance. The fact that there is aerobic contribution to high intensity exercise should not come as a great surprise as even during maximal intensity exercise tests, designed to elicit peak oxygen uptake values, there is energy contribution from anaerobic sources. This is evidenced by the 500-600% mean increase in whole blood lactate concentration from rest values observed in nine and 10 year old children, immediately following peak oxygen uptake determination on the treadmill. Therefore, it is reasonable to accept that during high intensity exercise, there is an overlap in energy provision from the three energy systems. As the energy provision during high intensity exercise is concomitantly supplied by all the energy systems, it is impossible to devise a test, which taxes exclusively the power or capacity of the anaerobic system. However, for any test to be considered predominantly anaerobic, the energy contribution from oxidative metabolism must be minimised and conversely, the energy contribution from non-oxidative metabolism must be maximised.

## Methods of Computation and Comparison

A number of approaches have been used to estimate the extent of aerobic contribution toward high intensity exercise (Inbar et al, 1976; Kavanagh and Jacobs, 1988; Van Praagh et al, 1991). The most direct method is to measure the baseline oxygen uptake prior to the exercise and also during the high intensity exercise. The net oxygen uptake (exercise minus baseline) can then be computed. Hebestreit et al (1994), used this method of computation and reported that the net oxygen uptake of boys during a maximal 30-second cycling bout is higher than that of adult men. The oxygen uptake during a maximal exercise bout may also be compared to the peak oxygen uptake of the subjects. Employing this method, Van Praagh et al (1991), reported that for boys aged 7-14 years, the aerobic contribution to a 30-second WAnT reaches 60-70% of cycle ergometer-derived peak oxygen uptake values, but declines with increasing chronological age. Chia (1998) reported that in 48 boys and girls aged 9.9 years old, oxygen uptake over a 20s WAnT was 61% of peak oxygen uptake and up to 71% of peak oxygen uptake over a 30s WAnT.

Another method of estimating the aerobic contribution towards high intensity exercise is to convert the net oxygen uptake during the exercise to work units (i.e. joules) using a conversion factor of  $20.92 \text{ kJ}\cdot\text{L}^{-1}$  of oxygen, assuming 100%

carbohydrate oxidation (Respiratory exchange ratio = 0.99 for 30-second all-out test; Serresse et al, 1988). The aerobic contribution to the cycle test is given simply by the exercise oxygen uptake expressed in work units, divided by the total work done during the exercise, and finally expressing the ratio in percentage terms. Further refinement to this approach involves accounting for gross (muscular) efficiency or net efficiency, and factoring in, assumptions about the size and role of stored oxygen within the muscle, and the time delay for oxygen uptake at the mouth to reflect oxygen uptake at the muscle. A number of researchers used this approach, in different permutations to estimate the aerobic contribution to the 30-second WAnT (Hill & Smith, 1991, 1992, 1993; Serresse et al, 1988, Kavanagh & Jacobs, 1988; Williams, 1995).

The magnitude of aerobic contribution to a 30-second WAnT, using adult subjects is estimated at 13-28% (Inbar, et al, 1976), nine to 19% (Kavanagh and Jacobs, 1988), 28% (Serresse et al, 1988), 16-24% (Smith & Hill, 1991), and as high as 40% (Medbo and Tabata, 1989). One study by Stevens and Wilson (1986) reported the aerobic contribution to the WAnT in adult games players was 44.3%. Subsequently, Stevens and Wilson admitted a calculation error and amended the figure to 27%. (Inbar et al, 1996). The majority of tests, which focus on the interplay of the aerobic and anaerobic energy supply to a brief bout of maximal exercise, are based on adults-predominantly male. In many of the cases reported, the tests are based on differing assumptions, in some combination and permutation, about the assumed mechanical efficiency of an all-out cycling bout, the time delay in oxygen uptake and the size and role played by the oxygen stores in the muscle.

