

## Energy Sources at Peak All-out Exercise in Adolescents and Young Adults

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### Abstract

**Purpose:** To examine the aerobic energy portion utilized during the Wingate Anaerobic Test.

**Methods:** Power output was compared with direct values obtained from measured oxygen uptake ( $\text{VO}_2$ ), in 14 ( $14.4 \pm 1.0$  yrs) healthy adolescents and 14 young adults ( $26.0 \pm 1.0$  yrs).

**Results:** All subjects completed the exercise challenges without ECG abnormality. At rest, significant ( $P < 0.05$ ) differences were noted between the groups in heart rate, and diastolic blood pressure. At peak exercise, significant ( $P < 0.05$ ) differences were noted between adolescents and young subjects for oxygen uptake ( $21.5 \pm 0.3$  vs.  $18.3 \pm 0.3$   $\text{mL O}_2 \times \text{kg}^{-1} \times \text{min}^{-1}$  respectively), power output for 30 s ( $0.63 \pm 0.3$  vs.  $0.78 \pm 0.3$   $\text{LO}_2 \times \text{min}^{-1/2}$  respectively), aerobic energy portion utilized ( $40.7 \pm 4.7$  vs.  $17.7 \pm 3.2$  % respectively) and lactic acid ( $8.5 \pm 0.7$  and  $12.6 \pm 1.1$   $\text{mmol} \times \text{L}^{-1}$  respectively). In addition, differences were seen in heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial blood pressure.

**Conclusions:** The results reflect a significant noticeably lower anaerobic power output during adolescence, which suggests that glycolytic activity is age-dependent. This may be related to different muscle substrate, enzyme activity and differences in phosphorus compounds between fast and slow fiber types. As a result, adolescents relied more on oxidative metabolism compared to young adults.

**Keywords:** Anaerobic; Adolescent; Peak power; Anaerobic capacity; Anaerobic power; Energy source

### Introduction

Muscle contraction and, therefore, all exercise are dependent on the breakdown of adenosine triphosphate (ATP) and the concomitant release of free energy [1]. This free energy release is coupled to the energy requirements of cell work. High-intensity exercise can result in up to a 1,000-fold increase in the rate of ATP demand compared to that at rest [2].

Energy is derived from each of the energy-producing pathways during almost all exercise activities. There are two main energy pathway processes that function collectively to supply the energy requirements of muscle:

- The anaerobic pathway (including the energy from high-energy phosphate compounds) which regenerates ATP at high rates yet is limited by the amount of energy that can be released in a single bout of intense exercise [3], and
- The aerobic system with enormous capacity to re-synthesize ATP yet, limited in its ability to produce energy rapidly [3]

The Wingate Anaerobic Test (WAnT) is a 30 s test commonly used to estimate anaerobic work capacity. However, the test may be too short to fully deplete anaerobic energy reserves [4,5]. The test is a constant work-load with high-intensity exercise, and oxygen deficit,

providing a measure of anaerobic capacity, while exposing the subjects to a very high degree of sudden strenuous all-out exercise [6]. In young healthy subjects a significant percentage of the energy provided during the WAnT is aerobically derived and is not accounted for when quantifying anaerobic capacity as the total work performed [7]. It is assumed that this type of activity will have the effect of placing a large metabolic load on immature skeletal muscles [8]. When compared to adults, muscle mass in adolescents is lower and the relative development of aerobic and anaerobic pathways is different [9]. In anaerobic tasks or sports events such as sprint cycling, jumping or running, the adolescents' performance is distinctly lower and poorer than that of adults. This partly reflects adolescents' lesser ability to generate mechanical energy from chemical energy sources during short-term intensive activity [8,10].

During growth and maturation, the study of very brief high-intensity exercise has not received the same attention as aerobic performance. Consequently, the effect of adolescence on the aerobic and anaerobic pathways during strenuous exercise is unclear. Since previously it has been suggested that energy is derived from each of the energy-producing pathways during almost all exercise activities [3], the present study was designed to examine the effect of all-out anaerobic exercise stress on the relative contribution of the energy systems during single bouts of maximal anaerobic exercise. A particular emphasis has been placed on the role of the aerobic energy system during the WAnT in adolescent males.

