PERFORMANCE OF 11 AND 12 YEAR-OLD BOYS ON AN ALL-OUT 90-SECOND CYCLING TEST

RICHARD N. CICCHINE

B.P.E., Brock University, St. Catharines, 1978
B.Ed. , Queen's University, Kingston, 1979

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

IN THE SCHOOL

OF

PHYSICAL EDUCATION

ACCEPTED
FACULTY OF GRADUATE STUDIES
[redacted]
DEAN
DATE

We accept this thesis as conforming
to the required standard.

[redacted]
Dr. D. Docherty

[redacted]
Dr. H. Wenger

[redacted]
Dr. J. Hayward

[redacted]
Dr. L. Ollila

UNIVERSITY OF VICTORIA

Supervisor: Dr. D. Docherty

Abstract

The purpose of the study was to describe the anaerobic capabilities of 11-and 12-year-old boys (N=20) on an all-out 90 s cycle ergometer test by comparing their performance to that of a group of active men (N=19). Performance on the 90 s cycle ergometer test was separated into four components: anaerobic-alactic power (AAP) and capacity (AAC) (0-10 s), and anaerobic-lactic power (ALP) and capacity (ALC) (10-90 s). Each measure was expressed in absolute terms and expressed relative to body weight. Anaerobic performance was correlated to height, weight, sum of skinfolds, and thigh volume. Post-exercise blood lactate (BL), maximum heart rate (MHR), $\dot{V}O_2$ max, and percent (%) drop-off of power output (Watts) were also measured.

Blood lactate values at both 2 min (BL-2) and 5 min (BL-5) post-exercise were significantly ($p<0.001$) higher for the men than for the boys. Values at BL-2 were 13.5 $mmol \cdot l^{-1}$ (3.4) for men and 9.1 $mmol \cdot l\text{-}l^{-1}$ (1.7) for boys. Values at BL-5 were 12.5 $mmol \cdot l^{-1}$ (2.8) and 8.3 mmol.l-1 (1.6) for men and boys respectively. No difference was found in relative VO_2 max ($ml \cdot kg \cdot min^{-1}$). Significant differences ($p<0.001$) in MHR and absolute $\dot{V}O_2$ max ($l \cdot min^{-1}$) were observed between boys and men.

Absolute and relative values for all four components of the 90 s test were significantly higher ($p<0.001$) in the adult group.

Compared to the men, the absolute values of the boys for AAP, AAC, ALP, and ALC were 33.2%, 32.3%, 33.6%, and 40.5% of the values for the men, respectively. However, compared to the men, the relative values of the boys for AAP, AAC, ALP, and ALC were 65.2%, 63.1%, 65.4%, and 79.2% of the values attained by the men, respectively. The % drop-off in absolute and relative power output from 0-90 s was significantly greater ($p<0.05$) for the men (50.4% and 50.4%) than the boys (41.3% and 41.4%) respectively.

Body size, particularly weight, was strongly related to anaerobic performance in boys and men. Correlation coefficients greater than 0.85 were found between body weight and performance on three of the four anaerobic measures (AAP-r=0.91, ALP-r=0.90 and ALC-r=0.86) for the boys. A stepwise multiple regression analysis indicated that weight accounted for 82%, 81%, and 74% of the variance for AAP, ALP, and ALC respectively. When AAC was the dependent variable, thigh volume was the first predictor and accounted for 39% of the variance. For the men weight showed a moderate to strong correlation with AAP(r=0.82), AAC(r=0.84), ALP(r=0.82), and ALC(r=0.74) and produced R^2 values of 0.67, 0.70, 0.68, and 0.54 respectively.

An intercorrelational matrix showed a strong within performance relationship on all four absolute anaerobic measures in both groups (r=0.65 to 0.98 for boys and 0.76 to 0.99 for men). Relative measures of anaerobic performance were moderately to highly correlated with AAP, AAC, and ALP for both groups (r=0.65 to 0.88 for boys and 0.76 to 0.97 for men). The r values were low than the relative values for both groups, and weight was the strongest anthropometric predictor of anaerobic performance for both boys and men.

Examiners:

[redacted]

Dr. D. Docherty, Supervisor (School of Physical Education)

[redacted]

Dr. H.A. Wenger, Departmental member(School of Physical Education)

[redacted]

Dr. J. Hayward, Outside member (Department of Arts & Sciences)

[redacted]

Dr. L. Ollila, External examiner (Faculty of Education)

Contents

Tables

Figures

Acknowledgements

I express my gratitude and friendship to many people. Dr. D. Docherty provided unending guidance, understanding and above all, patience during the preparation of this document. Drs. H.A. Wenger, J. Hayward, and L. Ollila gave their thoughts and ideas to the editorial process. Dr. W. Muir and Eugene Dean provided their assistance on the statistical aspects of this study. Mr. Bob Britten, computer science teacher, Glenlyon-Norfolk School, helped bring me out of the word processing dark-ages. I owe him a great deal of thanks for his unending patience. Finally, thank you to my family in Toronto and my friends at Glenlyon-Norfolk School for their love and support.

Dedication

This thesis is dedicated to my dear wife, Jennifer, to whom I owe a great deal for her unending love and devotion and without whom this whole process would not have been possible. I also dedicate this thesis to my daughters, Sarah and Michaela, who have slowed the process down but made it more worthwhile.

Introduction

Many of the sports in which young boys are involved, such as soccer, swimming, ice hockey, wrestling, cross-country running, and certain track and field events, demand high intensity work for short periods of time. The energy required for such activity is derived predominantly from anaerobic metabolism. Katch, Weltman, Martin, and Gray (1977) identified sports such as ice hockey, soccer, tennis, and football as demanding greater anaerobic than aerobic metabolism. Green (1979) also stated that ice hockey is an activity that involves intermittent bouts of high intensity work for brief periods. Anaerobic energy metabolism is also considered vital to success in soccer (Mosher, Rhodes, Wenger, & Filsinger, 1985). Trained cross-country runners utilize the anaerobic system especially during the last part of an event and the finish (Adams, 1985).

Since the work of Astrand (1952) and Eriksson and Saltin (1974) it has been stressed that children are efficient in obtaining energy from the breakdown of adenosine triphosphate (ATP) and creatine phosphate (CP) required in short, intense activities but are less able to perform all-out exercise which emphasizes the anaerobic lactacid energy system. Compared to adults, the capacity of this system in children is considered considerably lower (Hughson, 1986). During activity involving high intensity exercise, the breakdown of glucose and muscle glycogen are the main sources of energy production. Eriksson and Saltin (1974) suggest children are handicapped in this type of anaerobic performance when compared with adults.

The apparent inability of children to work at high intensities for periods of 15-90 s, requiring anaerobic glycolysis, could be due to the physiological characteristics of the prepubescent child. It has been suggested that possible reasons for this reduced ability to produce energy from the anaerobic-lactic system are a lower resting level of glycogen, a slower rate of anaerobic glycolysis (Eriksson & Saltin, 1973, 1974), and a faster adaptation to aerobic metabolism at the start of exercise (Macek & Vavra, 1977). Other explanations are the low activity level of the rate limiting enzyme phosphofructokinase (PFK) (Eriksson, Gollnick, & Saltin, 1973, 1974) or a higher percentage of slow oxidative muscle fibres (Bell, MacDougall, Billeter, & Howald, 1980).

The development of the Wingate Anaerobic Test (WAnT) has assisted sport scientists and coaches in their assessment of the capabilities of children and adults to perform anaerobic exercise. Adopted from the cycle test of Cumming (1973), the WAnT has been employed in testing the anaerobic fitness of young runners (Tharp, Johnson, & Thorland, 1984; Tharp, Newhouse, Uffleman, Thorland, & Johnson, 1985; Thorland, Johnson, Cisar, Housh, & Tharp, 1987), swimmers (Reilly & Bayley, 1988), and wrestlers (Sady, Thompson, Wade, Berg, & Savage, 1984). Adaptations to the WAnT have been developed to test anaerobic performance of the upper body in judoists, gymnasts, and rowers (Sharp & Koutedakis, 1987).

To date, the majority of anaerobic tests using prepubescent subjects and/or adults have incorporated the original 30 s WAnT (Bar-Or et al., 1980; Docherty, Wenger, & Collis, 1987; Goslin & Graham, 1985; Grodjinovsky, Inbar, Dotan, & Bar-Or, 1980; Patton, Murphy, & Frederick, 1985). However, the 30 s WAnT is considered to be too short in duration to adequately challenge the anaerobic lactic capacity of an individual. A few studies have utilized an all-out test of 60 s for adults (Hakkinen, Rahkila, & Alen, 1985; McKenna, Green, Shaw, & Meyer,1987) and prepubescent groups (Mero, Kauhanen, Peltola & Vuorimaa, 1988,1989). Researchers at Laval University utilized a 90 s bicycle test with adult subjects to predominantly challenge anaerobic lactic energy production (Serresse et al., 1989; Simoneau, Lortie, Boulay, & Bouchard, 1983; Boulay, written communication, 1985). No studies were found that used such a test to determine the anaerobic lactic capacity performance of 11-and 12-year-old boys. Therefore, the purpose of the present study was to describe the anaerobic performance of 11- and 12-year-old boys as measured by a single, all-out cycle ergometer test lasting 90s.

Research Questions

The following research questions served as a guide for investigation:

1) Is there a difference between the boys and men in post-exercise blood lactate (BL) and maximal heart rate (MHR)?
2) Is there a difference between the boys and men in the four components of anaerobic performance?
3) Is there a difference in % drop-off of power output over 90 s between boys and men?
4) Is there a difference between boys and men in absolute and relative $\dot{V}O_2$ max?
5) What is the relationship between the different anaerobic performance components for boys and men?
6) Which anthropometric measurement(s) best predicts anaerobic performance in boys and men?

Need for the Study

The results of this study will assist coaches, trainers, teachers, and sport scientists toward a better understanding of the anaerobic performance of 11-and 12-year-old males.

Definitions

Anaerobic Energy System (ATP-CP phase)- An energy system that occurs in the absence of oxygen, in which ATP is resynthesized with the energy that is available from the breakdown of creatine phosphate (CP) (Fox & Mathews, 1981).

Anaerobic Energy System (Glycolytic phase)- An energy system that supplies energy for the resynthesis of ATP from the incomplete breakdown of carbohydrates (glycogen) to lactic acid (Fox & Mathews, 1981).

Aerobic System (Oxidative system)- An energy system that utilizes oxygen for the breakdown of carbohydrates and fats to carbon dioxide and water. This system requires a series of complex chemical reactions (Fox & Mathews, 1981).

Anaerobic Alactic Power (AAP)- The peak power output (5 s intervals) during maximal effort from 0 to 10 s (Bouchard, Taylor, & Dulac,1982).

Anaerobic Alactic Capacity (AAC)- The total energy output during a maximal effort from 0 to 10 s (Bouchard et al., 1982).

Anaerobic GLycolytic Power (ALP)- The peak power output (5 s intervals) during a maximal effort highly saturated in glycolytic energy production calculated from 10-90 s (Bouchard et al., 1982).

Anaerobic GLycolytic Capacity (ALC)- The total energy output during a maximal effort from 10-90 s (Bouchard et al., 1982).

Delimitations

1) The study was restricted to 11 and 12 year old males (N=20) from Glenlyon-Norfolk School who volunteered for the study.
2) The adult male subjects (N=19) attended the University of Victoria and volunteered for the study.

Limitations

1) The results of this study are applicable only to the populations from which the subjects volunteered.
2) The study is limited by the degree of the subject's physical fitness. This is an aspect of consideration for both groups.
3) The study is limited by the degree of maximal effort that each subject puts into the all-out ride.
4) The study is limited in determining the optimal resistance setting on the cycle ergometer for each of the subject groups.
5) The components of the anaerobic performance are inferred from the different time periods rather than directly measured.
6) Differences in response to internal and external motivation during the performance test between the boys and men may have occurred; therefore, performance measures may have been affected.
7) The sample numbers (N=20 boys and N=19 men) are small for descriptive statistics.

Methods

Subjects

Twenty active 11 and 12 year-old boys from grades 5, 6 and 7, attending Glenlyon-Norfolk School in Victoria, British Columbia, and nineteen men (ages 18-28 years) from the University of Victoria, volunteered for the study. Following familiarization with the equipment and testing procedures, informed written consent was obtained from all subjects and the children's parents or guardians. The boys were observed for facial and axillary hair and did not exceed stage 1 according to the pubescent rating scale described by Ross and Marfell-Jones (1982).

Anthropometric Measures

Skinfold thicknesses, measured using the Harpenden skinfold calipers, were taken at the triceps, subscapular, supra-illiac, abdominal, front thigh, and medial calf sites. The protocol followed the procedures described by the International Working Group on Kinanthropometry (Ross and Marfell-Jones, 1982).