There is a lack of uniformity and standardisation in the use of different tests and methods in the calculations that are used to assess the extent of the aerobic contribution. For instance, some researchers based their results on single 30-second Douglas bag samples (Medbo & Tabata, 1989), whereas others used breath-by-breath analysis (Kavanagh & Jacobs, 1988; Williams, 1995). Where breath-by-breath methods are used, some of them are not true breath-by-breath data based on mass spectroscopy, but rather, they are based on extrapolations of data, which in the strict sense are not true individual breath-by-breath data. In the Medbo and Tabata study cited, the work duration was longer (34s) and it is therefore expected that the overall aerobic contribution is higher than the 30-second WAnT. Additionally, the test protocol was based on a cycle sprint to exhaustion at a constant power output of  $9.1\text{W}\cdot\text{kg}^{-1}$  in comparison with a cycle sprint of 30 seconds in the WAnT, which cranked out variable power outputs

throughout the test. Contrarily, when the maximal exercise duration is reduced from 30s to 20s, the aerobic contribution is markedly reduced for a given mechanical efficiency (Chia, Armstrong & Childs, 1997).

It is inevitable that any useful estimate of the aerobic contribution to a high intensity exercise task requires important basic assumptions (often based on indirect evidence or at best, informed conjecture of the investigators), fundamentally related to the following to be addressed:

- Efficiency-with what efficiency is the group of subjects performing the measure work?
- Time delay-when does oxygen uptake at the mouth represent oxygen uptake in the exercising muscles-as a consequence of the cardio-dynamic effect?
- Oxygen stores-what is the size and how much energy is provided from the use of oxygen stores?

Indeed, in order for any estimate of the aerobic contribution to a high intensity exercise task such as the WAnT, to be meaningful, one needs to argue the case why certain assumptions (preferably backed by experimental data, or the lack of data) upon which the calculations are based, are chosen over others. Hill and Smith (1991) clearly demonstrated that the use of a set of different assumptions (but not all permutations) in the calculation of the aerobic contribution to the WAnT produces a range of results, which span 14.4-28.6%.

### Assumptions related to Efficiency

Efficiency can be expressed as muscular efficiency (ME) or gross efficiency (the term mechanical efficiency has also been used) or net efficiency (NE). Muscular efficiency is expressed as the ratio of the work done to the energy expended (Astrand, 1986). Gross efficiency is usually measured by the gross oxygen cost (Gaesser & Brooks, 1975). Net efficiency is expressed as a ratio of the work accomplished to the energy expended above baseline requirements. The energy expended above baseline requirements is computed by the subtraction of baseline oxygen uptake prior to the exercise from the oxygen uptake during the exercise bout. A study by Rowland et al (1990) estimated the mechanical efficiency of sub-maximal cycle ergometer-exercise by examining delta efficiency, which is given by the energy required to increase exercise work by a given load (change in mechanical work accomplished with an increase in exercise intensity divided by the corresponding change in oxygen cost). However ME and NE appear to be the preferred choices for representing efficiency, among

investigators. For instance, Davies and Sandstrom (1989) and Serresse et al (1988) used ME values 22- and 16% respectively, whereas, Kavanagh and Jacobs (1988), used NE values of 13-, 20- and 25%. Smith and Hill (1992) used ME of 22% and NE of 25% to estimate the aerobic contribution to a 30-second WAnT. Calculations of energy expenditure that use NE requires a subtraction of measured baseline oxygen uptake from oxygen uptake measured during the work bout.

According to Astrand (1986) one of the greatest difficulties about ascribing efficiencies is that there are no methods available for an exact measurement of the mechanical efficiency of non-steady state, anaerobic-type work. Efficiency of cycling during steady-state exercise is easily determined as the oxygen uptake is relatively constant and is directly proportional to constant sub-maximal work demand. However, such is not the case with a 30-second all-out cycle sprint where biomechanical factors such as pedal speed, work intensity, and crank angle (deVries, 1974) all affect efficiency. Cycling at greater speeds or higher exercise intensities (as is the case in the WAnT), results in decrements in efficiency. In a review by Taylor et al (1950), net efficiency values in adults range from 23-13.8%, with a mean value of 17.6%. Estimations based on adenosine triphosphate turnover during 30 seconds of isokinetic sprint cycling exercise show that ME can be as low as 13% (Kavanagh & Jacobs, 1988, cited in personal communication with McCartney, 1987). In addition, most physiological-based data which employ ME in their computations ignores the contribution of internal work i.e. energy that is needed to overcome the inertia and internal resistance of the limbs (Kaneko & Yamazaki, 1978).

