Ventilatory Threshold and Peak $\dot{V}O_2$ Responses in Prepubescent Children following a High Intensity Training Program.

A Masters Thesis
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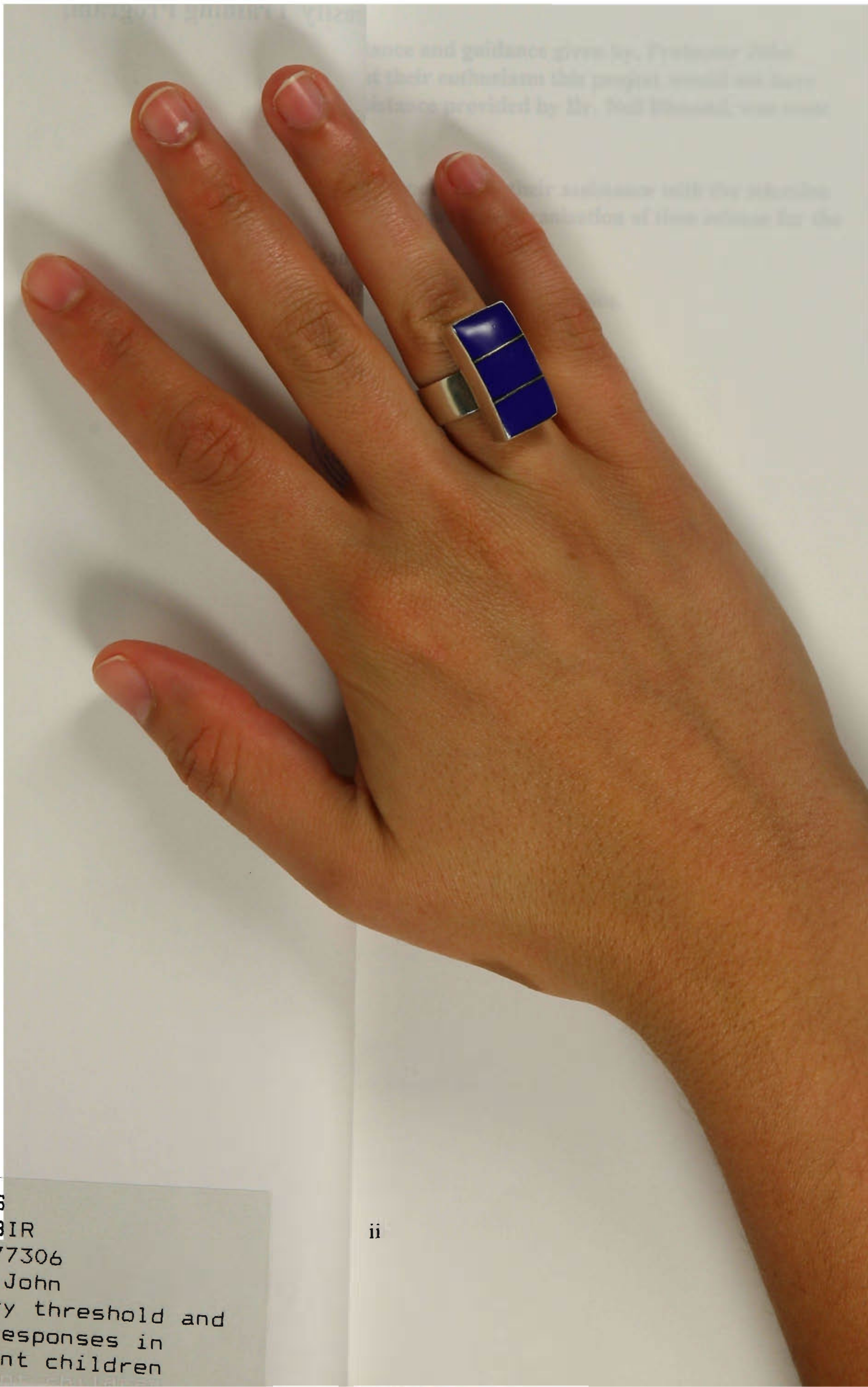

DEDICATION

This thesis is dedicated to my very supportive family.

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ABSTRACT.

The focus of this study was to examine the influence of a high intensity training program on selected cardiovascular exercise responses in a group of prepubescent males. Thirteen healthy boys with a mean age of 10.0 years were randomly assigned to either control or an exercise group. Children in the exercise group participated in a ten week, three sessions per week, training intervention program. At the completion of the ten week training period the groups were reversed and the control group became the exercise group for the second ten week training program. The initial training group became the control or detraining group. Peak and submaximal cardiovascular exercise responses were measured on four occasions over the two training periods. Polar 'Sports Tester' Heart Rate Monitors were used during all of the training sessions which enabled heart rate data to be collected and stored during the exercise periods. A variety of exercise modes were used, these included, treadmill running, a variety of bicycle ergometers, monitored jogging trails and a modified basketball game. The duration of each training session was between 30 - 40 minutes, with the best 30 minutes of heart rate data used to estimate the work intensity during the study. No statistically significant changes occurred for absolute $\dot{V}O_2$ $l.min^{-1}$ and relative Peak $\dot{V}O_2$ ($ml.kg.^{-1}min^{-1}$). There were significant changes recorded at the 0.05 level of significance for the following measures; $\dot{V}O_2$ at V Slope breakpoint ($\dot{V}O_2$ vs $\dot{V}CO_2$), and $\dot{V}O_2$ at VT as a percentage of peak $\dot{V}O_2$. The main finding from this study was that, ventilatory threshold may be a more sensitive indicator of change in training responses for children.

CHAPTER 1. INTRODUCTION.

CHAPTER 1.

INTRODUCTION.

Cardiorespiratory responses to exercise training are reasonably well understood in adult populations (Dudley et al., 1982, Henrikson and Reitman, 1977). For example, approximately 15-30% improvement in some cardiorespiratory parameters can be expected in adults following twelve weeks of moderate to high aerobic training. Payne and Morrow (1993) suggested that there was a widespread belief that children are just as aerobically trainable as adults. Studies examining the ability of children to improve their maximal aerobic power ($\dot{V}O_2$ peak) have however, yielded inconsistent findings. Rowland (1997) reported that there is sufficient evidence to suggest that the magnitude of cardiorespiratory improvements following endurance training are attenuated in children compared with adults. An examination of the limitations in the existing literature reveals a need to identify the most appropriate test protocols for detecting changes in the cardiorespiratory parameters following exercise intervention. Rowland (1989a) indicated that there was no consensus among paediatric exercise researchers that the tests presently constructed for assessing various components of cardiorespiratory fitness truly served their designed purpose. Expressing aerobic power in relation to various body dimensions in adults, remains somewhat consistent over time. In childhood, the validity of relative aerobic power is problematic. This is associated with growth-related changes in the majority of the dimensions of the body, most commonly used to express relative aerobic power. Thus detecting changes related to exercise intervention rather than growth may require sensitive physiological parameters.

GENERAL AND SPECIFIC AIMS OF THE STUDY.

The focus of the study was to examine the influence of a high intensity exercise training program on selected cardiorespiratory and anthropometric parameters of the prepubescent males. The study aimed to monitor changes in ventilatory threshold (VT) and peak $\dot{V}O_2$ scores, during an exercise training program and compare the performances of an exercise group, with an aged, sex and fitness matched control group.

The Specific Aims of this Study Are:

1. To assess changes in cardiorespiratory function and body composition during a short-term (10 weeks) training program in pre-pubescent males, who were assigned to one of two groups (experimental or control).
2. To identify the test protocols more sensitive to changes elicited by exercise training in pre-pubescent males.

Limitations and Delimitations of the Study.

In conducting the study, the following limitations that were perceived as beyond the control of the researcher were recognised:

1. The influence that the involvement in extra curricula sporting activities may have had on the performance results of the subjects over the duration of this exercise intervention study was considered as a limitation. It was beyond the scope of the researcher to attempt to intervene into the extra curricula choices of activity of the 13 boys recruited for the study.
2. Time constraints caused by the duration of the school term, limited the duration of the intervention program to a ten week training study. The routine and compliance of training sessions within the school week of one complete term was perceived as an unavoidable limitation of the study.
3. A further limitation to the study was found in the interruptions to training caused by minor illness which held the potential to impede a subject's progress during a training program, and could have influenced the performance results from the laboratory test sessions.
4. A limitation of the work with children in this study was the moral and ethical constraints imposed on the type of testing which could be used. Specifically, in this study invasive protocols such as blood lactate or muscle biopsies were considered inappropriate.

Delimitations.

In this study the following delimitations were selected by the researcher:

1. Recruitment for the exercise intervention study demonstrated the study was delimitated to male subjects from the preadolescent stage of development.
2. Larger sample numbers would have provided a greater statistical power for the evaluation of the result. This factor however, had to be balanced with the need for small numbers of subjects to enable close supervision of the training intensities during each session to

maintain the quality of the research. Therefore the study was delimited to a total of 13 subjects; half of whom participated in training, while the remaining half comprised the control group.

3. The frequency and duration of each training session were selected by the researcher on the basis of previous research. In this study participants were delimited to exercise training three times per week over a 10 week duration.
4. The choice of equipment used in both the laboratory test sessions and the training sessions represent a further delimitation of the study.
5. A final delimitation is found in the research design selected for this study (a cross-over design). It was devised to both strengthen the homogeneity of the sample population and to broaden the scope of evaluation of the results for both the training and detraining phases of the intervention program.

DEFINITION OF TERMS

Aerobic metabolism.

The aerobic system refers to the body's ability to oxidise energy substrates in the mitochondria of the cell in order to resynthesise energy potential in the form of adenosine triphosphate (ATP) (Brodner, 1986). During steady state, exercise of a moderate intensity, oxygen is available to accept the final hydrogen atoms in the metabolic pathway of the Electron Transport Chain. Aerobic metabolism largely provides the energy required during prolonged periods of exercise. The upper limit of aerobic metabolism is reached when the rate of oxygen supply can no longer match the metabolic needs of the cell and anaerobic metabolism predominates.

Anaerobic.

Anaerobic energy production of ATP occurs predominantly without the need for adequate supplies of oxygen. The two mechanisms available as energy sources for the anaerobic metabolism are the phosphocreatine and the lactic acid systems. Anaerobic metabolism enables the body to exercise at relatively high intensities for a short period of time.

Maximal Oxygen Uptake ($\dot{V}O_2$ max).

Maximal O_2 uptake is a clearly defined physiological state in which the limits of O_2 delivery/uptake have been met (Rowland, 1996b). This is a point reached during prolonged and incremental exercise and is dependent on maximal cardiac output and the maximal arterio-venous oxygen difference (Saltin, 1992). $\dot{V}O_2$ max is regarded as a reliable indicator of an adult's aerobic fitness. It is expressed in absolute terms ($l.min^{-1}$) or, in relative terms most commonly, when body mass is taken into consideration ($ml.kg.^{-1}min^{-1}$).

Peak $\dot{V}O_2$

Peak $\dot{V}O_2$ often replaces the term $\dot{V}O_2$ max in children, as it is less certain that they will always attain a plateau in $\dot{V}O_2$ during exercise challenges which aim to elicit maximal exercise levels. Rowland (1996b) favours the use of terms exhaustive or peak exercise as these indicate the best effort that paediatric subjects may be willing to provide. Factors such as local fatigue, or a limited ability to tolerate the pain sensations associated with peak exercise, may limit children's potential to obtain a maximal effort.

$\dot{V}O_2$.

Oxygen consumption, may be used as an indirect estimate of energy metabolism at rest or during exercise (McArdle et al., 1996). The calculation of oxygen consumption, involves subtracting the amount of O_2 exhaled from the amount of O_2 inspired. The equation is derived from the Haldane Transformation, $\dot{V}O_2 = (\dot{V}_I \,.\, F_I\, O_2) - (\dot{V}_E \,.\, F_E\, O_2)$ and symbolises the calculation for oxygen consumption. Measures of oxygen consumed ($\dot{V}O_2$) by the body per unit of time, are most commonly expressed in units of millilitres per kilogram of body mass ($ml.kg^{-1}min^{-1}$) or litres per minute ($l.min^{-1}$) under standard environmental conditions (standard temperature pressure dry, or STPD).

$\dot{V}CO_2$.

$\dot{V}CO_2$ is the amount of CO_2 expired from the body per unit time. Similar to $\dot{V}O_2$, $\dot{V}CO_2$ is expressed in units of millilitres per kilogram of body mass ($ml.kg^{-1}min^{-1}$) or litres per minute ($l.min^{-1}$) under standard environmental conditions (standard temperature pressure dry, or STPD). Calculation of carbon dioxide is represented by the following equation, $\dot{V}CO_2 = (\dot{V}_E \,.\, F_E\, CO_2) - (\dot{V}_I \,.\, F_I\, CO_2)$. Measurements of both $\dot{V}O_2$ and $\dot{V}CO_2$ can be determined using a gas analyser and a ventilometer for measuring the volume of expired gas (Powers and Howley, 1997).

VE.

Ventilatory equivalent (VE) for oxygen, (litres of air expired per litre of oxygen consumed) can be symbolised as $\dot{V}_E/\dot{V}O_2$. In young adults $\dot{V}_E/\dot{V}O_2$, averages 25:1, up to approximately 55% of maximal oxygen uptake. In children who exercise at a similar exercise intensity, the average ratio is approximately 32:1 .

Ventilatory equivalent for carbon dioxide ($\dot{V}_E/\dot{V}CO_2$), is the ratio of the volume of gas expired to the volume of carbon dioxide produced (Davis, 1985a).

Ventilatory Threshold.

During incremental exercise, the level of oxygen consumption ($\dot{V}O_2$) steadily increases. It rises to a point above which aerobic energy production is significantly supplemented by anaerobic energy pathways. This results in a non-linear increase in lactate and metabolic acidosis and is termed the ventilatory threshold (Wasserman, 1987a). The most specific criterion for the determination of ventilatory threshold is a systematic increase in $\dot{V}_E/\dot{V}O_2$ without a concomitant increase in $\dot{V}_E/\dot{V}CO_2$. The relative stability in $\dot{V}_E/\dot{V}CO_2$ denotes proportional increases in ventilatory drive and an additional production of CO_2 which is produced from non-metabolic sources of $\dot{V}CO_2$ (Davis, 1985a). Increased anaerobic metabolism results in increased production of lactic acid and its associated hydrogen ions. The buffering of additional hydrogen ions is associated with the formation of non-metabolic CO_2. This acts almost simultaneously as a trigger to increase ventilatory drive. With both $\dot{V}_E$ and $\dot{V}CO_2$ increasing, the resultant ratio ($\dot{V}_E/\dot{V}CO_2$) remains relatively stable.

RER (Respiratory Exchange Ratio).

Because of differences in the composition of carbohydrates, fats and proteins, different amounts of oxygen are required to completely oxidise the carbon and hydrogen atoms in the molecule to the end products, of carbon dioxide and water (McArdle et al., 1996). It is possible to estimate the type of substrate being oxidised by calculating the RER. Under submaximal steady state conditions. RER or the $\dot{V}CO_2/\dot{V}O_2$ ratio measured in expired gas, has been utilised as an indicator of the respiratory quotient at the cellular level. An RER value of 0.7 would indicate that predominantly fat was being oxidised. A value of 1.0 would mean that carbohydrates are the likely source of fuel for energy. In adults, lactate production during exercise intensities above ventilatory threshold, markedly increases RER values. As a consequence, the additional CO_2 produced from bicarbonate buffering, results in values that exceed those reflecting RQ (Rowland, 1996b). Children appear to display lower RER values and generate less lactate than adults (Zwiren, 1989., Cooper, 1995).

Lactate.

Lactate is the predominant fixed acid produced during exercise. It is possible for lactate to diffuse from anaerobically contracting muscle tissue and be metabolised by muscle fibres that are still operating aerobically (Mazzeo et al., 1982). Lactate will accumulate in the blood during exercise when glycolysis proceeds at a faster rate than pyruvate can be utilised by the aerobic oxidative mechanisms of the mitochondria (Wasserman et al, 1986). Lactate can begin to disproportionately accumulate in the arterial blood at efforts ranging from 50-70% of maximal oxygen uptake (Shephard et al., 1968).

CHAPTER 2. REVIEW OF LITERATURE.

CHAPTER 2.

REVIEW OF LITERATURE.

Three major topics will be addressed in this review of literature:

1. Maturational-related changes in aerobic function in children.
2. Children and aerobic training responses.
3. Physiological tests used to detect changes associated with aerobic training.
   (a) Peak $\dot{V}O_2$.
   (b) Ventilatory threshold.

1. Maturational-related changes in aerobic function in children.

Maturation and Maximal Aerobic Power.

As a measure of aerobic function, peak $\dot{V}O_2$ expressed in absolute terms ($l.min^{-1}$) in children will continue to rise during the developmental years. Krahenbuhl et al. (1985) observed that before puberty the age-related increases in $\dot{V}O_2$ peak were close to linear with an average rise of approximately 225 $ml.min^{-1}$ of oxygen, for each year after the age of six. These increases are reported to reflect the increasing dimension of the oxygen delivery chain, which includes the ability of blood to transport oxygen via the pulmonary, cardiac, and vascular systems to satisfy metabolic needs of the growing child (Rowland, 1990a). Mirwald and Bailey (1986) suggested that a typical 8 year old boy will increase his $\dot{V}O_2$ peak from 1.42 $l.min^{-1}$ to 2.12 $l.min^{-1}$ by the age of 12 years. Bar-Or, (1983) contended that the mean values for peak $\dot{V}O_2$ are greater in males than females. Mirwald and Bailey, (1986) reported that at the age of 10 years $\dot{V}O_2$ peak values were 16% greater in Canadian boys than girls. Krahenbuhl et al. (1985) suggested that this gender difference was related to a number of factors, including muscle mass, haemoglobin concentration, and physical activity levels. Rowland (1990a) supported this view when he reported that an average 8 year old boy has a haemoglobin concentration of 12.9 g/dl and that by 17 years, the concentration is 15.5 g/dl, representing a 20% increase in haemoglobin mass relative to body weight. Boys have a greater proportion of lean body mass than girls even during the prepubertal years which may also relate to enhanced aerobic power (Rowland, 1990a). Malina and Bouchard (1991) reported that sex-related differences in aerobic power prior to puberty may be explained through socio-cultural factors.

Shephard (1992), was critical of the earlier training studies on prepubertal children, for including pubertal subjects. An appreciation of the complexities of the growth processes and the variability of the timing of these events can enhance a researcher's awareness of the effects that these processes can have on the results. Malina and Bouchard (1991), reported that with increasing age, there is a predictable, sequential, development in a range of physiological functions in the child. There is however, considerable variability in the rate of development among young populations and the changes will not necessarily progress in a uniform manner. The precise triggers for changes in growth patterns are not well understood. Borms (1986) reported that early maturers may demonstrate positive training effects compared with their average or late maturing counterparts. This may however, be more representative of males than females and differences may manifest as advantageous or disadvantageous depending on the context of a specific sport or activity (Malina and Bouchard, 1991).

The outcome of biologically-based maturational changes may lead to the improvement in exercise performance. Testosterone has been recognised as an important contributor in altering physical capacity at puberty (Rowland, 1997). Its influence on aerobic trainability is thought to be due to the changes it produces in physiological and metabolic characteristics such as:

1. The increase in skeletal mass, which promotes muscular strength and provides the cellular make-up to enhance aerobic and anaerobic performance (Powers and Howley, 1997). For example, it was recently hypothesised that increased skeletal muscle mass strengthens the pumping action of venous return and thus may enhance end diastolic volume (Rowland, 1997).

2. Cardiac size and function also appear to be affected by testosterone. In adults an increase in stroke volume appears to be the principal factor responsible for improvement in $\dot{V}O_2$ max with endurance training. In addition, an increase in ventricular contractility and increases in plasma volume associated with growth at puberty will improve cardiac output which will enhance oxygen uptake at maximal exercise (Rowland, 1997).

Table. 2. 1: Growth Changes in Cardiorespiratory Parameters Between the Ages of 8-12 years.

CARDIORESPIRATORY PARAMETERS	AVERAGE CHANGE WITH GROWTH	RELATIVE CHANGE
Mean heart weight	from 119 to 168 g	an increase of 42%
Estimated left ventricular volume at rest.	Echocardiographic assessment	enlarged by 52%
Lung vital capacity	from 1890 to 2800 ml	increased by 48%
$\dot{V}O_2$. max	from 1.42 to 2.1 $l.min^{-1}$	an increase of 49%

Source: Adapted from Rowland (1990a)

Potential growth-related changes in several cardiorespiratory parameters which may occur during the prepubescent period are outlined in Table 2.1. Growth hormone is produced by the anterior pituitary gland and is primarily responsible for growth during childhood. This hormone also stimulates other end organ responses, and causes an increase in both skeletal and heart mass as well as an enhanced cardiac contractility, and an increased capillarisation and mitochondrial capacity (Rowland, 1997). The role of growth hormone in exercise in individuals who are also "growing" is not well understood. In active young athletes two sources of growth hormone may be available to stimulate growth; one from additional activity and the other from growth-related stimulants. Cooper, (1995b) postulated however, that in young athletes who train excessively (eg. malnourished female gymnasts), there may be a major imbalance between the energy intake and the relatively higher energy demands of training. This may result in a suppression of growth, through a diminished influence of the "growth-related" source of growth hormone.

Table 2.2. Maturational and training related changes in selected physiological functions

PHYSIOLOGICAL FUNCTION.	CHANGES WITH AGE AND MATURATION.	CHANGES WITH TRAINING.
Maximal $\dot{V}O_2$ ($l.min^{-1}$)	Increases	Increases
Maximal $\dot{V}O_2$ ($ml.kg^{-1}min^{-1}$)	No change	Decreases
Maximal Heart Rate ($b.min^{-1}$)	Decreases	No change
Maximal stroke volume ($ml.bt^{-1}$)	Increases	Increases
Maximal ventilation ($l.min^{-1}$)	Increases	Increases
VT as a % of $\dot{V}O_2$ max	Decreases	Increases
Maximal blood and muscle lactate concentration (mM)	Increases	Increases

VT denotes ventilatory threshold Source: Bar-Or and Malina, 1995.

Many of the physiological functions measured in an attempt to quantify training adaptations are also affected by and occur as a direct result of growth and maturation (Table 2.2.). Therefore, it is difficult to assess the contribution provided by an exercise training stimulus in children, from those attributable to normal growth. Accounting for changes becomes even more problematic as some of these normal growth functions change in the same direction that may be expected from training during growth (Bar-Or, 1989).

Anthropometric changes in maturation and training.

