THE RELATIONSHIP BETWEEN AEROBIC AND ANAEROBIC EXERCISE CAPACITIES IN PRE-PUBERTAL CHILDREN

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ABSTRACT

It is well established in athletic adult individuals that specialization to an aerobic or anaerobic phenotype can occur. Less is known about this specialization in children. While childhood participation in organized sports is increasing, very little is known about the physiological potential of young athletes. For example, the development of the aerobic and anaerobic energy systems in relation to each other in children is not well known. Many children are being put on training programs before puberty without any knowledge as to whether or not this can influence specialization to an aerobic or anaerobic phenotype. Early authors basing their results on twin studies, suggested a strong genetic component to aerobic or anaerobic phenotypes (Klissouras et al., 1973). This was not confirmed by muscle biopsy studies in children (Bell et al., 1980) and in fact Bouchard et al. (1992) have proposed a strong environmental or training influence to athletic performance. The purpose of this study was to look at the question of metabolic specialization in pre-pubertal children before they had any influence of growth or maturation or training effects. The hypothesis was that if specialization exists, then those children with the better anaerobic capacity would have the lower aerobic capacity and vice versa. An attempt was made to screen out the better sprint and endurance performers with field tests, as it was felt that if specialization was occurring it would most likely be present in this group of individuals.

A total of 42 pre-pubertal children from one school completed the study. Mean age was 9.31 years (range 8-11 years). All children initially completed field tests of 50 yard run and 1600 yard run to determine the best sprint and endurance performers. The sprint group (S) performed the 50 yard run under 8.50 seconds, while the endurance group (E) ran 1600 yards under 8 minutes. A questionnaire was filled out to exclude subjects who were involved with a track club or regular training program. On a separate day laboratory tests and anthropometric measures were performed. The laboratory tests performed in

random order consisted of a Wingate protocol for anaerobic parameters on one day and a Quinton cycle ergometer test for aerobic parameters on another day.

Statistical analysis consisted of a zero order correlational analysis for the dependent variables of age, sex, height, weight, sum of skinfolds, sprint run time, endurance run time, anaerobic capacity, peak and mean anaerobic power, and aerobic capacity. In addition a Hotelling's T^2 test was performed to determine significant differences between the sprint and endurance groups.

The results showed no significant differences between the sprint or endurance groups with respect to anthropometric or laboratory measures. There was a trend for the sprint group to have higher peak anaerobic power 9.43 ± 0.87 W/kg (S) versus 8.67 ± 1.25 W/kg (E). However, they also showed a trend towards higher aerobic power 52.03 ± 7.97 ml/kg/min (S) versus 47.73 ± 9.25 ml/kg/min (E). This suggests no specialization. In addition the correlational analysis showed high positive correlations between mean anaerobic power and VO_{2max} ($r = 0.88$) and peak anaerobic power and VO_{2max} ($r = 0.82$) suggesting that those children who do best aerobically also do best anaerobically in the pre-pubertal age group.

The evidence provided from this study suggests that pre-pubertal children are metabolic non-specialists. Therefore rigorous training programs trying to implement aerobic or anaerobic specialization in this age group are likely not beneficial. The specialization seen in adolescents and adults may be secondary to growth or maturational changes after puberty and this would most likely be the better stage to begin regular training programs in children.

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INTRODUCTION

Sports and exercise continue to be an important part of North American culture. This is increasingly evident in the pediatric age group. Childhood participation in organized sports is increasing in record numbers. Along with this comes increasing pressure to improve performance. As a result, there is now increasing emphasis to start endurance and strength training regimes on children at younger and younger ages. It has been estimated that in the United States alone, more than 7 million boys and girls are involved in competitive high school sports. In addition, at least 20 million children aged 8-16 are involved in community sponsored athletic programs requiring regular training.[75] While much research is underway regarding the potential cardiovascular health benefits of exercise in children, there is less information on the basic physiological potential of young athletes. Whether or not pre-pubertal children are able to specialize to strength or endurance events is not well studied. In fact the development of the aerobic and anaerobic systems in relation to each other in childhood is not well known. In both adults and adolescents, the physiological characteristics of elite athletes may be quite specialized. For example, sprinters have well developed musculature and high anaerobic performance, but they have an average or below average aerobic capacity. In contrast, long distance runners are typically lean and highly aerobic with below average anaerobic capacity.[10,47,53] Does this same level of specialization or anthropometric difference exist in pre-pubertal children, or is this a training effect? The question of metabolic specialization in this younger age group remains unanswered. This thesis is an attempt to explore this question further. The literature review will focus on muscle biopsy and twin studies which try to determine the genetic versus environmental influences to exercise capacity in children. As well the result of training studies in children will be discussed to see if there is any possible improvements to cardiovascular capacity from training before puberty. Finally a review of those studies which have directly compared the aerobic and anaerobic energy systems and their relationship to each other in children will be addressed.

LITERATURE REVIEW

Many eastern European sport systems assume that potential talent is determined at a young age. In fact it was assumed that as much as 70% of the maximal oxygen uptake and 80-90% of the anaerobic work capacity were dependent on heredity.[64] A common cliche amongst many coaches and exercise scientists is that if one wishes to be a successful Olympic athlete, they should chose their parents carefully. This attitude of genetic predisposition to exercise capacity persists even today despite more and more evidence suggesting that environmental and training effects may play a greater role in ultimate performance than genes alone. In reviewing the literature on the role of heredity in the development of the anaerobic and aerobic energy systems in children, two areas will be discussed; first, a brief review of the studies utilizing muscle biopsies in children, followed by a summary of the knowledge derived from twin studies and some of their major flaws.

MUSCLE BIOPSY STUDIES IN CHILDREN

As one would expect, the ethical constraints of performing muscle biopsies in children have limited the number of articles published in this area. Colling-Saltin in 1978 looked at the histochemistry of skeletal muscle in the human fetus and suggested that at birth 40% of the fibers were type I, 30% type IIa, and only 10% type IIb. It was felt that 20% of the fibers were undifferentiated at birth.[31] Bell et al. followed this up in 1980 with muscle biopsies on 13 six year old Swiss children (7 females and 6 males) and found that the percentages were now 58.8% type I, 21.5% type IIa, and 19.7% type IIb.[16] They felt that full differentiation had occurred by this age, and in fact they concluded that these child non-athletes showed the same fiber type distribution as sedentary adults. This was confirmed by Glenmark et al.[50] who followed 55 untrained men and 26 untrained women with muscle biopsies at both age 16 and 27. The type I fibre percentage changed from 51% to 54% in women and 55% to 48% in men in the 2 testing periods. Another interesting finding in both of these studies was that the muscle fiber type distribution did not correlate with maximal aerobic capacity (VO_{2max}). For example in the 6 year old children r = 0.24 for VO_{2max} and percent slow twitch oxidative fibers. Similar results were obtained by Mero et al. on 18 boys aged 11-13 years.[76] They found a low correlation (r = 0.3) for type II muscle fiber type and anaerobic power. These studies are in contrast to those performed in adult athletes who show a strong correlation between fiber type and aerobic or anaerobic performance.[51,54] One of the major weaknesses of these muscle biopsy studies is that they measure the structural rather than the functional characteristics of muscle tissue. The rate of utilization of the enzymes in the metabolic pathways, the mechanical efficiency of the muscle tissue, and the neuromuscular functioning of the body are all factors that play an important role in performance. Unfortunately these factors cannot be measured by muscle biopsies, and may explain the lack of correlation between fiber type area and aerobic or anaerobic performance in the child. As well, ethical constraints of performing biopsies in pre-pubertal children have significantly restricted the role of using this tool in further studying metabolic specialization in children.

In summary, the suggestion from these studies is that children do not have the inherent metabolic pathways to achieve specialization in either an aerobic or anaerobic performance. However, since specialization is seen in adulthood, it would appear that other factors such as hormonal influences, improvement in mechanical efficiency or training effects may play a role as the child matures. The effect of training was studied by Fournier et al. who showed that a training effect could occur in 16-17 year old boys.[48] In their study, an endurance training regime resulted in significant increases in type I and IIa muscle fiber area along with an increase in the activity of the enzymes of the Kreb's cycle. Likewise, sprint training showed increases in the activity of the glycolytic enzymes. Unfortunately, a similar study has not been done in pre-pubescent children and therefore the question of whether or not metabolic specialization exists in childhood remains.

TWIN STUDIES

Another method that has been used to determine the effects of heredity on athletic performance, is to study twins. This was felt to be the "gold standard" for non-invasive testing and has led to many of the assumptions that are present in the exercise community today. In 1971, Klissouras compared monozygotic and dizygotic twin pairs to factor out the genetic component to performance measures. They studied 15 pairs of male monozygous (MZ) and 10 pairs of male dizygous (DZ) twins whose ages ranged from 7-13 years. All subjects were exercised to exhaustion on a treadmill to determine their VO_{2max}. The intrapair differences between MZ and DZ twin pairs disclosed the variability in aerobic power to be 93.4% genetically determined. Similar results for anaerobic capacity and maximum heart rate revealed 81.4% and 85.9% respectively.[57] They followed up this study in 1973 with a wider age group, studying 23 MZ and 16 DZ twins aged 9-52 years, and found similar results with VO_{2max} showing greater intrapair differences among DZ than MZ twins. Although both of these twin studies as well as another study by Komi and Karlsson[61] showed such strong heritability estimates, their results were not reproduced by other authors. Howald[52] in 1976 suggested that environmental influences (especially physical activity) were more important in predicting physical performance capacity than genetic factors. Using 11 pairs of MZ twins and 6 pairs of DZ twins, he found no statistically significant intrapair differences between the two groups. However, when one member of the twin pair was put on a training program for 23 weeks, significant differences were found for VO_{2max}, heart volume, and muscle enzyme activity. Adams et al. also found similar results.[1] Unfortunately both of these studies used subjects who were definitely post-pubertal and therefore more likely to have been affected by varying environmental influences than pre-pubertal children would.

In their 1991 twin study, Fagard et al.[46] tried to factor out the effect of environmental influences by utilizing a questionnaire to determine past and present health status, smoking habits, alcohol consumption, and previous and current sports participation. They studied 29 pairs of MZ twins and 19 pairs of DZ twins with age range 18-31 years. After adjusting for environmental influences, they determined that the genetic variance for peak oxygen uptake was 66% and for anaerobic capacity 57%. These numbers were much lower than the initial estimates by Klissouras and Komi et al., but they still suggested a significant genetic contribution to aerobic and anaerobic performance. This same group of authors also tried to study 6-8 year old MZ and DZ twin pairs, but because of methodological difficulties they could not perform expired gas analysis and therefore did not report maximal oxygen uptake.[22] However, they did perform echocardiographic analyses of these children and found no significant genetic effect on left ventricle internal diameter or wall thickness. Their conclusion was that the significant genetic inheritance of maximal aerobic power was due to non-cardiac factors or to cardiac factors which were only expressed during exercise.

In trying to summarize all the results of twin studies, Bouchard et al. in their excellent review article in 1992 indicated that the "magnitude and nature of the interaction effects between the genotype and the level of physical activity and training remains unknown."[27] They cautioned that many factors need to be controlled in twin studies, including sample size, differential effects of age and sex according to twin types, and differences in means and variances between the twin populations. In 1983 they had reviewed all the twin studies which had controlled for these factors, and found that the overall genetic contribution to maximal aerobic capacity was probably about 60%.[29] However, their group went on to do much more exhaustive work on nuclear family studies including siblings, twins and parent-child relationships. These studies suggested less than a 25% heritability estimate for VO_{2max} once age, gender, body mass and composition had been controlled.[65] It was felt that the differences between these nuclear family studies and the previous twin studies was because of problems encountered in differentiating the common environmental effect shared by twins. Bouchard states "most of the individual differences in aerobic performance phenotypes in the untrained state are caused by nongenetic factors, such as habitual level of physical activity, dietary factors, smoking habits, and other lifestyle components. The genetic effect for various aerobic performance phenotypes is generally low and in some cases zero."[27]

Thus it appears the pendulum has swung from the early 1970's when it was felt that greater than 90% of VO_{2max} was genetically determined, to the present state where it appears that environmental factors are the major influence on VO_{2max}. As with many areas of science, the definite answer remains unknown, but probably lies somewhere between the two extremes.