Weight (kg) was taken prior to the test and used to calculate resistance settings for the 90 s cycle ergometer test. Height(cm) was measured with the head held in the Frankfort Plane using the stretch stature technique recommended by Ross and Marfell-Jones

(1982). Thigh length (cm) and three thigh circumferences (cm) were taken using a Lufkin flexible metal tape, calibrated in centimeters with millimeter gradations, to predict thigh volume (cm^3) (Jones and Parsons, 1969).

Physiological Measures

Heart rate (HR) was monitored during the cycle test. Maximal heart rate (MHR) was recorded immediately at the end of the test and during the first 30s of recovery using an ECG. Blood samples were taken from a prewarmed fingertip as outlined by Komi, Rusko, Vos, and Vihko (1977) and Eriksson, Gollnick, and Saltin (1973) to determine blood lactate (BL). Samples were taken at rest and at 2 (BL-2) and 5 (BL-5) minutes post-exercise. All blood samples were collected in a 25 micro-litre pipette and immediately analysed using a commercial lactate analyser (YSI model 23A).

Aerobic Testing

A direct measurement of maximal aerobic power (VO_2 max) was performed on a Quinton electrically braked cycle ergometer (model 844) according to the protocol recommended by Thoden, MacDougall, and Wilson (1982). The pedalling cadence was maintained at approximately 60 rpm throughout the test. $\dot{V}O_2$ max was considered to have been achieved when a leveling off (as observed by a change $<100 \cdot ml \cdot min^{-1}$) or a slight decrease occurred in $\dot{V}O_2$ with an increased work load. Peak $\dot{V}O_2$ was considered to be equivalent to

$\dot{V}O_2$ max when the age-predicted maximum HR was attained and an R value greater than 1.00 was observed.

Anaerobic Testing

A 90 s all-out cycle ergometer (Monark) test was employed to assess anaerobic performance capabilities. Seat height was adjusted for each subject and toe clips with straps were used to prevent the feet from slipping. The subject warmed up at a pedalling speed of 50 rpm for 1 minute against a resistance of 0.5 kp (boys) or 1.0 kp (men). A 3 minute rest on the cycle ergometer occurred prior to the anaerobic 90 s test. Before the test began, subjects were instructed to pedal as fast as possible from the outset and attempt to maintain the greatest pedal speed throughout the entire test period. The flywheel resistance on the Monark cycle ergometer was calibrated before each testing session and adjusted for each subject relative to body weight (0.045 $kp \cdot kg^{-1}$ for the boys and 0.065 $kp \cdot kg^{-1}$ for men).

At a predetermined signal the subject began pedalling as rapidly as possible against a low resistance, which was quickly set to the appropriate level within 2-3 s. A modified ECG was used to count pedal revolutions. A GraLab electronic clock was activated when the resistance was reached. Subjects cycled as fast as possible for the duration of the test while remaining in the seated position. At the completion of the 90 s test the resistance setting was immediately reduced to 0.5 kp or 1.0 kp for boys and men, respectively, to allow for a cool-down period and to reduce the possibility of fainting, following the recommendations of Sargeant, Hoinville, and Young (1981).

Subjects were verbally motivated to cycle with maximum effort for the entire duration of the test. Anaerobic performance was calculated as four components: anaerobic-alactic power (AAP), anaerobic-alactic capacity (AAC), anaerobic-lactic power (ALP), and anaerobic-lactic capacity (ALC) as recommemded by Bouchard et al., (1982) and utilized by Simoneau et al., (1983) and Serresse et al., (1989). Power outputs were calculated over 5 s intervals as in previous studies (Evans & Quinney, 1981; Grodjinovsky et al., 1980; Taunton, Maron, & Wilkinson, 1981). AAP was calculated as the peak power of any 5 s interval between 0 and 10 s and measured in Watts (W). AAC was measured using the total number of pedal revolutions and resistance setting within the first 10 s of the 90 s all-out test and calculated in joules (J). ALP was calculated as the peak power output (W) in a 5 s interval observed between 10 and 90 s (Simoneau et al., 1983). ALC was measured using the total number of pedal revolutions between 10 and 90 s (J) since Margaria, Aghemo and Rovelli (1966) estimated that energy production within this time is predominantly from anaerobic glycolytic means. A 30 s capacity measure was also calculated in J and $J \cdot kg^{-1}$ for each group in order to be able to make comparisons with other cycle ergometer tests of this duration.

The percentage (%) drop-off of power output (W and $W \cdot kg^{-1}$) was observed at 5 second intervals from 0-90 s during the cycle test. The information was used to determine if and where a difference between boys and men may occur.

Statistical Analysis

Means and standard deviations were calculated for both groups on all dependent variables. Student's t tests were carried out to discriminate between boys and men on all absolute and relative measures of anaerobic performance. Pearson product moment correlations were used to determine relationships between anaerobic performance and the anthropometric measures and also to determine the relationships between the four components of anaerobic performance. A step-wise multiple regression was used in order to determine the anthropometric characteristic(s) which best predicted anaerobic power and capacity. Statistical significance was set a-priori at $p < 0.05$.

Results

Table 1 presents mean values (SD) for age and the four anthropometric measures of the boys and men. On average the men were 11.3 years older, 29.8 cm taller and 38.9 kg heavier than the boys. The mean thigh volume of the men was 2851.9 cm greater than the boys. No significant difference occurred between the mean values of the sum of skinfolds for the two groups.

Table 2 displays absolute ($l \cdot min^{-1}$) and relative ($ml \cdot kg \cdot min^{-1}$) $\dot{V}O_2$ max, resting BL, post-exercise BL, and MHR for both groups. A significant difference ($p<0.01$) occurred between the mean values of resting BL. BL-2 and BL-5 were significantly different at the $p<0.001$ level. In both instances the men had higher lactate values (13.5 $mmol \cdot l^{-1}$ (3.4) and 12.5 $mmol \cdot l^{-1}$ (2.8) than the boys (9.1 $mmol \cdot l^{-1}$ (1.7) and 8.3 $mmol \cdot l^{-1}$ (1.6). Significance ($p<0.001$) also occurred between the two groups for MHR and absolute $\dot{V}O_2$ max ($l \cdot min^{-1}$). However, there was no significant difference when $\dot{V}O_2$ max was calculated relative to body weight ($ml \cdot kg \cdot min-^{1}$).

The different anaerobic performance values calculated from the 90 s cycle test for each group are presented in Table 3. The groups showed significant ($p<0.001$) differences in all anaerobic performance components. Mean peak power between 0 and 10 s was 236.5 W (39.8) and 711.5 W (130.3) for boys and men respectively.

Table 1
Physical Characteristics of Men and Boys Mean (SD)

Descriptive variable	Boys (n=20) Mean (SD)	Men (n=19) Mean (SD)
Age (yr)	11.4 (0.6)	22.7 (2.9)
Height (cm)	150.7 (6.9)	180.5 (6.6)
Weight (kg)	40.3 (5.8)	79.2 (10.7)
Sum of Skinfolds* (mm)	64.4 (25.9)	64.1 (18.6)
Thigh Volume (cm^3)	2841.7 (632.5)	5693.6 (957.5)

* Based on sum of triceps, subscapular, iliac crest, abdominal, front thigh and medial calf skinfold measures.

Table 2
Physiological Test Results for the 90 s Cycle Test Mean(SD)

Variable	Boys (n=20) Mean (SD)	Men (n=19) Mean (SD)	Significance
Blood lactates ($mmol \cdot l^{-1}$) 90 s test			
Rest	1.0 (0.4)	1.5 (0.4)	*
2 min post-exercise	9.1 (1.7)	13.5 (3.4)	**
5 min post-exercise	8.3 (1.6)	12.5 (2.8)	**
MHR (bpm)	196.4 (7.5)	185.3 (8.2)	**
$\dot{V}O_2$ max. ($l \cdot min^{-1}$)	2.2 (0.3)	4.0 (0.6)	**
($ml \cdot kg \cdot min^{-1}$)	53.4 (5.5)	50.9 (6.0)	n.s.

** = $p < 0.001$
* = $p < 0.01$
n.s. = not significant - $p > 0.05$

During this same time period the boys had an anaerobic alactic capacity of 2222.7 J (613.4) compared to 6876.8 J (1223.7) for the men. Peak power, during any 5 s interval between 10 and 90 s, was 216.5 W (39.6) for boys and 642.8 W (108.0) for men. Total anaerobic capacity, calculated between 10 and 90 s, was 13046.0 J (2041.3) and 32136.8 J (5517.8) for boys and men, respectively. The 30 s capacity measures of 6360.3 J (1093.4) for boys and 18403.6 J (3057.3) for men were also significantly different ($p<0.001$). When values were calculated relative to body weight ($W \cdot kg^{-1}$ and $J \cdot kg^{-1}$), a significant difference ($p<0.001$) also occurred between groups in all measures of anaerobic performance.

Table 3
Anaerobic Performance Measures Mean (SD)

Variable	Boys Mean (SD)	Men Mean (SD)	Significance
Absolute Values			
AAP (W)	236.5 (39.8)	711.5 (130.3)	**
AAC (J)	2222.7 (613.4)	6876.8 (1223.7)	**
ALP (W)	216.5 (39.6)	642.8 (108.0)	**
ALC (J)	13046.0 (2041.3)	32136.8 (5517.8)	**
30 s Cap (J)	6360.3 (1093.4)	18403.6 (3057.3)	**
Relative Values			
AAP ($W \cdot kg^{-1}$)	5.8 (0.4)	8.9 (.09)	**
AAC ($J \cdot kg^{-1}$)	54.7 (12.2)	86.7 (8.2)	**
ALP ($W \cdot kg^{-1}$)	5.3 (0.4)	8.1 (0.7)	**
ALC ($J \cdot kg^{-1}$)	321.9 (24.4)	406.5 (45.2)	**
30 s Cap ($J \cdot kg^{-1}$)	156.5 (10.4)	232.5 (19.6)	**

** = $p<0.001$

Figures 1 and 2 show the power outputs (W and $W \cdot kg^{-1}$) for boys and men respectively. The percent (%) drop-off of power output is presented in Table 4. For absolute and relative % drop-off, during the anaerobic alactic (0-10 s) component of the 90 s test, a significant difference of $p<0.05$ occurred between boys (9.8% and 10.1%) and men (4.5% and 4.7%). Over the entire test (0-90 s) a significant ($p<0.05$) difference in % drop-off occurred in both absolute and relative power outputs between boys (41.3% and 41.4%) and men (50.4% and 50.4%) respectively.

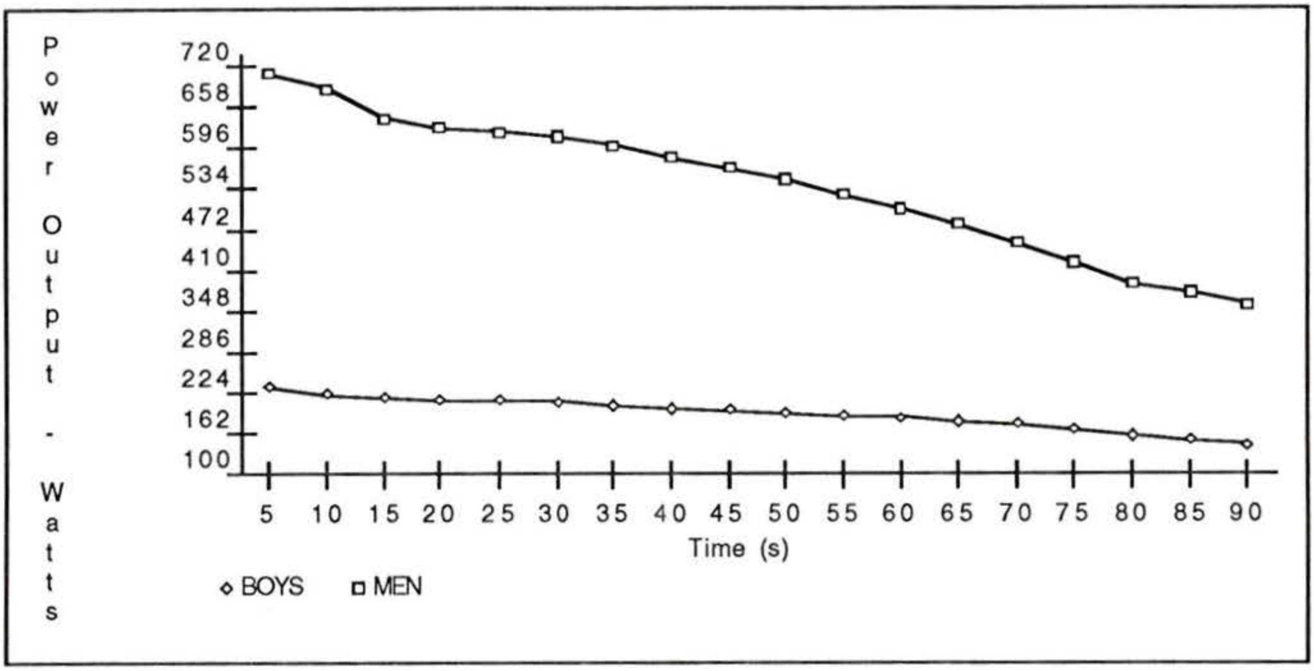

Figure 1. Power Output Scores (W) for Boys (n=20) and Men (n=19) (averaged over each 5 s period).