Rowland (1996b) suggested that the physiological response to exercise in childhood must be understood in the context of changes in body composition during growth. Krahenbuhl et al. (1985) reported that correlations between peak $\dot{V}O_2$ and body weight in paediatric studies in general have been modest (r = 0.60-0.80). Paediatric subjects who are more muscular and less fat, demonstrate peak $\dot{V}O_2$ values which more closely correlate to body weight than their peers. A high correlation (r = 0.94) for peak $\dot{V}O_2$ and body weight, was reported by Mayers and Gutin (1979) in a study on pre-adolescent distance runners. Researchers have observed that children with excessive body fat perform poorly in task oriented physical activity, particularly in weight bearing activity (Boileau and Lohman, 1989, Watson, 1988). In general, subcutaneous fat stores slowly decrease to their lowest levels between the ages of 6 and 8 years, then increase throughout most of the remaining pre-pubertal years. A noticeable decline in fat mass coincides with the onset of the growth spurt (11-12 for girls and 14-16 for boys) (Tanner, 1978). Mean fat mass in females is greater than in males from mid childhood onwards (Malina and Bouchard, 1991). Bar-Or and Malina (1995) reported that training associated changes in fatness in children are well documented, however, the longer term affects of on adipose tissue and metabolism remain unclear. In sedentary adults, a decrease in fatness as a result of a training has been attributed to a reduction in size of the fat cells rather than changes in the number of cells (Bjorntop et al., 1972). A 20 week training study conducted by Despres et al. (1984) using adult subjects, reported enhanced lipolysis and a reduction in adipose levels. Some early studies on pre-adolescent children however, which evaluated the influence of exercise training programs on body composition reported non-significant reductions in body fat (Gilliam and Freedson, 1980, Lussier and Burskirk, 1977). In both of these studies, the short-term duration of the programs (no more than 12 weeks) may not have been of sufficient time to elicit a significant body fat reduction in the subjects. These two studies also failed to provide of measures of the precise exercise intensity at which the subjects trained. It is possible that the exercise intensity may have been too low to stimulate substantial fat metabolism (Romyn, 1993). Moody et al. (1972) examined body composition changes in normal and overweight groups of high school girls (15-16 yrs) before and following a 15-29 week jogging program. The results from both programs indicated a significant reduction in body weight and body fat, with a corresponding increase in lean body mass compared with an age matched control group. Sallis et al. (1995) reviewed weight loss programs in children through school based exercise intervention studies and concluded that this type of intervention was likely to be unsuccessful in reducing the fat mass of overweight young populations. Sallis et al. (1995) believed that weight reduction in childhood was a highly complex issue and likely to be only minimally influenced by caloric expenditure offered by a school based intervention program. This was also related to an inability of the school to account for home and culturally based nutritional practices.

Determining the developmental stages of maturation.

A number of the previous training studies on prepubertal children, have been criticised for including participants of mixed pubertal status (Shephard, 1992). It is possible that a growth and performance enhancement coincident with increasing pubertal status may have confounded the results of these studies by masking the true effects of exercise stimulus in only subjects with advanced pubertal ranking. Theoretically, subjects of the same pubertal status will participate in an exercise intervention study with a similar potential to improve exercise performance. Sallis (1994) defined the period of adolescence as occurring between the ages 11 through 21 years. The meta-analysis conducted by Payne and Morrow (1993) on children's aerobic fitness, used the age of 13 years as the transition from preadolescence to adolescence. Researchers often describe maturational status using a series of developmental pictures and descriptions corresponding to five discrete stages of sexual maturation of breast development, genital development and, or pubic hair development (Tanner, 1969). Since then, Ross and Marfell-Jones (1991) have devised a 6-point scale for pubic hair development and a 5 point scale for breast and genital development. The revised version is however, less practical in that the method requires direct measurement of the testicles and therefore cannot be used outside a clinical setting. Determining the developmental stage of maturation, however, remains an important consideration for exercise training programs in paediatric populations.

2. Children and aerobic training responses.

Aerobic Training and Training Study Design.

The literature is both limited and inconclusive concerning the effects of aerobic training on the prepubescent child. The early training studies have been the subject of considerable scrutiny over the past two decades (Bar-Or, 1989, Cunningham et al., 1984, Payne and Morrow, 1993, Rowland, 1985, Shephard, 1992, Vaccaro and Mahon, 1987, Weymans et al., 1986).

Cunningham et al. (1984) reviewed 18 studies conducted in the period 1966-1981 in which the subjects' ages ranged from 7-18 years. All of the studies used $\dot{V}O_2$ max as the criterion for assessing the effectiveness of the aerobic training program. Following participation in an aerobic training regimen, the results from the studies spanned the full spectrum of possible outcomes and varied from positive aerobic gains to no change. Cunningham et al. (1984) also noted that the major research design errors were, no control group, irregular training sessions, the lack of control over work intensity during sessions, and a lack of random assignment of subjects to control and training groups.

Rowland (1989b) stated that there is very limited information available which examine variables essential in training studies, such as intensity, duration, and frequency and how they impact on the trainability of paediatric subjects. Rowland (1989b) expressed that there was a general lack of sound research design and inconsistencies in protocols, and intervention designs used in previous paediatric studies. For example, many of the early aerobic training studies in paediatric populations, failed to consider and, or, control for "naturally occurring factors" such as the influence of growth and maturation on performance, or the initial fitness levels of subjects in the training studies. Subsequently, much of the past research has produced results from which it is difficult to draw firm conclusions about the training program and its effectiveness on younger populations.

In a review of training programs for the prepubescent child, Bar-Or (1989) noted that none of the studies achieved significant increases in $\dot{V}O_2$ peak expressed in relation to body mass (ml.kg.$^{-1}$ min^{-1}). Several studies have reported improved mechanical efficiency and submaximal aerobic function, as a result of training, following relatively short term training programs (Becker and Vaccaro, 1983, Massicotte and MacNab, 1974). The factors contributing to improved mechanical efficiency may include enhanced neuromuscular co-ordination, lower heart rate, improved stroke volume, increased arterio-venous oxygen extraction, or greater thermoregulatory control during exercise. Implicit in the observation of improved submaximal efficiency is the fact that if aerobic training occurs submaximally and not at maximal intensities, then more changes are likely to be found at the submaximal rather than maximal levels of testing. Thus, if children are predominantly training submaximally, expectations of changes at maximal intensity may be unrealistic.

A meta-analysis conducted by Payne and Morrow (1993) examined the effects of physical activity, gender, experimental research design, and the duration and intensity of the exercise intervention on the $\dot{V}O_2$. peak results reported from paediatric aerobic training studies. Their analysis of the literature identified 69 studies which had examined the effects of exercise on the aerobic fitness of children. Of these, only 28 studies, were considered acceptable for further evaluation. Acceptance was based on successfully meeting the following criteria; recruitment of normal subjects who were 13 years of age or less, employment of protocols which included $\dot{V}O_2$ peak measures using open circuit spirometry, presentation of results in means and standard deviations for both the experimental and control groups, and the inclusion of a control group of subjects who represented an untreated group in a cross-sectional design or from a pre-test in a pre-test design. The authors also used the guidelines of the American College of Sports Medicine (1990) to determine appropriate exercise duration and frequency imposed during training. It must be noted that these guidelines were established for adults as no guidelines existed for children. Results from the meta-analysis reported relatively small to moderate increases between pre to post-exercise intervention tests for $\dot{V}O_2$ peak in most of the studies complying with the criteria deemed as acceptable within the described research design.

Table. 2. 3: A sample of earlier studies reporting peak $\dot{V}O_2$ changes with exercise training program intervention.

AUTHOR/S (yr)	Age (yr) sex (M/F) & N	TRAINING	TRAINING INTENSITY	FINDINGS
Becker and Vaccaro, 1983.	9-11 yr N = 11 M exp'l group 11 M control	3 sessions x 8 wks	cycle ergometers HR at 50% between VT and HR max until volitional fatigue or for a maximum of 40 mins.	Peak $\dot{V}O_2$ exp group 20% increase, control was 10%. (P>0.05)
Gilliam and Freedson, 1980.	8.5 yr N = 11 M & F +12 control	25 min x 4 sessions x 12 wks	Aerobic activity which required 'continuous movt'. for the entire session HR every 5 min during exercise.	No significant difference in peak $\dot{V}O_2$ pre- to post-training
Lussier and Buskirk, 1977.	8-12 yr N = 26 M & F	4 sessions x 12 weeks	Cycle ergometer.	$\dot{V}O_2$ ↑, 6.8%
Massicotte and MacNab, 1974.	11-13 yr N = 36 M (3 groups of 9 + 9 in the control group)	3 target heart rate groups T1. 170-180 T2. 150-160 T3. 130-140 T4. Control. 12 min x 3 sessions x 6 wks	All testing and training was conducted on bicycle ergometers, using an ECG to monitor HR and to adjust work load according to performance during previous sessions.	11% ↑ in Peak $\dot{V}O_2$ (P<0.05) for the T1 training group but not T2, T3 or the control.
Savage et al. 1986.	8-9 yr + adults. N = 34 boys + 34 male adults	3 sessions x 11 wks.	A running program. two experimental groups, E1. at 85% of HR max E2. at 68% of HR max	Boys, 6.7% ↑ in Peak $\dot{V}O_2$. (P<0.05) (E1) Adults. 7.9% ↑ in $\dot{V}O_2$ max (P<0.05) (E2)
Stewart and Gutin, 1976.	10-12 yr N = 13M exp'l + 11M control	4 sessions x 8 wks	A running program. 1-3 min runs at 90% HR max, with one minute rests.	No difference in peak $\dot{V}O_2$
Yoshida et al. 1980	5 yr N = 30 M & F	1-3 or 1 sessions x 28 weeks,	Running program.	No difference in peak $\dot{V}O_2$.

↑ = increase.

Massicotte and MacNab, (1974) demonstrated a sophisticated approach in relation to the research design (Table 2.3). The study (1974) carefully controlled the duration and frequency of the training session. Heart rate was measured using an ECG during training as well as during the testing. Furthermore the intervention design was a progressive increase in work loads set for each individual and these work loads continued to be modified as the training progressed. The study also attempted to resolve the problem of identifying minimum heart rate necessary to elicit a cardiovascular improvement during training. Massicotte and MacNab (1974) however, reported an 11% improvement in peak $\dot{V}O_2$ with only three, 12 minute training session on a cycle ergometer per week for six weeks, when other researchers, with more intense training sessions, (4 sessions x 8 weeks) were unable to elicit a similar high level of improvement (Stewart and Gutin, 1976). Massicotte and MacNab (1974) failed to report pubertal assessment. Shephard, (1992) speculated that some of the subjects in the Massicotte and MacNab (1974) study may have entered puberty before the data collection was completed, and consequently that growth may have facilitated the larger than expected observed improvement.

Gilliam and Freedson, (1980) conducted a 12 week training program with 8 year old male and female children who trained for four 25 minute sessions per week of "continuous" activity. Although the intensity of the exercise intervention was described as moderate to high intensity, heart rate monitoring was only recorded every 5 minutes. The nature of the heart rate monitoring, may have compromised the potential accuracy of the description of the intensity of the training study, by the relatively large intervals between each measurement. Thus, it is possible that large amounts of valuable heart rate information were not recorded. Explanations for the resultant no change in maximal aerobic power of the 8 year old subjects may have been more evident with more precise measures of exercise intensity during the training study.

A study undertaken by Becker and Vaccaro (1983), examined the cardiorespiratory changes following an 8 week training program with children aged 9-11 years. This study required subjects to participate in 3 sessions per week for 8 weeks of endurance training. The mode of exercise was described as cycle training and the intensity of participation involved cycling at heart rates representing half way between the ventilatory threshold (VT) and the maximum heart rate for a maximum of 40 minutes or until volitional fatigue. The research design was based on the training intensities used by Davis et al. (1979), and Sady et al. (1980), in their studies using adult populations. Changes in peak aerobic power were reported in both groups (20 and 10% improvement in the experimental and control groups, respectively) however, the results were not different ($P<0.05$). One suggestion for this outcome was, that the physical activity levels of the control group could not be practically controlled. The study by Yoshida et al (1980) using 5 year old subjects, reported non significant differences in peak $\dot{V}O_2$ in the control group and the experimental group after the 28 week training period of a running program which occurred on 1-3 days per week. The inconsistency in the frequency of training during this study may have affected the results of this study.

Pate and Ward (1990) suggested that prepubescence may be a unique developmental period with regard to adaptations to endurance training. Many of the earlier training studies with children resulted in a wide range of changes in peak $\dot{V}O_2$ scores. Errors in research design in some of these studies reflect the need for careful control in planning and implementing exercise training programs with prepubescent populations (Table 2.3).

A summary of considerations for research design in exercise intervention studies with children

The following discussion includes a summary of considerations that must be addressed when designing an exercise intervention study.

a. One of the criticisms of the earlier studies on children was that some of the subjects were into the adolescent phase, and hence mixed pubertal status may have influenced results and may have represented errors in experimental design (Shephard, 1992). This difficulty is due to the heterogeneity of the growth patterns during this period. It is problematic when researchers need to separate the results of the study into the contribution of changes due to training from the changes influenced by growth (Cunningham et al., 1984). Bar-Or (1989) suggested that studies evaluating the aerobic trainability of different maturation groups require a controlled, randomised design with stratification for prepubescent, pubescent and postpubescent groups as well as a matched training dose.

b. Studies with small group sizes and studies that lack control groups for comparisons have made it difficult to draw firm conclusions from the results of research conducted in some of the earlier exercise intervention studies (Shephard, 1992, Zwiren, 1989).

c. The variability in training duration, frequencies, and work intensities during exercise intervention studies, have made inter-study comparisons and interpretation of results from some studies difficult (Shephard, 1992).

d. Some subjects may have a high level of initial aerobic fitness and consequently the training programs would have needed to be quite demanding to induce a training improvement (Rowland, 1997, Shephard, 1992).

e. Adult studies theoretically have a greater chance of having an inactive control group, than studies seeking sedentary behaviour patterns in children. Researchers often fail to recognise the innate high levels of physical activity in the presumed to be inactive control group (Payne and Morrow, 1993).

f. Rowland (1990a) warned that in paediatric studies where volunteers were used as subjects, usually the most 'physically capable' volunteer. Therefore, it would be unlikely to have 'normal' physiological data representative of the total paediatric population. Hence a description of the process of subject selection is an important consideration as part of the research design.

g. There is a need for sensitive, simple and valid measurement tools for use in exercise training studies. Cunningham et al. (1984) reported that the difficulty in developing training evaluation methods were reflected in the number of exercise mode, frequency, duration and intensity that have been tried and found wanting.

h. Insufficient or inadequate documentation of training intensity, inappropriate (anaerobic) exercise, and poorly described testing methods were also reported as a common flaw in the existing literature on aerobic exercise training in childhood (Rowland and Boyajian, 1995).

I. If the training intensity was not at maximal effort, then the principle of specificity would suggest changes may not be possible (Rushall and Pyke, 1990).

More recent training studies.

A range of possible problems involved in the design and implementation of an exercise training program with prepubescent populations is evident in the literature emerging from the 1970s and 1980s. More recent studies have attempted in their design to conform to more scientifically and rigorously controlled study designs and to avoid the problems previously discussed. In general, recent studies have focussed on improving the accuracy and reliability of results in research on paediatric populations. A review of these studies is presented in Table 2.4.

The complexities in designing and implementing training studies are such, that even researchers with recognised skills in the field paediatric research, do not always manage to account for all intervening variables. Recently, Rowland (1996) described a 13 week training study involving 31 children (N = 20 females and 11 males) aged 10-12 years. He (1996) observed a 5.4% increase in $\dot{V}O_2$ peak ($ml.kg^{-1}min^{-1}$)as a result of the training program. The training program was well designed and monitored in that it consisted of three sessions of sustained exercise per week, with two week blocks of aerobic dance, aerobic step, distance running and circuit activities. Subjects wore portable heart rate monitors and were encouraged to maintain heart rates in the range of 170-180 $b.min^{-1}$. The study included an experimental and control design. In the final analysis it was found that, the increase in $\dot{V}O_2$ peak may have been influenced by the fact that three of the 11 boys, displayed a number of characteristics which suggested the onset of puberty such as pubic hair, voice changes and facial hair. A mixed pubertal status also occurred in the female subjects, as two of the 20 girls had experienced menarche.

Table. 2. 4: A selection of more recent exercise intervention studies reporting changes in peak $\dot{V}O_2$.

RESEARCH	AGE (yr), Sex (M & F) & N	TRAINING	TRAINING INTENSITY	FINDINGS
Eliakim et al. 1996.	15-17 yr N = 44F (22 control & 22 exp).	5 sessions x 5 weeks	A 2 hour endurance session	A 12 $\pm$ 4% increase in maximal oxygen uptake ($p=0.004$). Thigh muscle volume increased by 4.3% $\pm$ 1% ($p=0.0002$).
Haffor et al. 1990.	10.8 $\pm$0.4 yr N = 6M in exp and control groups	50 min x 5 sessions x 6 weeks	25 and 50% above their anaerobic threshold levels.	Peak $\dot{V}O_2$ ($l.min^{-1}$) increased 19% but was not different ($P>0.05$)
Mahon and Vaccaro. 1989.	10-14 yr N = 16M in exp & control	8 weeks of run training	70-80% of peak $\dot{V}O_2$.	Peak $\dot{V}O_2$ increased 7.5% ($P<0.05$)
McManus, et al. 1997.	9.6 yr N = 30 F (12 in prog.1, 11 in prog. 2, & 7 in control)	Two programs of 3 sessions x 8 weeks	Prog 1 = cycle ergometer Prog 2 = sprint running	Both training groups increased their peak $\dot{V}O_2$ scores ($p<0.05$)
Rotstein et al. 1986.	10.2 - 11.6yr N = 28 M	3 sessions x 9 weeks.'	Interval training	Peak $\dot{V}O_2$ improved 7% but was not different ($P>0.05$).
Rowland et al. 1996.	10.9 - 12.9 yr N 31= (20 F & 11 M + a control group)	25 min x 3 sessions x 13 weeks	HR targets 170-180 $b.min^{-1}$ during "aerobics"	Peak $\dot{V}O_2$ improved 5.4%
Rowland and Boyajian. 1995.	10.9 - 12.8 yr N = 24 F	30 min x 3 sessions x 12 weeks	Endurance sessions with mean HR of 166 $b.min^{-1}$	Peak $\dot{V}O_2$ improved 6.6%
Welsman, et al. 1997.	10.2 yr N = 51 (17 in prog. 1, 18 in prog. 2, +16 in control group)	Two programs of 3 sessions x 8 weeks	Prog 1 = aerobic training Prog 2 = cycling at 160-170 $b.min^{-1}$	Peak $\dot{V}O_2$ did not change significantly in either training group.

F = female. M = male.

One of the studies outlined in Table 2.4, examined the effects of interval training on peak $\dot{V}O_2$ and VT in five 11 year old males (Haffor, 1990). The subjects trained for 50 minutes, 5 times per week over a six week period. Training involved relatively high intensities of 25-50% above the VT. The authors reported that the training program resulted in an increase in both anaerobic threshold (22%, $P<0.05$) and $\dot{V}O_2$ uptake (19% $P>0.05$). The non significant result for peak oxygen consumption was explained by the small sample size and observed large variation within the groups after training. In contrast, a nine week high intensity interval training program involving twenty-eight 10-11 year old boys, found that while there was an increase in the $\dot{V}O_2$ peak, the anaerobic threshold actually decreased (Rotstein et al., 1986). The study by Eliakim et al. (1996) was unique in its focus on the training responses in female adolescents because of its use of advanced methodologies in quantifying energy expenditure. Magnetic resonance imaging was used to evaluate changes of muscle mass, and double labelled water technology was used to evaluate total energy expenditure during the training study. A relatively intensive training regime which required subjects to participate in endurance training for at least 60 minutes per day, 5 days a week, over a 5 week duration, resulted in an approximate 12% increase in peak oxygen consumption in the exercise intervention group.

Of the eight studies reported in Table 2.4, peak $\dot{V}O_2$ was reported to increase in six of the studies undertaken. While Eliakim et al. (1996) reported a 12.1% increase in peak $\dot{V}O_2$ scores, the subjects in the study were 15-17 year old adolescent females. In the five remaining studies, only two used clearly defined prepubertal subject populations (Rotstein et al., 1986, Welsman et al., 1997). Without clarification of the pubertal status in the remaining studies presented in Table 2.4, it is possible that they may have included early pubertal subjects who ultimately may have masked the true treatment effect.

3. Physiological tests used to detect changes associated with aerobic training.

1. Peak $\dot{V}O_2$.

In children the maximal performance level is referred to as peak $\dot{V}O_2$ as it is less certain that they will always reach the adult-based criteria for maximal exhaustion (Zwiren, 1989). In children, it may be that factors such as local fatigue and motivation limit their performance. While $\dot{V}O_2$ max (ml.kg^{1}min^{1}) is an accepted measure of changes in fitness status in the adult, its value as a sensitive marker of aerobic training in children remains uncertain. Rowland (1991) reported that when the results of all the cross-sectional studies on children are combined, peak $\dot{V}O_2$ relative to body weight in boys, remains essentially unchanged between 6-16 years (Freedsom and Goodman, 1993). The literature includes a number of allometric scaling equations that attempt to equalise differences in peak $\dot{V}O_2$ scores and body dimensions during growth (Welsman et al., 1993, Winter, 1992). These include expressing $\dot{V}O_2$ peak in relation to body weight, surface area, lean body mass, skeletal age and height. Despite its limitations, $\dot{V}O_2$ (ml.kg.$^{-1}$min^{-1}) remains the most common means for researchers to express $\dot{V}O_2$ performance scores (Rowland, 1991). It is difficult to discriminate between the changes caused by growth and the possible changes created by exercise intervention programs. After puberty the adolescent male can reflect similar patterns of change as the adult in response to training (Rowland, 1990a).

Table. 2.5. Relative changes in peak $\dot{V}O_2$ (ml.kg^{-1}.min^{-1}) associated with training in children and adolescents.

AGE (yrs)	N	≤ 0%	+1 - 5%	+6 - 10%	11 - 15%	≥ 15%
≤10	13	4	8			1
10-13	12	1	2	3	2	4

Source, Pate and Ward, 1990.

Table 2.5 represents the number of training studies and the degree of change (%) recorded for each study (Pate and Ward, 1990). It is of some interest that the 10-13 years age group has a greater number above the 5% level, compared with the less than ten years of age group. It is possible that some subjects in this age group are entering puberty and growth factors are influencing the results.

Table. 2. 5. Application of the presentation of training study results originally used by Pate and Ward (1990) to changes in $\dot{V}O_2$ max (ml.kg^{-1}min^{-1}) reported in more recent studies with children and adolescents

AGE (yrs)	N	≤ 0%	+1 - 5%	+6 - 10%	11 - 15%	≥ 15%
10-13	8	1	2	4	0	1

Modified from Pate and Ward (1990).