EXERCISE PHYSIOLOGY AND TRAINING STUDIES IN CHILDREN

First a brief discussion of the concept of physical fitness and some of the results of training studies in children will be presented. This will be followed by a review of those studies specifically comparing the relationship of aerobic and anaerobic energy systems in children.

PHYSICAL FITNESS

Malina has stated that physical fitness consists of: i) cardiovascular endurance, ii) muscular strength and endurance, iii) flexibility, iv) body composition (especially fatness), v) motor skills including agility, balance, coordination, and speed.[68] Each of these areas has been reviewed extensively, but for purposes of my discussion, I will concentrate on cardiovascular endurance as a measure of physical fitness. Cardiovascular endurance is often synonymous with aerobic capacity. It can be expressed as maximum oxygen consumption or $V0_{2max}$. $V0_{2max}$ can be measured in different ways. The two most common methods are to have subjects run on a treadmill or else cycle on a bicycle ergometer. Different studies have utilized these varying methods and have yielded contrasting results. The bicycle ergometer is relatively inexpensive and portable, but has the disadvantage of engaging a smaller muscle mass which may cause local fatigue and terminate exercise before actual maximal capacities have been reached. The treadmill engages a larger muscle mass and improves the chances of obtaining a true aerobic capacity limited by central rather than peripheral factors. Its major disadvantages are that it is more expensive and less portable than a cycle ergometer. Boileau et al.[25] reported $V0_{2max}$ values of 7-8% higher on the treadmill than the cycle ergometer. More importantly, it was found that those athletes who were trained on a running program and were tested on a treadmill had higher $V0_{2max}$ results than those trained on a running program and tested on a cycle ergometer. This has been a flaw in some training studies.

Krahenbul et al.[62] reviewed the normal $V0_{2max}$ patterns of growing children who were not on any specific training program. They compared over thirty different cross-sectional and longitudinal studies which included 5,793 males and 3,508 females and came up with the following conclusions. In terms of absolute $V0_{2max}$ expressed in l/min., males and females are similar until age 12. Then males show a progressive increase, while females decrease such that at age 16, males have 50% greater $V0_{2max}$ than females. This difference persists into adult life. It was felt this difference could be related to; i) greater development of muscle mass in males due to testosterone secretion during the growth spurt, ii) increased hemoglobin concentration in males versus females again 2^{o} to testosterone secretion, iii) more time spent performing heavy exercise and its social importance in males at this age group. In terms of relative $V0_{2max}$ expressed in ml/kg/min., males tend to show little or no increase throughout adolescence, while females show an actual decrease. The difference between the two groups at age 16 is approximately 32%. The decrease in females is felt to be related to the increased subcutaneous fat in females at this age. Because of this, it has been suggested that lean body mass (LBM) may be a better unit of weight measurement. However, studies utilizing LBM have failed to show any greater predictive power than those utilizing total body mass. This may be because of the inherent difficulties in measuring LBM through doubly indirect measurements as pointed out by Martin et al.[69]

Whether or not training can alter these normal growth changes in $V0_{2max}$ is still controversial. Bale[9] has suggested exercise in pre-adolescent children causes minor changes at the peripheral level, such as improved oxygen extraction and a biochemical adaptation in the trained muscles, whereas in post-adolescence, exercise changes central factors such as stroke volume (SV) and cardiac output (Q). Sady[89] agreed that certain improvements such as Q, SV, and heart rate (HR) did not differ between children and adults. However, he felt that children and adults differed in oxygen extraction capability and local muscular blood flow. Bar-Or[10] also felt that a-v02 diff did not change in children during exercise because it was already near maximal levels at rest.

CROSS-SECTIONAL TRAINING STUDIES IN CHILDREN

Many of the early studies fell into this category. Typically a group of physically active children were compared to a group of physically inactive children. These types of studies allowed for large numbers of children to be assessed over a short time period. Although relatively easy to conduct, these studies have a major flaw in that they cannot partial out the effects of growth and maturation from those of training. Many of these early studies [6,7,36,71,88,96,100] reported that the $V0_{2max}$ was higher in the trained group of children than in the untrained group. The difference appeared to be more pronounced as the child became older. However, a big flaw in this line of thinking is the concept of pre-selection. That is, many of these studies looked at elite athletes in the trained group. It is possible that these athletes migrated to their sport because of natural genetic endowment thereby falsely inflating $V0_{2max}$ values in the exercise group. Thus, although cross-sectional studies imply an improvement in $V0_{2max}$ in children who are engaged in competitive sports, they do not let us make any definitive statements about the relative importance of age, genetic disposition, growth, maturation and training to cardio-respiratory capacity.[102]

LONGITUDINAL TRAINING STUDIES IN CHILDREN

Longitudinal studies provide a better research design because subjects in the trained group can be matched with an identical control group who differ only in the amount of physical activity they undertake. Therefore, changes due to growth and maturation can be accounted for. Despite this proviso, longitudinal studies have still given quite conflicting results.

Studies showing no improvement in VO2max

In general, studies showing no improvement with training are fraught with poor methodological design. Several studies did not have control groups.[14, 17, 34, 55, 78] Even when control groups were used, I could not find any study (other than the twin study by Weber et al.[106]) that matched subjects by biological age. Most studies matched children by chronological age, and this is a significant problem especially before puberty. In this age group, children with a similar chronological age can have quite variable levels of maturity. Therefore, the differential effects of growth hormone, bone age, and body size are not accounted for in studies that only compare children by biologic age. As well, most studies utilized too heterogeneous an age group, thus possibly contaminating their samples with some children who had gone through growth spurts.[30, 38, 45, 66, 70, 95, 103, 105] In addition many of the studies used children who were too young. This was especially evident in the study by Yoshida et al.[107] who found no training effect in 5 year old children. Several authors have indicated that aerobic capacity may not be trainable until a child achieves his peak growth spurt.[36, 59, 77] This may not occur until age 14 in boys.

A further problem is the lack of an adequate intensity or duration in the training protocol. Bar-Or and Zwiren[14] studied 9-10 year old boys who were part of an increased physical education program 3-4 times per week for 20-25 minutes. They were trained for a 9 week period. Mocellin and Wasmund[78] used interval training in boys and girls aged 8-10 for 7 weeks. Stewart and Gutin[95] studied 10-12 year old boys who underwent interval training for 8 weeks. None of these longitudinal studies showed an improvement in VO_{2max} with training. As pointed out by Vaccaro and Mahon[102] and later reiterated by Rowland[84] and Pate and Ward[80] none of these studies satisfied the American College of Sports Medicine (ACSM) criteria for improving aerobic fitness.[3] Massicotte and MacNab[70] performed an interesting training study to look at this problem of exercise intensity on VO_{2max}. Boys aged 11-13 were exercised at three different levels of HR intensity. One group exercised at HR's of 130-140, a second group at HR's 150-160, and a final group at HR's 170-180. Only the latter group showed an improvement in VO_{2max} averaging 11%.

The problem of pre-selection that was seen in cross-sectional studies is also evident in longitudinal studies. Daniels and Oldridge[38] for example found no improvement in VO_{2max} in fourteen boys aged 10-15 who had been distance trained for 22 months. Their subjects started with a mean VO_{2max} of 59.5 ml/kg/min. It could well be that these subjects were already functioning at their maximal capacity, and therefore their ability to increase aerobic capacity any further would be limited. Cumming et al.[34] and Kellet et al.[55] had similar results with subjects whose VO_{2max} ranged up to 65 ml/kg/min.

Studies showing an improvement in VO2max

Those studies which avoided the pitfalls mentioned in the previous section have for the most part reported an improvement in VO_{2max} with endurance training. For example Ekblom[43] found a 10% increase in VO_{2max} in 11 year old boys who were trained on a running program for 6 months. No improvement was found in aged matched controls who were not trained. Vaccaro and Clarke[100] followed young swimmers aged 9-11 who were training 4 times per week for 7 months and found a 15% improvement in VO_{2max}, while untrained controls only improved 5%. Brown et al.[30] reported an improvement in VO_{2max} of 26% in twelve girls aged 8-13 who performed cross-country run training for 12 weeks. These as well as other training studies in children were reviewed by Rowland in

1985. In his review of the literature, he found 9 studies which appeared to utilize training programs of adequate frequency, intensity, and duration to improve aerobic performance. Of these, 8 studied $V0_{2max}$ specifically. Six of these eight studies showed an improvement in $V0_{2max}$ averaging 14% (range 7-26%). Rowland summarized his review by stating that the "data appear to indicate that when endurance training programs are of sufficient duration and intensity an improvement in aerobic power in children can be elicited similar to that observed in adults." Further reviews of this topic have come to similar conclusions. Pate and Ward[80] were only able to find 12 training studies in children under 13 years of age that met the criteria of proper experimental design with adequate training protocols and statistical analysis. Eight of the twelve studies showed a clear improvement in relative $V0_{2max}$ in the experimental group. This increase averaged 10.4% (range 1.3 - 20.5%). The average increase in the control groups was 2.7% (range -3.3 - +9.9%). Their conclusion was that pre-pubescent boys can physiologically adapt to endurance exercise training, but to a lesser extent than post-pubescent boys. This view was also supported by Vaccaro and Mahon[102] as well as Krahenbul et al.[62] in their review papers.

Thus it now appears that the question of aerobic trainability in children has been answered, and it is accepted by most scientists in the pediatric exercise community that pre-pubertal children can marginally improve aerobic capacity with training. Unfortunately these training studies do not address the issue of whether or not children can specialize to an aerobic or anaerobic phenotype, and the question of metabolic specialization in pre-pubertal children remains unanswered.

AEROBIC VERSUS ANAEROBIC PERFORMANCE IN CHILDREN

One way to approach the question of genetic influence on athletic performance without having to perform muscle biopsies or do twin studies is to study the relative contributions of aerobic and anaerobic energy pathways in the same child. In other words, the concept of metabolic specialization. It can be argued that if there is a genetic predisposition to performance, then pre-pubertal children with high aerobic capacities will perform better in endurance events, while those with high anaerobic capacities should excel in sprint events. Surprisingly, this concept has not been well studied in prepubertal children. In fact, it appears that the opposite may be true in children. Numerous anecdotal reports have indicated that the child who is the best sprinter in his class is often the best long distance runner as well.[10] Some authors have challenged these observations by stating that the results may be influenced by early maturation of body size or skill level in those children who perform well. Although this may be a factor, those studies which have controlled for body weight, height, and age have still shown a high correlation between maximal aerobic performance and maximal anaerobic capacity in children. For example, Inbar and Bar-Or studied 8-12 year old swimmers and found that those who did best on a Wingate anaerobic test also had the highest maximal oxygen uptake.[53] As well, Davies et al.[39] showed a strong correlation ($r = 0.8$) between anaerobic power (as measured by the Margaria step test) and VO_{2max} (as measured on a bicycle ergometer) in 92 boys and girls aged 6-16 years. Palgi et al. used a treadmill to measure VO_{2max} and the Wingate test for measuring anaerobic capacity in 30 girls and 28 boys aged 10-14 years old. They also found a high correlation between these two measures ($r = 0.7$).[79] Falk and Bar-Or[46] tried to isolate children across different maturational levels to see if this had an influence on metabolic specialization. Their results showed strong correlation's between aerobic and anaerobic power in the pre-pubertal and mid-pubertal age groups ($r = 0.73$ and 0.87 respectively). However the late pubertal group showed lower correlation ($r = 0.54$) suggesting that specialization may not occur until after puberty or at least late adolescence. One concern with this study however was that the sample sizes in the 3 groups was small (n = 5 in the late pubertal group) and there was unequal sample sizes. Krahenbul et al.[63] also suggested a difference before and after puberty. They studied 6 boys at age 10, and then again at age 17. They found that the correlations between aerobic and anaerobic capacity were higher at age 10 and lower at age 17, suggesting that some specialization had occured after puberty. Thorland et al.[99] looking at female sprinters came to similar conclusions. Although all these studies showed good correlation (suggesting no specialization occurs in children), they all suffered from various methodological flaws. These include;

i) the age ranges studied were quite variable and may have contained many children who were post-pubertal.

ii) blending male and female results may be acceptable in the very young age groups, but may lead to differences in the older subjects.

iii) the effects of training in the subjects was not controlled.

iv) poor protocol for determining VO_{2max} in children - especially in the Davies et al. study.