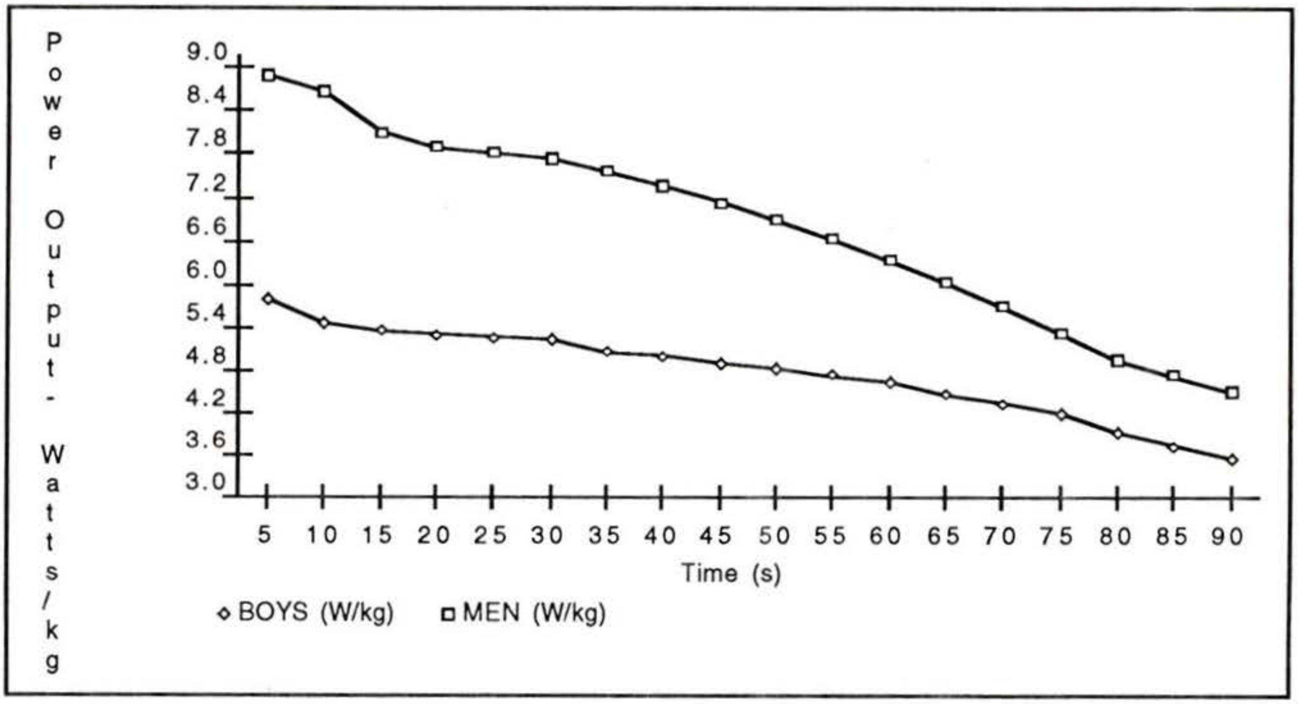

Figure 2. Power Output Scores ($W \cdot kg^{-1}$) for Boys (n=20) and men (n=19) (averaged over each 5 s period).

Table 4
Percent Drop-off in Power Output for Boys (n=20) and Men (n=19) (90 s Cycle Test)

Percent drop-off	0-10 s		0-30 s		0-90 s	
	(Abs.)	(Rel.)	(Abs.)	(Rel.)	(Abs.)	(Rel.)
boys	9.8%	10.1%	14%	14.4%	41.3%	41.4%
men	4.5%	4.7%	14.7%	14.8%	50.4%	50.4%
Significance	$p<0.05$	$p<0.05$	n.s.	n.s.	$p<0.05$	$p<0.05$

Correlation Coefficients (Pearson r)

Tables 5 and 6 present the Pearson product moment correlation coefficients between the anthropometric variables and anaerobic performance for boys and men, respectively. Generally, for the 11 and 12 year old boys, the r values were higher than for the men when anthropometric parameters, especially body weight, were correlated with absolute anaerobic performance. Body weight was also highly correlated with AAP (r=0.91), ALP (r=0.90) and ALC (r=0.86) for boys. A lower correlation (r=0.60) was observed between body weight and AAC. For adults, high correlations were also observed between body weight and absolute values of the four anaerobic energy components, the highest of these occurring with AAC (r=0.84). For both groups, the correlations between the anthropometric measures and relative values of the anaerobic measures were low (r<0.51 for men and 0.02 to 0.41 for boys).

Table 5
Pearson Correlation Coefficients Between Anthropometric Characteristics and Anaerobic Performance of Boys.

	AAP	AAC	ALP	ALC
Height	.70	.39	.67	.69
Weight	.91	.60	.90	.86
Skinfold	.48	.43	.46	.33
Thigh Volume	.83	.62	.84	.81

Table 6
Pearson Correlation Coefficients Between Anthropometric Characteristics and Anaerobic Performance of Men.

	AAP	AAC	ALP	ALC
Height	.56	.57	.61	.63
Weight	.82	.84	.82	.74
Skinfold	.24	.22	.13	.14
Thigh Volume	.69	.70	.67	.68

The intercorrelational matrix indicates a moderate to strong relationship between all four components of the anaerobic performance (absolute) for boys (Tables 7 and 8). The r values ranged from 0.65 to 0.98, with the strongest relationships occurring between AAP and ALP (r=0.98) and between ALP and ALC (r=0.91).

The relationship between the four components of anaerobic performance was stronger for the men. Correlation coefficients ranged from 0.76 to 0.99. The highest r values were observed between AAP and AAC (r=0.99), AAC and ALP (r=0.95) and AAP and ALP (r=0.93) for men. Relative measures of anaerobic performance (Tables 9 and 10) did not show strong relationships between the four components. For both groups low r values were found between ALC and the other anaerobic measures of AAP, AAC and ALP (r=0.37, 0.32 and 0.53 for the boys; and r=0.35, 0.38 and 0.66 for the men, respectively).

Table 7
Intercorrelational Matrix: Anaerobic Measures (Boys) (Absolute Scores)

	AAC	ALP	ALC
AAP	.76	.98	.87
AAC		.79	.65
ALP			.91

Table 8
Intercorrelational Matrix: Anaerobic Measures (Men) (Absolute Scores)

	AAC	ALP	ALC
AAP	.99	.93	.76
AAC		.95	.78
ALP			.87

Table 9
Intercorrelational Matrix: Anaerobic Measures (Boys) (Relative to Body Weight)

	AAC	ALP	ALC
AAP	.65	.88	.37
AAC		.72	.32
ALP			.53

Table 10
Intercorrelational Matrix: Anaerobic Measures (Men) (Relative to Body Weight)

	AAC	ALP	ALC
AAP	.97	.76	.35
AAC		.82	.38
ALP			.66

Multiple Regression Analysis

Results from the stepwise multiple regression analyses are displayed in Tables 11, 12, 13, and 14. For the boys, weight was the strongest predictor variable, but only for three of the four absolute anaerobic performance criterion variables, AAP (R^2 = 0.82), ALP (R^2 = 0.81) and ALC (R^2 = 0.75). Thigh volume was the first predictor for absolute AAC. However, this independent variable only accounted for 39.1% of the variance. Absolute ALC was the only criterion variable which showed a second predictor. Sum of skinfolds entered in the second step of the analysis and improved the accounted for variance by 8%.

For the men, weight accounted for the greatest portion of the variance on all four absolute anaerobic performance criteria and was thus entered into the regression model as the first predictor. The R^2 values were 0.67, 0.70, 0.68, and 0.54 for AAP, AAC, ALP, and ALC respectively. Only one independent variable, sum of skinfolds, entered as a second predictor and only on absolute ALP. The variance was improved by 11%. The other anthropometric measures did not add any appreciable strength to the prediction.

Relative measures of the four anaerobic performance components were also used as criterion variables. Sum of skinfolds was the only predictor variable which was strong enough to enter on the first step of the multiple regression analyses for both boys and men. This anthropometric measure was the strongest predictor for boys on ALC (R^2 = 0.24) and for men on ALP (R^2 = 0.26).

Table 11
Multiple Regression Statistics (Absolute Scores) (Boys)

Criterion Variable	1st Predictor	Partial R^2	2nd Predictor	Partial R^2	df	Total R^2
AAP	weight	0.82	--	--	17	0.82
AAC	thigh vol.	0.39	--	--	17	0.39
ALP	weight	0.81	--	--	17	0.81
ALC	weight	0.75	skinfold	0.08	17	0.83

Table 12
Multiple Regression Statistics (Absolute Scores) (Men)

Criterion Variable	1st Predictor	Partial R^2	2nd Predictor	Partial R^2	df	Total R^2
AAP	weight	0.67	--	--	18	0.67
AAC	weight	0.70	--	--	18	0.70
ALP	weight	0.68	skinfold	0.11	18	0.79
ALC	weight	0.54	--	--	18	0.54

Table 13
Multiple Regression Statistics (Relative Scores) (Boys)

Criterion Variable	1st Predictor	Partial R^2	2nd Predictor	Partial R^2	df	Total R^2
AAP	No variables entered.					
AAC	No variables entered.					
ALP	No variables entered.					
ALC	skinfold	0.24	--	--	17	0.24

Table 14
Multiple Regression Statistics (Relative Scores) (Men)

Criterion Variable	1st Predictor	Partial R^2	2nd Predictor	Partial R^2	df	Total R^2
AAP	No variables entered.					
AAC	No variables entered.					
ALP	skinfold	0.26	--	--	18	0.26
ALC	No variables entered.					

Discussion

Anthropometric and Physiological Variables

As would be expected with two groups that had a mean age difference of 11.3 years, height, weight, and thigh volume were significantly different. However, the sum of skinfold measures were similar (64.4 mm and 64.1 mm for the boys and men respectively).

The mean weight of the boys was heavier than that for similar age groups as reported by Eriksson (1972), Eriksson et al. (1974), Fellmann et al. (1988), Inbar and Bar-Or (1986) and Sady et al. (1984). This was also the case for the men. They were also generally heavier than active men in other studies of anaerobic performance (Manning, Dooly-Manning, & Perrin, 1988; McKenna et al., 1987; Serresse et al., 1989).

The mean $\dot{V}O_2$ max (litres and $ml \cdot kg^{-1}$) values for the group of boys are greater than the mean values for the same age groups reported by Eriksson (1972), Erikisson and Saltin (1973, 1974) and Gilliam, Sady, Thorland, and Weltman, (1977). As shown by Inbar and Bar-Or (1986) $\dot{V}O_2$ max is independent of age,particularly when expressed as $ml \cdot kg^{-1} \cdot min^{-1}$. In the present study the boys had a lower mean $\dot{V}O_2$ max than the men when expressed in $l \cdot min^{-1}$ but no significant difference when expressed in $ml \cdot kg \cdot min^{-1}$.

Maximum blood lactates ($mmol \cdot l^{-1}$) reflect muscle lactate concentrations after exercise and increase with age during puberty (Eriksson & Saltin, 1974). Maximum blood lactates of the boys in this study were higher than for boys of a similar age (x=11.6 years) but, as expected, lower than the subjects reported by Eriksson & Saltin (1974) who were 15.5 years of age. It should be noted that Eriksson and Saltin (1974) took blood samples immediately after maximal exercise, whereas, in the present study blood samples were taken 2 minutes after maximal exercise. Shephard (1982) stated that an earlier peaking of blood lactate concentrations in children could be an explanation for the difference between children and adults. Blood lactates at 5 minutes post exercise (BL-5), for the boys, were lower than was found after 5 minutes in groups of prepubescent tennis players, weight lifters, endurance runners, and a control group, as indicated by Mero et al. (1988). However, the sprint runners in the Mero et al. study had blood lactates equal to the subjects in the present study. The BL-2, 9.1 $mmol \cdot l^{-1}$ (1.7), was the highest for the boys. Both the BL-2 and BL-5 lactate levels of the boys were lower than for the prepubertal athletic and control groups reported by Mero et al. (1989). The differences observed between Mero et al. (1988, 1989) and the present study could be due to the fact that the anaerobic cycle tests of Mero et al. lasted only 60 s and the resistance setting was higher causing greater lactate production.