The studies selected for Table 2.6. represent the more recent studies, and are unlikely to have been included in the evaluations compiled by the earlier reviewers (Bar-Or, 1989, Cunningham et al., 1984, Payne and Morrow, 1993, Rowland, 1985, Shephard, 1992, Vaccaro and Mahon, 1987, Weymans et al., 1986). Adopting the presentation of findings used by Pate and Ward (1990), the more recent studies outlined in Table 2.5 have been further represented in Table 2.6. The majority of the recent studies reported a positive change in peak $\dot{V}O_2$ as a result of a training intervention. This may reflect a more measured approach taken in establishing the research design, better measuring techniques, or greater control in conducting the training study.

Ventilatory Threshold

Some of the paediatric research over the last two decades has focused on the possibility that ventilation kinetics may offer a more sensitive measure of cardiovascular performance (Ciozzo et al., 1982, Davis et al., 1979, Reybrouck et al., 1983, Washington et al., 1988). Researchers have reported that in adults, VT is a more accurate predictor of endurance performance than is OBLA (at a 4 mM lactate concentration) (Reybrouck et al., 1986, Tanaka et al., 1986). Wolfe et al. (1986), were able to predict performances in adolescent female runners, by using $\dot{V}O_2$ or heart rate at VT. Washington et al. (1988) suggested that heart rate at VT in children, is variable in subjects of similar physical fitness, hence, heart rate at VT cannot be predicted and must be individually measured.

It must be noted that not all exercise physiologists embrace the concept of ventilation threshold (Gladden, 1984, Yeh, et al., 1983). There has been an enthusiastic debate concerning the assumptions that surround the theory of threshold dynamics. The following is a summary of some of the terminology, key issues and concerns arising from this debate.

Terminology.

A review of the available literature revealed a loose interchange of terminology by the researchers while referring to anaerobic threshold. A disproportionate increase in the ventilatory equivalent (VE) for $\dot{V}O_2$ ($\dot{V}_E$ / $\dot{V}O_2$) without a similar rise in the VE for $\dot{V}CO_2$ ($\dot{V}_E$ / $\dot{V}CO_2$) for example, has been referred to as anaerobic threshold, ventilatory aerobic threshold, VT, or ventilation threshold 1 (VT_1), (Keith et al., 1992, McLellan, 1987, Washington, 1993). Further, observation of the VE data shows an increase in VE for both $\dot{V}O_2$ and $\dot{V}CO_2$. This additional increase has been called the respiratory compensation for metabolic acidosis (Wasserman et al., 1973), anaerobic threshold (Skinner and McLellan, 1980), ventilation threshold for long term exercise (Reybrouck et al., 1983), and VT 2 (McLellan, 1985). Recently, attention has been given to V slope analysis (Wasserman et al., 1990). Wasserman et al. (1990) advocated the use of the V slope analysis for detection of the shift to a greater contribution from anaerobic metabolism. This theory centres on $\dot{V}CO_2$ as a continuous function of $\dot{V}O_2$ for evaluation of ventilation threshold. The point of deflection when $\dot{V}CO_2$ is plotted against $\dot{V}O_2$ is said to denote the first ventilation breakpoint, as a result of excess CO_2 as a direct effect of increased anaerobic metabolism. Wasserman et al. (1990) reported that V slope analysis was a sensitive index of metabolic acidosis even in individuals with impaired respiratory mechanics. An individual's anaerobic threshold has been described as the highest metabolic rate at which predominantly aerobic metabolism can be maintained at a steady-state during prolonged and or, incremental exercise (Keith et al., 1992, Wasserman et al., 1973). For the purpose of this study, the respiratory events that occur during high intensity exercise will be referred to as the 'ventilatory threshold'.

Ventilatory threshold - Background.

The concept of ventilatory threshold is based on the assumption that a measurable physiological event occurs during incremental exercise, when the buffering of the hydrogen ions associated with build up of lactic acid in the active muscle results in the formation of non-metabolic CO_2. The additional CO_2 is associated with a marked increase in ventilation. The result is a deflection point in the VE for $\dot{V}O_2$, ($V_E / \dot{V}O_2$) without a similar rise in the VE for $\dot{V}CO_2$ ($V_E / \dot{V}CO_2$). It is denoted as the ventilatory threshold (Wasserman et al., 1973).

Spirited debate has occurred between researchers on threshold dynamics over the past two decades. The critics of the 'anaerobic threshold' concept maintain that further scientific evaluation is required before it can be used as a physiological marker (Brooks, 1985, McLellan, 1987). The controversy has focused on a number of issues including terminology, uncertainty over the mechanisms driving the threshold concepts, and the variability in the interpretation of the data collected.

The bicarbonate buffer system.

Supporters of the ventilatory threshold concept consider the role of the buffer system as important in the chain of events which occur during the onset of metabolic acidosis, as denoted by increases in lactate concentrations, and a decrease in pH (Wasserman et al., 1973). The bicarbonate buffer system consists of a mixture of carbonic acid (H_2CO_3) and sodium bicarbonate (Na HCO_3) in the same solution. Carbonic acid in solution almost immediately dissociates into carbon dioxide and water and the net result is a high concentration of dissolved carbon dioxide but only a low concentration of acid (Guyton, 1986). The increase in the chemical activities occurring at a ventilatory threshold are summarised in the following reactions:

Figure 2.1. Chemical activities occurring at a ventilatory threshold.

$$\boxed{La^- + H^+ + Na^+HCO_3 \leftrightarrow NaLa + H_2OCO_3 \leftrightarrow H_2O + CO_2 + NaLa.}$$

The buffering of hydrogen ions associated with accumulating lactic acid results in an increase in the partial pressure of CO_2 (PCO_2) in the capillaries of the lungs. Ventilatory control mechanisms act to maintain acid base balance, by triggering an increase in ventilation to remove excessive CO_2. As lactic acid increases during exercise, ventilation increases in response to two different CO_2 sources. The first source is the metabolic CO_2 generated from aerobic metabolism, and the second source is derived from the excess non-metabolic CO_2 from the buffered lactic acid (Davis 1985b, Washington 1989, Wasserman et al., 1990). Saltin (1992) postulated that as the lactate hydrogen ion concentration in active muscle rises during exercise, it may alter the pH level and stimulate the chemoreceptors, which in turn may also increase ventilatory drive and CO_2 removal.

A summary of possible factors contributing to disproportionate rises in VE during incremental exercise .

Astrand and Rodahl (1986) suggested that there are a number of possible theories to explain the regulation of breathing. No one theory unequivocally explains how respiratory volume adapts to the range of stresses associated with exercise. While increases in lactate may appear to be the main contributor to the non-linear rise in ventilation rate during incremental exercise, a number of authors have proposed a range of additional factors which can influence an increase in ventilation (Jones, 1988, McLellan, 1987, Saltin 1992, Wasserman et al., 1990).

1. The proprioceptive stimulatory reflexes in the muscle and joints can transmit impulses to the respiratory centre to increase ventilation during exercise (Guyton 1986).

2. As the exercise intensity increases, fast twitch muscle fibres (FT) can be recruited and receptors in muscle spindles in the FT fibres may send afferent signals directly to the respiratory centre, which stimulate a higher rate of respiration. FT fibres, have a higher glycolytic capacity than slow twitch muscle fibres and consequently result in greater production of lactate from anaerobic metabolism (Jones, 1988).

3. Increased lactic acid as previously stated assists the increase in ventilatory drive (Wasserman et al., 1990).
4. Collateral impulses from the brain to the respiratory centre may coincide with muscle activation from the vasomotor centre during physical activity (Guyton 1986).
5. Increases in catecholamines and potassium with increased exercise intensity, may also influence ventilation rates (Astrand and Rodahl, 1986).
6. An increase in body temperature may stimulate the respiratory centre and indirectly increase the rate of cell metabolism (Guyton, 1986).

Children and threshold dynamics.

As has previously been suggested, ventilatory threshold expressed as a percentage of peak $\dot{V}O_2$, may be better than peak $\dot{V}O_2$ scores, as an indicator of aerobic power and even training responses in children (Reybrouck et al., 1983). VT can be determined non-invasively and this makes it an attractive technique for use when working with young children in the laboratory environment.

There is considerable support in the literature for the use of ventilatory threshold measures (Ciozzo et al., 1982, Davis et al., 1979, Duncan et al., 1996., Mahon and Vaccaro, 1989, Reybrouck et al., 1983, Rowland, 1996b, Washington et al., 1988). Rowland (1996b) suggested that with training, changes in ventilatory threshold as a percentage of peak $\dot{V}O_2$ can increase, following either endurance (aerobic) and interval training (anaerobic), and concluded that changes can be used as an index of either anaerobic or aerobic fitness. Duncan et al. (1996) reiterated that the physiological events mediating VT are controversial. The authors however, believed that VT has been shown to correlate well with indices of aerobic function and have also been found to be an accurate predictor of field-based endurance performances in adults and children.

Some authors have suggested that children appear to have a much higher VT than adults (Carlson et al., 1990, Rotstein et al., 1986). Reinhard et al. (1979) suggested it is possible for the VT of children to occur at 90% of their maximum capacities, while the adult scores tend to coincide at around 50-60% of their maximum energy output.Naughton et al. (1992) obtained a VT at 75% of peak $\dot{V}O_2$, in children 10-12 years. Reybrouck et al. (1985) found that higher VT values were found in the more active boys than the less active boys. Cooper (1995b) reported that the energy costs of high intensity exercise normalised to the actual work done (O_2/joule) is higher in children, which suggested less dependence on anaerobic metabolism. Rowland (1990) reasoned that reports of higher VT values in children (Nudel et al., 1989) can be effectively cancelled by an equal number reports of very low relative VT percentages in other paediatric populations (Table 2.7).

Table 2.7: Ventilatory Threshold (VT) comparisons in studies using treadmill testing, on children and adolescence. (VT expressed as a percentage of $\dot{V}O_2$ peak.)

AUTHOR/S and YEAR	AGE (yr)	VT as % of $\dot{V}O_2$ peak.
Cunningham. (1990) #	15.9	79.0%
Duncan, et al. (1996)	8.9 - 11.5	63.5%
Kanaley and Boileau (1988)	8.7 - 11.8 13.1 - 14.6 18.7 - 24.4	68.8% 65.4% 58.5%
Mahon and Marsh, (1992)	-	72.0%
Nudel et al. (1989) #	8 - 17	80.6%
Reybrouck, et al. (1985)	-	68.0%
Naughton et al. (1992)	10-12	75.9%

well trained athletes.

Information contained in Table 2.7 represents a number of researchers who have completed studies which have included ventilatory threshold levels in children and adolescents. The table demonstrates a spread of results which may reflect, the genetic variability of children and their responses, and, or adaptations to training. Of concern is the possibility that the estimation of results may be influenced by variations in the test protocols and techniques used to determine threshold levels.

Zwiren (1989) reported that at maximal performance levels children generate less lactate and excess CO_2 than adults. From this observation it may be reasonable to expect delayed or relatively high markers of anaerobic metabolism in incremental exercise performed by children.

The lower anaerobic power characteristics in young children compared with adults may be associated with the enzymatic properties of the muscle in children. Eriksson et al. (1972) biopsied the quadriceps muscle in 11-13 year old boys, and found a higher concentration of the oxidative enzyme succinate dehydrogenase and a lower activity of the glycolytic enzyme phosphofructokinase (PFK) than in adults. The effects of training on 11-15 year olds demonstrated increases in the concentrations of glycogen, PFK activity, and an increased rate of glycogen utilisation, even though end values remained quantitatively less than adults (Eriksson et al., 1972). From the training study, it appears reasonable to expect a relatively higher onset of markers of anaerobic metabolism following exercise in children.

With maturity, differences in metabolic responses between children and adults attenuate. In a study of boys aged between 6-18 years, Reybrouck et al. (1985) reported an increase in the anaerobic capacity with growth. Bar-Or (1989) also reported that VT showed a significant decrease with age and postulated that this represented a transition from a dependence on the aerobic system, into more powerful and sustainable anaerobic performances. In addition, the role of hormonal changes occurring during puberty in metabolic responses of active muscle is not well understood (Cooper, 1995b), and may further alter the mechanisms behind the onset of VT.

Reliability and validity of testing procedures.

The following discussion focus on the reliability, validity and the reproducability of a selection of the procedures used commonly to detect changes in aerobic / anaerobic function following aerobic based exercise intervention.

a. Determining the breakpoint in threshold kinetics.

The traditional method of determining the breakpoints in VT, involved trained and practiced researchers visually examining the graphed data points to select deflection points (William et al., 1992) or the intersection of lines of best fit to locate the ventilatory threshold. Some researchers have reported the use of computerised regression analysis to establish deflection points (Beaver et

al., 1986). In most cases however, the authors reported a high correlation between the computer results and the use of skilled reviewers (Beaver et al., 1986, Orr et al., 1982).
William et al. (1992) visually determined VT using two experienced observers, with 'disagreements resolved in conference'. Mahon and Vaccaro, (1989) also used two skilled technicians who were familiar with the indicators of VT to confirm deflection points in the data. The availability of computer graphics packages has enhanced the quality of the computer print-outs, which can in turn improve the accuracy of breakpoint selection. Beaver et al. (1986) used the V slope method to determine VT, via both a computerised regression analysis program and a panel of six experienced reviewers using the traditional visual method. Determination of mean values for VT using the two approaches, did not differ significantly (Beaver et al., 1986).

Not all researchers agree on the optimal method for detecting a deflection point in ventilatory parameters during incremental exercise. Yeh et al. (1983) reported a wide variability (16%) when using visual determination of VT Gladden (1984) was also concerned with the inaccuracy of this technique, and suggested that the use of breath by breath metabolic measurement might improve the accuracy of breakpoint determination. In response to this suggestion, Washington (1993) indicated that the extra data points produced by this technique would make it difficult to determine the point at which VT occurred. Subjects with erratic breathing patterns during exercise, however, make it difficult to determine a breakpoint threshold (Davis, 1976). Universal agreement on a more precise method of determining ventilatory threshold, would be a welcome improvement for researchers employing this potentially important characteristic of aerobic and anaerobic function.

Table 2.8 presents a review of studies and the methods used to determine VT. Chicharro (1995) attempted to detect the anaerobic threshold of 25 subjects aged 10.5 years through the analyses of changes in saliva, lactate from finger prick blood samples and respiratory data. Chicharro (1995) believed that saliva data supported the more traditional measures of detecting VT from respiratory and blood lactate. Cunningham et al. (1990) compared peak oxygen uptake, VT and running economy to field based performance on a 5 km run in 24 females aged approximately 16 years. In this study VT was assessed from the aforementioned changes in VE s. In these well trained females, the VT was reported to be a significant predictor of field based performance. Beaver, (1986) used a computerised regression analysis of the slope of the CO_2 production ($\dot{V}CO_2$) vs O_2 uptake ($\dot{V}O_2$) plot in 10 adult subjects. This method was known as the V-slope method. The deflection point in this plot denoted the beginning of the excess CO_2 output generated from the buffering of $[H^+]$. Beaver (1986) compared the breakpoint in the V-slope method to deflection in the ventilatory equivalent data. The author reported consistently higher VT values from ventilatory data when compared with the values obtained from the V-slope analysis (2.51 ± 0.42 vs 1.83 ± 0.30 $l.min^{-1}$). Orr et al. (1982) implemented a computer-based linear regression model to determine ventilatory threshold by plotting $\dot{V}_E$ vs $\dot{V}O_2$. The computer generated results were compared to values determined by 'visual' evaluation. The correlation coefficient between the two detection methods was 0.94. Unfortunately, when compared with the data available on adults, not as many of the comparative studies have been as thoroughly investigated in paediatric populations.

Table. 2. 8: Review of studies using different methods to determine Ventilatory Threshold.

AUTHOR/S and YEAR	AGE (yr), SEX (M & F) and N	METHOD OF DETECTING VT	FINDINGS
Chicharro, 1995.	10.5 years N = 25 (19 M & 6 F)	saliva, blood samples and VE deflection point #	The results showed the validity of the saliva threshold as a new means of detecting anaerobic threshold.
Cunninham. 1990.	15.9 years N = 24 F	VE deflection point #	VT occurred at 79% of $\dot{V}O_2$ max. VT good predictor of 5 km run time.
Beaver, 1986.	19-39 years N = 10 M	VE deflection point # V-slope	VE deflection point was higher than the breakpoint in the V-slope analysis
Reinhard et al. 1979.	20-65 years N = 116 (66 M & 50 F).	VE deflection point # and blood lactate	Reported a higher $\dot{V}O_2$ at VT for the males. VT was negatively correlated to age.

#VT was the breakpoint from linearity of $\dot{V}_E / \dot{V}O_2$ while $\dot{V}_E / \dot{V}CO_2$ remained unchanged plotted against time.

F = female. M=male.

Table. 2. 9: A selection of training studies and the methods used to determine Ventilatory Threshold.

AUTHOR/S and YEAR	AGE (yr), SEX (M & F) and N	TRAINING	TRAINING INTENSITY	MODE OF DETECTING VT	FINDINGS
Haffor et al. 1990.	10.8 years N = 6M & control	50 min x 5 sessions x 6 weeks	25 and 50% above VT.	VE deflection point #	VT, expressed as % $\dot{V}O_2$ max increased by 22% (P<0.05).
Mahon and Vaccaro. 1989.	10-14 years N = 16M & control	8 weeks of training	running at 70-80% of peak $\dot{V}O_2$	VE deflection point # & $PETO_2$ & PET CO_2 plotted against time	A 7.2% increase in VT expressed as a % of peak $\dot{V}O_2$ (P<0.05)
Rotstein et al. 1986.	10.2 - 11.6 years N = 28M	12 minutes x 3 sessions x 9 weeks	interval training.	blood lactate breakpoint and 4 mM detection point	A decrease in LT * expressed as a % of peak $\dot{V}O_2$ (4.4%) (P>0.05)
Becker and Vaccaro, 1983.	9-11 years N = 22 (11 M exp'l & 11 M control)	3 sessions x 8 weeks	cycle ergometers HR at 50% between VT and HR max	VE deflection point #	Mean values for VT increased in both the experimental and the control groups (exp 28%, and 13% control).

* denotes lactate threshold F = female. M = male.

#VT was the breakpoint from linearity of $\dot{V}_E / \dot{V}O_2$ while $\dot{V}_E / \dot{V}CO_2$ remained unchanged plotted against $\dot{V}O_2$.

Table 2.9 displays a number of training studies in which submaximal ventilatory breakpoints (VT) have been tested in children. Predominantly changes in VT have been detected following exercise training programs. Perhaps because of its non-invasive nature, the most common method of assessment of VT in younger populations appears to be the ventilatory deflection point.

b. Accuracy of Maximal/Peak O_2 testing.

Maximal O_2 testing is considered highly reproducible if a suitable test protocol is used. Paterson et al. (1981) reported a reliability coefficient of r = .95 from a treadmill running protocol, used in testing boys 10-12 year old, who were tested 3 times a week over a 4 week period. Reliability and validity of peak aerobic power were evaluated by Golden et al. (1991). Using 237 subjects ages ranging from 7-17 years, on a cycle ergometer protocol, Golden et al. (1991) reported a test re-test reliability coefficient of r = .83 for peak $\dot{V}O_2$. Turley et al. (1995) conducted a reliability study using a treadmill and cycle ergometer for measuring peak $\dot{V}O_2$ ($ml.kg^{-1}.min^{-1}$). Both modes of exercise proved to be reliable measures of $\dot{V}O_2$ max, with interclass correlations ranging from R = .63 to .90.

c. Criterion for accepting Peak $\dot{V}O_2$ in laboratory testing with children.

The $\dot{V}O_2$ peak score is traditionally accepted when at least two of a number of criteria are observed (Cunningham., 1990). One of the major criteria for $\dot{V}O_2$ peak is the attainment of an age predicted heart rate max in the final stage of maximal effort testing (Cunningham, 1990). As previously stated, the sensitivity of these heart rate max formula-based criteria is somewhat diluted by the fact that all children and young adolescents would be expected to attain the same heart rates (Rowland, 1990a). A further criteria for accepting data as representative of a maximal effort a respiratory exchange ratio of 1.0 or greater (Rowland, 1995).

The plateau concept is based on the supposition that there is a point during incremental exercise at which the body's ability to transport and use oxygen reaches a maximum and at which no further increase in $\dot{V}O_2$ will occur despite increases in work rate (Duncan et al., 1996a).

Rowland and Cuningham (1992) suggested that a $\dot{V}O_2$ plateau as a criteria for peak $\dot{V}O_2$ was not a reliable indicator when working with prepubescent children and that a plateau was likely to occur in about 50% of subjects tested. Armstrong et al. (1995) conducted peak oxygen consumption tests on 111 boys, (mean age 11 years) and reported that only one quarter of the boys demonstrated a plateau in $\dot{V}O_2$. Several possible explanations have been postulated as attributing to the absence of a plateau in maximal effort test results in children. First, the children may not be motivated to perform to true maximal levels, and hence the term peak may be more appropriate than maximal effort. Second, it has been suggested that because of immature anaerobic power in children, they may be less able to sustain the work rates at towards the completion of a maximal performance test, and may fatigue earlier than adult populations (Armstrong et al., 1995). A third explanation could be that the metabolic gas collection equipment which is predominantly designed for use with adults may not be appropriate in detecting fine changes in gas exchange of children during testing. Rowland (1990a) suggested further clarification is required of the influence of valve dead air space, tubing diameter, and mixing chamber size in gas collection with paediatric subjects.

Rowland and Cunningham (1992) described an additional criterion for determining the presence of a plateau, which they believed was sensitive enough to allow for individual differences. The authors (1992) described the inability of $\dot{V}O_2$ to increase during the final minute of exercise by a value more than two standard deviations below the mean changes in $\dot{V}O_2$ (for each minute) during the submaximal phase of the test. Despite this adjustment to the protocol, Rowland and Cunningham concluded that only a minority of children were able to meet this criteria for a $\dot{V}O_2$ plateau during maximal performance tests. Rowland and Cunningham (1992) however, concluded that the requirement of a plateau did not appear useful as a criterion for defining $\dot{V}O_2$ peak in children. Of 16 studies reviewed by Rowland and Cunningham (1992) the percentage of subjects who achieved a plateau ranged from 21-95%.

Suitability of test protocols for use with children.

The completion of a peak $\dot{V}O_2$ test in children requires a test protocol that elicits a maximal cardiovascular effort. In addition, if VT data are required, a protocol that provides a clearly defined breakpoint for ventilatory threshold also needs to be determined. In summary, there is a need to establish the type of the equipment to be used, the design of the test protocol, and the influence of these choices on the desired results of tests for VT and maximal aerobic performance (Wasserman et al., 1990, Rowland, 1996b). The literature provided a broad range of test protocols for use with pediatric subjects.

a. Test protocols and Ventilatory Threshold.