## Methods

### Subjects

Fourteen adolescents all males ( $14.4 \pm 1.0$  years) participated twice a week in a regular physical education classes and 14 healthy sedentary young males ( $26.0 \pm 1.0$  years) volunteered for this study. Adolescents were recruited from nearby schools and the young men from the Wingate College student body. Subjects were judged free of coronary artery disease by clinical history, absence of major risk factors and by normal graded exercise stress test. A written informed consent was obtained from each young adult and subject's parents for the adolescents. The informed consent was approved by the Clinical Science Center Committee on Human Subjects.

### Procedure and measurements

Each subject reported to the laboratory two times. Sessions were spaced at least 48 h apart and on average at intervals of no more than one week. The first session was devoted to accustoming the subjects to the study procedures and to the general scope of the study. During this session each subject underwent a graded exercise stress test for health screening. During the 2<sup>nd</sup> session following warm-up, subjects were asked to perform the 30 s all out WAnT [11], utilizing a weight-adjusted Monark cycle-ergometer (Model 864). Subjects were seated on the ergometer with their feet fastened to the pedals by means of racing-type toe-clips, and seat height was adjusted while making sure that the knee is almost straight ( $5^\circ$ ) in bottom stroke with ankle in neutral position.

The anaerobic test consisted of 30 s supra-maximal pedaling against a constant resistance determined relative to the subject's body mass; for adolescents  $45 \text{ gr} \times \text{kg}^{-1}$  body weight and for the young  $80 \text{ g} \times \text{kg}^{-1}$  body weight [12,13]. At the command "start", the subject commenced peddling as fast as he could against the leg ergometer's inertial resistance only. The full, predetermined resistance load was applied within 3-4 s once the inertial resistance had been overcome. Pedal revolution count started at that instant by means of an electro-mechanical counter and subjects maintained an all-out effort throughout the test. Strong verbal encouragement was given to ensure maximal effort. Tests were performed at the same time of the day in order to avoid diurnal variations.

Adipose fat assessment included measurement of total body weight ( $\pm 0.05 \text{ kg}$ ), and skin fold thicknesses at 8 sites ( $\pm 1 \text{ mm}$ ). Anthropometric procedures [14] Oxygen uptake was determined breath by breath utilizing the Medical Graphics (St. Paul, MN) metabolic cart. The metabolic cart was calibrated before each test with known primary standard quality gases. Heart rate and electrocardiogram were monitored continuously, using a Burdick Eclipse 400 3-channel, 12-lead ECG recorder system, and oscilloscope. Five-second recordings were obtained at rest and at peak exercise.

### Calculations

Peak power output (PP) for 30 s was calculated as follow:

$$PP (\text{mLO}_2 \times \text{kg}^{-1} \times 30 \text{ s}^{-1}) = (D \times R \times 2 \text{ mLO}_2) + (\text{VO}_2 \text{ rest}/2)$$

Whereas: D=distance ( $\text{rpm} \times 6 \text{ m}$ ); R=resistance;  $2 \text{ mLO}_2$ =energy cost per pedal revolution,  $\text{VO}_2$ =oxygen uptake ( $\text{L} \times 30 \text{ s}^{-1}$ ).

$$\text{Aerobic energy portion (\%)} = (\text{VO}_2/\text{PP}) \times 100$$

Whereas:  $\text{VO}_2$ =Oxygen uptake ( $\text{LO}_2 \times 30 \text{ s}^{-1}$ ), PP=Peak power output

Fatigue index (%) was calculated as the absolute difference between the highest pedal revolutions for 5 s and the lowest pedal revolutions for 5 seconds divided by the highest pedal revolutions for 5 s.

Mean arterial blood pressure ( $\text{mmHg}$ )= $[(\text{systolic pressure}-\text{diastolic pressure})/3+\text{diastolic pressure}]$

### Lactic acid concentration

A  $25 \mu$  fingertip blood sample was taken at rest and during the 2<sup>nd</sup> minute post exercise for the determination of lactic acid concentration at peak anaerobic effort. The sample was immediately transferred to a micro-tube containing  $100 \mu$  of 7% perchloric acid. The tubes were centrifuged after standing for at least 1 h. Twenty microliter aliquots of the supernatant were subsequently used for lactic acid analysis on the Analox LM3 analyzer (Analox Instruments, England; Reagent Kit No. GMRD-071).