Post-exercise fingertip blood samples were not collected by Simoneau et al. (1983) or Serresse et al. (1989) on the 90 s cycle test; therefore, a direct comparison cannot be made to the men in the present study. However, blood samples were collected after cycle ergometer tests of 30 s (Goslin & Graham, 1985) (peak blood lactates=13.3 mmmol·l^{-1}), 40 s (Watson and Sargeant, 1986) (peak blood lactates=11.5 mmol·l^{-1}) and 60 s (Hakkinen et al., 1985) (peak blood lactate=16.2 mmol·l^{-1}). The highest level of blood lactate, 13.5 mmol·l^{-1} (3.4), for men was found to occur at 2 minutes post-exercise (BL-2).

Comparisons in peak blood lactate levels between boys and men have been made by Eriksson and Saltin, (1974), Inbar and Bar-Or, (1986) and Mero et al., (1989). The results of the present study are similar to those of previous studies, showing an increase in maximal blood lactate levels after intense cycle ergometer exercise from prepuberty to adulthood. The limiting factors of lactate accumulation in boys are still unknown. A possible reason is a lower concentration of the enzyme PFK (Eriksson et al., 1973). It is also suggested that in children there is a greater O_2 transport in blood per kg of muscle (Koch, 1980) and greater O_2 utilization (Eriksson, 1972). Because the present study focused on power and capacity measures for four components of anaerobic performance within a single all-out test and excluded biochemical measures, it is difficult to identify the reason(s) for the differences between boys and men.

In addition to the differences in the biochemical substrates between boys and men in testing the anaerobic performance of children, the psychological factors that limit performance must also be considered. Motivation is of extreme importance in performing high intensity tests. This is true for external motivation from the tester and self-motivation from the children. In a test of the duration and intensity presented in the current study children are inclined to pace themselves and decrease their effort when pain occurs. It is difficult to persuade a child to attempt all-out effort (Shephard, 1982). Use of the Borg 6-20 category scale of relative perceived exertion (RPE) (Borg, 1962) has been recommended by Bar-Or (1983) and Ward and Bar-Or (1990) as a method to assist children in their perception of exercise. Such a scale could be incorporated in the study of all-out anaerobic performance in children.

Anaerobic Performance Variables

It has been documented that children are similar to adults in their ability to perform activities of short, all-out effort lasting up to 10 s (Paterson, 1980), but lack the ability to utilize the anaerobic glycolytic energy system in activities lasting between 10 s and 2 min (Eriksson & Saltin, 1974; Inbar & Bar-Or, 1986). In order to quantify these statements many authors have utilized the original 30 s Wingate Anaerobic (WAnT) test in identifying anaerobic capabilities of young boys (Cumming, 1973; Inbar & Bar-Or, 1975, 1977, 1986; Sady et al., 1984; Tharp et al., 1984; Tharp et al., 1985). A limited number of studies have investigated the anaerobic performance of young boys using a cycle ergometer test longer than 30 s (Mero et al., 1988, 1989).

The anaerobic performance measures obtained for 11-and 12-year-old boys in the present study were based on an all-out 90 s cycle ergometer test. The results from the boys are difficult to compare directly with other anaerobic tests because of the differences in resistance, duration of the test, and calculation of power and capacity. Tharp et al. (1984, 1985) used the protocol of the WAnT and calculated the highest work performed in any 5 s interval and the total work performed during 30 s as indices of "anaerobic power" and "anaerobic capacity" respectively. Anaerobic performance was expressed in kilogram metres (kgm). Sady et al. (1984) used a flywheel resistance of 0.066 $kg \cdot kg^{-1}$ BW. They discarded the first 5 s interval and calculated anaerobic power as the peak power output during any of the subsequent 5 s intervals (W) and anaerobic capacity, the total power output (J) from 5 - 30 s of exercise. The AAP of the boys in the present study is similar to the values reported by Sady et al. (1984).

Docherty et al. (1987) used a resistance of 0.060 $kg \cdot kg^{-1}$ BW and calculated anaerobic performance as average power over 15 s and average power over 30 s and expressed the values in W and $W \cdot kg^{-1}$ for a group of boys (x=12.6 [1.4] years of age). Pretest and post-test power outputs of the boys were higher than the scores of the boys in the present study even though the values were averaged over 15 and 30 s (336.9 W (75.7) and 359.8 W (79.3) compared to 236.5 W (39.8)). However, the boys in the Docherty et al. (1987) study were top level hockey or soccer players and had just completed their competitive seasons.

Mero et al. (1988) used a resistance of 0.060 $kg \cdot kg^{-1}$ BW but a duration of 15 s to determine anaerobic power and a 60 s time period to determine anaerobic capacity and expressed results in $W \cdot kg^{-1}$. In a later study, Mero et al. (1989), expressed performance in $J \cdot kg^{-1}$. The relative anaerobic power measures ($W \cdot kg^{-1}$) of the subjects in Mero et al. (1988) were slightly higher than those of the boys in the present study. Differences may be attributed to the fact that the subjects in Mero et al. (1988) were taken from athletic groups. The pretraining anaerobic capacity measures calculated over 60 s for the control group in Mero et al. (1989) were comparable to the ALC ($J \cdot kg^{-1}$) of the boys in this study (324 $J \cdot kg^{-1}$ compared to 321 $J \cdot kg^{-1}$), even though the Mero et al. (1989) test lasted 60 s compared to 90 s in the present test. No other studies were found that used a 90 s all-out cycle ergometer test for this age group.

While 90 s cycle tests have been conducted with men (Simoneau et al., 1983; Serresse et al., 1989) the test protocols were different. In both studies a resistance of 0.05 $kp \cdot kg^{-1}$ body weight was used compared to 0.065 $kp \cdot kg^{-1}$ in the current study. Comparable results occurred in AAC and ALC measures with the males in Simoneau et al. (1983). Values for AAC were 6876.8 J for the men in this study and 6849 J for the males in the study by Simoneau et al. (1983). ALC mean values were also similar (32136.8 J compared to 34218 J). Also, relative ALC values for the men in the current study (406.5 $J \cdot kg^{-1}$) fell within the range of values reported by Serresse et al. (1989) (383 to 558 $J \cdot kg^{-1}$).

The results for AAP, presented here, compare well with those of adult male students (Crielaard & Pirnay, 1981) and adult, national level wrestlers (Hakkinen et al., 1985). However, it should be noted that the Crielaard and Pirnay cycle ergometer test was stopped after a few seconds when maximal power was attained and began to decline and that Hakkinen et al. (1985) calculated relative power output over 15 s.

The highest power output in a 5 s interval has been found by Evans and Quinney (1981) and Watson and Sargeant (1986). Direct comparisons of scores with the present study were difficult. With a resistance setting of 0.075 $kp \cdot kg^{-1}$ and a duration of 40 s, a mean anaerobic power of 868.6 W was reported by Watson and Sargeant (1986) for ice hockey players. Using various resistance settings to determine the true force to elicit maximal power output in 30 s, Evans and Quinney (1981) calculated a mean 5 s peak power output of 838.6 W for male physical education students and varsity athletes. The mean value of AAP of 711.5 W for the men in the current study could be a result of a lower level of anaerobic fitness than the subjects in the two previously mentioned studies or different resistance settings.

Anaerobic alactic performance measures obtained in the present study are not consistent with Eriksson (1972), Eriksson and Saltin (1973, 1974) and Eriksson et al. (1973, 1974). These authors state that children are not compromised in anaerobic power and capacity tests lasting up to 15 s. The statements are based on biochemical analysis and were not validated through performance tests. In the present study the boys and men were significantly different ($\underline{p}<0.001$) on both absolute and relative measures of anaerobic alactic power and capacity. A mean difference of 475 W indicates that the boys produced absolute peak power outputs between 0 and 10 s that were 33.2% of the men. The absolute values of mean power and peak power reported by Inbar and Bar-Or (1986) are similar to the present study (30% of the young adults). Relative values of mean power in children represented 85% of that achieved by young adults in the second and third decades as reported by Inbar and Bar-Or (1986). Relative peak power ($W \cdot kg^{-1}$) in the children was 70% of the values observed in the third decade. The anaerobic alactic capacity measure of 54.7 $J \cdot kg^{-1}$ (12.2) for the boys in the present study was 63.0% of the value attained by the men (86.7 $J \cdot kg^{-1}$ 8.2). Mero et al. (1989) observed a 19% increase in relative anaerobic capacity on a 15 s cycle ergometer test and a 17% increase ($J \cdot kg^{-1}$) on a 60 s test in the athletic group from prepuberty to puberty. However, if the anaerobic performance measures were normalized using dimensional analysis, such as weight$^{2/3}$ or height$^{2.25}$ (Bailey, Ross, Mirwald, & Weese, 1978), as apposed to gross weight, the relative differences may have been reduced.

It has also been suggested that children are limited in regards to anaerobic glycolysis which restricts their ability to perform high intensity work from 10 s to 2 min (Eriksson & Saltin, 1974). Performance measures of the boys and men in the present study are similar to the findings of Eriksson (1972) in the anaerobic lactic component of the 90 s test. Low PFK activity in the boys was reported as one explanation for a lower anaerobic lactic capacity (Eriksson, 1972). However, these results were not validated through the use of performance tests. Eriksson (1972) based his observations on biochemical analysis. This study compared the actual performance of boys and men on a 90 s test which is regarded as a good measure of ALC. The total capacity of the 90 s test measured from 10-90 s indicated that the boys attained absolute values (J) that were 40.6% of the men. However, relative values ($J \cdot kg^{-1}$) of the boys during this same time-frame were 79.2% of the men.

Mero et al. (1989) showed a significant difference ($p<0.001$) in anaerobic work ($J \cdot kg^{-1}$) for an athletic group of young boys on both a 15 s and a 60 s cycle test after three years of training (prepuberty to puberty). In the present study relative values of anaerobic alactic capacity ($J \cdot kg^{-1}$) and anaerobic lactic capacity ($J \cdot kg^{-1}$) were significantly ($p<0.001$) greater for the men.

Percentage drop-off

Calculations on the percentage (%) drop-off of absoltue and relative power output indicated that there was a significant difference ($\underline{p}<0.05$) between boys and men when calculated 0-10 s and 0-90 s. Katch et al. (1977) reported a greater % drop-off in a cycle test of 2 minute duration and all-out pedal revolutions than was observed in the current study. The absolute and relative % drop-offs for the men in the present study were (4.5% and 4.7%, from 0 to 10 s; 14.7% and 14.8%, from 10 to 30 s; and 50.4% and 50.4%, from 0 to 90 s). The boys in the present study showed a % drop-off of 41.3% and 41.4% for absolute and relative power output respectively from 0 to 90 s. This indicates that they were either using a greater amount of aerobic metabolism by this point or the resistance setting was not great enough to elicit a more substantial % drop-off.

Anthropometric and Anaerobic Performance Variables

The high correlations between weight and anaerobic power and capacity for the 11-and 12-year-olds are similar to those found by Cumming (1973) and Tharp et al. (1984, 1985). For the men in the present study, the correlations between weight and anaerobic performance are similar to those found by Goslin and Graham (1985) ($\underline{r}$=0.83 for peak power and $\underline{r}$=0.88 for mean power). The present study, however, does not support the findings of Manning et al. (1988) in which a correlation coefficient of 0.66 was found between weight and anaerobic power and a correlation coefficient of 0.50 between weight and anaerobic capacity.

The stepwise multiple regressions carried out in this study indicated weight as the strongest predictor of anaerobic performance for both men and boys. For the men this is in agreement with the findings of Katch (1974) for the men. For the boys, weight was a stronger predictor variable than it was for the group of men indicating the need to normalize data for body weight rather than using absolute values, especially when comparing different age groups.

Conclusion

The present study has attempted to quantify the anaerobic capabilities of young boys by comparing their performance on a 90 s cycle ergometer test to the the performance of adult males (mature model). In general the boys showed considerably lower results on all four components of anaerobic performance. However, even when corrected for weight the adult males still had significantly higher performance values. The results do not support previous statements that suggest similar capabilities between young boys and adults in short, exhaustive exercise up to 15 s. They do support the contention that boys are limited in their ability to perform all-out exercise that demands intense utilization of the anaerobic glycolytic system. This is in contrast with the tendency for children to maintain an activity pattern which emphasizes repeated short, apparently maximal efforts.