The literature indicates that the most precise estimate of VT is in a protocol that involves the use of short, incremental exercise test, with approximately one minute per work increment (Reybrouck et al., 1983, Whipp, 1986). Variation in test techniques or protocols may produce a range of responses which mask accurate interpretation of results. From research with adults, Wasserman et al. (1990) suggested that high VT scores expressed as a percentage of $\dot{V}O_2$ max may also have occurred through missing the VE for $\dot{V}O_2$ break point and instead, choosing the more prominent VE for CO_2 (the respiratory compensation point).

Duncan et al., (1996). examined the exercise responses of 10 prepubescent male subjects. The results of the study showed that VT was 8-10% higher on the treadmill test when compared with results obtained on the cycle ergometer When however, VT was expressed as a percentage of $\dot{V}O_2$ peak, there was no difference (Duncan et al., 1996).

Wasserman et al. (1990) suggested that tests should be completed in approximately 8 - 12 minutes. Protocols which use smaller increments could result in an increase in lactate concentrations too small to produce a detectable increase in CO_2 buffering. Gaisl (1988) reported that 12-16 work increments were appropriate for maximal aerobic tests in children and further suggested that the total test duration for children should not be longer than 15 minutes. Zwiren (1989) stated it was important that test results are not influenced by local muscle fatigue, which might terminate the test prior to exhausting aerobic mechanisms in the individual. Naughton et al. (1992) reported similar ventilatory threshold values from two different maximal effort treadmill test protocols involving 30, 60, and 90 second increments in 10 year old males. It is possible however, that discrepancies in the type of exercise test selected for VT may preclude researchers from conducting inter-study comparisons (McArdle et al., 1996, Rowland, 1996b).

b. Heart rate and children.

Selecting a target training heart rate for children is problematic in light of a lack of sound scientific findings. Heart rate target zones during aerobic exercise training programs for children have often been based on the methods used for adult training programs. Rowland (1996b) postulated that the traditional formula, (220 b.min^{-1} - chronological age) which is a prediction of maximal heart rate in adults, may not be relevant for children as their maximal exercising heart rates are essentially unchanged until their late teens. Furthermore, the inter-individual variance in maximal heart rates, makes it difficult to prescribe heart rate targets to suit even specific populations of children (Rowland 1989b). Gilliam et al.(1981) suggested, that if the adult-based formula for a heart rate for exercise training needs to be sustained for a 30 minute duration to promote cardiovascular fitness, then applying this to children would require exercising at a target heart rate of 160 b.min^{-1}. Gilliam et al. (1981) observed spontaneous play activity in children, and reported that during periods of free play children seldom experience heart rates greater than 160 b.min^{-1}. To further complicate the problem, early studies were limited in the nature of the heart rate recording equipment which required fixed ergometry or 'spot checks', to monitor heart rate levels in the subjects who were involved in more free ranging activities. It was possible to use an electrocardiogram (ECG), which is considered the gold standard for heart rate recording, (Whitehurst, 1996) however, it is impractical for use outside the laboratory, (Bar-Or et al., 1996) or to monitor a number of subjects training concurrently in an exercise intervention program. The Polar Sports tester (XL and the PE 3000) has been validated against the ECG in research studies for both adult and children, and has become a valuable research tool for use in pediatric studies (Bar-Or et al., 1996, Treiber et al., 1989).

c. Maximal/Peak aerobic power tests during treadmill testing - speeds and gradient.

A review of the literature on maximal aerobic power tests using a treadmill, exposed a considerable variety of approaches used with children. Weymans et al. (1986) recommended, a treadmill protocol for children starting at a fixed speed of 5.6 $km.hr^{-1}$, with the gradient increased stepwise by 2% grade every minute, until exhaustion or voluntary termination. The treadmill test protocol used by Buono (1989) to measure $\dot{V}O_2$ max in children 10-18 years, consisted of 3-minute stages at 3\4\5, and 9.6 $km.hr^{-1}$, followed by increases in gradient of 2.5% per minute, to exhaustion (Buono, 1989). In a research study examining ventilatory threshold and peak $\dot{V}O_2$ on a graded treadmill test, Duncan et al. (1996) utilised increases in one minute increments and progressed in the following manner: 4.8 $km.hr^{-1}$ and 2% grade, 4.8 $km.hr^{-1}$ and 4%, 5.6 $km.hr^{-1}$ and 5%, 5.6 $km.hr^{-1}$ and 7%, 5.6 $km.hr^{-1}$ and 9%, 7.2 $km.hr^{-1}$ and 4%, 8.0 $km.hr^{-1}$ and 4%, 8.8 $km.hr^{-1}$ and 4%. From this point the speed was held constant and elevation was increased 2.5% every stage until the termination of the test. Subjects were instructed to run when the belt speed reached 7.7 $km.hr^{-1}$. Rowland and Boyajian (1995) used a treadmill walking protocol in children where subjects walked at 5.2 $km.hr^{-1}$ on a 6% slope for 4 minutes. After this, the speed of the treadmill was increased to 5.6 $km.hr^{-1}$ with the gradient increased 2% every minute until volitional exhaustion. Patterson, (1981) conducted a study on the effects of different treadmill speeds on the variability of $\dot{V}O_2$ max in children. It was reported that the walk protocol was 8% lower ($ml.kg.^{-1} min^{-1}$) than the results obtained from the running test protocols. The inter-class correlation coefficient for the walk and run protocols was R = 0.56. Thus, it appears that no one protocol has to date been universally accepted for use in paediatric subjects and perhaps more importantly, strong consideration needs to be directed towards the nature of the protocol imposed in this groups from this population.

Summary.

Several issues on the aerobic trainability of children remain unclear. Much of the earlier research involving aerobic based exercise intervention, has been marred by poor research design. It appears that the more traditional markers of aerobic performance in adult studies may not be as suitable in children's studies, in terms of both the intensity of training and the selection of tests and criteria appropriate for detecting changes associated with exercise intervention. For ethical reasons, non-invasive tests are required when working with children. This limits the current range of tests available in the exercise laboratory setting. New tests, modified test protocols, and how the nature of the prescription including an appropriate exercise intensity for a training study with children, need to be re-examined. Cooper (1995b) posed the challenge, that the approach in paediatric research must be more realistically focused on how children exercise in real life, the developmental needs of growing children, and how best this can be measured.

CHAPTER 3. METHODOLOGY.

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METHODOLOGY.

Subjects.

Thirteen healthy boys with a mean age of 10.0 (± 0.3) years were randomly assigned to either a control or exercise group. All were volunteers from the same primary school in metropolitan Melbourne. Approval from Victoria University's Ethics Committee, was obtained prior to the commencement of the program. Medical information (Appendix 3.1) was gained from the parents and the school.

Parents were requested to verify the pubertal status of their child by looking at a series of developmental pictures and descriptions corresponding to Tanner stages of sexual maturation (1969) (Appendix 3.2). This request was delayed until the last phase of the testing to ensure that the subjects were prepubescent at the end of the study.

Research Design.

Children in the exercise group participated in a ten week, training intervention program, involving three sessions per week. At the completion of the ten week training period, the groups were reversed, and the control group became the exercise group for the second ten week training program. The initial training group became the control or detraining group. Peak and submaximal cardiovascular exercise responses were measured on four occasions over the two training periods (Table. 3.1).

Table 3. 1: Research design and time frame of the study.

INTERVENTION PROGRAM NO.1. 10 WEEKS.		DETRAINING	INTERVENTION PROGRAM NO.2. 10 WEEKS.	
TEST.1. COMPLETED THE WEEK PRIOR TO THE FIRST INTERVENTION PROGRAM.	TEST 2. COMPLETED DURING WEEK 11.	A THREE WEEK PERIOD.	TEST 3. COMPLETED DURING WEEK 15.	TEST 4. COMPLETED DURING WEEK 26
PEAK $\dot{V}O_2$.	PEAK $\dot{V}O_2$.		PEAK $\dot{V}O_2$.	PEAK $\dot{V}O_2$.
ANTHROPOMETRIC MEASURES	ANTHROPOMETRIC MEASURES		ANTHROPOMETRIC MEASURES	ANTHROPOMETRIC MEASURES

ANTHROPOMETRIC MEASURES.

Anthropometric measures were used to reflect growth patterns of the individuals during the study period. The anthropometric descriptors selected for the present study included, standing height, body mass, and skinfold measures.

Standing Height.

A portable Harpenden stadiometer was used during all test sessions. Care was taken that the stadiometer was used in a vertical position and that the children were standing erect. Procedures followed have been previously described (Draper et al., 1991).

Body Mass.

Body mass of subjects was recorded using Salter Electronic scales (± 5 grams) model E1200. Subjects were required to sit stationary on a chair that had been zeroed on the scales immediately prior to each test. Body mass was recorded to the nearest 0.001. Subjects were weighed at each of the four test sessions. Scales were calibrated with known volumes of water on the day prior to each testing session

Skinfold Measurement.

Harpenden skinfold calipers were used for all of the skinfold measures. The same set of calipers were used during test sessions and the calipers were calibrated prior to use. The same tester performed all skinfold measures during each of the four test sessions. All measures were taken on the right side of the body. The technique for measuring skinfold has also been previously described (Draper et al., 1991). An inherent problem in this measure of body composition is the individual difference in the distribution of body fat (Boileau et al., 1988). In addition, equations used to estimate body composition in children are subject to error and misinterpretation (Rowland, 1996b).

The skinfold sites selected for this study were triceps, subscapular, biceps, suprailiac, axilla, mid-abdominal, medial calf, and mid thigh. Two measurements were taken at each site and if the second measurement was within 2 mm of the first then the measure was recorded and the two scores averaged. A complete record of all skinfold site results is presented in Appendix 3.3.

Familiarisation Sessions for Laboratory Testing.

Prior to the start of the study, both the experimental and the control groups were familiarised with the test equipment and the work environment to be used during the study period. Teachers and parents were encouraged to attend these sessions with the objective of minimising concerns that the children might have had as a result of working in the laboratory setting. Both the experimental and the control groups needed to be familiarised with the test equipment as up to 8% increases in peak $\dot{V}O_2$ scores have been reported after a familiarisation testing session (Zwiren, 1989). These sessions were undertaken in the week prior to the commencement of the study.

The Training Program.

A variety of exercise modes was used during the two training intervention programs. These included; treadmill running, cycle ergometers, monitored jogging trails and a modified basketball game. The basketball game was designed with minimal rest periods and small groups in an effort to keep heart rate levels above their heart rate targets for the duration of each of the games. The duration of each training session was between 30 - 40 minutes, with the best 30 minutes of heart rate data used to estimate the work intensity during each session. Training sessions were conducted in a number of sites at Deakin University. An exercise physiology laboratory, a basketball sized gymnasium, a 3.1 km outdoor running track, and a 200 m circular running track were available to participants. The exercise laboratory provided access to 2 motorised treadmills, 5 Monark cycle ergometers, and an electronic cycle ergometer (Cybex) which was configured to provide competition in a computerised cycling game. Sessions were closely supervised as training engaged 6 or 7 subjects and there was usually 2 or 3 staff to assist with the training. A rotational format was used to maintain optimal work from the boys and to maintain interest. If a subject requested extra time at a particular location, this was usually granted. The treadmills were popular with the boys who were capable runners. The electronic bike was popular with everyone. Initially, the objective was to encourage set workloads for each subject on each piece of equipment. This practice became too tedious for the participants, as they did not cope well with constant focus on work loads. It proved better to motivate them to exercise at relatively high intensities and at the same time allow some flexibility, so that they could slow down if they became tired, and then increase the pace when they were ready. This resembled the spontaneous nature of play that would be expected in a school playground or in children's sport or physical education. The heart rate monitor was the key form of biofeedback for participants during training. During each session, the heart rates could be checked and after each session a print out of their performances could be viewed to evaluate the exercise intensity. Some participants worked harder than others, and intra-individual variability was also observed. Each participant was encouraged to maintain the work intensities set for them. In most cases this was a heart rate level selected on the ability of the subject for the duration of the training session.

The 200 m running track was close to the exercise laboratory and was a valuable alternative for the boys who required a change from the laboratory. A game of modified basketball in the gym was the most popular activity. Work output in all of these sessions was very high. Competition among these boys was a very strong motivator. The objective in the game was to keep going, with no out of bounds rules and without stopping for fouls. One of the subjects lacked the skills to participate at the level of the other boys. This was recognised early and he was given a special program on the electronic bike. Fortunately the boy did not associate his lack of basketball skills with the switch to the cycle ergometer program, in that he thought he was helping the staff with a special project. A river track (3.1 km) was only popular with the runners. This provided an additional element of choice. All sessions were longer than the mean duration of 30 minutes. Some sessions were as long as 45-50 minutes, however the duration depended on the motivation and the activity.

Training Intensities.

During the early training sessions each boy was encouraged to exercise at work zones in which they felt comfortably challenged. As each subject became accustomed to the various exercise modes used during the study, the intensity of performance was increased to adapt to the capabilities of the individual. Polar 'Sports Tester' Heart Rate Monitors (Polar Electro Oy, Finland) were used during all of the training sessions. Heart rate data was collected and stored in memory every five seconds during the exercise periods. Computer print-outs generated using Polar Software from each session, provided a visual representation of the physical performance of each child fitted with a heart rate monitor during each training session. Using the hard data collected from the heart rate computer print-out and a subjective evaluation of each child's performance during the training sessions (changes in skin colour, perspiration, continuity of performance and verbal feedback from each subject on perceived training intensity), it was possible to nominate target heart rates for each boy. Every effort was made to provide encouragement during each training session. While most of the participants were self motivated and enjoyed the challenges and tasks set, there were days when they found it more difficult to perform at the nominated levels. Care was taken not to over stress the boys, if they appeared to be fatigued from involvement in school or extra curricula activity programs. Parents were frequently consulted on how their sons were coping with the training sessions. Even in the training environment of high motivation. it was difficult to maintain consistently high work loads for all participants throughout each training session. Some boys required more stimulation and encouragement than others. This focus on the quality or intensity of work became the single most important objective during each of the training sessions.

DATA COLLECTION AND PROCEDURES.

Heart Rate Recording.

Polar Sports Heart Rate monitors were used to provide a continuous recording of the child's heart rate during all peak $\dot{V}O_2$ treadmill testing as well as during training sessions. This enabled comparisons of physical intensity levels to be made between the laboratory test data and the heart rate responses recorded during the training program. The Polar Heart Rate monitor consisted of a thin, elastic chest strap which contained a transmitter and a computerised wrist watch receiver. Operating the heart rate modality of the Polar monitor was a relatively simple procedure. After a few sessions the boys were able to assist in setting the recording function and during the activity phase were attentive if the recording function was accidentally stopped. The ability to measure heart rate over prolonged periods is important in clinical observations and research (Kempler et al., 1996a).

LABORATORY BASED TEST PROTOCOLS

Peak $\dot{V}O_2$. An incremental treadmill run to exhaustion.

The following test protocol was selected for the prepubescent child: Each incremental stage of the graded test had a duration of one minute. Tests started at 0% grade at 4 $km.hr^{-1}$, and increased by 2 $km.hr^{-1}$ until the RER of the child approached 1.0. At this point the speed was maintained and the elevation was increased by 2% grade, each minute until volitional exhaustion. This test protocol was used as it satisfied most of the concerns that were raised in the literature reviewed concerning the duration of the test and the need for a multistage, continuous design. All subjects were provided with verbal encouragement by the researchers. A staff member was positioned at the back of the treadmill, for safety. This position, involved the person straddling the moving belt, with the task of supporting the subject if he lost his footing during the final stages of his peak effort. As previously mentioned heart rates were recorded continuously during each test, using a Polar Heart Rate monitor.

Gas Analysis.

Gas exchange values were measured using a standard open circuit technique, incorporating a computerised metabolic cart. Expired air volume was measured by a Pneumoscan ventilometer with a Mark 2 turbine flow transducer. Gases were analysed for the fractions of O_2 and CO_2 by Applied Electrochemistry analysers S-3A (O_2) and CD-3A (CO_2). The analysers were calibrated before and after each test, using calibrated gases of known concentrations (CIG. Melbourne, Analytical grade gas). Subjects breathed through a Hans Rudolp 2 way valve piece (dead space through the valve system was 50 ml), and used a small mouth piece suited to paediatric subjects.

An IBM PC linked via an A to D converter calculated directly from the metabolic cart. Data were averaged every 15 seconds and used to calculate $\dot{V}O_2$ uptake, $\dot{V}CO_2$, the respiratory exchange ratio, ventilatory equivalents ($\dot{V}_E / \dot{V}O_2$, $\dot{V}_E / \dot{V}CO_2$) and expired ventilation.

Peak $\dot{V}O_2$ Score - Criterion.

The Peak $\dot{V}O_2$ score was accepted if at least two of the following criterion were present,

1. an RER of 1.0 or above,
2. a plateau in the heart rate towards the completion of the test
3. a maximal heart rate at or above 200 $b.min^{-1}$.
4. failure of $\dot{V}O_2$ to increase more than 2 $ml.kg.^{-1}min^{-1}$ despite a further increase in workload (Zwiren, 1989).

Procedures for detecting Ventilatory Threshold.

Ventilatory threshold (VT) was defined as a deflection point occurring in incremental exercise which is represented by a non-linear increase in the ventilatory equivalent (VE) for oxygen consumption ($\dot{V}O_2$) (also symbolised as $\dot{V}_E / \dot{V}O_2$) without a corresponding change in the VE for carbon dioxide production ($\dot{V}CO_2$) (also symbolised as $\dot{V}_E / \dot{V}CO_2$) (Wasserman and Whipp, 1973). Concomitantly there may be a marked increase in heart rate and respiratory exchange ratio (RER).

Graphs of these metabolic events were created using Microsoft Excel version 5.0. Three trained and practised researchers were requested to independently assess each graph and indicate where the breakpoint occurred. The breakpoint for VT was accepted if at least two investigators agreed on the point chosen. An example of this process is included in Appendix 3.4.

ANALYSIS OF DATA.

Micro Soft Excel version 5.0. was utilised to store all of the data collected from the training program as well as the information collected from the pre and post test sessions. Data are presented as means and standard error of the means (mean ± SEM).

Statistical interpretation of the data.

This study used a cross over model where there were two training sessions of ten weeks, and each subject participated as an experimental subject in one of the two training periods and as a control subject in the other training period. For the comparisons of means, the statistical method was a 2 x 2 x 2 ANOVA with repeated measures over time: (**2** ***groups***; control and experimental, **x 2** ***stag*es** or training programs, number one and number two. **x 2** repeats of the *pre and post testing sessions*).

From the statistical package SPSS (version 7), the General linear Model (GLM) - repeated measures procedure was selected. The crossover model provided the opportunity to evaluate the overall treatment effect of the exercise intervention and the detraining effect for the first experimental group when they subsequently became the control group.

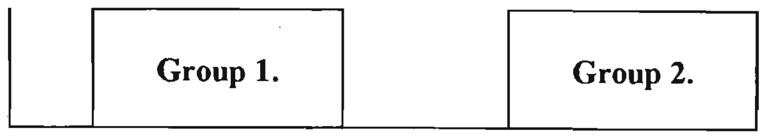
SUMMARY OF STATISTICAL METHODS.

The ANOVA model used in the present study presented four levels of analysis. It initially provided a main effects analysis of the data by group, by stage or program. In addition the interactive effects of each program and the groups were provided. The analysis also compared the pre and post testing results and its interactive effects in the two programs. Finally and most importantly the treatment effect denoted by the interaction analysis of group x stage x test was conducted.

Table 3. 2: Summary of the Methods Type I, T. 2, T. 3, T. 4, sum of squares. Diagrammatical interpretation.

Note. 'Stage' in SPSS language refers to the intervention or exercise program.

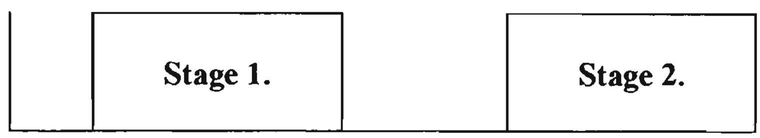
T. I = Group - this treatment analysed for a main effect of group.



**Exercise in stage 1.
Control in stage 2.**

**Control in stage 1.
Exercise in stage 2.**

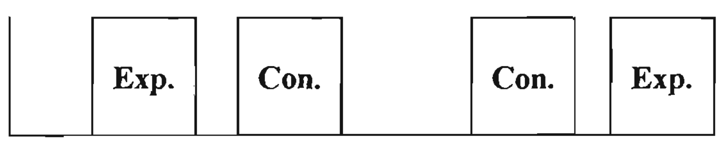
T. 2 = Stage - this analysis looked for a main effect of the two training programs



**Both groups
in the first program**

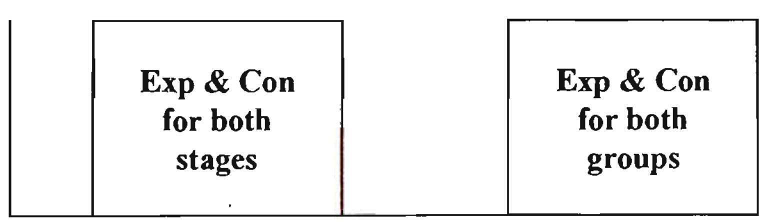
**Both groups
in the second program**

Stage by group

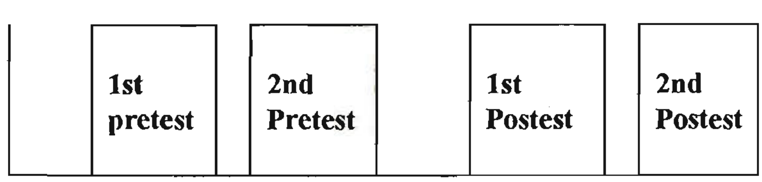


Stage 1. **Stage 2.**

T. 3 = Pre & Post. - a main effect for pre and post test results, with groups collapsed.

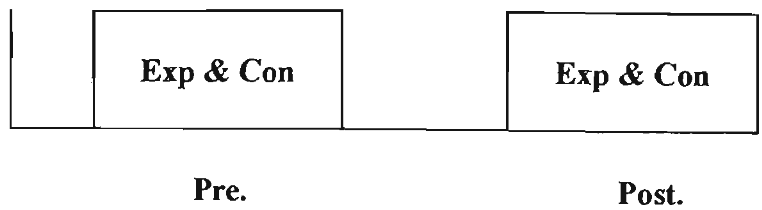


Pre **Post**

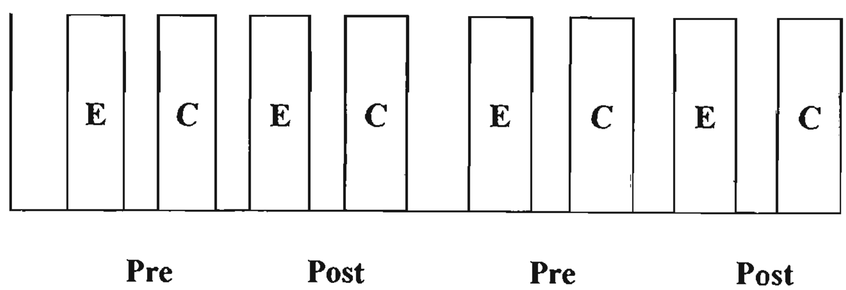


Both groups in pre tests **Both groups in post tests**

T. 4 = Stage x Pre and Post



T. 4 = Group x stage x pre & post.* - testing for interactive effect of the treatment programs.



* T.4 was designed to provide a statistical representation of the treatment effect in this exercise intervention study. This was the most important part of the statistical, as it measured the interaction between the two groups of subjects, the performances on the pre and post test and assessed the influence that the treatment or training effect between the groups.