Another concern is that if one is trying to determine specialization, it may be wiser to sample those subjects with better performance results. Of interest, I have only been able to locate a few papers that studied these characteristics in elite pre-pubertal subjects. Mayers and Gutin[73] studied 8 elite male cross-country runners aged 8-11 years and found a lower correlation (r=0.46) between anaerobic capacity on Wingate and aerobic capacity on treadmill testing in this group of subjects than in a similar age matched group of non-running subjects (r=0.8). This would suggest that specialization was occurring in the elite running athletes. Although not reporting actual r values, Mero et al.[76] also studied elite sprinters (n=3) and elite endurance runners (n=4) aged 11-13 in Finland. Although their sample size was small, they did not reproduce the Mayers and Gutin results. In their study there was no significant difference between the 2 groups with the sprinters having a

VO_{2max} of 57.5ml/kg/min and the endurance runners 60.5ml/kg/min. The results from the Mayers and Gutin study were interesting in that they suggested that genetic specialization could occur in the pediatric age group. However these results should be taken with caution since all the subjects in the running group were undergoing a rigorous training program for at least 2-5 years prior to the testing procedures. It may be that the training program induced changes in the muscle fibers and allowed for central adaptations to occur. Thus it would be the training effects rather than genetic predisposition that resulted in the specialization seen in this study.

In summary, those studies comparing the relationship between the aerobic and anaerobic energy systems in the same child have shown some conflicting results. Most studies have suggested that there is no metabolic specialization[10, 39, 53, 76, 79, 83] . A few studies have hinted that specialization may occur after puberty[46, 63, 99] . One study[73] has suggested that specialization does exist if an elite enough population is sampled.

STATEMENT OF THE PROBLEM AND PROPOSED STUDY

The issue of metabolic specialization to aerobic or anaerobic phenotypes has not been well addressed. There is an assumption that it does exist genetically and therefore many coaches have implemented aerobic or anaerobic training programs prior to puberty to try to maximize performances in their athletes. This study is an attempt to address the question of metabolic specialization in pre-pubertal children. It is apparent from the literature review that no clear consensus has been reached regarding this question. The ideal study would look at a group of untrained children who performed well at either a sprint or an endurance discipline and then follow them longitudinally through puberty to determine whether or not their ratio of anaerobic to aerobic exercise capacity changed through the pubertal period. The volume, intensity, and frequency of their training would have to be controlled during the study period. Obviously this type of longitudinal study would be difficult to perform.

An alternate approach would be to study a group of pre-pubertal children at a fixed point in time before they have undergone any rigorous training protocol. This would give us a group of subjects with no influence of either maturation or training effects. These children would then undergo both field and laboratory tests to determine if those with the better aerobic capacity had the lower anaerobic capacity and vice versa. The field tests would also act as a screening method to study sub-groups of individuals with the better sprint and endurance run times. If results show no specialization in this age group, then coaches could be instructed to delay more vigorous training protocols until after the child has attained puberty.

DEFINITIONS

Endurance run:	for purposes of this study, the run distance was set at 1600 yards. This is because the grass track at the school measured 200 yards. For this age group, it was felt this would be an adequate test of aerobic performance.
Sprint run:	a concrete track measuring 50 yards was used. It was felt this would be more of an anaerobic test than 100 yards, which in some children would incorporate a significant aerobic component.
Anaerobic capacity:	the total power output during a 30 sec. Wingate cycle ergometer test. Considered a rough measure of lactic acid component of non-oxidative metabolism.
Mean power:	the average power generated during the Wingate test. Determined by dividing the total power by 30 sec.
Anaerobic power:	the highest 5 sec. power output during the 30 sec. Wingate test. Considered a rough measure of alactate component of non-oxidative metabolism. Also known as peak power for purposes of this study.
Aerobic capacity:	peak oxygen uptake which for purposes of this study will be determined by cycle ergometer testing.
Fatigue Index:	ratio between the lowest and highest 5 sec. power output during the Wingate test.

Both the Wingate anaerobic power and anaerobic capacity tests have been found to correlate highly with measures of sprint activity such as the 100m dash.[11] As well, there is a high correlation between maximal or peak oxygen uptake and long distance running performance such as the 3000m race.[8]

PURPOSE OF THE STUDY

The purpose of this study is to determine whether metabolic specialization to either aerobic or anaerobic energy systems occurs in pre-pubertal children.

HYPOTHESES

1. Those children with the best sprint performance will have a higher anaerobic capacity, while those with the best endurance performance will have the higher aerobic capacity.

2. Those children with the highest aerobic capacity will have the lowest anaerobic capacity and vice versa. This will be reflected by high (significant) negative correlation's between peak anaerobic and aerobic power measurements.

3. The Wingate test will correlate highly with the sprint performance time, while the cycle VO_{2max} will correlate highly with the endurance run time.

LIMITATIONS

The results of the study will be limited by:

1. Errors of data collection by the testing equipment. This will be minimized by calibrating before each test.
2. VO_{2max} and Wingate testing protocol. Protocols used by previous researchers on similar aged children will be followed.
3. Controlling for the effects of training. The questionnaire process will exclude those subjects from track clubs or those involved in regular training.
4. Choice of dependent variables. It is felt that even in this younger age group, the VO2max is an acceptable measure of aerobic fitness[11,22] and the Wingate test for anaerobic capacity.[4]
5. Motivation of the subjects to perform the tests. Both the field and laboratory tests will be performed in groups so that each child will be encouraged to keep up with their peers. The concept of pacing will be explained and taught to each group prior to the endurance run. As well prizes will be given to the subjects who complete all the tests.
6. Sample size. The sample size will be limited by the costs of conducting the laboratory tests and the availability of volunteer subjects from the school district.
7. Environmental conditions. The nature of the field and the weather conditions at the time of the field tests may influence the results. We will attempt to do all the field tests during similar conditions over the summer. If it is raining, the field tests will be postponed.

DELIMITATIONS

The results of the study will be delimited by:

1. Studying subjects of one school or district. This limits the generalizability of the results, but it does help restrict differences related to cultural or socioeconomic factors.
2. Age of the subjects. By studying children between the ages of 8-11, we are hoping to ensure there are no influences of growth or maturational effects influencing metabolic specialization.

METHODOLGY

Subjects

The data for this study was collected using subjects from the Homma Tomekichi elementary school in Richmond, British Columbia during June, 1994. Initial interest in the study was discussed with the school principal, and then consent forms (Appendix A) were mailed to the parents of all the children in grades 3-5 who were between the ages of 8-11 years old. 44 of the 115 available students (28 males, 16 females) returned their consent forms for the study. These students were then given a questionnaire (Appendix B) to determine what type of extra-curricular sporting activities they were involved in. The number of weekly hours spent in these sports or on any other regular training was estimated. None of the subjects was part of a track or running club, although one boy had competed in the 3000m race at the provincial elementary track and field championships in the previous year. He did not do any training for this. Although some of the children were quite sedentary, the majority were involved in recreational sports outside of school. The most popular sports were soccer, baseball, and swimming. As a result most of the children were involved in regular sporting activities averaging 6-8 hours per week. No subject volunteered more than 10 hours/week of sport and no subject was on a fixed running or training program. Prior to testing, all subjects were cleared medically to participate in the study. Only one boy had asthma which was well controlled with inhalers as required.

Testing Procedures

The field tests and the laboratory tests were performed on separate days for each child. The children were divided into eleven groups of four. Each group rotated through four stations with two field tests and two laboratory tests. The two field tests were performed on the same day, but the two laboratory tests were performed on separate days (never on the same day as a field test). Some children had the field tests first while others had the laboratory test first.

Field testing

Prior to the field tests all the children were advised regarding the concept of pacing and had a pacer run with them to encourage finishing the endurance run. The sprint run was always performed before the endurance run.

The sprint run was performed on an asphalt tarmack at the school. A 50 yard distance was measured off. A stop watch measuring to 1/100ths of a second was used at the finish line. Each subject repeated the run twice and the best time was recorded. Subjects were given verbal encouragement by the other children and the examiners.

The endurance run was performed on a grass field at the school. One lap of the field measured 200 yards, and the subjects ran eight laps. This test was only performed once. As mentioned, the children were taught to pace themselves but they did run in groups, so were encouraged to try to keep up with the others in the group. The examiners did run with the children to give encouragement. It should be noted that the weather conditions were quite similar for all the days of field testing.

Laboratory testing

The laboratory testing was conducted on two separate days, but not always in the same order for each child. One day consisted of anthropometric measurements and either a Wingate test or a cycle ergometer test. The next day would consist of the remaining laboratory test.

Anthropometric tests

The same examiner tested on each day. Basic measurements were performed for height (standing barefoot), weight (wearing gym shorts and T-shirts), and sum of six skinfolds. The skinfold measures were performed in triplicate using Harpenden calipers at the triceps, subscapular, abdomen, suprailiac, anterior thigh, and medial calf sites. The averages at each site were summed to create a skinfold score (SOS) for each subject.

<u>Anaerobic Laboratory Measurements</u>

A portable Monark cycle ergometer model 814E was brought to the school and used to perform a 30 second Wingate Anaerobic Test. Prior to the test the subjects were allowed to adjust the seat height to get comfortable and they would warm-up for 3 minutes at low exercise intensity. A force setting of 75g/kg resistance was applied for each subject. This setting has been shown to reproduce optimal force in children.[40, 41, 53] Measurements for anaerobic capacity, and peak and mean anaerobic power as well as fatigue index were determined.

<u>Aerobic Laboratory Measurements</u>

Peak oxygen uptake (VO_{2max}) was determined utilizing a progressive exercise test on a portable Quinton uniwork cycle ergometer model 845 brought to the school. The child maintained a pedalling rate of 50 rev/min. while the load was increased by 25W every 2 minutes. A Medical Graphics 2001 metabolic cart was used for collection and analysis of expired gases. VO_{2max} was considered to be the highest VO_2 value obtained over two consecutive 15 sec. periods. The test was terminated usually based on subject volitional fatigue such that they could not maintain their pedalling rate or their position on the bike. The test was also terminated if 2 of the following 3 parameters was achieved:

1) Plateau in VO_2 response or < 2ml/kg/min rise in VO_2 with a progressive increase in slope.
2) RER > 1.0.
3) HR > 195 beats/minute.