The boys in the present study were active but not involved in high level competitive sports and, therefore, may not have previously experienced work at this intensity level. The group of men used in the present study included some subjects that were involved in varsity rugby and intense energy output had been previously encountered.

It is possible that differences in anaerobic power and capacity are attributable to the speed of pedal revolutions or the resistance setting. However, pedal revolutions throughout each test were maintained in the recommended range, and it is unlikely that higher loads could have been tolerated. It does seem, therefore, the resistance setting was optimal and power output was probably maximal.

Suggestions for Future Investigation

Continued study of anaerobic performance of prepubertal boys is needed, particularly longitudinal studies to evaluate the developmental aspects of anaerobic performance. In addition, a 90 s all-out cycle ergometer test using prepubescent subjects from a variety of activity levels would provide insight on the effect of activity on anaerobic performance.

A further study of pedal revolutions and resistance settings for prepubescent boys is needed to optimize peak power output.

More knowledge is also needed on perceived maximal efforts in children of different age groups and conditioning levels on high intensity exercise of 1-2 min. This will assist researchers in analyzing the age-related and ability differences in the perception of exercise.

It should also be stressed that, since it is unethical to use invasive techniques on children in this country, performance must continue to be measured by external means. The advent of nuclear magnetic resonance (NMR) will provide an acceptable mechanism to study the biochemical response of children to exercise although its expense and accessibility remain prohibitive.

References

Adams, I. C. (1985). A comparison of eleven- and twelve-year-old males' cross-country running performance. Journal of Human Movement Studies, 11, 69-73.

Astrand, P.-O. (1952). Experimental studies of physical working capacity in relation to age and sex. Munksgaard: Copenhagen.

Bailey, D.A., Ross, W.D., Mirwald, R.L., & Weese, C. (1978). Size Dissociation of maximal aerobic power during growth in boys. Medicine and Sport, 11, 140-151.

Bar-Or, O. (1983). Pediatric sports medicine for the practitioner. New York: SpringerVerlag.

Bar-Or, O., Dotan, R., Inbar, O., Rothstein, A., Karlsson, J, & Tesch, P. (1980). Anaerobic capacity and muscle fibre type distribution in man. International Journal of Sports Medicine, 1(2), 82-85.

Bell, R.D., MacDougall, J.D., Billeter, R., & Howald. H. (1980). Muscle fiber types and morphometric analysis of skeletal muscle in six-year-old children. Medicine and Science in Sports and Exercise, 12(1), 28-31.

Borg, (1962). Physical performance and perceived exertion. Gleerup, Lund.

Bouchard, C., Taylor, A.W., & Dulac, S. (1982). Testing maximal anaerobic power and capacity. In J.D. MacDougall, H.A. Wenger & H.J. Green (Eds.), Physiological testing of the elite athlete, (pp. 61-73). Champaign, Illinois: Human Kinetics Pub. Co.

Crielaard, J.M., & Pirnay, F. (1981). Anaerobic and aerobic power of top athletes. European Journal of Applied Physiology, 47, 295-300.

Cumming, G.R. (1973). Correlation of athletic performance and aerobic power in 12 to 17 year old children with bone age, calf muscle, total body potassium, heart volume and two indices of anaerobic power. In O. Bar-Or (Ed.), Pediatric work physiology: Proceedings of the fourth international symposium, (pp. 109-134). Israel, Wingate Institute.

Docherty, D., Wenger, H.A., & Collis, M.L. (1987). The effects of resistance training on aerobic and anaerobic power of young boys. Medicine and Science in Sport and Exercise, 19(4), 389-392.

Eriksson, B.O. (1972). Physical training, oxygen supply and muscle metabolism in 11-13-year old boys. Acta Physiologica Scandinavica, (Suppl. 384), 1-48.

Eriksson, B.O., Gollnick, P.D., & Saltin, B. (1973). Muscle metabolism and enzyme activities after training in boys 11-13 years old. Acta Physiologica Scandinavica, 87(4), 485-497.

Eriksson, B.O., Gollnick, P.D., & Saltin, B. (1974). The effect of physical training on muscle enzyme activities and fiber composition in 11 year-old boys. Acta Paediatrica Belgica, 28 (Suppl.), 245-252.

Eriksson, B.O., & Saltin, B. (1973). Muscle metabolism and anaerobic metabolism in prepubertal boys before and after physical training. In O. Bar-Or (Ed.), Pediatric work physiology: Proceedings of the fourth international symposium, (pp. 173-181). Isreal, Wingate Institute.

Eriksson, B.O., & Saltin, B. (1974). Muscle metabolism during exercise in boys aged 11 to 16 years compared to adults. Acta Paediatrica Belgica, 28, (Suppl.), 257-265.

Evans, J.A., & Quinney, H.A. (1981). Determination of resistance settings for anaerobic power testing. Canadian Journal of Applied Sport Sciences, 6(2), 53-56.

Fellmann, N. et al. (1988). Anaerobic metabolism during pubertal development at high altitude. Journal of Applied Physiology, 64(4), 1382-1386.

Fox, E.L., & Mathews, D. K. (1981). The physiological basis of physical education and athletics. Philadelphia: Saunders College Publishing.

Gilliam, T.B., Sady, S., Thorland, W.G., & Weltman, A.L. (1977). Comparison of peak performance measures in children ages 6 to 8, 9 to 10, and 11 to 13 years. Research Quarterly, 48(4), 695-702.

Goslin, B.R., & Graham, T.E. (1985). A comparison of 'anaerobic' components of O_2 debt and the Wingate test. Canadian Journal of Applied Sport Sciences, 10(3), 134-140.

Green, H.J. (1979). Metabolic aspects of intermittent work with specific regard to ice hockey. Canadian Journal of Applied Sport Sciences, 4(1), 29-34.

Grodjinovsky, A., Inbar, O., Dotan, R., & Bar-Or, O. (1980). Training effect of the anaerobic performance of children as measured by the Wingate anaerobic test. In K. Berg, & B.O. Eriksson (Eds.), Children and Exercise IX (pp. 139-145). Baltimore: University Park Press.

Hakkinen, K., Rahkila, P., & Alen, M. (1985). Anaerobic power during the course of one-minute strenuous muscular performance. Journal of Human Movement, 11, 237-250.

Hughson, R (1986). Children in competitive sports - A multi-disciplinary approach. Canadian Journal of Applied Sport Sciences, 11(4), 162-172.

Inbar, O. & Bar-Or, O. (1975). The effects of intermittent warm-up on 7-9 year-old boys. European Journal of Applied Physiology, 34, 81-89.

Inbar, O. & Bar-Or, O. (1977). Relationships of anaerobic and aerobic arm and leg capacities to swimming performance of 8-12 year-old children. Symposium on Pediatric Work Physiology, (pp 283-292).

Inbar, O. & Bar-Or, O. (1986). Anaerobic characteristics in male children and adolescents. Medicine and Science in Sports and Exercise, 18(3), 264-269.

Jones, P.M.R. & Parsons, J. (1969). Anthropometric determination of leg, fat and muscle plus volume on young male and female adults. Journal of Physiology, 204, 63-66.

Katch, V. (1974). Body weight, leg volume, leg weight and leg density as determiners of short duration work performance on the bicycle ergometer. Medicine and Science in Sports, 6(4), 267-270.

Katch, V., Weltman, A., Martin, R., & Gray, L. (1977). Optimal test characteristics for maximal anaerobic work on the bicycle ergometer. Research Quarterly, 48(2), 319-327.

Koch, G. (1980). Aerobic power, lung dimensions, ventilatory capacity and muscle blood flow in 12-16 year old boys with high physical activity. In K. Berg & B.O. Eriksson (Eds.). Children and exercise IX, (pp.99-108). Baltimore: University Park Press.

Komi, P.V., Rusko, H., Vos, J., & Vihko, V. (1977). Anaerobic performance capacity in athletes. Acta Physiologica Scandinavica, 100, 107-114.

Macek, M., & Vavra, J. (1977). Relationship between aerobic and anaerobic energy supply during maximal exercise in boys. International Symposium on Pediatric Work Physiology, 7th (1975). Frontiers of Activity and Child Health: Proceedings of the VII Intenational Symposium of Pediatric Work Physiology, pp. 157-159. Quebec: Editions du Pelican.

Manning, J.M., Dooly-Manning, C. & Perrin, D.H. (1988). Factor Analysis of various anaerobic power tests. The Journal of Sports Medicine and Physical Fitness, 28, 138-144.

Margaria, R., Aghemo, P., & Rovelli, E. (1966). Measurement of muscular power (anaerobic) in man. Journal of Applied Physiology, 21(5), 1662-1664.

McKenna, M.J., Green, R.A., Shaw, P.F., & Meyer, A.D.McR. (1987). Tests of anaerobic power and capacity. The Australian Journal Science and Medicine in Sport, 19(2), 13-17.

Mero, A., Kauhanen, H., Peltola, E., & Vuorimaa, T. (1988). Changes in endurance, strength and speed capacity of different prepubescent athletic groups during one year of training. Journal of Human Movement, 14, 219-239.

Mero, A., Kauhanen, H., Peltola, E., & Vuorimaa, T. (1989). Transfer from prepuberty to puberty: effects of three years of training. Journal of Human Movement Studies, 16(6), 267-278.

Mosher, R.E., Rhodes, E.C., Wenger, H.A. & Filsinger, B. (1985). Interval training: the effects of a 12-week programme in elite pre-pubertal male soccer players. The Journal of Sports Medicine, 25, 5-9.

Paterson, D.H. (1980). Physiological peculiarities of children. Coaching Science Update, 1979/1980 Edition, 38-40.

Patton, J.F., Murphy, M.M. & Frederick, F.A. (1985). Maximal power outputs during the Wingate anaerobic test. International Journal of Sports Medicine, 6(2), 82-85.

Reilly, T. & Bayley, K. (1988). The relation between short-term power output and sprint performance of young female swimmers. Journal of Human Movement, 14, 19-29.

Ross, W.D., & Marfell-Jones, M.J. (1982). Kinanthropometry. In J.D. MacDougall, H.A. Wenger, & H.J. Green (Eds.), Physiological testing of the elite athlete (pp. 75-115). Champaign, Illinois: Human Kinetics Pub. Co.

Sady, S.P., Thompson, W.H., Wade, H., Berg, K., & Savage, M. (1984). Physiological characteristics of high-ability prepubescent wrestlers. Medicine and Science in Sports and Exercise, 16(1), 72-76.

Sargeant, A.J., Hoinville, E., & Young, A. (1981). Maximum leg force and power output during short-term dynamic exercise. Journal of Applied Physiology, 51(5), 1175-1182.

Serresse, O., Ama, P.F.M., Simoneau, J.A., Lortie, G., Bouchard, C., & Boulay, M.R. (1989). Anaerobic performances of sedentary and trained subjects. Canadian Journal of Sport Science, 14(1), 46-52.

Sharp, N.C.C., & Koutedakis, Y. (1987). Anaerobic power and capacity measurements of the upper body in elite judo players, gymnasts and rowers. The Australian Journal of Science and Medicine in Sport, 19(3), 9-13.

Shephard, R.J. (1982). Physical activity and growth. Chicago: Yearbook Medical Publishers, Inc.

Simoneau, J.A., Lortie, G., Boulay, M.R. & Bouchard, C. (1983). Tests of anaerobic alactacid and lactacid capacities: Description and reliability. Canadian Journal of Applied Sport Sciences, 8(4), 266-270.

Taunton, J.E., Maron, H., & Wilkinson, J.G. (1981). Anaerobic performance in middle and long distance runners. Canadian Journal of Applied Sport Sciences, 6(3), 109-113.

Tharp, G.D., Johnson, G.O., & Thorland, W.G. (1984). Measurement of anaerobic power and capacity in elite young track athletes using the Wingate test. Journal of Sports Medicine, 24, 100-106.

Tharp, G.D., Newhouse, R.K., Uffelman, L., Thorland, W.G., & Johnson, G.O. (1985). Comparison of sprint and run times with performance on the Wingate Anaerobic test. Research Quarterly for Sport and Exercise, 56(1), 73-76.

Thoden, J.S., MacDougall, J.D., & Wilson, B.A. (1982). Testing aerobic power. In J.D. MacDougall, H.A. Wenger, & H.J. Green (Eds.), Physiological testing of the elite athlete (pp. 75-115). Champaign, Illinois: Human Kinetics Pub. Co.

Thorland, W.G., Johnson, G.O., Cisar, C.J., Housh, T.J., & Tharp, G.D. (1987). Strength and anaerobic responses of elite young female sprint and distance runners. Medicine and Science in Sports and Exercise, 19(1), 56-61.