Nominal significance level.

The alpha level of 0.05 was the accepted significance level in all statistical treatments. The two levels of factors within the treatment of the data with a 2 x 2 x 2 ANOVA model, excluded the necessity for a post hoc analysis of the data.

Research Hypothesis.

If a prepubescent child participates in a high intensity exercise intervention program, there will be increases in peak $\dot{V}O_2$, and ventilatory threshold values.

Statistical Hypothesis.

H_o: The mean increase for peak $\dot{V}O_2$, and ventilatory threshold for the experimental group, will not differ from the mean increase for the control group.

H_o: $u_e = u_c$

H_a: The mean increase in peak $\dot{V}O_2$, and ventilatory threshold for the experimental group, will be of a greater magnitude than the mean increase for the control group.

H_a: $u_e = u_c$

CHAPTER 4 RESULTS.

CHAPTER 4

RESULTS OF ALL LABORATORY TESTS.

The following chapter presents the results of the study under the following major topics;

A. Descriptive data.

B. Comparisons between the first and second training programs.

C. The training data.

D. Level of statistical significance.

A. DESCRIPTIVE DATA.

The descriptive data presented in Table 4.1 summarise the mean data for the exercise and control groups, across the 4 testing periods.

Table 4. 1: Mean descriptive data for the subjects for; Exercise/Control, Pre and Post testing for each of the two training sessions.

DESCRIPTIVE DATA FOR ALL TESTS.								
	FIRST TRAINING PROGRAM				SECOND TRAINING PROGRAM			
	EXERCISE	EXERCISE	CONTROL	CONTROL	EXERCISE	EXERCISE	CONTROL	CONTROL
	PRETEST	POSTTEST	PRETEST	POSTTEST	PRETEST	POSTTEST	PRETEST	POSTTEST
AGE (yr)	9.91 ±0.45	10.09 ±0.45	10.12 ±0.53	10.29 ±0.53	10.62 ±0.47	10.79 ±0.55	10.45 ±0.46	10.62 ±0.54
MASS (kg)	34.65 ±0.84	35.40 ±0.85	33.14 ±1.15	32.80 ±0.95	33.67 ±0.97	33.93 ±0.97	35.87 ±1.00	37.59 ±0.88
HEIGHT (cm)	139.79 ±1.69	140.44 ±1.69	137.24 ±2.34	137.30 ±1.95	137.88 ±1.96	139.92 ±1.97	141.05 ±1.96	142.39 ±1.70
BMI ($kg.m^2$)	17.57 ±0.73	17.77 ±0.79	17.26 ±1.20	17.12 ±1.00	17.44 ±0.98	17.08 ±0.77	18.19 ±1.01	18.35 ±0.79
SUM OF SKINFOLD (mm)	92.54 ±1.37	87.26 ±1.33	68.48 ±1.66	70.28 ±1.40	73.70 ±1.43	68.13 ±1.38	96.67 ±1.64	95.03 ±1.62

Mean ± SEM.

For comparative purposes subjects in the present study have been compared with the existing normative data from the Australian Health and Fitness Survey (Pyke, 1985).

The 50th percentile from the Fitness Survey for body mass of the 10-year-old male was 33.5 kg. The mean body masses from the present study group 34.6 kg. Thus the subjects in this study are represented in the 60th percentile. For height the 50th percentile for the 10-year-old male, was 140.7 cm. In the present study group, the mean was 139.5 cm, which was equal to the 42nd percentile. Thus the mean values indicate that compared with the reference group, the study group subjects were a little heavier (60th percentile) and not quite as tall (42nd percentile) as the average boy of their age in 1985.

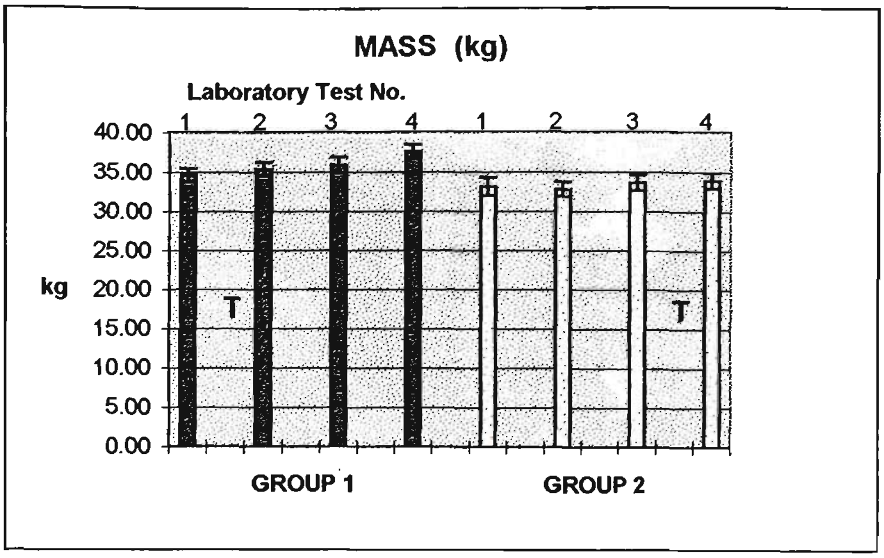
Skinfold measures in this study were presented as a skinfold sum of nine sites. The Australian Fitness Study (Pyke, 1985), presented the results as percentiles for selected individual sites. Table 4.2 presents a comparison of a score for each skinfold site, which is an averaged taken over the 4 test sessions, for all subjects. More fatty tissue was noted in the present study than the children sampled during the 1985 study. This may in part, have contributed to the slightly higher body mass values recorded for the study group, than the randomised and representative population of 10 year old males from the 1985 study.

Table 4. 2: Skinfold comparisons with the *Australian Health and Fitness Survey norms (1985).

SKINFOLD SITE	AUSTRALIAN FITNESS NORMS (1985). Boys aged 9-12 years (50th. Percentile) (mm)	THIS STUDY Mean of all tests for each skinfold site (mm) (Percentile equivalent 1985)
TRICEPS	9.8 - 10.2	12.0 [25th]
SUBSCAPULAR	5.7 - 6.4	7.0 [35th]
MID-ABDOMINAL	6.6 - 8.5	10.6 [35th]
BICEPS	5.0 - 5.4	5.6 [45th]
SUPRAILIAC	5.0 - 6.2	6.4 [45th]

*Australian Health and Fitness Survey norms (Pyke, 1985).

Figure 4. 1: Mean results for mass for each group, at each of the 4 test sessions.

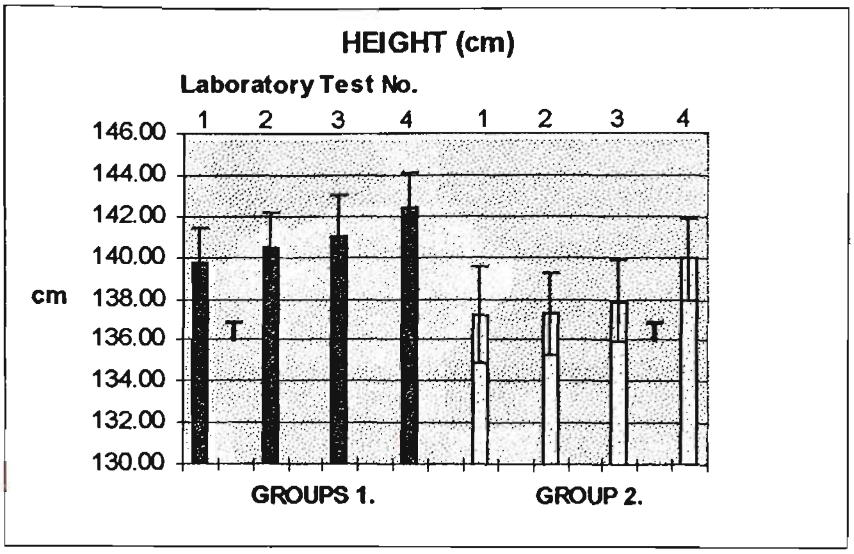


'T' denotes location of the intervention training program for each group. Group 1 was the experimental group during the first and second test period then switched to be the control group during the final two tests. Group 2 was the control group during the first part of the study, and then became the experimental group with the training program positioned between the third and the final test session.

Figure 4.1, illustrates a small increase in body mass over the period of the study period, which is presented as mean data for the two groups. Figure 4.2 presents height changes recorded during the study. A continuous increase in height was expected, when the values were viewed as mean values for each group.

The mean height for group 1 (Figure 4.2) was greater than group 2 at all stages of the program. This difference may be attributed to the random sampling with small numbers. Proportional gains for both height and mass are presented in Table 4.3. For the subjects in the present study, gains in height over the duration of the present study ranged from 0.5 to 6.0 cm. While range for mass varied from, 1- 4 kg over the same time period.

Figure 4. 2: Mean height for both groups, at each of the 4 test sessions.



'T' denotes the intervention training program and its location in relation to the four laboratory test sessions for each group.

Table 4. 3: Individual Height and Weight Results and comparisons with the Australian Health and Fitness Survey Norms-1985

Subject	Height (cm) Tests ** 1 & 4		Percentiles for Height	Height gain (cm)	Body Mass Tests 1 & 4		Percentiles for body mass	Body mass gain (kg)
1	145.1	145.9	75 - 80th	0.8	39.0	43.0	85 - 93rd	4.0
2	126.0	127.4	below 5th	1.4	21.8	23.2	below 5th	1.4
3	137.0	143.0	30 - 65th	6.0	36.5	39.3	70 - 85th	2.7
4	137.3	140.9	30 - 50th	3.6	31.4	33.3	30 - 45th	1.9
5	150.6	154.0	95th +	3.4	39.5	43.3	60 - 76th	3.7
6	148.0	148.5	90th	0.5	39.3	42.0	85 - 93rd	2.6
7	135.1	138.0	20 - 35th	2.9	35.0	39.0	65 - 85th	4.0
8	132.2	135.6	5 - 15th	3.4	26.3	28.0	5 - 10th	1.7
9	135.1	138.5	45 - 65th	3.4	31.4	33.0	30 - 45th	1.6
10	153.0	157.7	95th +	4.5	51.0	52.1	95th +	1.1
11	130.2	133.0	5 - 10th	2.8	28.6	29.9	10 - 15th	1.3
12	136.0	137.4	20 - 30th	1.4	28.4	29.4	10 - 15th	1.0
13	135.0	137.5	15 - 30th	2.5	29.8	32.2	15 - 35th	2.4

****Test data from the first test session, compared with results of the final test session.**

The mean data presented on the subjects in this study does not give an appreciation of the differences that existed between the subject, nor the rate of change that occurred in terms of growth, during the period of the research study. Table 4.3 provides a view of the distribution of height and weight values for the subjects, when compared with the Australian Health and Fitness Survey norms (1985). The collection period presented in Table 4.3, occurred between test 1 and test 4, and encompassed 169 Days (June to December). Percentile ranking of body mass and height data ranged from below the 5th percentile to over the 95th percentile. The velocity of height was determined from height in centimetres for the duration of time between the first and the forth test periods (169 days). When compared to the Height Velocity Chart (Tanner and Davis, 1985) (Appendix 4.1), the majority of the boys were in a relatively dormant growth period. Normally however, a valid height velocity measure requires height change recorded over the period of a year (Tanner and Davis, 1989). The NCHS growth curves for children (1989), also showed the subjects in the present study were represented through the full spectrum of height and weight values, for males aged ten years.

Table 4. 4: Mean data from the first training program displaying percentage change for each test in maximal effort data ($\dot{V} O_2$)

FIRST TRAINING PROGRAM. 1. MAXIMAL EFFORT DATA.						
	EXERCISE PRETEST	EXERCISE POSTTEST	% CHANGE	CONTROL PRETEST	CONTROL POSTTEST	% CHANGE
$\dot{V} O_2$ (l.min^{-1}).	1.72 ±0.11	1.76 ±0.11	+2.27	1.66 ±0.17	1.53 ±0.13	-7.83
$\dot{V} O_2$ (ml.kg.$^{-1}$min^{-1}).	50.88 ±3.37	51.23 ±3.35	+0.68	51.36 ±4.07	48.25 ±4.66	-6.00
PEAK HEART RATE. (b.min^{-1}).	202 ±3.57	200 ±3.56	-0.79	206. ±2.74	203 ±2.85	-1.55
RER. (At peak $\dot{V} O_2$).	1.06 ±0.15	1.09 ±0.15	+2.70	1.09 ±0.21	1.04 ±0.17	-4.50

Mean ± SEM.

Table 4. 5: Mean data from the first training program displaying percentage change for each test in the ventilatory threshold data.

FIRST TRAINING PROGRAM. 2. VENTILATORY THRESHOLD PROFILE.						
$\dot{V} O_2$ at VT BREAKPOINT (l.min^{-1}).	1.12 ±0.15	1.26 ±0.16	+11.11	1.26 ±0.22	1.15 ±0.18	-8.70
$\dot{V} O_2$ at VT (% $\dot{V} O_2$ peak)	64.58 ±2.35	71.58 ±1.67	+9.77	76.42 ±2.44	74.68 ±2.88	-2.31
HR at VT BREAKPOINT.	148 ±4.90	155 ±3.45	+4.30	168 ±6.16	169 ±6.64	+0.35
HR at VT (%HR max)	73.50 ±1.97	77.69 ±1.94	+5.39	81.57 ±1.99	83.15 ±2.54	+1.90

Mean ± SEM.

B. COMPARISONS BETWEEN THE FIRST AND SECOND TRAINING PROGRAMS

Comparisons between the first and second training programs are presented in Tables 4.4, 4.5, 4.6, and 4.7.

Table 4.4 presents the percentage change in $\dot{V}O_2$ at VT as percentage of max and displays an increase in both training programs ($P < 0.05$). In the first training program, the increase was +9.77% between the pre and post tests. In the second training program, the increase was equally as large as +10.11%. During the same testing period, the control groups displayed a -2.31% and -2.90% decrease, in programs 1 and 2, respectively.

The mean percentage change for $\dot{V}O_2$ at VT breakpoint ($l.min^{-1}$) during the first training session, was also positive, with an +11.11% increase for the experimental group and a -8.70 % decrease for the control group. The second training program was less predictable, as both the experimental and control group displayed an increase in their performance (+6.20 and +7.90% respectively).
Although HR at VT as a percentage of peak heart rate was not different ($P < 0.05$), the results provide positive trends, as shown by the percent changes. Experimental groups were +5.39 and + 6.20%, respectively, compared with the control group's percentage changes of +1.90 and -2.54%, respectively (Tables 4.5 and 4.7).

In summary, the first training program produced mostly positive increases in the results of the selected cardiorespiratory parameters measured in the experimental group, between pre and post tests. Seven of the 8 measures displayed an increase. The results of the control group showed 5 of the 8 cardiorespiratory parameters as decreases, when the results from pre-tests were compared with the post test data collection.

Percentage changes presented during the second training program were not as predictable. The experimental group displayed 5 increased and 3 decreased values in the selected cardiorespiratory parameters. A review of the results from the control demonstrated 4 increases and 4 decreases in the cardiorespiratory parameters.

Table 4. 6: Mean data from the second training program displaying percentage change for each test in the maximal effort data.

SECOND TRAINING PROGRAM 1. MAXIMAL EFFORT DATA.	EXERCISE PRETEST	EXERCISE POSTTEST	% CHANGE	CONTROL PRETEST	CONTROL POSTTEST	% CHANGE
$\dot{V}O_2$ ($l.min^{-1}$)	1.74 ± 0.16	1.68 ± 0.18	-3.44	1.67 ± 0.11	1.86 ± 0.13	+9.60
$\dot{V}O_2$ ($ml.kg.^{-1}min^{-1}$)	52.48 ± 2.69	50.01 ± 3.15	-4.7	47.71 ± 3.37	49.95 ± 2.49	+4.48
PEAK HEART RATE. ($b.min^{-1}$)	201 ± 2.71	200 ± 1.76	-0.74	202 ± 4.26	200 ± 3.70	-0.98
RER. (At peak $\dot{V}O_2$)	1.06 ± 0.17	1.07 ± 0.17	+0.90	1.06 ± 0.17	1.12 ± 0.15	+5.3

Mean ± SEM.

Table 4. 7: Mean data from the second training program displaying percentage change for each test. Ventilatory threshold profile.

SECOND TRAINING PROGRAM. 2. VENTILATORY THRESHOLD PROFILE.						
$\dot{V}O_2$ at VT BREAKPOINT ($l.min^{-1}$).	1.19 ± 0.18	1.27 ± 0.19	+6.20	1.16 ± 0.18	1.26 ± 0.16	+7.90
$\dot{V}O_2$ at VT (%O_2 peak)	67.92 ± 3.65	75.56 ± 3.75	+10.11	71.01 ± 2.46	68.19 ± 3.50	-2.90
HR at VT BREAKPOINT ($b.min^{-1}$).	161 ± 8.16	165 ± 8.29	+2.42	163 ± 5.72	160 ± 4.20	-2.21
HR at VT (% HR max)	79.73 ± 3.19	85.02 ± 3.43	+6.20	80.82 ± 2.39	79.76 ± 1.46	-2.54

Mean ± SEM.

C. THE TRAINING DATA.

Table 4.8 and 4.9 represent the mean data for the 30 minute training sessions; for each subject. Data are presented under the following parameters:

1. Mean training heart rate,
2. Mean, peak heart rate recorded during the laboratory testing sessions,
3. Mean percentage heart rates above 150, 160, 170 & 180 $b.min^{-1}$,
4. Changes in skinfold measurements before and following the exercise intervention programs (Table 4.4),
5. Detraining.

Table 4. 8: A summary of the data for each subject's mean training performance during the first training program.

FIRST TRAINING PROGRAM.								
SUBJECT	Mean Training HR ($b.min^{-1}$)	Peak HR from Lab. Tests ($b.min^{-1}$)	Highest HR from Training ($b.min^{-1}$)		% TRG* HR<150	% TRG HR<160	% TRG HR<170	% TRG HR<180
1	160	187	197		74.66	55.58	33.33	11.08
2	173	209	217		100	77.75	64.75	47.50
3	172	205	217		100	69.61	57.54	40.31
4	188	206	212		100	89.93	82.07	69.80
5	172	194	203		100	76.93	65.69	45.31
6	174	197	204		100	76.4	63.53	39.60
7	156	187	202		64.7	37.27	20.45	6.72
MEAN	170. 61	197. 60	207.42		91.33	69. 06	55. 33	36. 90
±SEM.	3.39	3.42	2.98		5.69	6.58	7.99	8.25

TRG* = Training.

Table 4. 9: A summary of the mean data for each subject's mean training performance during the second training program.

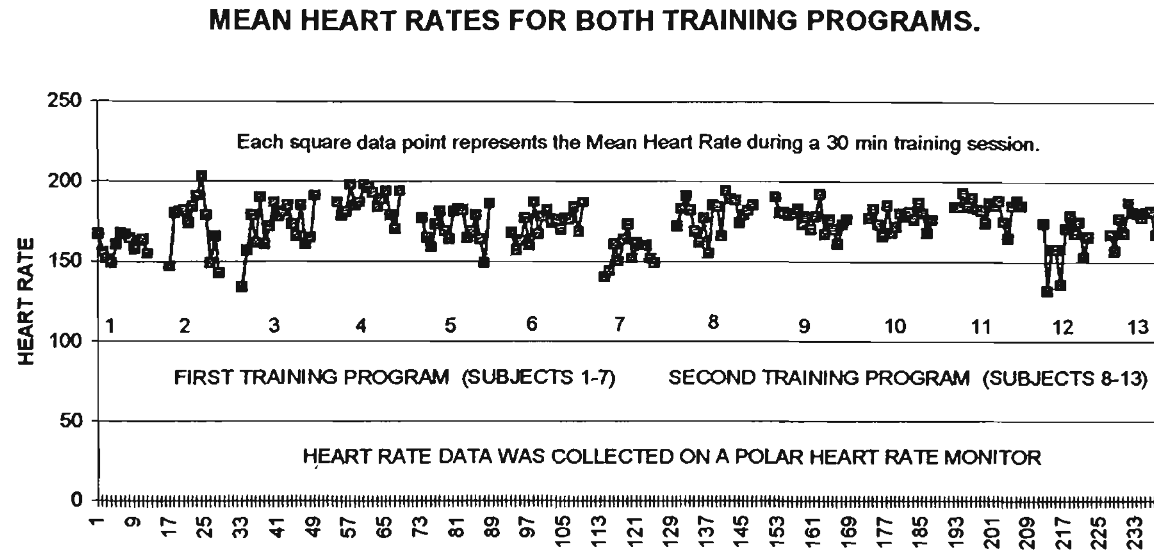
SECOND TRAINING PROGRAM.								
	Mean Training HR (b.min^{-1})	Peak HR from Lab. Tests (b.min^{-1})	Highest HR from Training (b.min^{-1})		% TRG* HR<150	% TRG HR<160	% TRG HR<170	% TRG HR<180
8	179	202	207		100	82.94	74.22	58.20
9	177	200	212		100	82.06	69.62	48.00
10	177	199	203		100	86.50	77.37	60.50
11	183	204	210		100	87.64	81.21	69.92
12	161	196	204		68	46.54	36.72	33.09
13	176	203	208		100	79.80	67.00	45.72
MEAN	**175. 50**	**200. 8**	**207.3**		**94.66**	**77. 58**	**67. 69**	**52. 57**
±SEM.	**3.07**	**1.20**	**1.40**		**5.33**	**6.31**	**6.53**	**5.30**

TRG* = Training.