The subjects were allowed to warm-up for 2-3 minutes on the cycle prior to the testing. As with the Wingate test, the subjects were given verbal encouragement both by the examiners and the other children in their group.

STATISTICAL ANALYSIS

Two subjects (both female) did not complete all the tests. Therefore we had 42 subjects (28 males, 14 females) for whom we measured 14 variables. This included age, height, weight, sum of skinfolds (SOS), sprint time (50 yards), endurance run time (1600 yards), anaerobic capacity (total work), peak anaerobic power, mean anaerobic power, fatigue index (FI), heart rate (HR), aerobic capacity, ventilation (VE), and oxygen saturation (SaO2) (Appendix C). The laboratory tests were calculated both as absolute values and relative values (absolute values/weight in kg.)

Pre-determined performance criteria from the field tests were used to separate the better performing subjects into a sprint (S) and an endurance (E) group. Sprint athletes were those children who ran under 8.50 seconds on the 50 yard test. Endurance athletes were those who ran under 480 seconds in the 1600 yard test. These values were extrapolated from the times recorded by the last place finishers in the Provincial Elementary Track and Field Championships in 1993 for the eight year old age group (ie. likely the minimum times required to compete in the Championships).

The means and standard deviations for all the variables were calculated. Zero order correlation matrices were constructed for both the group as a whole, as well as for the sprint and endurance groups. Tests of significance on individual r values were performed to determine if the correlation was significantly different from $r=0$. $p <.05$ was used for the level of significance in the correlational statistics.

In addition a Hotelling's T^2 test was performed between the sprint and endurance groups to determine if there was significant differences between the groups with respect to aerobic, anaerobic, or anthropometric parameters. The level of significance was set at $p < .05$. All statistical analysis was performed on a SYSTAT computer program.

RESULTS

A total of 44 subjects enrolled for this study. One female did not participate in the 1600 yard run or the laboratory tests and another female did not participate in the bicycle ergometer and therefore their results were excluded. This left us with 42 subjects (28 males and 14 females) for whom we had complete data. The physical characteristics of these subjects is shown in Table 1. The mean age of all subjects was 9.31 years (range 8-11 years). Males and females were similar in physical characteristics with only a slight trend for males to be heavier (36.09 kg. males vs. 31.79 kg. for females) (p=0.10). All subjects were felt to be pre-pubertal and well below the average age of peak height and weight velocity (males ≈ 14 years, females ≈ 12 years [67]).

Table 1

Physical Characteristics

All Subjects

	Females (n=14)	Males (n=28)	Total (n=42)
Age (yrs)	9.21±0.80	9.36±0.91	9.31±0.87
Ht (cm)	136.24±6.19	139.58±7.84	138.47±7.43
Wt (kg)	31.79±3.23	36.09±9.30*	34.66±8.05
SOS (mm)	48.38±16.23	51.60±30.95	50.53±26.77

*p=0.10

The field test results (Table 2) showed a trend for males to perform better. In the 50 yard run the males had an average time of 9.12 sec. while the females ran 9.32 sec. In the 1600 yard run the males averaged 545.57 sec. while the females averaged 586.64 sec. These differences did not reach statistical significance but are similar to previous studies. [39, 79]

Table 2

Field Test--Run Times

All Subjects

	Females (n=14)	Males (n=28)	Total (n=42)
50 yd run (sec)	9.32±0.65	9.12±0.64	9.19±0.64
1600 yd (sec)	586.64±80.28	545.57±92.62	559.26±89.87

In terms of laboratory parameters, there was a significant difference between the males and females in some aerobic indices (Table 3), as well as anaerobic power and capacity (Table 4). Both absolute and relative VO_{2max} were higher in males reaching a significant difference with respect to absolute VO_{2max}; 1.59 l/min (M) versus 1.30 l/min (F) ($p < 0.001$). Ventilation was also higher in males; 55.48 l/min (M) versus 47.61 l/min (F) ($p < 0.01$) suggesting larger lung capacities. Anaerobic power (both absolute and relative) was higher in the males; 294.36 Watts (M) versus 232.21 Watts (F) ($p < 0.01$) for absolute peak power and 8.29 W/kg (M) versus 7.23 W/kg (F) ($p < 0.05$) for relative peak power. Similarly, mean power was higher at 6.12 W/kg (M) versus 5.36 W/kg (F) ($p <0.05$).

Table 3
Aerobic Parameters
All Subjects

	Females (n=14)	**Males (n=28)**	**Total (n=42)**
Absolute VO_{2max} (l/min)	1.30±0.19	1.59±0.22**	1.49±0.25
Relative VO_{2max} (ml/kg/min)	41.21±5.61	45.41±9.55	44.01±8.60
Ventilation (l/min)	47.61±5.82	55.48±9.74*	52.86±9.34
Heart Rate (bpm)	203.93±11.19	198.14±11.17	200.07±11.38
SaO_2 (%)	95.29±1.33	94.54±1.60	94.79±1.54

* p<0.01
**p<0.001

Table 4

Anaerobic Parameters

All Subjects

	Females (n=14)	Males (n=28)	Total (n=42)
Absolute Peak Power (W)	232.21±58.11	294.36±67.91**	273.64±70.62
Relative Peak Power (W/kg)	7.23±1.57	8.29±1.27*	7.94±1.45
Relative Mean Power (W/kg)	5.36±1.00	6.12±1.02*	5.87±1.06
Anaerobic Capacity (kJ)	5.10±1.02	6.45±1.25**	6.00±1.33
Fatigue Index (%)	58.34±16.96	55.74±9.86	56.6±12.52

* $p<0.05$
**$p<0.01$

Table 5

Zero Order Correlation Matrix for the 42 Subjects

Sex	1.00											
Age	0.08	1.00										
Height	0.21	0.54	1.00									
Weight	0.26	0.48	0.78	1.00								
SOS	0.06	0.29	0.34	0.81	1.00							
50 yd run	-0.15	-0.08	-0.04	0.32	0.64	1.00						
1600 yd run	-0.22	0.12	0.07	0.39	0.62	0.77	1.00					
Anaer. Cap.	0.48	0.41	0.66	0.64	0.26	-0.35	-0.20	1.00				
Rel PP	0.35	0.08	0.06	-0.18	-0.39	-0.63	-0.52	0.51	1.00			
Rel MP	0.34	-0.09	-0.19	-0.40	-0.56	-0.73	-0.63	0.43	0.85	1.00		
Abs VO_{2max}	0.56	0.15	0.49	0.35	-0.06	-0.44	-0.52	0.71	0.48	0.40	1.00	
Rel VO_{2max}	0.23	-0.30	-0.33	-0.63	-0.76	-0.63	-0.72	0.00	0.56	0.73	0.44	1.00

$p<0.05$ for r values ≥ 0.50

The zero order correlation matrix for the 42 subjects is shown in Table 5. Despite the inference that taller, bigger children do better in sporting events, this was not evident in this study. There were no significant correlation's for age, height, sex, or weight with either sprint or endurance run performance. The only anthropometric variable with a significant correlation was the sum of skinfolds. This correlated positively with both the sprint run ($r = 0.64$) and the endurance run ($r = 0.62$). This suggests that children with higher percentage body fat had higher run times and therefore poorer performances on the field tests. This was also evident in the laboratory tests, with $r = -0.76$ for VO_{2max} and -0.56 for relative mean power. Weight did play a role in some of the laboratory measures of performance with heavier children producing more total work ($r = 0.64$) on the Wingate, but lower VO_{2max} values ($r = -0.63$) on the bicycle ergometer.

With respect to the question of metabolic specialization, it is interesting to note that the correlation between 50 yard and 1600 yard run times was quite high ($r = 0.77$) ($p < 0.001$). Those children who did best in an aerobic performance event also did well in the anaerobic performance event. This would suggest no specialization in this age group. The laboratory measures of relative VO_{2max} and relative peak power ($r = 0.56$, $p < 0.05$) and relative mean power ($r = 0.73$, $p < 0.001$) were also positive and high, as was the r value for anaerobic capacity and absolute VO_{2max} ($r = 0.71$).

As noted in the statement of the problem, one possibility for lack of documentation of metabolic specialization in the pre-pubertal age group is that most papers have studied average individuals and not those who were better performers in either a sprint or endurance event. It can be argued that if metabolic specialization exists, it would be more likely in those individuals who are performing at a higher level. In adults, maturation or training may influence better performances, but in untrained pre-pubertal children, the better performances would have to be genetic and dominance of one energy system over the other would imply true metabolic specialization. The present study looked at this issue by isolating a subgroup of individuals from the sample of the whole group who met pre-determined performance criteria. Table 6 describes the physical characteristics of these individuals. The endurance group (E) ran 1600 yards in less than 8 minutes (480 sec.), while the sprint group (S) ran 50 yards in less than 8.5 seconds. There were 7 subjects who qualified in each group (6 males and 1 female in each group). Three males qualified in both groups. The results show no significant differences between the groups with respect to age, height, weight, or sum of skinfolds. Therefore it did not appear as if there were specific anthropometric factors influencing performance in this age group (ie. sprinters were not heavier and long distance runners were not leaner as seen in adults).

Table 6

Sprint Versus Endurance Group

Descriptive Data

	Endurance (N=7)	Sprint (N=7)	P Value
Age (yrs)	9.43±0.98	9.43±0.54	1.00
Height (cm)	139.71±6.04	138.71±7.56	0.79
Weight (kg)	34.33±4.93	31.17±4.87	0.25
SOS (mm)	38.77±13.00	28.66±3.61	0.07
50 yd run (sec)	8.71±0.24	8.40±0.20	0.02
1600 yd run (sec)	457.57±30.8	503.86±72.98	0.15

With respect to aerobic parameters (Table 7) and anaerobic parameters (Table 8), there were once again no significant differences between the sprint and endurance groups. The only trend was for the sprint group to have higher relative peak and mean anaerobic power on the Wingate test (9.43 W/kg (S) versus 8.67 W/kg (E) for peak power and 6.81 W/kg (S) versus 6.16 W/kg (E) for mean power). However, the sprint group also showed a trend towards higher relative VO_{2max} (52.03 ml/kg/min (S) versus 47.73 ml/kg/min (E)). Although surprising, this result further confirms that there is no specialization in this age group.

Table 7

Sprint Versus Endurance Group

Aerobic Parameters

	Endurance (N=7)	Sprint (N=7)	P Value
Absolute VO_{2max} (l/min)	1.70±0.24	1.61±0.27	0.50
Relative VO_{2max} (ml/kg/min)	47.73±9.25	52.03±7.97	0.37
Ventilation (l/min)	57.84±12.86	55.86±12.25	0.77
Heart Rate (bpm)	198.86±10.75	202.57±12.15	0.56
SaO_2 (%)	94.29±1.11	94.14±1.07	0.81

Table 8

Sprint Versus Endurance Group

Anaerobic Parameters

	Endurance (N=7)	Sprint (N=7)	P Value
Absolute Peak Power (W)	297.43±62.75	293.29±52.26	0.90
Relative Peak Power (W/kg)	8.67±1.25	9.43±0.87	0.21
Relative Mean Power (W/kg)	6.16±0.91	6.81±1.05	0.24
Anaerobic Capacity (kJ)	6.32±1.19	6.29±1.03	0.96
Fatigue Index (%)	51.46±12.47	51.37±11.60	0.99

The zero order correlational matrix for the subgroup of top performers is presented in Table 9. Once again, there were no significant correlation's between anthropometric measures and performance on either the sprint or endurance run. A more interesting result however, is the correlation between the maximal aerobic and anaerobic capacities. The r value for relative VO_{2max} and relative peak power was 0.82 ($p < 0.05$), while relative VO_{2max} and relative mean power was 0.88 ($p < 0.05$). These high positive correlation's suggest no metabolic specialization and are similar to values of $r \approx 0.7\text{-}0.8$ seen in previous studies.[10, 39, 73, 79] It did not appear as if the better aerobic athletes had lower anaerobic capacity and vice versa.