Ward, D.S., & Bar-Or, O. (1990). Use of the Borg scale in exercise prescription for overweight youth. Canadian Journal of Sport Sciences, 15(2), 120-125.

Watson, R.C. & Sargeant, T.L.C. (1986). Laboratory and on-ice test comparisons of anaerobic power of ice hockey players. Canadian Journal of Applied Sport Sciences, 11(4), 218-224.

APPENDIX A

Review of Literature

Energy Systems

Green (1982) outlines the three sources of chemical energy for muscle contraction as creatine phosphate splitting, anaerobic glycolysis and aerobic (oxidative) metabolism. The energy-rich phosphate compounds, creatine phosphate (CP) and adenosine triphosphate (ATP), were described by Lohman in 1931 (cited in Karlsson, 1971) and referred to collectively as phosphagens.

ATP is a complex chemical compound stored in cells that allows for the production of mechanical work by way of the energy released from its breakdown. Fox (1984) termed ATP the "universal energy donor" in all cells. In order for this phosphate to be continually supplied to muscle cells, it must be resynthesized. The splitting of another high energy phosphate, CP, is one mechanism by which ATP is replenished (Gollnick & Hermansen, 1973). The reformation of ATP by these methods is termed alactic (Bouchard, Taylor & Dulac, 1982). During short, exhaustive exercise of up to 2 minutes, the energy required is derived almost entirely by anaerobic means (Hermansen, 1969). Approximately 70% to 85% of the energy required for supramaximal work of 30 s comes from the splitting and resynthesis of these high energy phosphates (Knuttgen & Saltin, 1972).

The work of Jacobs, Tesch, Bar-Or, Karlsson, and Dotan (1983b) are in agreement with this finding. Fifteen male and seven female adult subjects were used to evaluate the extent of anaerobic glycolysis after 10 and 30 s of supramaximal exercise. Muscle biopsies were taken after both 10 s and 30 s exercise bouts. Pronounced lactate accumulation was observed after the 10 s test. When lactate values were observed after the 30 s test it was noted that the values were only 40% higher than in the 10 s test. This suggests that anaerobic glycolysis occurs within the 10 s time frame. Gollnick and Hermansen (1973) calculated for their adult subjects that during maximal exercise of approximately 1 min, 60% of the energy requirements are derived from anaerobic processes.

When muscular contractions continue for longer than a few seconds, more complex chemical reactions are required to resynthesize ATP. The incomplete breakdown of carbohydrates (glucose) or muscle glycogen supplies the energy needed for continuation of work for several minutes. This method of supplying energy to the contracting muscle, called anaerobic glycolysis, results in the formation of lactate and the net gain of 3 moles of ATP. While the capacity of these systems to supply ATP is limited, the rate of supply is rapid. It is a beneficial method for the muscles to complete fast, heavy contractions (Karlsson, 1971).

In the presence of sufficient oxygen, a greater amount of ATP can be resynthesized for muscle contractions. The rate of production is limited compared to the anaerobic systems. This process, referred to as the aerobic energy system, uses the energy available from the breakdown of carbohydrates and fats with oxygen for the reformation of the ATP molecule.

Although research has been carried out in all three energy systems, most studies have examined aerobic power. Bouchard et al. (1982) state that researchers know less about the anaerobic energy sytem and therefore lean towards studies of the aerobic processes.

Hermansen (1969) points out that during periods of short exhaustive work, energy is derived from anaerobic means. When the work is prolonged beyond 10 minutes or more, aerobic processes dominate. When work is short and of high intensity, a number of limiting factors affect anaerobic metabolism: lactic acid accumulation, the speed of ATP production, intracellular pH, and the effect of diet, (i.e., the amount of glycogen in the system prior to exercise).

Eriksson & Saltin (1973, 1974) feel that enzymatic concentrations and capacities limit anaerobic work in children. However, Gollnick (1982) states that "it does not appear that the capacity of the enzymatic systems is a limiting factor to any type of exercise" (p. 20).

Using trained and untrained subjects, Karlsson (1971) showed that the greater the work intensity, the greater the amount of ATP and CP depletion, and the greater the accumulation of lactic acid. CP was shown to deplete more rapidly than ATP. He also pointed out that energy production from anaerobic glycolysis occurred prior to the total depletion of the energy-rich phosphagens. Jacobs, Bar-Or, Dotan, Karlsson and Tesch (1983) examined the changes that occur in skeletal muscle following a 30 s supramaximal bicycle test. Muscle samples were extracted from 14 female physical education students. The results were consistent with Karlsson (1971). Depletion of CP was more pronounced than that of ATP. Resting concentrations of ATP, CP, glycogen and lactate were significantly (p <0.0001) different than the pre-exercise values.

In evaluating aerobic and anaerobic efficiency, Gladden and Welch (1978) found that supplying energy anaerobically is no less efficient than when ATP is resynthesized aerobically for low-intensity, steady-state exercise. It was found that, regardless of the process used to supply energy, the efficiency of the work decreased as power output increased. This was observed even when the rate of work was below maximum.

Anaerobic Testing

Testing of the anaerobic energy system has lacked consistency in protocol. Bouchard et al. (1982) feel that this inconsistency stems from the lack of distinction between anaerobic alactic power and capacity and anaerobic lactic power and capacity. From the stair climb test of Margaria, Aghemo, and Rovelli (1966), to the cycle ergometer test of Tharp, Johnson, and Thorland (1984), different tests have been used to measure components of anaerobic energy production. Duration and intensity have presented the widest variation in test protocol.

Duration

Cycle tests of anaerobic performance have ranged from a few seconds (Crielaard and Pirnay, 1981) to two minutes (Katch, 1974). Some authors (Bar-Or et al., 1980; Goslin & Graham, 1985; Hakkinen et al., 1985; Horswill, Scott, Galea & Sung Han, 1988; Inbar & Bar-Or, 1975, 1977, 1986; Katch, 1974; Manning et al., 1988; Patton et al., 1985; Reilly & Bayley, 1988; Sady et al., 1984; Taunton et al., 1981; Tharp et al., 1984, 1985; Watson & Sargeant, 1986; Weltman, Moffat & Stamford, 1978) used only one set duration in their study, while others (Katch et al., 1977; Maud & Shultz, 1986, 1989; McKenna et al., 1987; Mero et al., 1988, 1989; Serresse et al., 1989; Simoneau et al., 1983) altered the time frame for the test.

Sargeant et al. (1981) measured five subjects cycling all-out for 20 s to determine maximum leg force and power output. Weltman et al. (1978) tested their subjects for 40 s to estimate anaerobic power and capacity. A 10 s time frame has been used to measure anaerobic alactic capacity and a 90 s test to determine anaerobic lactic capacity (Serresse et al., 1989; Simoneau et al., 1983). Szogy and Cherebitiu (1974) used a 60 s test to determine anaerobic capacity and found that 74% of the work performed during this time period was determined through anaerobic means. Anaerobic power and capacity has been evaluated from an all-out cycle test of 120 s (Katch and Weltman, 1979). Their results indicated that by 42 and 72 s slightly over 50 and 75% of the total power output had been accomplished, respectively.

The most common anaerobic test duration has been 30 s as described by Bar-Or (1978). This anaerobic cycle test, founded on work suggested by Cumming (1973), has been termed the Wingate anaerobic test (WAnT) because it resulted from research carried out at the Wingate Institute for Sport and Physical Education, Israel. Through research reviewed by Inbar and Bar-Or (1986) this test has been found to be reliable (test-retest correlation coefficients of 0.95-0.98) and valid when compared with 'anaerobic' running, swimming, and other anaerobic laboratory tests. Knuttgen and Saltin (1972) noted that 70-85% of the total energy expenditure for a test of this length was assumed to be delivered from anaerobic sources. Authors have adopted this test duration to measure anaerobic capacity (Bar-Or et al., 1980;), anaerobic power (Evans & Quinney, 1981; Sargeant et al., 1981), or both, (Katch & Weltman, 1979; Tharp et al., 1984).

Intensity

Tests of varying intensity have also appeared in the research. Intensity on a cycle ergometer can be adjusted by altering resistance or pedalling speed.

Resistance settings and pedal frequencies have been altered by investigators who have tried to obtain the optimal protocol for measuring aspects of the anaerobic energy system. Resistance was altered by Evans and Quinney (1981) to identify the force that elicited maximal power output in 30 s. Crielaard and Pirnay (1981) had subjects complete five tests of high intensity exercise not lasting more than a few seconds to compare anaerobic alactic power with aerobic power of top level sprinters, long-distance runners, and a group of untrained students. Resistance settings ranged from 0.04 to 0.07 $kg \cdot kg^{-1}$. The highest results, recorded by the authors, indicated that the mean alactic power was 551, 710, and 1021 W for long distance runners, controls, and sprinters, respectively. Crank velocities were varied from 23 to 171 rpm to determine the relationship between crank velocity and peak power output. Optimal peak and mean power outputs were determined from 30 s anaerobic cycle test by Smith (1987). The resistance setting to body weight ratios were found to be 0.094 kp for peak power output and 0.092 kp for mean power output. An optimum crank velocity to elicit peak power was determined to be 110 rpm (Sargeant et al., 1981).

Katch et al. (1977) completed a two part study with adults. In the first part, pedal revolutions varied between 60, 80, 100, and all-out rpm with a fixed resistance of 5.5 kp. The second procedure experimented with different resistance settings of 4.0, 5.0, and 6.0 kp. In this second experiment pedal frequency was maintained at an all-out cadence. From these two experiments, the authors outlined the optimum test characteristics for maximum anaerobic functioning on a cycle ergometer as being (1) 40 s duration, (2) resistance set between 5.0 and 6.0 kp and (3) an all-out pedalling cadence.

Evans and Quinney (1981) disagree with the concept of a set pedal frequency and resistance setting. They feel there is an optimal combination of resistance and pedalling speed to elicit true maximal power output for an individual. These authors concluded that the use of reliable regression formulae would be a better method than a standardized protocol. Sargeant et al. (1981) also advocate the importance of a force velocity relationship that will optimize power output.

Some authors have set a standard resistance for all subjects (Cumming, 1973; Katch et al., 1977; Maud & Shultz, 1986, 1989; Weltman et al., 1978). Most others have set resistance relative to body weight. Among these authors there appears to be a great deal of variation in the resistance settings used in tests of identical duration. Grodjinovsky et al. (1980) set a resistance of 0.045 $kg \cdot kg^{-1}$ BW for their 30 s bike test, while Tharp et al.(1984, 1985) set resistance at 0.075 $kg \cdot kg^{-1}$ BW in their studies with elite young track athletes (ages 10 - 15 years). This was also the resistance set by Goslin and Graham (1985), Horswill et al. (1988), and Maud and Shultz (1986, 1989). Bar-Or et al. (1980) had adult subjects pedal for 30 s against a resistance of 0.045 $kg \cdot kg^{-1}$.

Simoneau et al. (1983) and Serresse et al. (1989) used two different settings. A resistance of 0.09 $kg \cdot kg^{-1}$ body weight was adopted for the 10 s anaerobic alactic capacity test and 0.05 $kg \cdot kg^{-1}$ was used as the relative setting for the lactic capacity test. It was found that the male subjects exhibited higher total work outputs in both tests than the women when expressed absolute or relative to body weight (Simoneau et al., 1983). Serresse et al. (1989) found the percent difference between males and females to be reduced in trained subjects, particularly marathon runners where the 10 s and 90 s work capacity scores attained about 92% of male values.

Nomenclature

The terms anaerobic power and capacity have caused a great deal of confusion in the literature. Authors have used these terms in a variety of ways. Inconsistencies have appeared since the anaerobic testing of Margaria et al. (1966). Their stair run lasted less than one second and was deemed a test of maximal anaerobic power. Cumming (1973) used a 30 s all-out bicycle ride and the Margaria stair run as an indication of anaerobic power in children. It has been indicated that the first six seconds of a 120 s bicycle test can be used to measure anaerobic power (Katch & Weltman, 1979). The 30 s cycle ergometer ride has been considered an all-out power test (Evans & Quinney, 1981) or a test of glycolytic power (Taunton et al., 1981).

Some authors (Katch & Weltman, 1979; Tharp et al., 1984) have used one bout of maximal exercise to measure both anaerobic power and anaerobic capacity. The terms power and capacity were combined by Taunton et al. (1981) when they stated "athletes in the present study did not elicit this kind of anaerobic power capacity" (p. 112). Bouchard et al. (1982) point out that whenever the anaerobic system is being assessed, it is important to establish a distinction between the capacity and the power of the system.