The exercise efficiency of young people has also been examined. Boys aged seven to 15 years have a mean net efficiency value of 19.7% (Taylor et al, 1950), while girls aged six to 14 years have an average net efficiency value of 17.3% (Bal et al, 1953). A study by Klausen et al (1985), that evaluated the mechanical efficiency of 53 children (boys and girls) aged seven to 14 years at sub-maximal cycle exercise intensities that resulted in heart rates of 120 and 160 beats per minute, demonstrated a mean delta efficiency value of 23.6%. Some researchers report no difference in efficiency values between children and adults. For instance, Rowland et al (1990), compared delta efficiency values of 19 prepubertal boys with 21 college men, and reported similar values (23.2% vs. 22.5%,  $p > 0.05$ ). Although it is difficult, if not impossible to assess accurately the efficiency of a maximal cycling task, a 22% muscular efficiency is suggested as appropriate for both aerobic and anaerobic exercise (Davies and Sandstrom, 1989). However, Smith and Hill (1991), are

of the opinion that a gross efficiency value of 22 % probably overestimates the aerobic contribution to measured work in a high power output task such as the WAnT because high pedal velocities achieved in the earlier stages of WAnT (rolling start) or mid-stages of the WAnT (stationary start) will be expected to be less efficient. Additionally, upper body muscles exerting a considerable amount of unmeasured forces on the handlebars reduce the overall muscle efficiency value. Instead net efficiency values of 16.2% (Serresse et al, 1988) and 18.5% (Smith and Hill, 1991) are suggested as suitable and defensible values of efficiency to adopt in the calculation of the aerobic contribution to the WAnT. These values are within the limits previously found by Taylor et al (1950) and Bal et al (1952) for children. As a direct determination of efficiency during a maximal cycling exercise bout, remains difficult and because the extant literature suggests a possible range of human efficiencies during cycling, adopting net efficiency values of 13% (Kavanagh & Jacobs, 1988) and 30% (Bar-Or, 1989) will apparently encompass both the lowest and highest efficiency values that are hypothesised for cycling.

### Assumptions related to Time-Delay

At the onset of exercise where there is increased oxygen demand at the tissue level, it is physiologically impossible for oxygen uptake at the mouth to immediately reflect the demand for oxygen at the tissue. Whipp et al (1982) and Hughson et al (1988), suggested that there is a time delay of 10-15 seconds before increased oxygen uptake at the muscle is reflected in an increase in oxygen uptake at the mouth. The time delay between increased tissue oxygen uptake and increased oxygen uptake at the mouth reflects a cardio-dynamic effect (Whipp et al, 1982). Even though the time delay of 10 - 15 seconds suggested are based on adults, it appears reasonable to account for some time delay when dealing with child subjects. Given that the majority view is that children have faster oxygen uptake kinetics, it is probable that children demonstrate a shorter time delay where oxygen uptake at the mouth reflects tissue oxygen uptake. The literature however, is silent on the oxygen uptake lag time in children. Where adults are concerned, factoring in the oxygen uptake lag time appears to be more crucial. Some investigators- Stevens and Wilson (1986), Kavanagh and Jacobs (1988), Medbo and Tabata (1989), Williams (1995) and Chia, Armstrong and Childs (1997) based their calculations without accounting for this time delay in oxygen kinetics. Consequently, their calculations probably overestimated the aerobic contribution to the 30-second WAnT, a view supported by Serresse et al (1988). Indeed, the value of 44.3 % reported by Stevens and Wilson (1986), was subsequently