Table 9

Zero Order Correlational Matrix for the Subgroup of Top Performers

Sex	1.00											
Age	-0.32	1.00										
Height	-0.18	0.07	1.00									
Weight	-0.36	0.36	0.83	1.00								
SOS	-0.45	0.63	0.08	0.59	1.00							
50 yd run	0.32	-0.08	-0.02	0.24	0.45	1.00						
1600 yd run	-0.37	0.49	-0.10	-0.17	-0.07	-0.31	1.00					
Anaer. Cap.	-0.02	0.21	0.25	0.52	0.36	-0.06	-0.33	1.00				
Rel PP	0.42	-0.12	-0.15	-0.16	-0.33	-0.43	-0.27	0.64	1.00			
Rel MP	0.29	-0.07	-0.57	-0.46	-0.20	-0.33	-0.14	0.51	0.83	1.00		
Abs VO_{2max}	0.28	-0.07	0.20	0.42	0.20	0.11	-0.64	0.84	0.63	0.42	1.00	
Rel VO_{2max}	0.44	-0.08	-0.41	-0.40	-0.27	-0.39	-0.38	0.44	0.82	0.88	0.51	1.00

$p<0.05$ for r values ≥ 0.80

An unusual result in the subgroup of better performers, was a trend towards a negative correlation between 50 yard and 1600 yard run times ($r = -0.31$). While this did not reach statistical significance, it was much different than the high positive correlation of $r = 0.77$ seen for the whole group of 42 subjects (Table 5). This result raises the possibility that in the pre-pubertal age group, if a select enough group of subjects is sampled, there may be some influence of specialization in track events (ie. the better sprinter may not be as good a long distance runner as evidenced by the negative correlation). However, it should be noted that a r value of - 0.31 yields a p value > 0.99 and therefore this trend is not statistically significant.

DISCUSSION

PHYSICAL CHARACTERISTICS

With respect to physical characteristics and performance times, the males and females in this study showed no statistically significant difference, although the trend was for males to perform better. This trend has also been shown in previous studies [39, 79] that despite similar height and weight, males have better performance times than females. Different theories have been proposed for this phenomenon including the fact that it may be socially more acceptable for males to participate in sports so they have more of a training effect than females. The other possibility is that males have larger muscle tissue or lean body mass. This was not measured in our study, although the sum of skinfolds in the two groups was similar.

Not many studies have directly compared both aerobic and anaerobic parameters in males and females before puberty. Davies et al.[39], studied males and females at different pubertal stages. They used different protocol for determining the anaerobic indices compared to our study. Their anaerobic power was measured using a Margaria step test. While they reported no significant difference between males and females, unfortunately they did not report the results in tabular form and therefore trends could not be evaluated. With respect to aerobic indices, their results were similar to this study with pre-pubertal males having greater ventilation than females (48.76 versus 39.86 l/min.) and also greater absolute VO_{2max} (1.38 versus 1.16 l/min.). They reported these differences as being statistically non-significant, but it should be noted that their sample size was quite small and therefore the power of the study was lower. Palgi et al.[79] looking at slightly older children (mean age = 11.9 years) showed no significant difference between males and females for either aerobic or anaerobic parameters. However, similar to our study, there was a trend towards higher relative VO_{2max} in males (47.3 ml/kg/min.) versus females (42.9 ml/kg/min.) Rutenfranz et al.[87] looked only at aerobic parameters. Again the trends were for higher absolute and relative VO_{2max} in males versus females (1.45 l/min. versus 1.21 l/min. for absolute VO_{2max} and 49.0 ml/kg/min. versus 43.4 ml/kg/min. for relative VO_{2max}). Most other studies looking at pre-pubertal children have not directly compared males to females.[63, 73, 83, 98, 99, 104] While our study did show some significant differences, it should be noted that there were unequal n's in the two groups with greater variability in the females (who had the smaller sample size). This could lead to a Type I error in our results. Nevertheless, it is interesting to see that the trend in the literature is for boys to have greater aerobic and anaerobic capacities than females, even in the pre-pubertal age group.

Compared to adults, this study was similar to others in suggesting that pre-pubertal children have lower absolute values for VO_{2max}, while the relative VO_{2max} is not different[10, 47, 62, 67, 109] (Table 3). In contrast, the anaerobic capacities of the children in this study were much lower than adult values suggesting that children are not the equals of their adult counterparts in this regard (Table 4). This finding has also been noted in previous studies and may be secondary to decreased levels of glycolytic enzymes in children, especially phosphofructokinase, or it may be due to less reliance or a lower rate of anaerobic utilization of glycogen in children. Blimkie et al.[23] have described an anaerobic-aerobic power ratio which they believe increases as the child matures. Other authors[46] have postulated maturity related changes in hormonal and neuromuscular status as playing an important role in the development of the anaerobic energy system as the child grows.

METABOLIC SPECIALIZATION

The data from this study did not support the first hypothesis that those children with the better sprint performance would have the higher anaerobic capacity; 6.29 kJ (S) versus 6.32 kJ (E) (Table 8). There was however, a trend towards higher anaerobic power measurements in the sprint group. Mean power; 6.81 W/kg (S) vs. 6.16 W/kg (E), and peak power; 9.43 W/kg (S) vs. 8.67 W/kg (E) were both higher in the sprint group. The sprint and endurance groups also did not show a significant difference in aerobic capacity (Table 7). In fact, surprisingly, there was a trend for the endurance group to have a lower aerobic capacity; 47.73 ml/kg/min. (E) vs. 52.03 ml/kg/min. (S). These results along with the finding of high positive correlations between VO_{2max} and both peak power ($r = 0.82$) and mean power ($r = 0.88$) (Table 9) would all support the notion of lack of specialization in this age group.

In the whole group of 42 subjects, there was a tendency for the anaerobic measures to correlate higher with the sprint run than the endurance run (Table 5). For peak power r = -0.63 for 50 yard run and r = -0.52 for 1600 yard run. For mean power r = -0.73 for 50 yard run and r = -0.63 for 1600 yard run. Similarily, the aerobic measures correlated higher with the endurance run than the sprint run. For relative VO_{2max} r = -0.72 for 1600 yard run and r = -0.63 for 50 yard run. What is interesting however, is that the differences are not as large as one would expect. It would appear that the children in this study were using a significant proportion of both their aerobic and anaerobic energy pathways for both the 50 yard and the 1600 yard runs. This is different than adults where the estimate is that in events less than 10 seconds duration more than 85% of the energy supply comes from non-oxidative sources such as ATP and creatinine phosphate stores (anaerobic pathways). In contrast, those events lasting longer than 10 minutes in duration use aerobic metabolism for 85% of the energy supply.[2] One explanation for the disparity between children and adults may be that in the pre-pubertal age group children depend less on anaerobic metabolism.[10, 46] They have lower muscle glycogen and phosphofructokinase concentrations as well as a lower rate of glycogen utilization compared to adults. Because of this, children may switch over sooner to utilizing aerobic energy pathways even in distances as short as 50 yards. This could explain the lack of metabolic specialization seen amongst the children in this study.

Another possible explanation may be that in this young age group, children have not maximized neuromuscular factors which would improve mechanical efficiency and economy of running.[46] Therefore, even though one child may have a higher anaerobic capacity than another, the performance times of the two in a sprint run may be similar. This would make it harder to determine the true "metabolic specialist". Unfortunately neuromuscular factors are hard (if not impossible) to measure and were not specifically examined in our study. The feeling however is that these factors would continue to improve as the child matures and this would result in improvement in anaerobic power over time. This would lend credence to those studies that seem to suggest that metabolic specialization does not exist until after puberty.[46,63,99]

Another way to improve the likelihood of obtaining true metabolic specialists would be to improve the sampling protocol so that the more "elite subject" gets tested. An interesting trend was noted in our study when this was done. The subgroup of top performers (Table 9) showed a negative correlation between 50 yard and 1600 yard run times (the better sprinter did worse on long distance running); $r = -0.31$. This was different than the group as a whole (Table 5) who showed a high positive correlation ($r = 0.77$). Mayers and Gutin[73] found similar results. Unfortunately neither in their study nor in ours did the results reach statistical significance and therefore this finding should be interpreted with caution. This is especially the case when taking into account that the correlation between the maximal laboratory values in the present study were quite high and positive; $r = 0.82$ and $r = 0.88$ for VO_{2max} and peak and mean power respectively (Table 9). Despite this, there does remain the possibility that if an elite enough group of subjects is sampled (ie. by further lowering the performance criteria in the sprint and endurance run), then metabolic specialization may indeed be found in this age group.

The findings of this study did not support our second hypothesis of the children with the highest aerobic capacity having the lowest anaerobic capacity and vice versa. As previously indicated, the correlation between the 50 yard and 1600 yard run times was high and positive; r = 0.77 (Table 5). In addition the laboratory measures also showed high positive correlations with an r value of 0.71 for anaerobic capacity and absolute VO_{2max}, and r = 0.73 and 0.56 for relative VO_{2max} and relative mean and peak power respectively. The lab values may be a more true measure of actual aerobic and anaerobic relationship as the field measures may have been influenced by climactic conditions, the child's judgement of pace, and the motivational level of the group of subjects he/she was placed in for the run tests.

<u>VALIDITY OF FIELD TESTS</u>

The third hypothesis suggested that the cycle ergometer would correlate highly with the endurance run time and the Wingate would correlate highly with the sprint run time. This did appear to be the case in this study. The r value on the aerobic tests for relative VO_{2max} and 1600 yard run was r = -0.72 (Table 5). On the anaerobic tests, the relative peak power and 50 yard run showed an r = -0.63 and relative mean power and 50 yard run was r = -0.73. Although not being a direct focus of this study, these results are helpful for coaches and teachers as it suggests that even in the pre-pubertal age group, field tests can be used as an accurate screening method in selecting individuals with better physiological capacity. Previous authors have confirmed that field tests can be valid estimators of fitness in adolescents and adults.[10, 54, 73, 79, 99] One note of caution however is evident in Table 5. The correlations between field and laboratory results were much higher when expressed relative to body weight. For the 50 yard run r = -0.35 for anaerobic capacity (expressed in kJ with no correction for body weight) but r = -0.73 and -0.63 for mean and peak power (expressed in Watts divided by body weight). The same result was evident for the 1600 yard run with r = -0.52 for absolute VO_{2max} (expressed in l/min.), but higher for relative VO_{2max} (expressed in ml/kg/min.); r = -0.72. This finding has been confirmed by others[39, 98] and should be borne in mind when standardizing results of tests such as the Wingate or the cycle ergometer.

It was also interesting to note that the use of a cycle ergometer, as opposed to a treadmill, still showed significant correlation's with the run tests. This is despite the use of different muscles for cycling versus running, but suggests that either modality can be used as an accurate estimator of fitness for future studies in pre-pubertal children.