Tharp et al. (1984) define anaerobic power as being "the highest work performed during any five second period" and anaerobic capacity as "the total work performed during the entire 30 s" test (p. 102). A 40 s test has also been employed as an estimate of anaerobic capacity while the highest power output observed in a 4 s interval has also been used as an estimate of anaerobic power (Weltman et al., 1978). Katch & Weltman (1979) used a 65 s interval for measuring power and a 120 s duration for measuring capacity.

It can be summarized that any measurement that incorporates a time component (ie. work per unit of time) is a measure of power, no matter what the interval may be. A capacity measure is always the total amount of work performed. The capacity measure is relative to that test duration only. For example, a 40 s test measures capacity specifically over that time period.

Distinguishing power and capacity into alactic and lactic components has been another concern for researchers. Some investigators have attempted to isolate only one of the four components of the anaerobic energy system. Others have dealt with more, either in a single test as Tharp et al. (1984), or separate tests as did Simoneau et al. (1983) and Serresse et al. (1989). Withers, McFarland, Cousins and Gore (1979) tested four different modifications to the Margaria stair run as a means of measuring anaerobic alactic power. When Margaria et al.` (1966) first developed this test, it was simply a measure of anaerobic power. Crielaard and Pirnay (1981) concentrated specifically on anaerobic alactic power.

Authors such as Katch and Weltman (1979) outlined the difference between alactic and lactic energy production but only considered the power of the alactic system and capacity of the lactic system. Simoneau et al. (1983) point out that in discussing the anaerobic energy system, it is important to distinguish between the alactic and lactic components. Very few authors have done so.

The discrepancy comes in the definition of alactic and lactic power and capacity. Green (1982) emphasizes that, in theory, two components of each energy system must be measured "for a comprehensive evaluation of the energy potential of the muscle" (p. 5). These components were conceptualized by Bouchard et al. (1982) as being anaerobic alactic power, alactic capacity, lactic power and lactic capacity. It is not known whether a single study has investigated and/or measured all four components of the anaerobic energy system. The difficulty comes in being able to differentiate between the alactic and lactic phases. Knowing when one dominates energy production and the other is minimally active has been difficult to determine. Anaerobic alactic power and anaerobic lactic capacity seem to be the most readily observed measures.

Adult Testing

Most anaerobic testing has been carried out on adults and predominatly with male subjects (Coggan & Costill, 1984; Evans & Quinney, 1981; Hakkinen et al., 1985; Katch, 1974; Patton et al., 1985; Schnabel & Kindermann, 1983; Taunton et al., 1981; Watson & Sargeant, 1986).

Studies have involved highly active subjects (Coggan & Costill, 1984; Evans & Quinney, 1981), physical education students (Bar-Or et al., 1980), miliary personnel (Patton et al., 1985), intercollegiate athletes (Katch, 1974; Watson & Sargeant, 1986) or elite athletes (Crielaard & Pirnay, 1981; Hakkinen et al., 1985; Komi et al., 1977; Schnabel & Kindermann, 1983; Taunton et al., 1981).

The questions asked in these studies have been as varied as the populations they studied. Taunton et al. (1981), for example, compared blood lactate levels and maximum anaerobic power in 15 highly trained middle and long distance runners. Using a 30 s Wingate anaerobic test, the authors found peak power and total power output to be higher in the middle distance runners. Blood lactates were observed to be lower in endurance athletes.

Komi et al. (1977) studied 89 athletes and 31 reference subjects for anaerobic performance characteristics at whole body and muscle tissue levels. The whole body variables of vertical velocity, leg force,and blood lactate were found to be related to muscle fibre composition (percent (%) fast twitch fibres (FT)). The authors also concluded that leg force was strongly correlated to body weight.

The extent to which anaerobic processes are affected by body weight was investigated by Katch and Weltman (1979). In their regression analysis they observed that 50% of the variance in total work output was accounted for by body weight. Leg volume and total body density accounted for less than 35%. Costill, Miller, Myers, Kehoe and Hoffman (1968) used 76 members of a physical conditioning class to determine the relationship between explosive leg strength and anaerboic power. The authors used the vertical jump, standing broad jump, 40-yd. dash, and squat weight lift as measures of explosive leg power and the Margaria test (Margaria et al., 1966) as a measure of maximum anaerobic power and maximum vertical velocity. Anaerobic power was correlated to dynamic leg strength, as measured by the squat leg lift ($\underline{r}$=.75), weight ($\underline{r}$=0.85) and lean body weight ($\underline{r}$=0.84). Therefore, absolute measures are not always the most applicable. In sporting events, where athletes must project their own body weight, relative measures are more appropriate.

The 19 males used in the study of Bar-Or et al. (1980) were physical education students (20-30 years of age). The purpose of the research was to investigate the relationship between performance on a 30 s cycle test and muscle fibre type distribution as a means of assessing maximal short-term muscular power. A positive relationship was shown to exist between anaerobic power and % FT fibres, % FT area, and the ratio of FT area/ST area in the quadriceps muscle.

Using adult subjects has allowed researchers to evaluate the anaerobic processes more directly with the use of muscle biopsies. Knuttgen and Saltin (1972) measured ATP, CP, and muscle and blood lactate levels in six male subjects after a 4 min cycle ergometer ride at 19-95% $\dot{V}O_2$ max. The results indicated that ATP decreased slowly, CP decreased rapidly above 60% $\dot{V}O_2$ max and muscle and blood lactate levels increased sharply above 60% $\dot{V}O_2$ max. These results support the results of Karlsson (1971) who found that CP decreases more rapidly than ATP with an increase in $\dot{V}O_2$ max. A rapid increase in the accumulation of muscle lactate took place at work loads 50-60% above $\dot{V}O_2$ max. Diamont, Karlsson, and Saltin (1968) evaluated muscle lactate concentrations before and after heavy exercise with the use of muscle biopsies. Muscle lactate values before exercise were higher than blood lactate values (3.0 $mmol \cdot l^{-1}$ compared to 1.4 $mmol \cdot l^{-1}$). After exercise muscle lactates were considerably greater than blood lactates (19.1 $mmol \cdot l^{-1}$ compared to 11.4 $mmol \cdot l^{-1}$).

Child Testing

Fewer researchers have studied the anaerobic performance of children compared to their aerobic capabilities. Direct measures in children of the anaerobic energy system are more difficult to obtain. Permission to extract muscle samples from children in Canada and United States is difficult to secure. For this reason many investigators in North America have studied the aerobic capabilities of children (Clarke, Vaccaro, & Andersen, 1984; Cunningham, 1979; Gilliam et al., 1977; MacDougall, Roche, Bar-Or & Moroz, 1983).

Much of the anaerobic testing that has used young subjects has been related towards training effects. Studies in Europe by Eriksson, Gollnick, and Saltin (1973, 1974) involved extraction of muscle samples from children, aged 11-13, to observe the effects of training on enzymatic activity. Eriksson et al. (1974) measured muscle metabolism and anerobic metabolism after training in prepubertal boys. It was observed that increased glycolysis does occur after training, suggesting greater PFK activity. An increase in PFK activity was observed from 8.4 mmol·g·min^{-1} before to 15.4 mmol·g·min^{-1} after 6 weeks of bicycle ergometer training 3 times a week.

Grodjinovsky et al. (1970) trained two groups 3 times per week for 6 weeks. One group trained on a cyle ergometer, while the second training group worked on sprint training. The training period was preceded by and concluded with a 30 s WAnT. Results showed that both of the training groups, but not the control group, increased their anaerobic capacity.

The 30 s cycle ergometer test has been used frequently with children. Cumming (1973) used an all-out 30 s cycle ergometer test as an index of anaerobic work to determine the relationship between the work rate (W) in 30 s and athletic performance. There was a high correlation between bodyweight and the 30 s test. However, this index of anaerobic work was deemed a poor predictor of performance in track and field events. Inbar and Bar-Or (1975) were interested in the response of children to warm-up. They used a 30 s all-out cycle ride, with resistance set at 0.035 kg·kg^{-1} BW as their anaerobic criterion task.

Tharp et al. (1984), studied 39 male (mean age 14.1 years) and female (mean age 13.7 years) track athletes (sprint and distance) on the WAnT to determine anaerobic power and capacity. There were six different groups tested. Sprinters showed higher anaerobic power and capacity measures than distance runners in all groups except the 10-to-11-year-old females.

Kurowski (1977) also used both male and female subjects (ages 9 through 15) in a test of anaerobic power. Ten trials of the Margaria

Step-Test were used to determine the difference between males and females of similar age and the effect of leg length on maximal anaerobic power. Significant ($p<0.05$) differences between sexes were noted only for absolute measures. A higher correlation was found between leg length and maximum anaerobic power ($r=0.71$) compared to the correlation between age and absolute anaerobic power ($r=0.68$).

Quantitative comparisons between children and adults on anaerobic capabilities have been negligible. Eriksson and Saltin (1974) compared boys to adults on muscle metabolism during exercise using the muscle biopsies and found similar relative levels of ATP and CP indicating that boys had comparable alactic capacity to adults. It was also observed that glycogen decreased gradually with exercise and to a lesser degree in the younger boys. The decrease in glycogen was accompanied by increases in maximal blood and muscle lactate concentrations that were lowest in the youngest age group. The authors concluded that "children are handicapped compared to adults in anaerobic lactic work of 15 seconds to 1-2 minutes" (p. 256). Shephard (1982) also pointed out that the average child has a lower blood lactate level compared with a well-motivated adult when working at 100% of $\dot{V}O_2$ max. Shephard explained this discrepancy could be due to a more rapid equilibrium of blood and muscle in children. He also feels that getting a child to assume an all-out effort is difficult and could be a contributing factor to the lower lactate values in children. Eriksson et al. (1974) stated that this difference could be due to a small relative muscle mass and lower concentrations of PFK in children.

Still, little is known about the anaerobic capabilities of children. Some of the work that has been carried out (Eriksson et al., 1973, 1974; Eriksson & Saltin, 1973, 1974) has not shown any functional or performance differences between children and adults, either absolute or relative. Also, differences in the four components of the anaerobic energy system between adults and children have not been clearly defined.

A review of the literature suggests that the anerobic performance capabilities of children have yet to be fully explored. Research should concentrate on the following concerns. First, anaerobic testing has varied greatly in design and protocol. Secondly, authors have not made clear distinctions between the four components of the anerobic energy system. Thirdly, to date, no single anaerobic test has attempted to quantitatively measure the four energy components in children and adults in a single all-out supramaximal test. And fourthly, comparative measures between adults and children have not considered the absolute and relative differences, nor the anaerobic performance characteristics, of children and adults.

References

Bar-Or, O. (1978). A new anaerobic capacity test: Characteristics and applications. Presented at the 21st World Congress in Sports Medicine, Brasilia.

Bar-Or, O., Dotan, R., Inbar, O., Rothstein, A., Karlsson, J, & Tesch, P. (1980). Anaerobic capacity and musclel fibre type distribution in man. International Journal of Sports Medicine, 1(2), 82-85.

Bouchard, C., Taylor, A.W., & Dulac, S. (1982). Testing maximal anaerobic power and capacity. In J.D. MacDougall, H.A. Wenger & H.J. Green (Eds.), Physiological testing of the elite athlete, (pp. 61-73). Champaign, Illinois: Human Kinetics Pub. Co.

Clarke, D.H., Vaccaro, P., & Andersen, N.M. (1984). Physiological alterations in 7- to 9- year-old boys following a season of competitive wrestling. Research Quarterly, 55(4), 318-322.

Costill, D.L., Miller, S.J., Myers, W.C., Kehoe, F.M. & Hoffman, W.M. (1968). Relationship among selected tests of explosive leg strength and power. Research Quarterly, 39(3), 785-787.

Coggan, A.R. & Costill, D.L. (1984). Biological and technological variability of three anaerobic ergometer tests. International Journal of Sports Medicine, 5(3), 142-145.

Crielaard, J.M., & Pirnay, F. (1981). Anaerobic and aerobic power of top athletes. European Journal of Applied Physiology, 47, 295-300.

Cumming, G.R. (1973). Correlation of athletic performance and aerobic power in 12 to 17 year old children with bone age, calf muscle, total body potassium, heart volume and two indices of anaerobic power. In O. Bar-Or (Ed.), Pediatric work physiology: Proceedings of the fourth international symposium, (pp.109-134). Israel, Wingate Institute.

Diamont, B., Karlsson, J., & Saltin, B. (1968). Muscle tissue lactate after maximal exercise in man. Acta Physiologica Scandinavica, 72, 383-384.

Eriksson, B.O., Gollnick, P.D., & Saltin, B. (1973). Muscle metabolism and enzyme activities after training in boys 11-13 years old. Acta Physiologica Scandinavica, 87(4), 485-497.