### Statistical methods

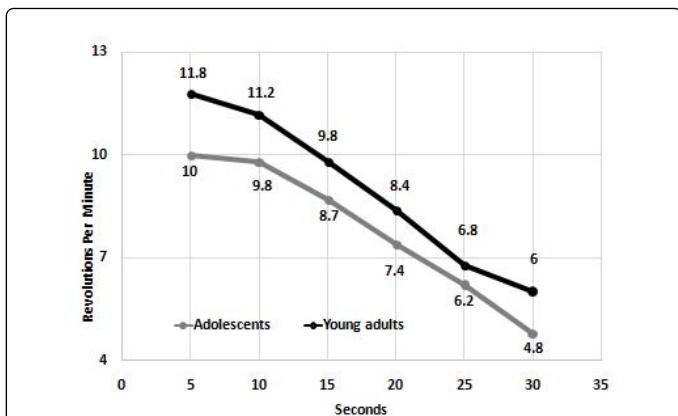
One-way ANOVA with repeated measures was employed for each of the variables measured in order to detect variations in the experimental parameters. In addition, the Students Newman-Keuls procedure was used for specific Post-Hoc comparisons.

## Results

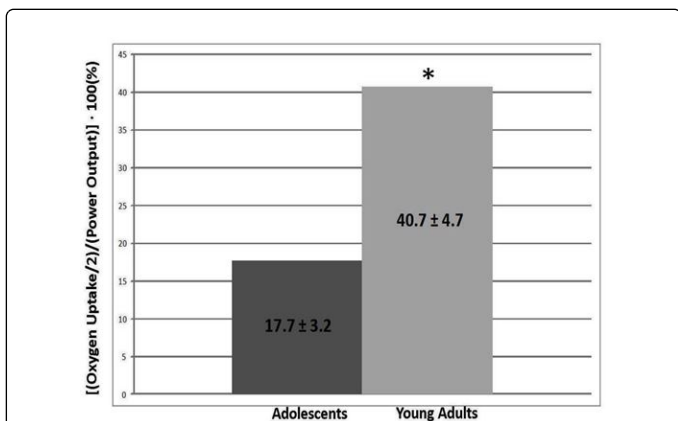
All subjects completed the exercise challenges without difficulties or abnormal symptoms. Mean descriptive data are presented (Table 1). Physiological responses at rest and during the WAnT are presented (Table 2). At rest, both groups had low body fat without significant differences, while lean body mass was significantly higher ( $p<0.01$ ) in the young adults. Adolescents demonstrated significantly ( $p<0.05$ ) lower values for systolic blood pressure while heart rate was higher, compared to young adult subjects. Mean revolution per minute for each 5 s measured throughout the WAnT for the adolescents and young subjects are presented (Figure 1). At peak WAnT, adolescents demonstrated significantly ( $p<0.05$ ) higher values for aerobic portion (Figure 2), and oxygen uptake, while peak power output (Figure 3), heart rate, lactic acid, systolic, diastolic and mean arterial blood pressures were significantly ( $p<0.05$ ) lower. Both groups demonstrated an equal, decrease force production during muscle contraction despite constant resistance (Fatigue index).

Variable	Adolescents	Young Adults
N of subjects	14	14
Age (years)	$14.1 \pm 1.0$	$26.0 \pm 1.0$
Weight (kg)	$44.3 \pm 3.1$	$71.6 \pm 3.0$
Height (cm)	$160.1 \pm 3.0$	$181.0 \pm 1.9$
Fat (%)	$11.4 \pm 1.3$	$11.7 \pm 1.9$
Lean body mass (kg)	$39.3 \pm 1.9$	$63.2 \pm 2.1$

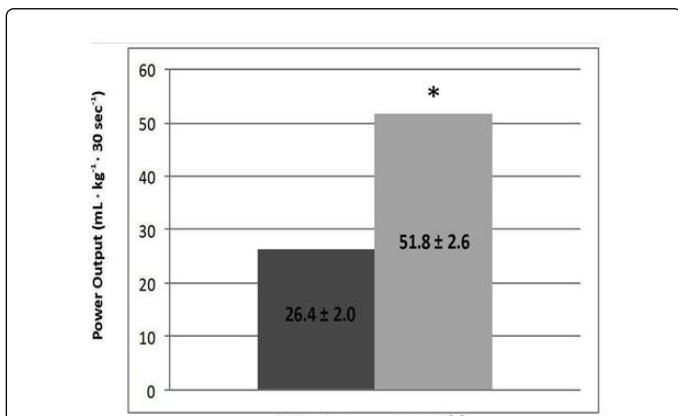
Table 1: Subjects' physical characteristics (mean  $\pm$  SD)



**Figure 1:** Mean revolution per minute for 5 s interval measured throughout the WAnT for the adolescents and young adult subjects.