SUMMARY

Several longitudinal and cross sectional studies have shown that training can improve VO_{2max} in pre-pubertal children.[36, 45, 77, 91, 104] However, not much research has been published regarding the relationship between the aerobic and anaerobic energy systems and their development with respect to each other in pre-pubertal children. Specifically, the question of metabolic specialization in the pre-pubertal age group remains unanswered. This issue may play a central role in the development of training programs for pre-pubertal children. Many coaches believe that children have a genetic predisposition to excel in either an aerobic or anaerobic discipline and therefore training geared towards these events at an early age can optimize performance. If indeed specialization does occur in this age group, then these more intense training programs may be warranted. Research in adolescents and adults has shown evidence of specialization, but whether this is related to training effects and maturation or whether it is a true genetic predisposition is not known. Most of the published literature on pre-pubertal children has suggested that they are non-specialists. The present study was an attempt to better determine the question of metabolic specialization in the pre-pubertal age group.

42 untrained pre-pubertal subjects were compared on both laboratory and field measures of aerobic and anaerobic performance. The hypothesis was that if metabolic specialization was occurring in this age group, those subjects with the better aerobic performance would have the lower anaerobic performance and vice versa (ie. there would be high negative correlation's between the two parameters). The results did not support any evidence of specialization with high positive r values of 0.77 between 50 yard and 1600 yard run times, and 0.56 between VO_{2max} and peak anaerobic power. Unlike adults, there was no difference in the body type or anthropometric measures of those children who did better on the sprint run versus those who did better on the endurance run. There was a suggestion however that children with higher body fat did worse in both events. Also heavier children had lower VO_{2max} values. The r values stayed high ($r = 0.82$) for VO_{2max} and peak anaerobic power even as we sampled a select group of better performers in whom we thought there may be a better chance of documenting specialization. Although there was a trend for the sprint athletes to have higher peak and mean anaerobic power than the endurance athletes, these results did not reach statistical significance. In fact the sprint athletes also showed higher aerobic capacity than the endurance athletes. Thus it was felt that in the pre-pubertal age group, those children who perform best aerobically also do best anaerobically. These results support those of others[10, 47, 63, 99] that in the pre-pubertal age group metabolic specialization is not occurring, even in those children who perform better in sprint or endurance events.

The results of this study also confirm that children have similar aerobic capacities as non-trained adults. However, with respect to anaerobic indices, children are not as developed as adults. In fact, some tests which are considered anaerobic for adults (ie. 100m sprint) may involve the use of significant aerobic pathways in children. In other words children may compensate for their anaerobic deficiencies by switching over sooner to aerobic pathways than adults do.

Another finding in this study was the evidence of high positive correlation's between field tests and laboratory tests in the pre-pubertal age group. In fact, the r values achieved using a bicycle ergometer in this study ($r = -0.72$ for VO_{2max} to 1600 yard run and $r = -0.63$ for peak power to 50 yard run) were quite similar to values obtained using a treadmill in other studies.[63, 73, 79, 83] This would suggest that field tests are a valid estimate of physical fitness in pre-pubertal children and that either the cycle or treadmill ergometer can be used for testing laboratory measures of physiological capacity in this age group.

CONCLUSIONS

On the basis of the statistical analyses and within the limitations and delimitation's of this study, it would appear that metabolic specialization does not occur in the pre-pubertal age group. This is evidenced by high positive correlation's between sprint and endurance run times and also high positive correlation's between aerobic and anaerobic capacity in the same child. Untrained pre-pubertal sprint athletes show no significant differences in either VO2max or anaerobic peak and mean power compared to untrained pre-pubertal endurance athletes.

RECOMMENDATIONS

1. The results of this study would suggest that since pre-pubertal children are not metabolic specialists, there is likely no strong benefits from coaches implementing rigorous aerobic or anaerobic training programs in this age group.

2. This study only focused on the pre-pubertal age group. Future research might consider a longitudinal design studying untrained children who are either better sprint or endurance athletes at different Tanner or maturational stages. Comparing aerobic and anaerobic parameters at different maturational stages may help delineate whether the metabolic specialization seen in adults is a growth (maturation) or training effect.

3. The entry criteria we utilized in this study for sampling the better performers may still not be rigid enough to truly select "elite" subjects. Future studies may try to sample a more select group of untrained athletes but this may be difficult to find as our experience suggests that even in this young age group, many children have started training with track or running clubs.

REFERENCES

1. Adams, T. F. ; F.Yanowitz, A. Fisher, J. Ridges, A. Nelson, A. Hagan, R. Williams, S. Hunt. "Heritability of cardiac size: an echocardiographic and electrocardiographic study of monozygotic and dizygotic twins". Circulation. 71:39-44, 1985.

2. Adams, W. C. "Exercise Physiology". In Adams, W.C. (ed.). Foundations of Physical Education, Exercise and Sport Sciences. 80-126, 1991.

3. American College of Sports Medicine. "Position statement on the recommended quantity and quality of exercise for developing and maintaining fitness in healthy adults". Med. Sci. in Sports and Exer. 10: vii-x, 1978.

4. Andersen, K. L.; V. Seliger, J. Rutenfranz, J. Skrobak-Kaczynski. "Physical performance capacity of children in Norway". Eur. J. Appl. Physiol. 35:49-58, 1976.

5. Armstrong, N.; J. R. Welsman. " Assessment and Interpretation of Aerobic Fitness in Children and Adolescents". Exer. and Sport Sci. Rev. 22: 435-476, 1994.

6. Ashton, N. G.; "Relationship of chronic physical activity level to physiological and anthropometric variables in 9-10 yr.old girls". Med. Sci. in Sports and Exer. 15:143, 1983.

7. Astrand, P.O.; L. Engstrom, B. Eriksson, P. Karlberg, I. Nylander, et al. "Girl Swimmers". Acta Paediatrica Scandinavica 147 (Suppl.):5-75, 1963.

8. Astrand, P.O.; K. Rodahl. "Textbook of work physiology". 3rd ed. New York: McGraw-Hill Book Co. 412-432, 1986.

9. Bale, P.; "The functional performance of children in relationship to growth, maturation, and exercise". Sports Medicine. 13(3):151-159, 1992.

10. Bar-Or, O.; "Pediatric Sports Medicine for the Practitioner". Springer-Verlag, New York, 1983.

11. Bar-Or, O.; "The Wingate test. An update on methodology, reliability and validity". Sports Medicine. 4:381-394, 1987.

12. Bar-Or, O.; "Disease specific benefits of training in the child with a chronic disease. What is the evidence?" Pediatric Exercise Science. 2:299-312, 1990.

13. Bar-or, O.; O. Inbar. "Relationships Among Anaerobic Capacity, Sprint, and Middle Distance Running of School Children." In Shephard, R. J.; H. Lavallee (eds.) Physical Fitness Assessment. pp. 142-147, 1978.

14. Bar-Or, O.; L. Zwiren. "Physiological effects of increased frequency of physical education classes and endurance conditioning on 9 to 10 year old girls and boys". In Pediatric Work Physiology: Proceedings 4th International Symposium. pp.183-198, Wingate Institute, Israel, 1973.

15. Baxter-Jones, A. D. G.; "Growth and Development of Young Athletes". Sports Medicine. 20(2): 59-64, 1995.

16. Bell, R. D.; J. D. MacDougall, R. Billeter, H. Howald. "Muscle fiber types and morphometric analysis of skeletal muscle in six-year-old children". Med. Sci. in Sports and Exer. 12(1):28-31, 1980.

17. Benedict, G.; P. Vaccaro,B. D. Hatfield. "Physiological effects of an eight week precision jump rope program in children". American Corrective Therapy Journal. 5:108-111, 1985.

18. Berenson, G. S.; "Cardiovascular risk factors in children". The Early Natural History of Atherosclerosis and Essential Hypertension. Oxford University Press, New York, 1980.

19. Berg, K.; J. Bjure. "Preliminary results of long term physical training of adolescent boys with respect to body composition, maximal oxygen uptake, and lung volume". Acta Paediatrica Belg. 28:183-189, 1974.

20. Berg, K.; S. P. Sady, D. Beal, et.al. "Development of an elementary school CHD prevention program". Physician and Sports Medicine. 11(10):99-105, 1983.

21. Beunen, G.; R. M. Malina. "Growth and physical performance relative to the timing of the adolescent spurt". Exer. and Sport Sci. Rev. 16:503-540, 1988.

22. Bielen, E.; R. Fagard, A. Amery. "Inheritance of heart structure and physical exercise capacity: A study of left ventricular structure and exercise capacity in 7-year old twins". European Heart Journal. 11:7-16, 1990.

23. Blimkie, C. J. R.; P. Roche, O. Bar-Or. "The Anaerobic to Aerobic Power Ratio in Adolescent Boys and Girls". In Rutenfranz, J.; R. Mocellin, F. Klint (eds.) Children and Exercise XII. Human Kinetics Publishers, Champaign, ILL. 31-37, 1986.

24. BoasF.; "The growth of children". Science 19:256-257, 1892.

25. Boileau, R. A.; V. H. Heyward, B. H. Massey. "Maximal aerobic capacity on the treadmill and bicycle ergometer of boys age 11-14 years of age". J. Sports Med. 17:153-162, 1977.

26. Bouchard, C.; M. R. Boulay, J. A. Simoneau, et al. "Heredity and Trainability of Aerobic and Anaerobic Performances". Sports Medicine. 5: 69-73, 1988.

27. Bouchard, C.; F. T. Dionne, J. A. Simoneau, M. R. Boulay. "Genetics of aerobic and anaerobic performances". Exer. Sport Sci. Rev. 20:27-58, 1992.

28. Bouchard, C.; R. Lesage, G. Lortie, et al. "Aerobic Performance in Brothers, Dizygotic and Monozygotic Twins". Medicine and Science in Sports and Exercise. 18(6): 639-646, 1986.

29. Bouchard, C.; R. M. Malina. "Genetics of Physiological Fitness and Motor Performance". Exercise and Sport Science Reviews. 11:306-339, 1983.

30. Brown, C. H.; J. R. Harrower, M. S. Deeter. "The effects of cross-country running on pre-adolescent girls". Med. Sci. in Sports and Exer. 4:1-5, 1972.

31. Colling-Saltin, A. S.; "Enzyme histochemistry of skeletal muscle of the human fetus". J. Neurol. Sci. 39:169-185, 1978.

32. Colling-Saltin, A. S.; "Skeletal Muscle Development in the Human Fetus and During Childhood". In Berg, K., and Eriksson, B. O. (eds.). Children and Exercise IX. University Park Press, Baltimore, MD. 193-206, 1980.

33. Cook, P.C., M.E. Leit. "Issues in the Pediatric Athlete". Orthopedic Clinics of North America. 26(3):453-464, 1995.

34. Cumming, G.R.; A. Goodwin, G. Bagley, J. Antel. "Repeated measurements of aerobic capacity during a week of intensive training at a youth track camp". Can. J. Physiol. Pharmacol. 45:805-811, 1967.

35. Cumming, G. R.; A. Goodwin, G. Bagley, J. Antel. "Failure of school physical education to improve cardiorepiratory fitness". Can. Med. Assoc. J. 101:69-73, 1969.

36. Cunningham, D. A.; R. B. Eynon. "The working capacity of young competitive swimmers, 10-16 years of age". Med. Sci. in Sports Exer. 5:227-231, 1973.

37. Cunningham, D. A.; D. H. Paterson, C. J. R. Blimkie, A. P. Donner. "Development of cardiorespiratory function in circumpubertal boys: a longitudinal study". J. Appl. Physiol. 56(2):302-307, 1984.

38. Daniels, J.; N. Oldridge. "Changes in oxygen consumption of young boys during growth and running training". Med. Sci. in Sports Exer. 3:161-165, 1971.

39. Davies, C. T. M.; C. Barnes, S. Godfrey. "Body composition and maximal exercise performance in children". Human Biology. 44(3):195-214, 1972.

40. Docherty, D.; E. Ready. "Draft copy of CASS standardized test protocol for testing youth and children". pp.27-29, 1990.