1. Mean training heart rate.

The mean training heart rate, was calculated by meaning all of the training heart rate data for each individual, during each session. Subject 4 was able to maintain the highest mean training heart rate at 187 b.min^{-1}. The same boy was able to perform for almost 70% of the time above 180 b.min^{-1}. Heart rate data for this subject were recorded during 15 training sessions (Figure. 4.10). (Appendix 4.2 contains details on the use of the Polar Heart Rate monitor during all sessions).

Figure 4. 3: Mean heart rates for both training programs



The information used to plot the mean data points presented in Figure 4.3 was collected using Polar Heart Rate monitors. Each subject was fitted with a heart rate monitor during more than half of the training sessions. The precise percentage of sessions monitored per subject varied between 60-80%. (Appendix 5.1).

Figure 4.3 demonstrates that prepubescent boys in the present study, were able to maintain high working heart rates for extended periods of time. This figure shows the mean values representing the intensity of activity, achieved during the training sessions. There was marked variation between the subjects' ability to maintain high heart rates. Three subjects (numbers 1,7, and 12 displayed heart rate performance data consistently below levels of other subjects. Subjects 2 and 4 were consistently working with very high mean heart rate data close to 200 b.min^{-1}.

2. Peak heart rates and mean, peak heart rate recorded during the laboratory testing sessions.

Table 4.10 represents the individual heart rate results for each subject from the four laboratory tests. The data collected shows marked individual differences between the subjects for the peak heart rate values achieved. Table (4.10) also includes mean peak heart rate values obtained during each training session. Standard deviations over the four tests ranged from 6.8 - 8.3 (SD) with mean values ranging from 200 - 204 b.min^{-1}.

Table 4. 10. Peak heart rates ($b.min^{-1}$) for each subject, from the four separate laboratory test sessions.

SUBJECT	Laboratory test 1 Peak HR ($b.min^{-1}$)	Laboratory test 2 Peak HR ($b.min^{-1}$)	Laboratory test 3 Peak HR ($b.min^{-1}$)	Laboratory test 4 Peak HR ($b.min^{-1}$)	Mean Peak HR ($b.min^{-1}$)
1	187	187	190	185	187
2	215	213	213	211	213
3	211	211	211	204	209
4	203	203	210	206	205
5	199	198	191		196
6	206	202		197	201
7	196	192	198	198	196
8	210	204	209	206	207
9	211	211	201	199	205
10	199	198	198	195	197
11	211	211	208	200	207
12	200	194	191		195
13		200	202	200	200
MEAN	**204**	**202**	**202**	**200**	
SD	**8.1**	**8.1**	**8.3**	**6.8**	
SEM	**2.3**	**2.2**	**2.4**	**2.1**	

3. Mean percentage of training heart rates above 150, 160, 170 & 180 $b.min^{-1}$.

The mean percentage training heart rate (% HR max), revealed a mixture of moderate and relatively high exercise intensity during the two training programs. There was a large range in heart rate and their associated work rates between subjects in this study. For example, the heart rate intervals reported above 180 $b.min^{-1}$, demonstrated that the percentage of time when subjects were able to exercise above this level during training, ranged from 6.7% to 69.92%.

Table 4.11: Heart rate intensities during training.

AVERAGE TRAINING HEART RATES FOR ALL RECORDED TRAINING SESSIONS FOR ALL SUBJECTS.					
SUBJECTS.	Number of monitored sessions	Mean training heart rate ($b.min^{-1}$)	% HR max from peak training HR ($b.min^{-1}$)	% HR max from the predicted 200 $b.min^{-1}$	PREDICTED 200 $b.min^{-1}$ (Stratton)**
1	12	160.4	**81.4**	**80.2**	200
*2	12	173.3	79.6	**86.6**	200
3	17	172.2	79.3	**86.1**	200
*4	15	187.6	**88.4**	**93.8**	200
5	17	171.6	**84.5**	**85.8**	200
*6	17	173.6	**85.0**	**86.8**	200
7	12	155.6	77.0	77.8	200
*8	22	178.9	**85.5**	**89.3**	200
*9	21	176.8	**85.8**	**88.4**	200
10	20	176.6	**88.7**	**88.3**	200
*11	19	183.2	**87.6**	**91.6**	200
12	20	160.9	**82.0**	**80.4**	200
13	13	175.7	**86.5**	**87.8**	200
Group mean	**16.6**	**172.8**	**83.9**	**86.3**	**200**
SEM	**±1.0**	**±2.5**	**±1.0**	**±1.3**	

*** More active children in the study as assessed by participation during the training sessions, and from the details included in the parental report concerning activity level outside of school.**
**** Source. Criteria reported by Stratton (1996).**

Table 4.12 represents the percentage of total training time (mean data for each subject) that subjects were able to maintain heart rates within targeted heart rate zones. As an example, subject 11 was able to maintain a heart rate above 180 $b.min^{-1}$ for 69.9% of the time during training. This may be described as an exceptionally high work rate.

Table 4.12: Percentage of time spent above selected heart rate training zones. Percentages represent a mean value for all recorded training sessions, for each subject.

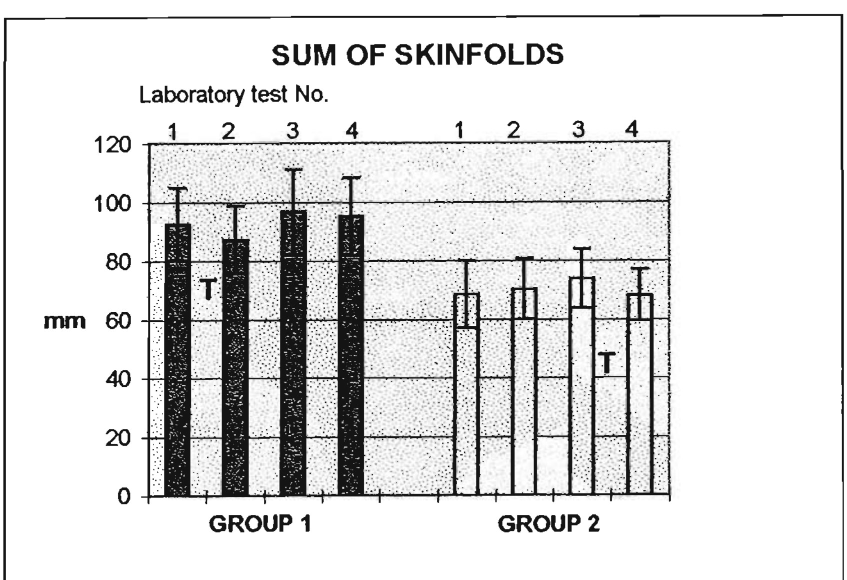
% HEART RATES ABOVE SELECTED HEART RATE LEVEL				
SUBJECT	% HR> 150 b.min^{-1}	% HR> 160 b.min^{-1}	% HR> 170 b.min^{-1}	% HR> 180 b.min^{-1}
*11	100	87.6	81.2	69.9
*4	100	89.9	82.0	69.8
10	100	86.5	77.3	60.5
*8	100	82.9	74.2	58.2
*9	100	82.0	69.6	48.0
*2	100	77.7	64.7	47.5
13	100	79.8	67.0	45.7
5	100	76.9	65.6	43.3
3	100	69.6	57.5	40.3
*6	100	76.4	63.5	39.6
12	68	46.5	36.7	33.0
1	74.6	55.5	33.3	11.0
7	64.7	37.2	20.4	6.7
Group mean	**92.8**	**72.9**	**61.0**	**44.1**
SEM	**±3.8**	**±4.6**	**±5.3**	**±5.4**

* Represents the more physically active subjects in the study. Based on a parental report, and on participation levels during training sessions

4. Changes in skinfold measurements before and following the exercise intervention programs

There was a recognisable, but not significant, decrease in skinfold totals following each of the intervention programs (Fig 4.4).

Figure 4. 4:. Sum of Skinfolds.



'T' denotes the intervention training program and its location in relation to the four laboratory test sessions for each group.

5. Detraining.

The data presented in Tables 4.13 and 4.14, illustrate the influence of detraining on $\dot{V}O_2$ at ventilatory threshold expressed as a percentage of peak $\dot{V}O_2$, and the values for $\dot{V}O_2$ (ml.kg.$^{-1}$min^{-1}) during the non training period for group 1, following the intervention program. Four weeks separated test 2 and test 3. A further 11 weeks separating test 3 from the final laboratory test session. There was a 4 % decrease in $\dot{V}O_2$ at VT (expressed as a % of peak $\dot{V}O_2$) recorded over the 15 week detraining period. Values for relative $\dot{V}O_2$ peak, did not change significantly, the small fluctuations may have been influenced by similarly small changes in body composition during the detraining period (Figure 4.4).

Table 4. 13 : Illustrates the changes that occurred for $\dot{V}O_2$ at VT as expressed as a percentage of $\dot{V}O_2$ Peak

Group 1	Experimental Pre Test 1.	Experimental Post Test 2.	Detraining Control test 3	Detraining Control test 4
$\dot{V}O_2$ at VT (% $\dot{V}O_2$ peak)	64.58 $\pm$2.35	71.58 $\pm$1.67	71.01 $\pm$2.46	68.19 $\pm$3.50

Table. 4. 14: Changes in Relative values for $\dot{V}O_2$ during the intervention and detraining periods

Group 1	Experimental Pre Test 1.	Experimental Post Test 2.	Detraining Control test 3	Detraining Control test 4
$\dot{V}O_2$ (ml.kg.$^{-1}$min^{-1}).	50.88 $\pm$3.37	51.23 $\pm$3.35	47.71 $\pm$3.37	49.95 $\pm$2.49

D. LEVEL OF STATISTICAL SIGNIFICANCE.

Interpretation - Level of Significance.

The level of significance for all measured values has been included in Tables 4.15 and 4.16. The square of the mean values represented by T.4 provided the most important information as it provided a statistical evaluation, between groups for pre and post testing by stage. Stage in this case represented the intervention program. The General Linear Model (GLM) with repeated measures, was able to accommodate the cross over research design used in this study.

There were significant changes recorded at the 0.05 level of significance for the following measures; $\dot{V}O_2$ ($l.min^{-1}$) at VT and $\dot{V}O_2$ at VT as a percentage of peak $\dot{V}O_2$.

Table 4. 15:. Level of significance for all measures and test items (part 1).

LEVEL OF SIGNIFICANCE.						
	AGE	HEIGHT	HR at VT%	HRatVT	HR.MAX	MASS
T.1. Between Subject Effect. GROUP	.341	.827	.023*	.255	.706	.771
T.2. Within Subject Contrast. STAGE	.000*	.000*	.201	.390	.207	.000*
STAGE BY GROUP	.272	.734	.456	.035	.094	.016
T.3. Within Subject Contrast. PREPOST	.000*	.001*	.016*	.141	.000*	.006*
PREPOST BY GROUP	.355	.962	.015*	.642	.570	.043*
T.4. Within Subject Contrast. STAGE BY PREPOST	.450	.071	.346	.558	.162	.915
GROUP BY STAGE BY PREPOST	.450	.678	.360	.218	.961	.502

Computed using alpha = .05

T.4 GROUP by STAGE by PREPOST. Parameters - Coeff. & SEM.						
Coefficient.	.002*	.128	1.486	3.88	.037*	.095
Standard Error of the Mean (SEM).	.003*	.299	1.519	2.93	.744	.136

Table 4. 16: **Level of significance for all measures and test results (part 2).**

LEVEL OF SIGNIFICANCE.						
	RER	SUMSKIN	VO_2 at VT	VO_2 at VT %	VO_2 $l.min^{-1}$	VO_2 $ml. kg^{-1} min^{-1}$
T.1. Between Subject Effect. GROUP	.427	.194	.418	.102	.963	.633
T.2. Within Subject Contrast. STAGE	.935	.358	.156	.893	.077	.999
STAGE BY GROUP	.583	.239	.868	.411	.533	.279
T.3. Within Subject Contrast. PREPOST	.367	.074	.181	.333	.740	.634
PREPOST BY GROUP	.199	.920	.409	.768	.038*	.152
T.4. Within Subject Contrast. STAGE BY PREPOST	.363	.631	.841	.902	.726	.772
GROUP BY STAGE BY PREPOST	.762	.089	.001*	.011*	.440	.445

T.4 GROUP by STAGE by PREPOST. Parameters - Coeff. & SEM.						
Coefficient.	.010*	1.974	.060	5.281	.025*	.263
Standard Error of the Mean (SEM).	.032*	1.036	.013*	1.604	.031*	.881

CHAPTER 5. DISCUSSION.

CHAPTER 5.

DISCUSSION.

Introduction.

This chapter initially summarises the major findings of the study. It then proceeds to present and discuss a number of potential explanations for these findings.

Review of major findings.

The first major finding was the significant increase in the $\dot{V}O_2$ at which the VT occurred, following the exercise intervention program. Associated with this improvement was a similar increase in the $\dot{V}O_2$ data at VT when it was expressed as a percentage of peak $\dot{V}O_2$.

The second major finding of the study was a lack of significant change following the treatment program in peak values for absolute ($l.min^{-1}$) and relative ($ml.kg.^{-1}min^{-1}$) peak $\dot{V}O_2$. No treatment effect was detected in the absolute ($b.min^{-1}$) and relative (%HR max) heart rate data at which VT occurred. Maximal heart rate remained constant across all testing sessions. Maximal values for respiratory exchange ratio (RER) also remained constant across the four testing sessions. Furthermore, estimates of body composition reported as BMI values and the sum of skinfold scores, did not change significantly as a result of the training intervention program.

Discussion - Major finding one.

Training related increases in Ventilatory Threshold.

Ethical and methodological constraints limit the scope of research with children. Consequently, the micro-structural changes which often describe the metabolic effects of exercise training studies in adults, are more difficult to obtain after similar intervention in paediatric populations. Limited data suggest that activity levels in specific glycolytic enzymes (eg. PFK), may be surpressed prior to puberty. These glycolytic enzymes however, have been reported to increase in response to exercise training in circumpubertal males (Eriksson et al., 1972). In the present study, there were no methodologies employed to provide observations of specific metabolic changes at the local muscle level. Therefore, it is difficult to identify the precise mechanisms by which the children in the present study demonstrated an improvement in the $\dot{V}O_2$ data at VT following the exercise training program. Theoretically however, it may be possible that an increased tolerance to lactic acid contributed to the training adaptations through a prolonged potential for aerobic metabolism and a delayed onset of VT. Concurrently, training may have improved the efficiency of lactate clearance and further enhanced the potential for aerobic metabolism (Weltman, 1995). As maximal and submaximal exercise lactate levels rise almost linearly with age during childhood (Rowland, 1996b), it is a reasonable assumption that children's potential to respond to exercise training could concomitantly increase. Weltman (1995) reported that in adult studies, lactate threshold (LT) breakpoints during exercise, may provide a better indicator of endurance performance, than max $\dot{V}O_2$. Weltman (1995) further suggested that changes in LT and OBLA (onset of blood lactate accumulation) were more related to local changes such as muscular oxidative activity rather than cardiovascular adaptations. In children, it may be that their albeit limited ability to generate lactate in the muscle during high intensity training, may be enough to stimulate an increase in their $\dot{V}O_2$ at VT without showing an increase in peak $\dot{V}O_2$ levels.

Possible explanations for the significant changes in Ventilatory Threshold obtained in the present study.

The following three possible explanations may be related to the significant changes observed in $\dot{V}O_2$ at VT in the present study. Each of these three explanations will then be discussed in the ensuing paragraphs.

The first explanation concerns the focus on high intensity activity during the training program which may have helped improve VT_1. The second explanation suggests that the results of improved $\dot{V}O_2$ at VT may have been influenced by a bias in the participants volunteering for the study who were enthusiastic about activity. The third explanation postulates that the use of VT in the present study when compared to traditional measures of cardiorespiratory function, may be seen as a more sensitive measure to the subtle changes which may occur in association with short-term exercise intervention studies in prep-adolescent children.

1. Training Intensities.

Nelson (1991) suggested that there was insufficient data on the amount and nature of physical activity needed for health benefits in children. Bailey et al. (1995), examined the nature of spontaneous activity in children. The authors (1995) revealed that the medium intensity duration of movement was 6 seconds, and high intensity activity lasted for little more than 3 seconds. Thus intermittent activity may be a natural mode of training for paediatric populations. The concept of the accumulation of intermittent activity patterns has grown in acceptance with older populations (De Busk et al., 1990) however, no research has been undertaken to evaluate the effects of intermittent play patterns in children (Morrow and Freedson, 1994). While the idea that a minimum of 35 min of activity a day may be adequate in the adult to provide health benefits, there is no firm evidence to suggest that this exercise prescription will be appropriate in populations of non-obese children. This question of how much is enough for health benefits, training maintenance, or improvement, remains open to conjecture. Stratton (1996) reviewed studies related to children's heart rates during physical education lessons. For his review Stratton (1996) suggested that child should be involved in moderate-to-vigorous physical activity (MVPA) which elicits a heart rate of 50% of maximum heart rate reserve (MHRR) for 20 minutes during each lesson. The author (1996) also included a criterion of 75% of MHRR, as a marker for high intensity physical activity in children. This exercise intensity was consistent with the suggestion by Massicotte and MacNab (1974), that a heart rate threshold of 170 b.min^{-1} was necessary to elicit an improvement in peak $\dot{V}O_2$ from high intensity exercise training. The majority of physical education lessons described by Stratton (1996), failed to achieve the criterion for high intensity exercise stimulus.

The present study attempted to work the children at relatively high exercise intensities in an effort to examine the child's potential to alter any of the cardiorespiratory parameters measured during peak $\dot{V}O_2$ testing. Heart rate means were consistently above the 75% MHRR level.

2. Self-selected enthusiastic subjects.

Genetic predisposition may have considerable influence over performances during the training program. Naughton et al. (1996) believed that when sporting and non sporting groups of children were compared, the sporting group usually demonstrated some physiological advantages. A critical concern is whether children participate in physical activity due to a predisposed physiological advantage, or whether these physiological adaptations occur as a consequence of habitual participation. The age at which training-related improvements emerge remains unclear. Most of the boys in the present study participated in 3 or more activities per week, in addition to their normal school sport. Thus it is possible that within the present study self-selection employed in the recruitment process could have resulted in the majority of participants being pre-disposed to a relatively high level of exercise intensity even prior to the exercise intervention (Appendix 5.1).

3. Sensitivity of Ventilatory Threshold as a measure of change following exercise intervention.

One of the specific aims of the study was to examine the sensitivity of ventilatory breakpoint as a marker of submaximal cardiorespiratory adaptation following aerobic training in children. In association with the training intervention program, there were two measures of $\dot{V}O_2$ at VT which marked a significance increase in the breakpoint within the ventilatory data . Reybrouck (1983) suggested that, when VT is expressed as a percentage of peak , it may be a better indicator of aerobic function than peak scores. This was supported by Wolfe (1986) who stated that VT was an easily measured and reproducible method of assessing exercise performance in children and adults. Furthermore, Washington, (1989) believed that because VT can be determined non-invasively the method provides an advantage for use in paediatric populations. Reinhard et al. (1979), and Rotstein et al. (1986) postulated that children may be globally fitter than adults and therefore demonstrate a higher VT than older, less active populations. Reybrouck et al. (1985) found higher VT values in more active boys when compared with their less active counterparts. Bar-Or (1989) reported that VT showed a substantial decrease with age and postulated that this shift was associated with an attenuated dependence on the aerobic system at relatively high exercise intensities.

Section summary.

The findings in the present study compare favourably with the current literature. The treatment effect observed after training appears to have raised the VT levels of the exercise groups. The results of this study would suggest that high intensity training can influence threshold levels in prepubescent children. Because of the relatively small number of studies profiling VT in the child based literature, Rowland (1996b) suggested that there is a lack of consistency on the methodologies employed to detect VT during childhood. Specifically, more research appears to be needed on test protocols, test to test reliability, and intra observer reliability in detecting VT among paediatric populations. Thus the findings of the present study need to be interpreted within the limitations of what is known and accepted about ventilatory threshold in children.

Discussion - Major finding two.

No statistically significant changes occurred for the aforementioned cardiorespiratory markers of exercise metabolism, and body composition estimates, measured at the start and end of the exercise intervention programs conducted with the prepubescent males in the present study. Each of the previously listed parameters will be addressed in the following discussion.

1. Peak $\dot{V}O_2$ ($l.min^{-1}$).

Some authors have suggested that absolute values for peak $\dot{V}O_2$ ($l.min^{-1}$) increase with growth up to the age of 25 years, then, depending on activity levels, the peak $\dot{V}O_2$ starts to decline (McArdle et al., 1996). The literature is divided over whether prepubescent children can increase absolute peak $\dot{V}O_2$ through training (Bar-Or, 1989, Cunningham, 1984, Payne and Morrow, 1993, Rowland, 1989b, Zwiren, 1989). The current study found that no differences occurred following the treatment program for peak values for absolute ($l.min^{-1}$) and relative ($ml.kg.^{-1}min^{-1}$) oxygen consumption. These findings were consistent with the similar studies completed by other paediatric researchers (Gilliam and Freedson, 1980, Rostein et al., 1986, Welsman et al., 1997, Yoshida et al., 1980). Other authors who have employed a similar training duration have reported significant improvements in peak $\dot{V}O_2$ values, after training (Mahon and Vaccaro, 1989, McManus et al., 1997, Rowland et al., 1996, Rowland and Boyajian, 1995). Tables 2.4 and 2.9 present a number of training studies of similar duration to the present study where prepubescent boys produced mixed findings in response to exercise intervention.

Shephard (1992) was critical of many of the earlier studies which failed to demonstrate changes in peak $\dot{V}O_2$ due to poor research design. He (1992) stated that a well-designed aerobic program can produce a positive outcome in fitness levels in prepubescent children. In contrast, Rowland (1996) recently revisited the 'trigger hypothesis' to help explain the disproportionate increase in the cardiorespiratory responses of adolescent males to exercise intervention when compared with their pre-adolescent counterparts. In this elegant review, Rowland (1996) linked enhanced cardiorespiratory adaptations to specific functions of the growth-related hormones inherent in pubertal changes in males. Implicit in the arguments promoting explicable changes in the cardiorespiratory improvements of adolescents are the counter-arguments supporting the lack of change in less mature populations. Other possible explanations for a lack of an increase in peak $\dot{V}O_2$ have been explained in the review of literature. These explanations include the fact that if the training intensity, was not at maximal effort, then the principle of specificity (Rushall and Pyke, 1990) would suggest that changes may not be apparent when tested at maximal levels of intensity. A further possibility may be associated with the relatively short-term duration of the program. The ten weeks of exercise intervention may not be the optimal duration in which to observe an increase in peak $\dot{V}O_2$ however, it is problematic to identify any specific duration from the literature. It is also possible that the majority of boys in the study were operating at, or around their phenotypical peak $\dot{V}O_2$ before the commencement of the study and therefore could not be expected to improve beyond this level of function.