**Figure 2:** Data for aerobic portion used at peak all out exercise for the adolescents and young adult subjects (mean ± SD); \*: Significant differences between groups (p<0.05).



**Figure 3:** Data for peak power output at peak all out exercise for the adolescents and young adult subjects (mean ± SD); \*: Significant differences between groups (p<0.05).

VARIABLE	ADOLESCENTS		YOUNG ADULT	
	REST	EXERCISE	REST	EXERCISE
VO <sub>2</sub> (mL·kg <sup>-1</sup> ·min <sup>-1</sup> )	3.2 ± 0.3	21.5 ± 0.3**	3.6 ± 0.2	18.3 ± 0.3
RPM	-----	46.9 ± 3.4	-----	54.0 ± 3.1
Fatigue Index (%)	-----	48.0 ± 2.4	-----	50.0 ± 2.1
HR (beats·min <sup>-1</sup> )	78.3 ± 8.2'	181.3 ± 7.4**	67.7 ± 8.3	187.2 ± 8.1
SBP (mmHg)	104.0 ± 6.1*	177.0 ± 13**	112.2 ± 5.9	198.1 ± 10.6
DBP (mmHg)	73.0 ± 5.3	76.0 ± 9.1**	75.1 ± 4.8	96.7 ± 8.8
MABP (mmHg)	83.3 ± 4.6	109.7 ± 6.2**	87.3 ± 5.1	130.5 ± 9.2
LA (mmol·L <sup>-1</sup> )	1.4 ± 0.3	8.8 ± 0.7**	1.3 ± 0.3	12.7 ± 1.1

**Table 2:** Physiological responses measured at peak Wingate Anaerobic Test (WAnT); Values are presented as means ± SD; \*: Significant differences between groups at rest (P<0.05); \*\*: Significant differences between groups at peak WAnT (p<0.05); VO<sub>2</sub>: Oxygen uptake; PP: Power output; RPM: Revolution Per Minute; HR: Heart Rate; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; MABP: Mean Arterial Blood Pressure; LA: Lactic Acid.

## Discussion

In the present study, adolescents and young adults both performed to their maximal work ability, as reflected by fatigue index. At peak anaerobic bout, both energy systems respond to the demands of intense exercise sequentially but in parallel manner. However, energy sources differed significantly between adolescents and young adults. In adolescents, the aerobic system played a major role, sufficient to meet the energy demands, while young adults relied more heavily on the anaerobic pathway. Since no differences were noted between both groups with regard to body's fat percentage it seems that muscle power capacity, are crucial performance components during anaerobic bouts subsequently [15]. The significant differences in active muscle mass involved between groups played a major role in the determination of the different energy source utilized by each group [16].

All-out WAnT is characterized by the attainment of peak power output in the first 5 to 10 s followed by a progressively declining power output until either completion of the test or voluntary cessation [17]. Compared to the adolescents, young adults demonstrated significantly (p<0.05) higher peak power output and lower oxygen uptake at peak WAnT suggesting, that the young adult subjects had higher peak rates of ATP re-synthesis from the ATP-PCr and glycolytic systems as suggested before [2]. When compared to young adults, the aerobic metabolism in adolescents, evaluated by measurement of maximal oxygen uptake, is either the same as in young adults or more developed when maximal oxygen uptake is related to body mass or lean body mass. Nevertheless, in adolescents maximal anaerobic power output developed during force-velocity test and peak WAnT test is lower than in young adults, even if it is expressed by total or lean body mass unit [9].

Therefore, the results of the present study do not appear to be explained by the constant power output exercise. They might reflect enhanced motor unit recruitment in adolescents with a greater

percentage of slow twitch fibers [13] and lower contractile speed [18]. However, the underlying mechanisms for these are not clear [19].