41. Dotan, R.; O. Bar-Or. "Load optimization for the Wingate anaerobic test". European J. of Appl. Physiol. 51:409-417, 1983.

42. Dunn, K.; "Twin Studies and Sports: Estimating the Future?" Physician and Sports Medicine. 9(5):131-136, 1981.

43. Ekblom, B.; "Effect of physical training in adolescent boys". J. Appl. Physiol. 27(3):350-355, 1969.

44. Elovainio, R.; S. Sundberg. "A five year followup study on cardiorespiratory function in adolescent elite endurance runners". Acta Paediatr. Scand. 72:351-356, 1983.

45. Eriksson, B.O.; G. Koch. "Effect of physical training on hemo-dynamic response during submaximal and maximal exercise in 11-13 yr old boys". Acta Physiol. Scand. 87:27-39, 1973.

46. Falk, B.; O. Bar-Or. "Longitudinal Changes in Peak Aerobic and Anaerobic Mechanical Power of Circumpubertal Boys". Pediatric Exer. Sci. 5:318-331, 1993.

47. Fagard, R.; E. Bielen, A. Amery. "Heritability of aerobic and anaerobic energy generation during exercise". J. Appl. Physiol. 70(1):357-362, 1991.

48. Fournier, M.; J. Ricci, A. W. Taylor, R. J. Ferguson, R. R. Montpetit, B. R. Chaitman. "Skeletal muscle adaptation in adolescent boys: sprint and endurance training and detraining". Med. Sci. in Sports and Exer. 14:453-456, 1982.

49. Geurlich, J.; R. Pyle. "Radiographic atlas of skeletal development of the hand and wrist". Stanford University Press, 1959.

50. Glenmark, B.; G. Hedberg, L. Kaijser, E. Jansson. "Muscle Strength from Adolescence to Adulthood - Relationship to Muscle Fibre Types". Eur. J. Applied Physiology. 68:9-19, 1994.

51. Gollnick, P. D.; R. B. Armstrong, C. W. Saubert, K. Piehl, B. Saltin. "Enzyme activity and fiber composition in skeletal muscle of untrained and trained man". J. Appl. Physiol. 33:312-319, 1972.

52. Howald, H.; "Ultrastructure and biochemical function of skeletal muscle in twins". Annals of Human Biology. 3(5):455-462, 1976.

53. Inbar, O.; O. Bar-Or. "Relationships of anaerobic and aerobic arm and leg capacities to swimming performance of 8-12 year old children". In Shephard, R.J. & Lavallee, H. (eds.) Frontiers of activity and child health. Pelican, Quebec, Canada. 283-292, 1977.

54. Kaczkowski, W.; D. L. Montgomery, A. W. Taylor, V. Klissouras. "The relationship between muscle fiber composition and maximal anaerobic power and capacity". J. Sports Med. 22:407-413, 1982.

55. Kellet, D. W.; P. L. T. Willian, K. J. Bagnall. "A study of potential Olympic swimmers. Part 2. Changes due to three months intensive training". Br. J. Sports Med. 12(2):87-92, 1978.

56. Kirk, R. E.; "Factors that Affect the Size of r". Statistics: An Introduction (3rd ed.). Holt, Rinehart, Winston Inc., Orlando,FL. 176-183, 1990.

57. Klissouras, V.; " Heritability of adaptive variation". J. Appl. Physiol. 31(3):338-344, 1971.

58. Klissouras, V.; F. Pirnay, J. M. Petit. "Adaptation to maximal effort: genetics and age". J. Appl. Physiol. 35(2):288-293, 1973.

59. Kobayashi, K.; K. Kitamura, M. Miura, H. Sodeyama, M. Miyashita, H. Matsui. "Aerobic power as related to body growth and training in Japanese boys: a longitudinal study". J. Appl. Physiol. 44:666-672, 1978.

60. Koch, G.; "Muscle blood flow in prepubertal boys. Effect of growth combined with intensive physical training". In Borms, J. and Hebbelnick, M. (eds.). Pediatric Work Physiology. Basel, S.Karger A-G, pp.39-46, 1978.

61. Komi, P.V.; J. H. T. Viitsalo, M. Havu, A. Thorstensson, B. Sjodin, J. Karlsson. "Skeletal muscle fibres and muscle enzyme activities in monozygous and dizygous twins of both sexes". Acta. Physiol. Scand. 100:385-392, 1977.

62. Krahenbul, G. S.; J. S. Skinner, W. S. Kohrt. "Developmental aspect of maximal aerobic power in children". In Terjung, R. L. (ed.). Exer. Sport Sci. Rev. 13:503-538, 1985.

63. Krahenbuhl, G.S.; D.W. Morgan; R.P. Pangrazi. "Longitudinal Changes in Distance-Running Performance of Young Males." Int. J. Sports Med. 10:92-96, 1989.

64. Kutsar, K.; "Hereditary prerequisites in the selection of potential talent". Modern Athlete and Coach. 29:12-14, 1991.

65. Lesage, R.; J. A. Simoneau, J. Jobin, J. Leblanc, C. Bouchard. "Familial resemblance in maximal heart rate, blood lactate, and aerobic power". Human Heredity. 35:182-189, 1985.

66. Lussier, L.; E. R. Buskirk. "Effect of an endurance training regimen on assessment of work capacity on prepubertal children". Annals of N.Y. Acad. of Sci. 301:734-737, 1977.

67. Malina, R. M.; "Physical Growth and Biological Maturation of Young Athletes". Exercise and Sport Science Reviews. 22: 389-433, 1994.

68. Malina, R. M.; In Bouchard,C., R. J. Shephard, T. Stephens, J. R. Sutton, B. D. Matherson. (eds.). "Exercise, fitness and health". Human Kinetics Publishers. Champaign,IL. pp.637-653, 1990.

69. Martin, A. D.; L. F. Spenst, D. T. Drinkwater, J. P. Clarys. " Anthropometric estimation of muscle in men". Med. Sci. in Sports Exer. 22(5):729-733, 1990.

70. Massicotte, D. R.; R. B. J. MacNab. "Cardiorespiratory adaptation to training at specified intensities in children". Med. Sci. in Sports Exer. 6:242-246, 1974.

71. Matsui, H.; M. Miyashita, M. Miura, K. Kobayashi, T. Hoshibawa, et.al. "Maximum oxygen uptake and its relationship to body weight in Japanese adolescents". Med. Sci. in Sports Exer. 4:29-32, 1972.

72. Maud, P. J.; B. B. Schultz. "Norms for the Wingate Anaerobic Test with Comparison to Another Similar Test". Research Quarterly for Exercise and Sport. 60(2):144-151, 1989.

73. Mayers, N.; B. Gutin. "Physiological characteristics of elite prepubertal cross-country runners". Med. Sci. in Sports Exer. 11:172-176, 1979.

74. McCormack, W. P.; K. J. Cureton, T. A. Bullock, P. G. Weyand. "Metabolic determinants of 1-mile run/walk performance in children". Med. Sci. in Sports Exer. 23(5):611-617, 1991.

75. McKeag, D. B.; "The role of exercise in children & adolescents". Clinics in Sports Medicine. 10(1):117-130, 1991.

76. Mero, A.; L. Jaakkola, P. V. Komi. "Relationships between muscle fibre characteristics and physical performance capacity in trained athletic boys". J. of Sports Sciences. 9:161-171, 1991.

77. Mirwald, R.L.; D. A. Bailey, N. Cameron, R. L. Rasmussen. “Longitudinal comparison of aerobic power in active and inactive boys aged 7.0 to 17.0 years”. Annals of Human Biology. 8(5):405-414, 1981.

78. Mocellin, R.; U. Wasmund. “Investigation on the influence of a running-training program on the cardiovascular and motor performance capacity in 53 boys and girls of a second and third primary school class”. In Pediatric Work Physiology: Proceedings of the 4th International Symposium. Wingate Institute, Israel. pp.279-285, 1973.

79. Palgi, Y.; B. Gutin; J. Young; D. Alejandro. “Physiologic and Anthropometric Factors Underlying Endurance Performance in Children.” Int. J. Sports Med. 5: 67-73, 1984.

80. Pate, R. R.; D. S. Ward. “Endurance exercise trainability in children and youth”. In Grana, W. A. (ed.). Advances in Sports Medicine and Fitness. Vol.3. Year Book Medical Publishers. Chicago,IL. pp.37-55, 1990.

81. Payne, G.V.; J. R. Morrow, Jr. “Exercise and VO_2max in Children: A Meta Analysis”. Research Quarterly for Exercise and Sport. 64(3): 305-313, 1993.

82. Rivera-Brown, A.M.; M. A. Rivera, W. R. Frontera. “Applicability of Criteria for $VO_{2\ max}$ in Active Adolescents." Pediatric Excercise Science. 4: 331-339, 1992.

83. Rotstein, A.; R. Dotan, O. Bar-or; G. Tenenbaum. ‘Effect of Training on Anaerobic Threshold, Maximal Aerobic Power and Anaerobic Performance of Preadolescent Boys”. Int. J. Sports Med. 7: 281-286, 1986.

84. Rowland, T.W.; “Aerobic response to endurance training in pre-pubescent children: a critical analysis”. Med. Sci. in Sports Exer. 17(5):493-497, 1985.

85. Rowland, T.W.; J. S. Staab, V. B. Unnithan, J. M. Rambusch, S. F. Siconalfi. “Mechanical Efficiency During Cycling in Prepubertal and Adult Males”. Int. J. Sports Med. 11: 452-455, 1990.

86. Rowland, T.W.; “Aerobic Exercise Testing Protocols”. In Rowland, T.W.(ed.). Pediatric Laboratory Exercise Testing: Clinical Guidelines. Human Kinetics Publishers, Champaign, ILL. 19-41, 1993.

87. Rutenfranz, J.; M. Macek, K. Lange-Andersen, R. D. Bell, J. Vavra, J. Radvansky, F. Klimmer, H. Kylian. “The Relationship Between Changing Body Height and Growth Related Changes in Maximal Aerobic Power.” European Journal of Appl. Physiology. 56: 725-736. 1987.

88. Sady, S. P.; W. H. Thompson, K. Berg, M. Savage. "Physiological characteristics of high ability prepubescent wrestlers". Med. Sci. in Sports Exer. 16:72-76, 1984.

89. Sady, S. P.; "Cardiorespiratory exercise training in children". Clinics in Sports Medicine. 5(3):493-514, 1986.

90. Shephard, RJ.; "Effectiveness of training programmes for pre-pubescent children". Sports Medicine. 13(3):194-213, 1992.

91. Sprynarova, S.; "Longitudinal study of the influence of different physical activity programs on functional capacity of boys from 11 to 18 years". Acta Paediatr. Belg. 28:204-213, 1974.

92. Sprynarova, S.; J. Parizkova, I. Jurinova. "Development of the functional capacity and body composition of boy and girl swimmers aged 12-15 years". In Borms, J. and Hebbelnick, M.(eds). Pediatric Work Physiology. Basel, S. Karger A-G. pp.32-38, 1978.

93. Sprynarova, S.; J. Parizkova; V. Bunc. "Relationships Between Body Dimensions and Resting and Working Oxygen Consumption in Boys Ages 11 to 18 Years". European Journal of Appl. Physiology. 56: 725-736. 1987.

94. Stevens, J.; "Applied multivariate statistics for the social sciences". Lawrence Erlbaum Associates Inc. Publishers. Hillsdale, N.J. pp. 141, 1986.

95. Stewart, K.J.; B. Gutin. "Effects of physical training on cardiorespiratory fitness in children". Research Quarterly. 47:110-120, 1976.