2. Heart Rate Measures.

Heart Rate at VT.

Heart rate at VT did not different with exercise intervention. The fact that the heart rate at which VT occurred did not change over the training period, may suggest that factors more sensitive than heart rate are related to improved cardiorespiratory efficiencies. For example, more efficient metabolic changes in lactate removal may occur without major changes in heart rates (Rowland, 1996b). Surprisingly few studies have reported changes in heart rate data when VT has been measured before and after exercise intervention in prepubescent populations.

Maximal Heart Rate.

Both longitudinal and cross-sectional studies have consistently reported that maximal heart rate up until the mid-adolescent years remains relatively stable (Bailey et al., 1978). Rowland and Boyajian (1995) reported no change in maximal heart rate values in any of the testing sessions in their endurance based training study with pre-pubescent children. Welsman et al. (1997) using pre-pubescent female subjects in a split mode of aerobic training ('aerobics' and cycle ergometer training program), reported no change in maximal heart rate to the first group and a decrease ($P < 0.05$) for the cycle ergometer group. Gilliam and Freedson (1980) also reported no change in maximal heart rate after training in a prepubescent population. In agreement with the aforementioned authors, no change in maximal heart rate occurred in this study. It is important to recognise that maximal heart rates vary significantly among individuals (Cummings and Langford, 1985). Peak heart rate data in this study on an individual basis, recorded during the laboratory testing sessions displayed a range from 187 $b.min^{-1}$ to 213 $b.min^{-1}$. Standard deviations for the study group over the four tests ranged from 6.8 - 8.3 with mean values ranging from 200 - 204 $b.min^{-1}$ among the four testing sessions. This results compared favourably with the data reported by Sheehan et al. (1987), who reported a maximal heart rate of 202 $b.min^{-1}$ with a standard deviation of 9 $b.min^{-1}$. Thus it appears reasonable to dismiss peak heart rate values as sensitive markers of cardiorespiratory changes following exercise intervention in younger populations.

Since maximal heart rate does not change appreciably in children after training, it would suggest that other mechanisms may be more sensitive to functional changes as a result of training. For example, improvement in cardiac output may be dependant on an increased stroke volume. Eriksson et al. (1972) reported an increase in peak stroke volume in prepubertal boys following an aerobic exercise training program. Rowland (1987), suggested that improved contractility in cardiac tissue was responsible for increased stroke volume during exercise in children. In addition Wilmore and Costill (1994) suggested that when compared with an adult, a child's arterial-venous oxygen difference may be increased, to compensate for the lower stroke volume. With the improving methodologies for cardiac output it is anticipated that issues relating to enhanced stroke volume with training are relatively closer to being resolved.

3. RER.

When compared with adults, children have lower RER values at maximal power outputs. Lower RER in children has been related to children generating less lactate and excess CO_2 than adults (Zwiren, 1989). No change occurred as a result of the intervention program in the present study and none was expected. Rowland and Boyajian (1995) and Welsman et al. (1997), also reported that RER values were not significantly different before and after aerobic training. Haffor et al. (1990), found that training did not alter RER values at max however, a significant increase was reported for RER values, at "anaerobic threshold". Haffor et al. (1990), speculated that the improvement in submaximal RER may have been related to an improvement in the glycolytic capacity of the subjects. No change for RER at VT was recorded in the Rowland and Boyajian (1995) study. The lack of agreement in the existing literature on RER at submaximal intensities may be difficult to ascertain if the recommended short, sharp protocols for obtaining VT (Wasserman et al., 1973) preclude the true steady state conditions under which RER values maintain their strongest submaximal meaning. Thus the RER data need to be interpreted within the context of the specific protocols employed in the testing.

4. Estimates of body composition.

Sum of Skinfolds.

There was a recognisable, but not significant, decrease in skinfold totals following each of the intervention programs (Table 4.1 and Figure 4.4). Gilliam and Freedson (1980) and Rowland and Boyajian (1995) also reported no significant changes in skinfold values following 12 weeks of aerobic training with pre-pubescent children.

The more active subjects carried less fatty tissue, than the less active subjects. Similarly, Bar-Or and Malina (1995), reported that youngsters who regularly engaged in physical activity, tended to have less fat mass than those who do not. Body composition has a significant influence on the physiological responses to exercise, as the individual with additional fatty tissue may find aerobic activity, more difficult (Watson, 1988). Variations in body composition, from short term training programs are more likely to reflect fluctuating levels of fatness with minimal or no changes in fat free mass (Boileau, 1985).

More research is required on the maturational differences in body composition during the paediatric years (Malina and Bouchard, 1991, Rowland, 1996b). While fat reduction induced by training in the adult is attributed to, a reduction in size of fat cells rather than the number of cells, little is known about the metabolism of adipose tissue in children in response to exercise training (Bar-Or, 1995).

Body mass index (BMI) is a gross estimate of body fatness. It is calculated from obtaining the mass of the individual divided by the square of height (kg/m^2). As with most measures of body composition measures, there are some limitations which must be understood when interpreting the data (Lohman, 1992). Rowland (1996b) reports that a fundamental problem with BMI is the possibility that muscle mass rather than excess adiposity, may contribute to excessive body weight relative to height. The BMI values for the participants in the present study, ranged between 17-18 kg/m^2, which is an acceptable range for 10 year old males (Hammer et al., 1991). No significant changes occurred in the values for BMI during the period of this research study. Perhaps because of the short term duration of the intervention program, and the initial leanness of the subjects, the resulting absence of change in BMI were not unexpected.

Detraining.

The cross over research design provided an opportunity to continue to monitor some of the subjects through a 'detraining' phase. The first training group, became the control group during the second half of the study, and consequently, their re-tests provided some measures of detraining.

The most sensitive measure for change during training in this study was an improved $\dot{V}O_2$ at VT. For the group who comprised the experimental subjects in the first training program, the percent change between test 1 and test 2 was 9% in the $\dot{V}O_2$ at VT. More than 12 weeks after completing the training, approximately half of the initial gain had declined in the $\dot{V}O_2$ at VT. Thus detraining in this group of prepubescent males was relatively slow. Endurance trained adult athletes after two to three months of inactivity, display no loss of muscle capillarization, and only a partial loss of mitochondrial enzyme activity with values stabilising at about 50% above values noted in untrained subjects. In addition, $\dot{V}O_2$ max and maximal arteriovenous O_2 difference remain 12-17% higher than levels found in untrained subjects (Coyle, 1984). While the existing literature appears to provide a limited understanding of the detraining effects that may be expected following a strength training program in prepubescent children (Blimkie et al., 1989), there appears to be even less understanding of detraining in cardiorespiratory parameters in healthy, and active young populations.

Values for $\dot{V}O_2$ ($l.min^{-1}$) continued to remain relatively stable during the training and monitored detraining periods. Slight increases observed over the four testing sessions may need to be considered in the light of the growth which occurred during the study period. This stability in peak oxygen consumption was exemplified by a non-significant 6% difference between tests one and four.

Relative values for $\dot{V}O_2$ (ml.kg.$^{-1}$min^{-1}), similarly did not appear to alter substantially over the duration of both the training and detraining programs. Contributing to the pattern of relatively no change during the detraining period was the influence of the self-selection by all participants of a relatively active lifestyle. Specifically, inter-school and extra curricula sports programs, were maintained during the entire study period and may have been influential in avoiding a decline in the existing maximal cardiorespiratory function, even when additional training ceased.

CONCLUSIONS.

Research has indicated that the prepubescent child has at best a blunted response to traditional physiological measurements of the cardiorespiratory effects of aerobic training (Rowland, 1995). Subjects in the present study exercised at relatively high intensities, and from a range of metabolic and anthropometric data collected during the study, only the data for $\dot{V}O_2$ at VT produced a significant improvement.

Genetics appears to contribute substantially to the variation in performance scores in aerobic power tests particularly in childhood (Malina and Bouchard, 1991). The data showed a considerable variation in physical performance capacities among the individuals in the study group. Thus, it is postulated that while the subjects were well matched for the conventional parameters, such as height and weight, other factors emerged creating marked within-group differences which may have substantially affected the results.

While there was an increase in both height and mass during the period of this research study, the influence was marginal. Any change as a result of growth in cardiorespiratory function over the relatively short term duration of the study may have been absorbed in the biological variability for this age group and may have been accounted for by the cross-over design and well matched experimental and control groups in the study. Therefore it is possible that the influence of growth during training could have been statistically minimised by the subject selection and research design.

The results of this study would suggest that the prepubescent male can, when involved in high intensity training, alter some metabolic parameters such as those reflected in the ventilatory threshold data. It may be speculated that even if training induced changes were more likely to manifest in an improved muscle oxidative function, the additional oxygen extraction capacity of the muscle may have delayed the onset of predominantly anaerobic metabolism and prolonged the aerobic contribution to the exercise responses elicited during maximal effort testing.

Future Research.

The present research examined the influence of high intensity training on selected cardiorespiratory parameters of the pre-adolescent child. Many issues have emerged from the existing literature and the present study which remain unresolved. These issues address the influence of the optimal exercise training intensity for effective and permanent improvements in cardiorespiratory function in preadolescent children. More importantly, it may be prudent to further address the nature of training perceived as motivating, enjoyable and empowering to the young participant.

There are a number of important questions in relation to paediatric exercise and training which were raised in a review of the findings of the present study.

1. Is intense aerobic training effective or even warranted prior to pubertal years? What if any, are the cardiorespiratory benefits that can be gained with early fitness intervention programs for children? What is the nature of improvement that can realistically be expected from high intensity exercise intervention studies conducted with prepubescent groups? If the peak aerobic function parameters are limited from this type of research, are there other less traditional tests that can show more sensitivity to change or perhaps may be more worthwhile pursuing. Is it possible that field based measurements of improved performance may provide greater feedback to the young athlete than laboratory based, which could result in insensitive changes over a training season? Could it also be speculated that a shift towards 'process' (training) based-goals rather than 'product' (testing) based-goals would be worthwhile when working with paediatric populations? Therefore, should there be a shift away from the fitness outcomes so often documented among the objectives for participation in activity by younger populations?

2. What is the link between regular physical activity in childhood, fitness, and a healthy life style in adulthood? Williams (1993), stated that the proper amount of exercise is important for the optimum development and health status of children. Too much or too little exercise may has the potential for adverse effects. What is the most effective intensity, frequency, duration and nature of activity that can be successfully implemented in prepubescent

populations? What focus should the schools and community groups take when formulating programs for children? Do some children need more exposure to physical activity than others? What are the existing approaches which appear to be most effective in motivating children to want to be active?

3. Paediatric activity may be more productive if exercise behaviours and skill development become the prime focus, and intense efforts to improve physical conditioning are delayed until after puberty (Payne and Morrow, 1992). Gutin and Owens (1996) recently discussed promoting exercise for cardiovascular health in children, and expressed the view that there were other good reasons to encourage children to exercise. They cited the promotion of other aspects of health such as, enjoyment, learning sports skills and psychosocial development as examples of alternative gains from a physically active lifestyle. Sallis (1994) supported this view, and believed that schools should be used to prepare children for a life time of physical activity. Bar-Or and Malina (1995) suggested that an exercise intervention program can produce some improvement in children with abnormal values for certain health indices. For example, improved lipoprotein levels (Widhalm, 1978), a reduction in adiposity and a reduction in resting blood pressure in hypertensive children (Hagberg et al., 1983). As young athletes perform at the highest levels of competitive sports, with bodies still growing and maturing, it is vital to understand the long-term consequences of these experiences. It is equally important to understand the types of exercise programs and the prescriptive strategies best suited to prepare the child for a lifetime of physical activity.

4. Has the time come to re-evaluate the testing protocols and procedures that would provide optimal data on exercise training programs? The potential to use recent technologies such as magnetic resonance imaging to provide an understanding of energy demands or changes in substrate utilisation over time, during exercise in children is gradually increasing for paediatric exercise scientists (Rowland, 1996b). Much remains unknown to date because the commonly used invasive procedures acceptable in adult based studies (such as arterial lines and muscle biopsies) have failed to obtain wide ethical approval for use in healthy young populations. For ethical reasons, studies with children cannot employ procedures that include pain, embarrassment or compromise a child's health (Bar-Or, 1996). Hence it is important to continue to seek test protocols and test procedures that enable more sensitive measures of the physiological changes that may occur in children due to exposure to physical training or activity.

5. A final question to be asked focuses on whether there is a need to examine the suitability of equipment used in research studies with children. Does the equipment need to be more

specifically designed to provide strong compatibility with the anatomical and physiological changes occurring of children. For example the influence of valve deadspace, tubing diameter and mixing chamber size in gas collection systems may need clarification (Rowland, 1990a). Agreement by paediatric researchers, on procedures, test protocols and equipment would be useful.

Summary.

This study examined the influence of a high intensity training program on selected cardiorespiratory parameters on a group of 13 prepubescent males. Possible changes in peak $\dot{V}O_2$ and VT values were the principle focus of this aerobic training study. Cardiorespiratory exercise responses were measured on four occasions over the two training periods. Height, body mass, and sum of skinfold measures were recorded to monitor growth rate changes during the period of the study. There were significant improvements in the $\dot{V}O_2$ at VT which increased in both training programs 9.77% and 10.11% between the pre and post tests. Percentage changes for $\dot{V}O_2$ at VT (% peak $\dot{V}O_2$) were also positive, with an 11.11% and 6.20% increase during the two training programs. The mechanisms by which an improvement in $\dot{V}O_2$ at VT can occur are not well understood. A greater extraction of lactate by body tissue in the body is one possible explanation. Some of the other mechanisms for improved $\dot{V}O_2$ at VT were postulated to include, an increase in stroke volume, an increased cardiac output, or an improved arterio-venous oxygen extraction.

Peak $\dot{V}O_2$ values, absolute or relative, did not change. These results are supported by the literature, particularly the more recent studies. The absence of change in $\dot{V}O_2$ peak values with training may also be attributed to a number of factors. One of the possible explanations for the absence of change in maximal aerobic power among participants is an existing optimal level of fitness in participants. It may also reflect a greater shift in submaximal rather than maximal values in supporting the specificity of aerobic training undertaken by participants. It is possible that a longer duration of training may have elicited changes in peak $\dot{V}O_2$. In the present study however, it appears that ventilatory threshold was a more sensitive marker of training-related change.

The training intensities produced an enthusiastic response from the boys in the present study. Similar effects in other paediatric populations remain speculative. The study confirms that the pre-adolescent males recruited for the study were capable of relatively high aerobic training for at least a ten week duration. It further agrees with several previous studies on the attenuated training potential of pre-adolescent males when traditional laboratory tests are used as markers of change.

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APPENDIX 3. 1

ETHICS.

(a) PARENTAL CONSENT FORMS.

(b) ETHICS COMMITTEE CONSENT FORMS.

(c) OVERVIEW OF APPLICATION TOHUMAN ETHICS COMMITTEE.

Appendix 3. 1. Parental Consent Form

PARENTAL CONSENT FORM.

Parents Name.

Your son **name** is invited to participate in a research study to evaluate the physiological responses to a Physical Education training program.

During 1990-91 a large number of children from twelve Primary School were tested as part of the **Health In Primary Schools** (HIPS) fitness program. A number of questions grew from that study in relation to the fitness capacities of primary school children.

This current study attempts to seek answers for some of those questions. The specific aim of this study is to examine the cardiovascular responses to training in children. The assumption in this study is that primary school aged children have different physiological capacities than the adult, if this is shown to be the case then school physical education programs may need to be subtly changed to suit the child's needs and not simply adopt the adult models for physical training and activity. This research study will involve the children in three physical education sessions per week and the study will be conducted over a 15 week period during terms 1 and 2 in 1994. As a parent you are welcome to observe any of the training sessions.

While, **childs name** will be encouraged to attend all training sessions to provide a continuity of the study, it is important to note that your son has the option to withdraw from the program at any time .

A series of familiarisation sessions will enable the children to experience the activities and the tests which will be used in the study. All testing and monitoring will be non invasive and all personal details will be confidential. Training sessions will be conducted at the Deakin University Campus and transport to and from the University will be by Mini Bus.

Further details concerning this research study can be obtained from John Birchall. Phone. _____________

In addition to a brief description of the research study (above) the STANDARD CONSENT FORM FOR SUBJECTS INVOLVED IN EXPERIMENTS, provided by Victoria University of Technology, and or Deakin University, will need to be completed by the parents of each child.

CONSENT ON BEHALF OF A MINOR.

DEAKIN UNIVERSITY AND VICTORIA UNIVERSITY OF TECHNOLOGY ETHICS COMMITTEE'S

I,__________________________________of______________________________

____

<u>Hereby give consent</u> for my son ____

be a subject in a research study to be undertaken

by, **John Birchall from the School of Human Movement Recreation and Physical Education from Deakin University. and _______________ Primary School.**

and I understand that the purpose of the research is

To examine the possible changes in 'fitness' of the boys as measured by changes in their cardiovascular capacities during a nine week training program.

<u>I acknowledge</u>

1. That the aims, methods and anticipated benefits have be explained to me.
2. That I voluntarily and freely give my consent to my sons participation in this research study.
3. I understand that aggregated results will be used for research purposes and may be reported in scientific journals and academic journals.
4. That all data collected will all be confidential.
5. That I am free to withdraw my consent at any time during the study, in which event my son's participation in the research study will immediately cease and any information obtained will not be used.

Signature: ____________________________ **Date:** __________

APPENDIX 3. 1. (First two pages from the application)

VICTORIA UNIVERSITY OF TECHNOLOGY

HUMAN ETHICS COMMITTEE

APPLICATION FOR APPROVAL OF PROJECT INVOLVING HUMAN SUBJECTS IN VICTORIA UNIVERSITY OF TECHNOLOGY

Note : This application form is included in the Human Research Register. If your project includes any information of a commercial or patentable nature this information should be sent separately and marked confidential.

PROJECT TITLE:

Ventilatory threshold and Peak VO2 (ml.kg.$^{-1}$min^{-1}) responses in prepubescent children following a high intensity training programme.

PRINCIPAL INVESTIGATOR/S:

DEPARTMENT: Physical Education & Recreation V.U.T.

Title of Project:

Ventilatory threshold and Peak VO2 (ml.kg.$^{-1}$min^{-1}) responses in prepubescent children following a high intensity training programme.

Aim of Project :

The focus of the study will be to examine the influence of a high intensity training programme on selected cardiovascular responses of the pre-pubescent child. Specifically the project aims to monitor changes in ventilation threshold values and peak VO2 scores for each child will be the prime objective in the testing.

Plain Language Statement of Project :

Within the available literature there is a lack of research focusing on the health related fitness needs of the prepubescent child. Many teachers of physical education in primary schools, sports administrators and coaches, assume that the child's cardiovascular characteristics will respond in a similar manner to the adult performer. As a result, children are frequently exposed to modified adult style fitness programmes which do not take into consideration the needs or the physical capacities of the child.

While the adult elite athlete will use information gained from testing to enhance personal performance, the focus with children should be to help maintain a healthy life style and identify those who most need programmes to increase their health related fitness (Zwiren 1989., Buono et al.,1989). Many disorders that appear later in life may begin during early childhood, such as obesity, some endocrine and neuromusculatory diseases, and ischemic heart disease (Macek 1986). Sleap (1990) suggested that there is now little doubt that an active lifestyle can help protect an individual from heart disease, and the primary school physical education programme has a major role to play in this aspect of disease prevention. Dennison et al. (1988) conducted an epidemiological study on fitness test scores of children (aged 10-11 years) to determine whether these scores could relate to future adult physical activity patterns. The more active or fittest children, continued to be active into the adult years. The study concluded that life-style habits were established during childhood and the identification of children with low fitness may benefit from intervention exercise programmes.

The results of this study may provide some direction in program design in the physical activity patterns of the Primary School aged child, which would be consistent with the recent initiatives of the current Governmental report on Physical andSport Education in Victorian schools (Directorate of School Education 1993).

Risks to the participants :

Only normal healthy children will be used in the study. Prior to subjects being included in the study the parents will be contacted and the school medical records consulted and children with chronic illness will be excluded. All training sessions will have small numbers of children(4-5) due to the type of equipment required for recording performance during these sessions. During the training phase each child will be supervised on a one to one basis. Any child who requests to stop during a test or training session will be able to do so immediately. In addition any child who wishes to withdraw from the study at any time will be free to do so. These conditions will be clearly explained to the children prior to the study beginning.

It is important to note that while the title of the study refers to "high intensity training", the children will however be working at a submaximal level of approximately 70-80% of their peak aerobic levels or lower for most of the time. All procedures are noninvasive and the protocols used are frequently used in child centred studies.

We submit that the physical and psychological risks to the participants are minimal and are outweighed by the potential benefits.

Number, type and age range of subjects :

Number : 20 Type : prepubescent boys Age : 10 years

Source of subjects and means by which subjects are to be recruited :

A primary school in the Burwood (Melbourne) area.

Premises on which project is to be conducted :

All pre and post testing will be completed in the Exercise Physiology Laboratory at Victoria University of Technology. The training aspect of the study will be undertaken at Deakin University Burwood Campus. A separate request for an ethics clearance for this study has been submitted to the Deakin Ethics Committee.

Data is to be analysed in the laboratories of the Exercise Metabolism Unit at VUT.

APPENDIX 3. 2.

SEXUAL MATURATION.

(a) INSTRUCTIONS TO PARENT(S) ON THE ASSESSMENT OF PUBERTAL STATUS.

(b) INFORMATION FROM TANNER (1962).

(c) STAGES OF PUBERTY (ADELAIDE CHILDRENS HOSPITAL, 1996)

INSTRUCTIONS TO PARENT(S) ON THE ASSESSMENT OF PUBERTAL STATUS. (INFORMATION FROM TANNER)

Parents were ontacted by phone to request that they assist in the pre-pubertal / pubertal status assessment, of their son. In addition some notes from Tanner (1962) were set to the parents to assist them in there evaluation. One boy was asssessed as "just starting" to grow pubic hair. Pubic hair was selected as the marker for start of adolecence.

development and pubic hair development are rated separately. All ratings are on a scale from 1 to 5, and the standards for pubic hair can this way be made the same in both sexes. If a composite sex-character-development rating is required the pubic hair rating can be averaged with the genitalia rating for boys and with the breast rating for girls. Naturally the ratings can be assigned with much more accuracy if a longitudinal study of a child is available, since they are really based on the occurrence of change from a previous state. However, fair accuracy is attainable even when the child is only seen once: pubic hair ratings are perhaps easier to give than genital or breast development ones under these circumstances. The rating in a longitudinal series refers to the actual time the stage in question is first observed and is not interpolated backwards half way to the previous examination as Nicolson and Hanley (1953) recommend, since this would be impossible for cross-sectionally given ratings.