There is no doubt that each system is best suited to providing energy for a different type of event or activity, yet this does not imply exclusivity [3], therefore, the aerobic pathway may play a major role in determining performance over short durations [2].

The magnitudes of the two energy systems response were related to age and not to absolute work-load. It is, however, well known that in all-out anaerobic activities the adolescent's performance is clearly not as good as that of the young adult. This to a degree reflects the adolescent's lesser capacity to produce mechanical energy from high-energy phosphate compounds during short-term high-intensity work or exercise [8], due to probable differences in phosphorus compounds between fast and slow fiber types [10]. In adolescents, the observed higher aerobic ability at peak WAnT may be due, at least partially, to the muscle immaturity which decreases capacity to produce ATP by anaerobic means. It seems the anaerobic bout facilitated aerobic metabolism in adolescents. This indicates that control of oxidative phosphorylation in response to heavy-intensity cycling exercise is age-dependent [3,20]. If adolescents do not use fast twitch motor units to the same extent as young adults, their muscles would be characterized by higher functional composition of slow twitch fibers and would be expected to have faster muscle oxygen uptake kinetics. Indeed, in comparison with young adults, adolescents have been repeatedly shown to attain a given percentage of the ultimate oxygen uptake response faster than adults [21]. Individuals with higher proportions of slow twitch fibers in the vastus lateralis muscle generate higher power outputs for the same oxygen uptake [22].

In the present study absolute workloads performed by each group were significantly lower in adolescents. These results are as previously reported, that anaerobic power output was shown to be lower during adolescence, with significant noticeably lower lactic acid values [9]. The latter lactic acid results support the hypothesis that the difference observed between adolescents and young adults during short-term muscle power testing is more related to neuromuscular factors, hormonal factors and improved motor coordination, glycogen content and lower anaerobic enzyme activities (lactate-dehydrogenase and phosphofructokinase) and glycogen content [9], rather than being an indicator of solely reduced lactate-producing glycolysis mechanism.

Although our adolescent subjects were challenged with a significant lower absolute resistance than that of the young adults, the portion of aerobic influence in the formation of ATP was significantly higher compared to that of the young adult group (40.7 vs. 17.7% respectively). The results in the present study for the portion of the aerobic pathway in the young adult group were lower than results reported previously [23]. The nature of the contractile and metabolic properties of skeletal muscle suggests that speed of shortening will influence energy turnover during contractions [24].

Discrepancy of the results may be due to mechanical efficiency, lactate turnover, dilution space for lactate, different test protocols, and/or sample size. Mean power measured during the 30 s WAnT has been previously used to indicate the peak rate of anaerobic energy release (anaerobic power) during cycling [25,26]. The mean power calculated in the present study during the 30 s WAnT has been used to reflect the maximal anaerobic power [27]. However, this conclusion has been discredited by several researchers who suggested that the work duration is too short, and that energy provided by the aerobic energy system is not accounted [26].

In the present study all subjects completed the exercise challenges without ECG abnormality. This differs from earlier studies on the effect of sudden strenuous exercise. It had been shown that sudden strenuous exercise without warm-up may produce ischemia-like ECG abnormalities in young healthy subjects [28]. Conversely, others have reported normal ECG during sudden strenuous exercise following warm-up [29]. It seems that our subjects, without ECG abnormalities, reached at peak exercise a balance stage of myocardial oxygen supply-demand.

## Conclusions

The results reflect a significant noticeably lower anaerobic power output during adolescence; their energy expenditure appears to rely more on oxidative metabolism compared to young adults. This suggests that glycolytic activity is age-dependent, owing to differences in phosphorus compounds between fast and slow fiber types, due to the nature of the contractile and metabolic properties of skeletal muscle as suggested previously, and that speed of muscle fiber shortening will influence energy turnover during contractions [24]. Therefore, in adolescents the 30 s. anaerobic bout is not strictly anaerobic, although it has a significant anaerobic component. Even though the absolute contribution of the aerobic pathway to the anaerobic bout was more in adolescents than in young adults, these results show that both aerobic and anaerobic processes contribute significantly during intense exercise lasting 30 s. in adolescents and young adults.

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