adjusted to 27 % when the time delay was factored in during re-calculation. Since it has been demonstrated that the increase in oxygen uptake during the first 45 seconds of an all-out sprinting bout is linear (Thomson and Garvie, 1981), the oxygen uptake during the first five seconds of the WAnT can be found by back-extrapolation from oxygen uptake data acquired during the five to 10 second period of the test (Serresse et al, 1988). After the five-second period, the aerobic contribution to the rest of the test is based directly on measured oxygen uptake during the test. Hill and Smith (1992), demonstrated that by accounting for the time delay in oxygen kinetics, aerobic contribution to the 30-second WAnT is reduced in the same group of subjects by a mean of 1.9 % for a set of two efficiency values (ME=22% and NE=25%), and a set of three oxygen store values (0-, 2-, 3- and 6mL·kg<sup>-1</sup>).

### Assumptions related to the Utilisation of Stored Oxygen

The size of the oxygen stores is reported at 3.5mL·kg<sup>-1</sup> body mass (Williams, 1995), 2.3mL·kg<sup>-1</sup> body mass (Barstow et al, 1990), 5.6mL·kg<sup>-1</sup> (Medbo & Tabata, 1989), 6.0mL·kg<sup>-1</sup> (Medbo et al, 1988), 6.4mL·kg<sup>-1</sup> body mass (di Prampero et al, 1983). Experimental data of Inman and colleagues (1987), showed that 139mL (equivalent to 2.3mL·kg<sup>-1</sup> body mass) of the oxygen stores are depleted from rest to a work rate of 100 watts. They also reported that 80% of the stores are used within the first 30 seconds of the exercise. It is thought that there are no gender differences in the size and utilisation of the stored oxygen (Hill & Smith, 1993). Ignoring the use of oxygen stores during an anaerobic exercise bout may underestimate the aerobic contribution. Depending on the size of the oxygen store selected, not accounting for the use of the oxygen stores underestimates the aerobic contribution to a 30-second WAnT by mean values which ranged from 4.1-10.6 %, in taking oxygen store values of 2.3mL·kg<sup>-1</sup> and 6.0mL·kg<sup>-1</sup>, and gross efficiency of 22% and net efficiency of 25% (Hill & Smith, 1992). However, the size of oxygen stores as with its role during all-out intensity exercise in adults and certainly in children, remains a matter of conjecture.

### Associated Research Data

A summary table based on work in the reported literature, on the aerobic contributions to high intensity cycle tests, provides an overview of the diversity of the results obtained.

## Conclusion

The energy systems operate in an integrative manner in response to the demands of exercise. It is therefore not surprising that during maximal intensity exercise of a short duration, there is energy supplementation from oxidative metabolism. In general, the magnitude of the aerobic contribution to high intensity exercise increases as the exercise intensity decreases and the exercise duration increases. It appears that the size of the aerobic energy contribution is greater in young people than in adults. The quantification of the aerobic contribution to high intensity exercise is fraught with difficulties owing to the number of assumptions involved in its computation. These assumptions include (a) the mechanical efficiency of high intensity exercise, (b) the oxygen uptake time delay and (c) the size of the stored oxygen stores.

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Table 1. Oxidative Energy Contribution to Maximal Intensity Exercise.