96. Sundberg, S.; R. Elovainio. "Cardiorespiratory function in competitive endurance runners aged 12-16 yrs. compared with ordinary boys". Acta Paediatrica Scandinavica. 71:987-992, 1982.

97. Tanner, J.M. "Growth at adolescence". 2nd ed. Oxford, Blackwell Scientific Publications, 1962.

98. Tharp, G.D.; R. K. Newhouse; L. Uffelman; W.G. Thorland; G.O. Johnson. "Comparison of Sprint and Run Times with Performance on the Wingate Anaerobic Test." Research Quarterly for Exercise and Sport. 56(1): 73-76, 1985.

99. Thorland, W.G.; G. O. Johnson, C. J. Cisar, T. J. Housh, G. D. Tharp. "Strength and Anaerobic Responses of Elite Young Female Sprint and Distance Runners". Medicine and Science in Sports and Excercise. 19(1):56-61, 1987.

100. Vaccaro, P.; D.H. Clarke. "Cardiorespiratory alterations in 9-11 year old children following a season of competitive swimming". Med. Sci. in Sports Exer. 10:204-207, 1978.

101. Vaccaro,P.; F. M. Galioto, L. M. Bradley, J. Vaccaro. "Effect of physical training on exercise tolerance of children after surgical repair of complex congenital heart disease". Med. Sci. in Sports Exer. 17:284, 1985.

102. Vaccaro, P.; A. Mahon. "Cardiorespiratory responses to endurance training in children". Sports Medicine. 4:352-363, 1987.

103. VanDobeln,W.; B.O. Eriksson. "Physical training, maximal oxygen uptake, and dimensions of the oxygen transporting and metabolizing organs in boys 11-13 years of age". Acta Paediatrica Scandinavica. 61:653-660, 1972.

104. VanEynde, B.V.; D. Vienne, M. Vuylskeke-Wauters, D. V. Gerven. "Aerobic Power and Pubertal Peak Height Velocity in Belgian Boys". European Journal of Appl. Physiology. 57: 430-434. 1988.

105. Vanfraechem, J.H.P.; R. Vanfraechem-Raway. "The influence of training upon physiological and psychological parameters in young athletes". J. Sports Med. 18:175-182, 1978.

106. Weber, G.; W. Kartodihardjo, V. Klissouras. "Growth and physical training with reference to heredity". J. of Appl. Physiol. 40(2):211-215, 1976.

107. Yoshida,T.; I. Ishiko, I. Muaoka. "Effects of endurance training on cardiorespiratory functions of 5 year old children". Int. J. of Sports Med. 1:91-94, 1980.

108. Zauner, C. W.; M. G. Maksund, J. Melichna. "Physiological Considerations in Training Young Athletes". Sports Medicine. 8(1): 15-31, 1989.

109. Zwiren, L.D. "Anaerobic and Aerobic Capacities of Children". Pediatric Exercise Science. 1: 31-44, 1989.

The second type of testing will involve exercise testing on a treadmill or stationary bicycle. Expired air will be collected through a mouthpiece to determine your childs heart and lung fitness. The testing may be done over a 2 day period and may require 2-3 hours each day. There will be no needles or bloodwork involved in the testing.

Risks and Benefits:

The exercise test is considered to be very safe and we do not expect that any child will have any side effects from doing the test. The child can stop the test anytime he/she wants to or if the test becomes painful. There is an extremely small risk of your child having heart or lung difficulties such as abnormal heart beat or asthma. The risk of this is not significantly greater than is likely to happen during normal sporting activities. The child's heart will be monitored during the test and a doctor will be available during testing at all times.

Confidentiality:

All the information which identifies your child will be strictly confidential. The study records will be available only to the participants and their parents, and members of the study team.

Participation in the Study:

You and your child are under no obligation to take part in this study. If you decide not to participate or if you decide to withdraw your child from the study before its completion, you are totally free to do so and such a decision will have no consequences for your child's medical care in the future.

Questions:

If you have any questions or concerns about the study now or in the future, please call us.

CONSENT

The fitness study has been clearly explained to me and I have read and understood the information provided. I request that my child be enrolled in the study. I understand that I have the right to decline to enter the study and to withdraw from it, for any reason, without any consequence to my child's present or future health care. I acknowledge that I have received a copy of this form for future reference.

Child's name:____

Parent's or Guardian's signature:______________________________

Date:____

Please print name:_______________________________________

Relationship to child:_____________________________________

I agree to take part in this study which has been explained to me. I understand that I do not have to take part if I do not want to and can leave the study at any time.

Child's signature:____
(to be signed by any child over 11 years and younger children at their discretion).

Witness's signature:______________________________________

Please print name:_______________________________________

Statement by physician or nurse:

I have carefully explained the nature, demands, and foreseeable risks of the fitness study to the parent or guardian named above and witnessed completion of the consent form.

Signature:____

Designation:____

Date:____

APPENDIX B

QUESTIONNAIRE

Name:____

Date of Birth:____

Grade:____

Medications:____

Do you play any sports outside of school? Yes ☐ No ☐

Which sports?
1.____
2.____
3.____

How many days in a week do you participate in that sport?
1.____
2.____
3.____

How many hours per day are you involved in that sport?
1.____
2.____
3.____

Do you compete in your sport? Yes ☐ No ☐

Local ☐ Provincial ☐ National ☐

Do you train with a track or running club? Yes ☐ No

APPENDIX C Raw Data For All Subjects (n = 44)

	Sub #	F=1; M=2	Age	Ht	Wt	SOS	Run-50 sec.	Run-1600 s...	PP-watts	PP-w/kg	Total Work	FI	HR	VO2 L/min	VO2ml/kg	VE	SaO2	Inpu...
1	1	1	10	130.0	32.9	79.3	10.31	688	103	3.13	2891	84.6	199	1.029	31.3	36.3	96	
2	2	1	10	139.5	31.1	32.5	10.41	782	214	6.88	3882	29.6	174	1.074	34.5	47.8	97	
3	3	2	10	143.0	39.8	61.6	9.52	601	314	7.88	7129	51.5	180	1.351	33.9	45.2	98	
4	4	1	9	137.5	30.5	45.9	9.88	690	214	7.01	4832	59.3	200	1.222	40.1	47.4	96	
5	5	2	9	133.5	27.5	27.9	8.34	411	266	9.68	5989	59.5	202	1.732	63.0	58.9	96	
6	6	2	9	144.0	54.5	128.3	10.99	856	342	6.28	6211	40.7	188	1.541	28.3	48.9	95	
7	7	2	9	133.0	29.3	36.8	9.15	590	215	7.35	5135	61.8	211	1.403	47.9	50.8	91	
8	8	1	10	145.0	34.9	32.3	8.02	583	293	8.40	5981	48.6	212	1.479	42.4	52.8	93	
9	9	2	8	139.0	37.1	54.2	9.14	553	295	7.94	7177	67.7	198	1.647	44.4	58.8	94	
10	10	2	8	136.0	33.5	37.2	8.68	532	293	8.75	6654	59.5	209	1.703	50.8	70.6	90	
11	11	1	9	135.0	29.4	31.1	9.10	556	146	4.96	4119	91.3	204	1.229	43.3	48.0	96	
12	12	2	8	131.0	27.5	28.6	8.98	467	215	7.84	4721	55.9	201	1.563	39.1	56.6	95	
13	13	2	9	137.0	30.6	33.3	8.19	548	293	9.59	6416	56.8	212	1.557	51.0	57.3	94	
14	14	1	10	151.0	36.3	55.4	9.19	547	333	9.17	6226	37.1	204	1.490	41.0	57.6	96	
15	15	2	9	149.0	35.7	25.4	8.58	473	295	8.25	5276	32.3	182	1.445	40.5	41.8	94	
16	16	1	9	128.0	25.8	41.0	9.01	544	209	8.12	5450	69.7	209	1.162	45.0	49.1	94	
17	17	2	10	142.0	52.0	137.9	10.77	707	317	6.09	5830	44.0	179	1.319	25.4	39.2	95	
18	18	2	10	136.0	35.5	68.9	8.93	491	352	9.89	6987	46.0	215	1.721	48.3	61.8	94	
19	19	2	11	161.0	59.5	98.5	9.09	632	413	6.95	9839	55.2	192	1.707	28.7	54.8	96	
20	20	1	10	139.0	37.9	57.4	8.69	480	285	7.52	6702	66.7	198	1.506	39.7	48.1	95	
21	21	2	10	145.0	36.0	33.5	8.87	482	342	9.49	7652	55.6	186	1.703	47.3	61.6	95	
22	22	1	10	135.0	33.5	81.0	8.67	563	222	6.62	5070	57.1	•	•	•	•	•	
23	23	1	10	136.5	29.7	29.6	9.09	553	241	8.11	5450	57.6	207	1.242	41.8	43.0	94	
24	24	1	9	133.0	30.3	67.2	9.23	587	261	8.63	5149	45.5	222	1.086	35.8	40.2	96	
25	25	2	10	138.0	32.0	49.5	9.70	514	261	8.17	5347	48.5	188	1.470	45.9	48.2	94	
26	26	2	11	141.0	39.9	53.1	8.82	480	361	9.06	7082	44.7	194	1.902	47.8	68.9	93	
27	27	2	9	143.5	36.9	34.0	8.54	415	399	10.82	8318	40.5	218	2.107	57.1	79.5	93	
28	28	2	9	136.0	29.3	25.9	8.56	510	279	9.52	6654	63.6	206	1.586	54.1	58.3	94	
29	29	2	8	124.0	24.6	42.1	9.73	606	215	8.76	5197	61.8	212	1.119	45.5	40.6	95	
30	30	2	8	138.0	29.6	30.6	9.49	484	215	7.28	5197	61.8	203	1.577	53.3	57.8	96	
31	31	2	9	136.0	29.8	25.8	8.80	500	247	8.29	5830	61.5	204	1.568	52.6	61.5	96	
32	32	1	8	135.5	32.3	43.6	9.08	510	222	6.87	5307	67.9	213	1.525	47.2	49.9	95	
33	33	1	8	133.0	31.1	55.0	10.05	563	214	6.87	4357	48.1	195	1.583	50.9	55.9	93	
34	34	1	9	129.0	34.2	71.4	9.26	580	261	7.63	5981	57.6	212	1.224	35.8	41.9	96	
35	35	1	8	135.4	28.6	35.8	9.18	550	228	7.96	5070	52.8	206	1.381	48.3	48.5	97	
36	36	2	10	140.5	34.5	37.0	8.64	491	301	8.73	7129	65.8	205	1.897	55.0	63.6	94	
37	37	2	9	138.0	41.8	90.8	9.64	661	314	7.51	6559	54.5	184	1.334	31.9	40.1	96	
38	38	2	10	141.0	34.9	45.0	9.00	477	261	7.49	6139	60.6	197	1.638	46.9	51.1	94	
39	39	2	9	139.2	29.6	33.8	9.16	499	184	6.21	4595	69.0	202	1.453	49.1	57.5	96	
40	40	2	9	140.0	39.3	59.2	9.28	575	247	6.29	6559	76.9	186	1.666	42.4	55.6	94	
41	41	2	10	127.0	23.6	30.3	8.43	561	228	9.67	5355	61.1	206	1.266	53.6	45.0	94	
42	42	2	11	159.5	55.9	90.9	9.14	586	485	8.67	9126	50.0	196	1.892	33.8	64.7	96	
43	43	2	10	137.0	30.3	24.8	8.32	574	293	9.67	6456	54.0	192	1.622	53.5	54.7	95	
44	44	1	9	141.0	37.9	800.0	•	•	266	7.02	5513	53.6	•	•	•	•	•	