Eriksson, B.O., Gollnick, P.D., & Saltin, B. (1974). The effect of physical training on muscle enzyme activities and fiber composition in 11 year-old boys. Acta Paediatrica Belgica, 28 (Suppl.), 245-252.

Eriksson, B.O., & Saltin, B. (1973). Muscle metabolism and anaerobic metabolism in prepubertal boys before and after physical training. In O. Bar-Or (Ed.), Pediatric work physiology: Proceedings of the fourth international symposium, (pp. 173-181). Israel, Wingate Institute.

Eriksson, B.O., & Saltin, B. (1974). Muscle metabolism during exercise in boys aged 11 to 16 years compared to adults. Acta Paediatrica Belgica, 28, (Suppl.), 257-265.

Evans, J.A., & Quinney, H.A. (1981). Determination of resistance settings for anaerobic power testing. Canadian Journal of Applied Sport Sciences, 6(2), 53-56.

Fox, S. I. (1984). Human physiology. Dubuque, Iowa: Wm. C. Brown Publishers.

Gilliam, T.B., Sady, S., Thorland, W.G., & Weltman, A.L. (1977). Comparison of peak performance measures in children ages 6 to 8, 9 to 10, and 11 to 13 years. Research Quarterly, 48(4), 695-702.

Gladden, B.L., & Welch, H.G. (1978). Efficiency of anaerobic work. Journal of Applied Physiology, 44(4), 564-570.

Gollnick, P.D. (1982). Peripheral factors as limitations to exercise capacity. Canadian Journal of Applied Sport Sciences, 7(1), 14-21.

Gollnick, P.D., & Hermansen, L. (1973). Biomechanical adaptations to exercise: Anaerobic metabolism. In J.H. Wilmore (Ed.), Exercise and sport sciences reviews (pp. 1-43). New York: Academic Press.

Goslin, B.R., & Graham, T.E. (1985). A comparison of 'anaerobic' components of O_2 debt and the Wingate test. Canadian Journal of Applied Sport Sciences, 10(3), 134-140.

Green, H.J. (1982). Overview of the energy delivery systems. In J.D. MacDougall, H.A. Wenger, & H.J. Green (Eds.), Physiological testing of the elite athlete (pp. 3-6). Champaign, Illinois: Human Kinetics Pub. Co.

Grodjinovsky, A., Inbar, O., Dotan, R., & Bar-Or, O. (1980). Training effect of the anaerobic performance of children as measured by the Wingate anaerobic test. In K. Berg, & B.O. Eriksson (Eds.), Children and Exercise IX (pp. 139-145). Baltimore: University Park Press.

Hakkinen, K., Rahkila, P., & Alen, M. (1985). Anaerobic power during the course of one-minute strenuous muscular performance. Journal of Human Movement, 11, 237-250.

Hermansen, L. (1969). Anaerobic energy release. Medicine and Science in Sports, 1(1), 32-38.

Horswill, C. A., Scott, J., Galea, P., & Sung Han, P. (1988). Physiological profile of elite junior wrestlers. Research Quarterly for Exercise and Sport, 59(3), 257-261.

Inbar, O. & Bar-Or, O. (1975). The effects of intermittent warm-up on 7-9 year-old boys. European Journal of Applied Physiology, 34, 81-89.

Inbar, O. & Bar-Or, O. (1977). Relationships of anaerobic and aerobic arm and leg capacities to swimming performance of 8-12 year-old children. Symposium on Pediatric Work Physiology, (pp 283-292).

Inbar, O. & Bar-Or, O. (1986). Anaerobic characteristics in male children and adolescents. Medicine and Science in Sports and Exercise, 18(3), 264-269.

Jacobs, I., Bar-Or, O., Dotan, R., Karlsson, J., & Tesch, P. (1983). Changes in muscle ATP, CP, glycogen, and lactate after performance of the Wingate anaerobic test. In H.G. Knuttgen, J.A. Vogel, & J. Poortmans (Eds.), Biochemistry of exercise (pp. 234-238). Champaign, Illinois: Human Kinetics Publishing Inc.

Jacobs, I., Tesch, P., Bar-Or, O., Karlsson, J., & Dotan. R. (1983). Lactate in human skeletal muscle after 10 and 30 s. of supramaximal exercise. Journal of Applied Physiology, 55(2), 365-367.

Karlsson, J. (1971). Lactate and phosphagen concentrations in working muscle of man. Acta Physiologica Scandinavica, (Suppl. 358), 7-72.

Katch, V. (1974). Body weight, leg volume, leg weight and leg density as determiners of short duration work performance on the bicycle ergometer. Medicine and Science in Sports, 6(4), 267-270.

Katch, V., & Weltman, A. (1979). Interrelationship between anaerobic power output, anaerobic capacity and aerobic power. Ergonomics, 22(3), 325-332.

Katch, V., Weltman, A., Martin, R., & Gray, L. (1977). Optimal test characteristics for maximal anaerobic work on the bicycle ergometer. Research Quarterly, 48(2), 319-327.

Komi, P.V., Rusko, H., Vos, J., & Vihko, V. (1977). Anaerobic performance capacity in athletes. Acta Physiologica Scandinavica, 100, 107-114.

Knuttgen, H.G. & Saltin, B. (1972). Muscle metabolites and oxygen uptake in short-term submaximal exercise in man. Journal of Applied Physiology, 32(5), 690-694.

Kurowski, Thomas T. (1977). Anaerobic power of children from ages 9 through 15 years. Unpublished master's thesis, Florida State University.

MacDougall, J.D., Roche, P.D., Bar-Or, O. & Moroz, J.R. (1983). Maximal aerobic capacity of Canadian school children: Prediction based on age-related oxygen cost of running. International Journal of Sports Medicine, 4, 194-198.

Manning, J.M., Dooly-Manning, C. & Perrin, D.H. (1988). Factor Analysis of various anaerobic power tests. The Journal of Sports Medicine and Physical Fitness, 28, 138-144.

Margaria, R., Aghemo, P., & Rovelli, E. (1966). Measurement of muscular power (anaerobic) in man. Journal of Applied Physiology, 21(5), 1662-1664.

Maud, P.J. & Shultz, B.B. (1986). Gender comparisons in anaerobic power and anaerobic capacity tests. British Journal of Sports Medicine, 20(2), 51-54.

Maud, P.J. & Shultz, B.B. (1989). Norms for the Wingate anaerobic test with comparison to another similar test. Research Quarterly for Exercise and Sport, 60(2), 144-151.

McKenna, M.J., Green, R.A., Shaw, P.F., & Meyer, A.D.McR. (1987). Tests of anaerobic power and capacity. The Australian Journal Science and Medicine in Sport, 19(2), 13-17.

Mero, A., Kauhanen, H., Peltola, E., & Vuorimaa, T. (1988). Changes in endurance, strength and speed capacity of different prepubescent athletic groups during one year of training. Journal of Human Movement, 14, 219-239.

Mero, A., Kauhanen, H., Peltola, E., & Vuorimaa, T. (1989). Transfer from prepuberty to puberty: effects of three years of training. Journal of Human Movement Studies, 16(6), 267-278.

Patton, J.F., Murphy, M.M. & Frederick, F.A. (1985). Maximal power outputs during the Wingate anaerobic test. International Journal of Sports Medicine, 6(2), 82-85.

Reilly, T. & Bayley, K. (1988). The relation between short-term power output and sprint performance of young female swimmers. Journal of Human Movement, 14, 19-29.

Sady, S.P., Thompson, W.H., Wade, H., Berg, K., & Savage, M. (1984). Physiological characteristics of high-ability prepubescent wrestlers. Medicine and Science in Sports and Exercise, 16(1), 72-76.

Sargeant, A.J., Hoinville, E., & Young, A. (1981). Maximum leg force and power output during short-term dynamic exercise. Journal of Applied Physiology, 51(5), 1175-1182.

Schnabel, A. & Kindermann, W. (1983). Assessment of anaerobic capacity in runners. European Journal of Applied Physiology, 52, 42-46.

Serresse, O., Ama, P.F.M., Simoneau, J.A., Lortie, G., Bouchard, C., & Boulay, M.R. (1989). Anaerobic performances of sedentary and trained subjects. Canadian Journal of Sport Science, 14(1), 46-52.

Simoneau, J.A., Lortie, G., Boulay, M.R. & Bouchard, C. (1983). Tests of anaerobic alactacid and lactacid capacities: Description and reliability. Canadian Journal of Applied Sport Sciences, 8(4), 266-270.

Szogy, A., & Cherebetiu, G. (1974). A 1-minute bicycle ergometer test for determination of anaerobic capacity. European Journal of Applied Physiology and Occupational Physiology, 33 (2), 171 176.

Taunton, J.E., Maron, H., & Wilkinson, J.G. (1981). Anaerobic performance in middle and long distance runners. Canadian Journal of Applied Sport Sciences, 6(3), 109-113.

Tharp, G.D., Johnson, G.O., & Thorland, W.G. (1984). Measurement of anaerobic power and capacity in elite young track athletes using the Wingate test. Journal of Sports Medicine, 24, 100-106.

Tharp, G.D., Newhouse, R.K., Uffelman, L., Thorland, W.G., & Johnson, G.O. (1985). Comparison of sprint and run times with performance on the Wingate Anaerobic Test. Research Quarterly for Sport and Exercise, 56(1), 73-76.

Watson, R.C. & Sargeant, T.L.C. (1986). Laboratory and on-ice test comparisons of anaerobic power of ice hockey players. Canadian Journal of Applied Sport Sciences, 11(4), 218-224.

Weltman, A., Moffat, R.J. & Stamford, B.A. (1978). Supramaximal training in females: Effects on anaerobic power output, anaerobic capacity, and aerobic power. Journal of Sports Medicine, 18, 237-244.

Withers, R.T., McFarland, K., Cousins, L. & Gore, S. (1979). The measurement of maximum anaerobic alactacid power in males and females. Ergonomics, 22(9), 1021-102

APPENDIX B

INFORMED CONSENT
FOR
PHYSIOLOGICAL ASSESSMENTS

In order to assess anaerobic performance the following laboratory assessments will be performed:

	Lab Initial	Subject (Parent/Guardian) Initial
Maximal Anaerobic Function		

You will exercise on a Monark Bicycle ergometer for 90 seconds with loads relative to body weight to elicit maximal anaerobic reponses in the following indicated components:

(a) anaerobic alactic power

(b) anaerobic alactic capacity

(c) anaerobic lactic power

(d) anaerobic lactic capacity

Blood Chemistry

Blood samples will be taken prior to, and 2 and 5 minutes post-exercise by

(a) finger tip prick

Body Composition

a) anthropometric measures

Tests will be administered by qualified personnel under the direct supervision of the investigator(s).

Blood samples will be taken by the investigator.

Test data and results will be treated in a confidential manner and used only to describe group responses.

	Lab Initial	Subject (Parent/Guardian) Initial

Absolute confidentiality of individual results will be maintained unless specific approval has been given to other use of the material by each subject, or guardian where necessary.

While it is highly unlikely that a subject should be injured or taken ill during a test, lab personnel are trained in emergency procedures and emergency equipment is on-site at all times.

All laboratory activity will be completed proximal to medical and/or paramedical assistance.

The maximal exercise loads imposed will not exceed those which might be expected of an individual during a hard cycle.

I have read the above and agree to participate in this research project at my own risk. I regularly take part in strenuous physical activity at least as intense as these tests. I realize that I may expect a thorough explanation and/or demonstration of any procedures and that I may terminate participation at any time in any or all procedures of my own volition.

Having voluntarily assumed participation and risks thereof, in the project, I hereby disclaim and release the University of Victoria, its agents,servants or employees, including all personnel involved in the reseach project fitness appraisal from any and all liability that might otherwise arise as a result of my participation as a research subject in this study/or fitness appraisal.

NAME:______________________________ DATE:______________

SIGNATURE:______________________________

I, the undersigned guardian, am guardian of ______________________ the intended subject. I have discussed the experimentation with the subject and have read the material supplied by the experimentors. I agree on behalf of the subject to permit his participation on the terms and subject to the waiver and release of the University of Victoria hereinbefore set out.

GUARDIAN'S SIGNATURE:____
(where applicable)

VITA

Surname: Cicchine Given Names: Richard Nicholas

Place of Birth: Toronto, Ontario Date of Birth: 19th May, 1955

Educational Institutions Attended:

Queen's University	1978 to 1979
Brock University	1975 to 1978

Degrees Awarded:

B.P.E.	Brock University	1978
B.Ed.	Queen's University	1979

Performance of 11 and 12 Year-Old Boys on an All-Out 90-Second Cycling Test

Autho[redacted]

Richard Nicholas Cicchine

April 30th, 1991