INVESTIGATORS	SUBJECT CHARACTERISTICS	TEST	MEASUREMENT MODE & PRINCIPAL ASSUMPTIONS	% AEROBIC CONTRIBUTION
Inbar et al, 1976	16 male and female athletes (Aged 16-22 y.)	30s WAnT	ME = 18%; oxygen deficit = oxygen debt	13
	16 male and female athletes (Aged 16-22 y.)	30s WAnT	ME = 22%	28.6
Thomson & Garvie, 1981		30s all-out running		25
Stevens & Wilson, 1986		Thirteen 30-s WAnT	ME = 25%; $\dot{V}O_2$ at the mouth equalled tissue $\dot{V}O_2$ . No correction for oxygen stores.	27
Kavanagh & Jacobs, 1988	5 subjects	Five 30-s WAnT	Breath-by-breath. ME = 25-; 20- & 13%. Subtraction of 1 MET ( $3.5 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) baseline $\dot{V}O_2$ . No correction for oxygen stores.	18.5, 14, 9 Inter-individual variation: 11.9-25.1
Serresse et al, 1988	25 fit male athletes	30s WAnT	Single 30s Douglas bag sample. $\dot{V}O_2$ at the mouth equalled tissue $\dot{V}O_2$ . No correction for oxygen stores.	28
Serresse et al, 1988	25 fit male athletes	90s maximal ergocycle	Single 90s Douglas bag sample. $\dot{V}O_2$ at the mouth equalled tissue $\dot{V}O_2$ .	46
Medbo & Tabata, 1989	14 subjects	Constant power output cycle-34s	34s Douglas bag samples. Total $\dot{V}O_2 + 30\%$ ( $6 \text{ mL} \cdot \text{kg}^{-1} \text{ BM min}^{-1}$ ) to account for stored oxygen.	40
Hill & Smith, 1991	6 men (Mean age 23 y.)	Twenty-three 30s WAnT	Net ME = 18.5-; 25%; gross ME = 22 % Subtraction of baseline $\dot{V}O_2$ (almost 2 METs)	16, 22, 24
Hill & Smith, 1992	12 men (Mean age 23 y.)	30s WAnT	Various permutations-gross efficiency = 22%; net efficiency = 25%; correction versus no correction for time delay for $\dot{V}O_2$ ; no correction for O <sub>2</sub> stores and correction for O <sub>2</sub> stores of 2.3 & 6 $\text{mL} \cdot \text{kg}^{-1} \text{ BM}$ .	Range 14.4-28.6
Hill & Smith, 1993	22 women (Mean age 22 y.) 16 Men (Mean age 23 y.)	30s WAnT	Gross efficiency = 22%. Time delay in $\dot{V}O_2$ of 10-15 s; O <sub>2</sub> stores of $2.3 \text{ mL} \cdot \text{kg}^{-1} \text{ BM}$	Women-25 Men-20
Van Praagh et al, 1991	101 boys (Aged 7-15 y.). Inclusive of 10 boys in 8-9 y. age span.	30-s WAnT	One Douglas bag sample. Ratio of $\dot{V}O_2$ over calculated external work done.	60-70% of peak $\dot{V}O_2$ but decreased with age
Williams, 1995	Women PE students	30-s WAnT	ME = 15- & 25%. $\dot{V}O_2$ at mouth equalled tissue $\dot{V}O_2$ . Stored O <sub>2</sub> equalled $3.5 \text{ mL} \cdot \text{kg}^{-1} \text{ BM}$ Baseline $\dot{V}O_2 = 1 \text{ MET}$ .	10, 17
	16 boys (Mean age 9.5 y.) 18 girls (Mean age 9.9 y.)	30-s WAnT	ME = 15- & 25%. $\dot{V}O_2$ at mouth equalled tissue $\dot{V}O_2$ . Stored O <sub>2</sub> equalled $3.5 \text{ mL} \cdot \text{kg}^{-1} \text{ BM}$ Baseline $\dot{V}O_2 = 1 \text{ MET}$ .	Boys-25, 41 Girls-23, 39
Chia, Armstrong & Childs, 1997	25 girls & 25 boys (mean age 10.1 y.)	20s WAnT	ME 13 & 30%. $\dot{V}O_2$ at mouth equalled tissue $\dot{V}O_2$ Baseline $\dot{V}O_2 = 1 \text{ MET}$	Range Boys-15.5-35.7 Girls-13.7-31.5
		30s WAnT	ME 13 & 30%. $\dot{V}O_2$ at mouth equalled tissue $\dot{V}O_2$ Baseline $\dot{V}O_2 = 1 \text{ MET}$	Range Boys-19.2-44.3 Girls-17.7-40.7
Chia (1998)	24 girls & 24 boys (mean age 9.9 y.)	20s WAnT	Expressed as % of peak $\dot{V}O_2$	Girls & boys-61
		30s WAnT	Expressed as % of peak $\dot{V}O_2$	Girls-71 Boys-69