The *genital development stages* are illustrated in Plate 5.

Stage 1. Pre-adolescent. Testes, scrotum and penis are of about the same size and proportion as in early childhood.

Stage 2. Enlargement of scrotum and of testes. The skin of the scrotum reddens and changes in texture. Little or no enlargement of penis at this stage (which therefore comprises the time between points T1 and P1 of the Stolz's terminology).

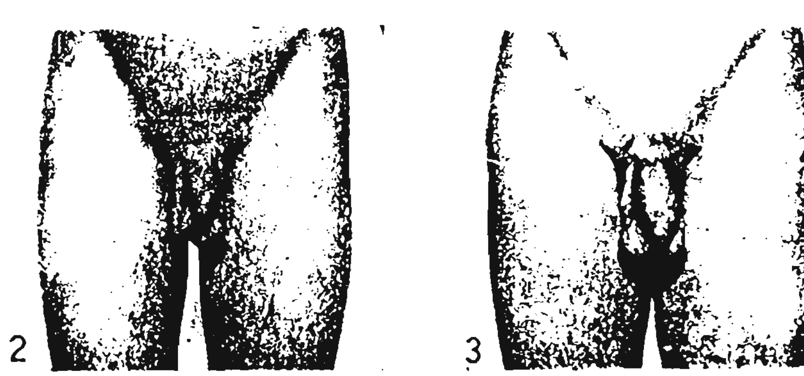
Stage 3. Enlargement of penis, which occurs at first mainly in length. Further growth of testes and scrotum.

The *pubic hair stages* are illustrated in Plate 6, for boys and girls.

Stage 1. Pre-adolescent. The vellus over the pubes is not further developed than that over the abdominal wall, i.e. no pubic hair.

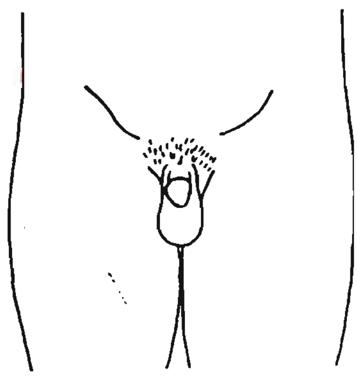
Stage 2. Sparse growth of long, slightly pigmented downy hair,

Plate 6

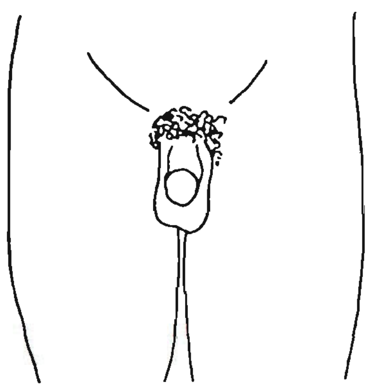


INFORMATION FROM TANNER (1962). & STAGES OF PUBERTY (ADELAIDE CHILDRENS HOSPITAL, 1996)

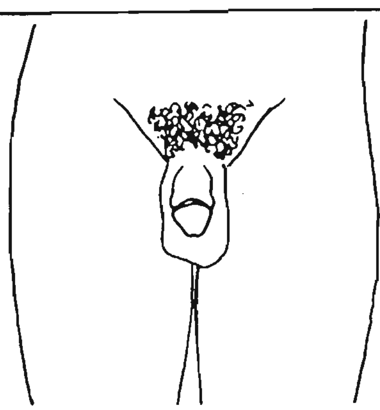
Genital and Pubic Hair Stages



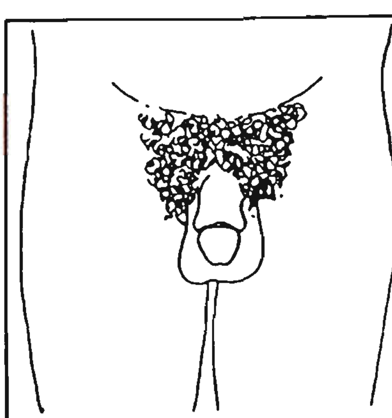
Genital 2/Pubic Hair 2



Genital 3/Pubic Hair 3



Genital 4/Pubic Hair 4



Genital 5/Pubic Hair 5

STAGES OF PUBERTY

Ages of attainment of successive stages of pubertal sexual development are given in the height centile chart overpage. The stage Pubic Hair 2+ represents the state of a child who shows the pubic hair appearance stage 2 but not stage 3 (see below). The centiles for age at which this state is normally seen are given, the 97th centile being considered as the early limit, the 3rd centile as the late limit. The child's puberty stages may be plotted at successive ages (Tanner, *Growth at Adolescence*, 2nd Ed., 1962). Testis sizes are judged by comparison with the Prader orchidometer (Zachmann, Prader, Kind, Haflinger and Budliger, *Helv. Paed. Acta*. 29, 61–72, 1974).

Genital (penis) development:

Stage 1. Pre-adolescent, testes, scrotum and penis are of about the same size and proportion as in early childhood.

Stage 2. Enlargement of scrotum and testes. Skin of scrotum reddens and changes in texture. Little or no enlargement of penis at this stage.

Stage 3. Enlargement of the penis which occurs at first mainly in length. Further growth of the testes and scrotum.

Stage 4. Increased size of penis with growth in breadth and development of glans. Testes and scrotum larger; scrotal skin darkened.

Stage 5. Genitalia adult in size and shape.

Pubic hair:

Stage 1. Pre-adolescent. The vellus over the pubes is not further developed than that over the abdominal wall, i.e. no pubic hair.

Stage 2. Sparse growth of long, slightly pigmented downy hair, straight or slightly curled at the base of the penis.

Stage 3. Considerably darker, coarser and more curled. The hair spreads sparsely over the junction of the pubes.

Stage 4. Hair now adult in type, but area covered is still considerably smaller than in the adult. No spread to the medial surface of thighs.

Stage 5. Adult in quantity and type with distribution of the horizontal (or classically 'feminine') pattern. Spread to medial surface of thighs but not up linea alba or elsewhere above the base of the inverse triangle (spread up linea alba occurs late and is rated stage 6).

Designed by the Department of Endocrinology,

The Adelaide Children's Hospital.

APPENDIX 3.3 .

SKINFOLD RESULTS FROM ALL TESTS FOR ALL SUBJECTS.

APPENDIX 3.3.								
	SKINFOLD SUM OF NINE.							
	EXPERIMENTAL GROUP NO.1. FIRST TEST							
Skinfold			6.5.94.					
SUBJECT	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
TRI	15.4	7.3	18.8	11.4	10.6	14	17.6	
SUBSCAPULAR	12.9	4.5	11.5	6	6.6	5.7	7.5	
SUP ILIAC	16.2	3	8.4	5	5.1	6.6	5.4	
MID AB	25.8	4.2	18.2	8.2	10.8	8.3	7.8	
PECT \	14.2	3.4	12.6	4.7	6.5	5.6	7.3	
MID AXILLA	10.2	3.8	10.4	6.4	5.3	5.4	4.8	
QUAD	22	10	26	15.3	19.2	19.6	23	
CALF	17	6	11.8	12.2	10.9	12.8	16	
BICEPS	8.7	4	9	5	4.3	6.4	5.2	
NO								**7**
TOTAL	**142.4**	**46.2**	**126.7**	**74.2**	**79.3**	**84.4**	**94.6**	**647.8**
MEAN								**92.54**
	SKINFOLD SUM OF NINE.							
	EXPERIMENTAL GROUP NO.1. POST TEST				14th -15June 1994.			
Skinfold								
SUBJECT	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
TRI	17.2	7	18.2	9.9	11.3	11.4	14.5	
SUBSCAPULAR	11.6	4.2	11	5.2	5.2	5.2	7.3	
SUP ILIAC	14.2	3.4	10	5.2	5.5	6.8	5.2	
MID AB	21	4	18.6	7.4	10.2	7.6	8.2	
PECT	13	3.3	11.8	4.5	6.1	5	6.5	
MID AXILLA	10.5	3.6	11	6	5.1	6.7	6.9	
QUAD	20.1	9.8	20	12.8	18	16	23	
CALF	15	7.3	12.1	11.7	10.6	10.2	15.8	
BICEPS	9	5	8.5	4.4	4.5	5.8	4.7	
NO								**7**
TOTAL	**131.6**	**47.6**	**121.2**	**67.1**	**76.5**	**74.7**	**92.1**	**610.8**
MEAN								**87.257**

APPENDIX 3.3.							
		SKINFOLD SUM OF NINE.					
		CONTROL GROUP NO.2. FIRST TEST					
Skinfold							
SUBJECT	**8**	**9**	**10**	**11**	**12**	**13**	
TRI	7.5	12.9	11.3	10.1	7.6		
SUBSCAPULAR	4.5	8.9	9.4	4.3	4.4		
SUP ILIAC	3.6	7.8	7.4	3.2	3.1		
MID AB	4.5	11.8	16	4.3	3.8		
PECT	3.6	7	10	3.6	3		
MID AXILLA	3.5	6.8	6.5	4.3	3.6		
QUAD	9.7	16.3	21.7	17	11		
CALF	7	8.5	11.9	11.5	4.3		
BICEPS	2.7	5.8	9	5.1	2.6		
NO							**5**
TOTAL	**46.6**	**85.8**	**103.2**	**63.4**	**43.4**	**0**	**342.4**
MEAN							**68.48**
		SKINFOLD SUM OF NINE.			14th -15June 1994.		
		CONTROL GROUP NO.2. SECOND TEST					
Skinfold							
SUBJECT	**8**	**9**	**10**	**11**	**12**	**13**	
TRI	7.6	13.2	11.4	10.3	7.8	10	
SUBSCAPULAR	4.6	9.8	9.8	4.4	4.4	7.4	
SUP ILIAC	3.7	8.1	7.5	3.2	3.1	5.1	
MID AB	4.5	12	17.4	4.5	4	12.8	
PECT	3.7	7.1	10.3	3.6	3.1	6.3	
MID AXILLA	3.6	7	6.5	4.4	3.7	5.8	
QUAD	9.9	17	22.1	11.8	11.3	16.8	
CALF	7.1	9.1	12.4	7.7	4.6	11.6	
BICEPS	2.8	6.3	9.4	2.4	2.7	5	
NO							**6**
TOTAL	**47.5**	**89.6**	**106.8**	**52.3**	**44.7**	**80.8**	**421.7**
MEAN							**70.28**

APPENDIX 3. 4.

CRITERIA DETECTION OF VENTILATORY THRESHOLD.

(a) CRITERIA FOR VT1 and VT2.

(b) SAMPLE OF DATA SHOWING VT1 - VT2.

(c) A SAMPLE WORK SHEET WITH ESTIMATION OF VT AS DETECTED USING THE V SLOPE METHOD (VO2 vs VCO2).

(d) SAMPLE METABOLIC RESULTS SHEET- VT ESTIMATIONS WERE COMPLETED USING THE PEAK VO_2 TEST RESULTS DATA.

APPENDIX 3. 5.

DETECTION OF THE VENTILATORY BREAKPOINT.

Determination of ventilatory threshold required a panel of three investigators to assess each peak VO2 treadmill test. Using the following criteria:

Ventilatory Threshold Determination

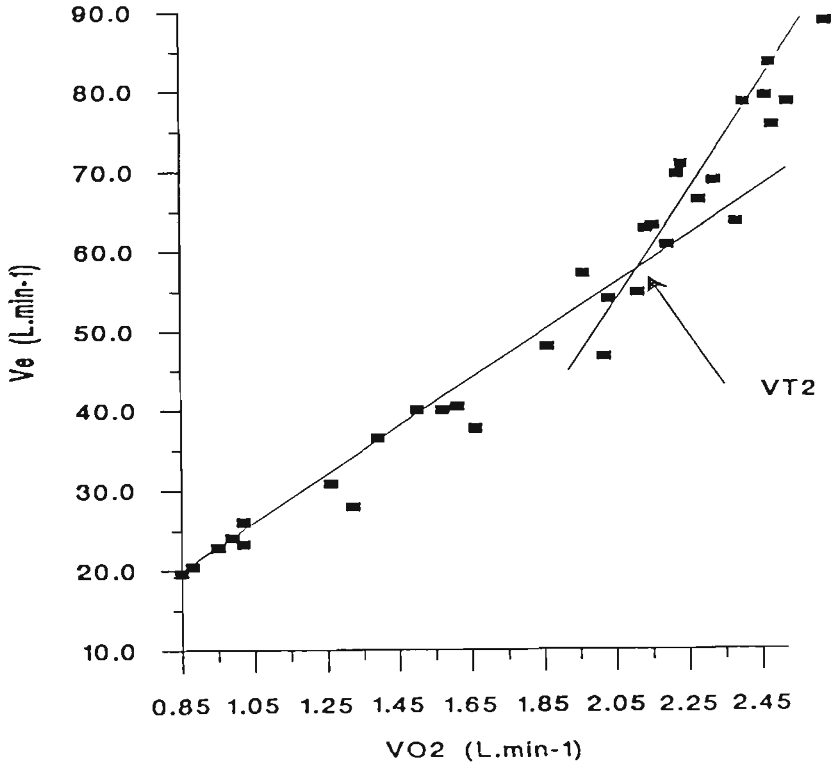
VTI Criteria.

1. Deflection of VE (ventilatory equivalent) for O_2.
2. No proportional change of VE for VCO_2.
3. Deflection of VO_2 (consumed) vs VCO_2 (produced).
4. A disproportionate increase in RER, usually resulting in an RER value exceeding 1.00.

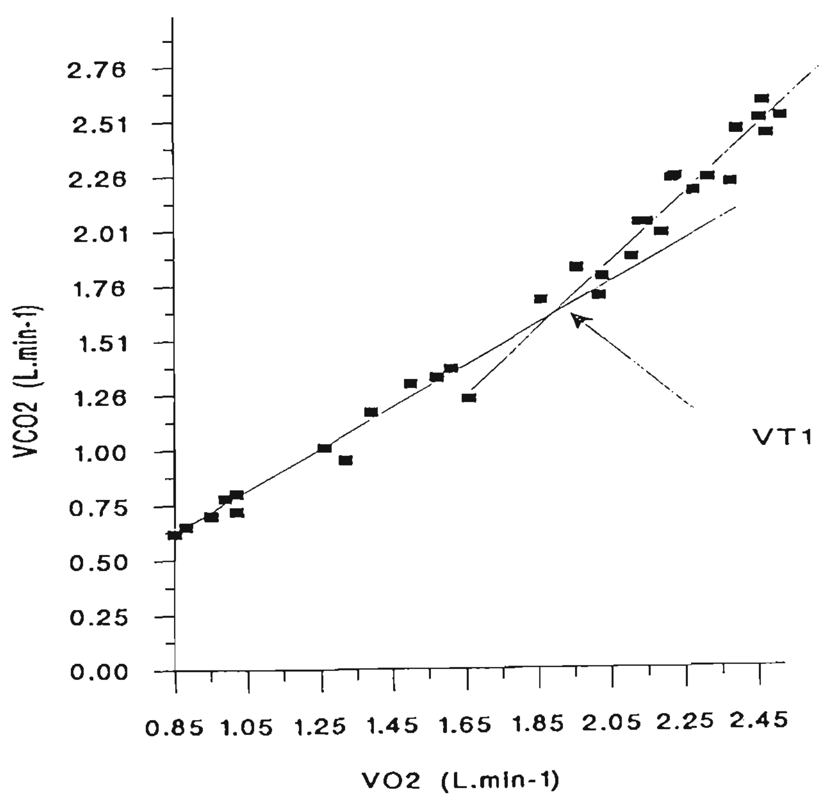
VT2 Criteria.

1. Deflection of VE (ventilatory equivalent) for VCO_2.
2. Deflection of Ve (ventilations) vs VCO_2.

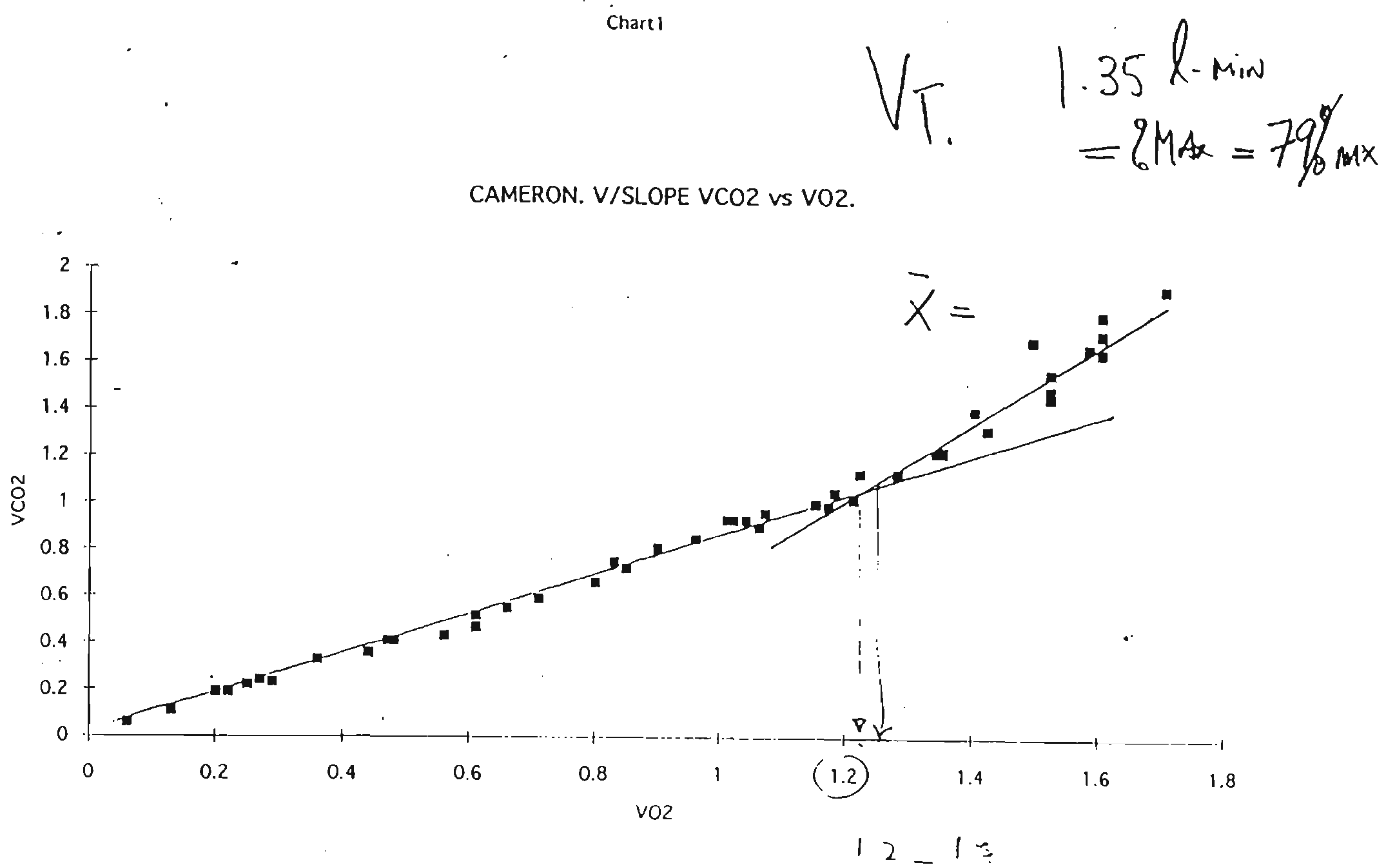
SAMPLE OF DATA SHOWING VT1 - VT2.



V/SLOPE VCO2 vs VO2



A SAMPLE WORK SHEET WITH ESTIMATION OF VT AS DETECTED USING THE V SLOPE METHOD (VO2 vs VCO2).



SAMPLE METABOLIC RESULTS SHEET- VT ESTIMATIONS WERE COMPLETED USING THE PEAK VO_2 TEST RESULTS DATA.

METABOLIC RESULTS

Name : martin Date : Weight : 28.6

Age : 10 Sex : m Height : 130.0

Barometric Pressure: 768.0 Drybulb Temp: 20.5 Wetbulb Temp: 15.0

Data Sample Rate : 1 Sec / Data Cadulated Every 15 Secs

Commments :

Pre study max

Filename For This Data .. jb mart

Frame	VO2 ml	VO2 L	VCO2 L	Rer	VBTPS	Hrate	o2pulse	Wo	VATPS	FeO2	FeCO2	Gas T	Ve/VO2	Ve/VCO2
0	9.1	0.26	0.21	0.81	12.62	0	260.48		11.6	18.58	2	22.43	48.45	59.85
1	6.22	0.18	0.16	0.9	7.83	0	177.95		7.2	18.29	2.46	22.43	44.02	48.73
2	11.39	0.33	0.29	0.88	13.06	0	326.22		12	18.03	2.64	22.4	40.03	45.27
3	8.62	0.25	0.22	0.9	9.14	0	246.86		8.4	17.79	2.89	22.37	37.03	41.35
4	16.98	0.49	0.44	0.91	19.59	104	485.98		18	18.03	2.71	22.4	40.3	44.21
5	14.16	0.41	0.36	0.9	15.67	0	405.35		14.4	17.92	2.78	22.4	38.66	43
6	14.2	0.41	0.38	0.93	14.8	109	406.4		13.6	17.71	3.04	22.35	36.43	39.32
7	23.49	0.67	0.54	0.8	21.33	0	672.4		19.6	17.33	3.02	22.39	31.72	39.62
8	25.36	0.73	0.61	0.85	23.18	123	726.1		21.3	17.32	3.17	22.43	31.92	37.77
9	28.44	0.81	0.72	0.88	26.65	0	814.4		24.5	17.38	3.23	22.46	32.73	37.08
10	25.6	0.73	0.67	0.92	24.48	130	733		22.5	17.43	3.29	22.47	33.39	36.36
11	31.32	0.9	0.82	0.92	29.26	0	896.8		26.9	17.35	3.36	22.5	32.63	35.65
12	30.17	0.86	0.83	0.96	30.11	143	863.7		27.7	17.54	3.31	22.6	34.87	36.15
13	31.35	0.9	0.84	0.93	29.25	0	897.5		26.9	17.33	3.43	22.59	32.59	34.88
14	40.25	1.15	1.09	0.95	37.93	149	1152.4		34.9	17.35	3.44	22.66	32.91	34.79
15	38.17	1.09	1.07	0.98	37.48	0	1092.7		34.5	17.48	3.41	22.72	34.3	35.1
16	35.88	1.03	1.03	1.01	37.03	160	1027.2		34.1	17.62	3.34	22.8	36.05	35.83
17	34.91	1	0.98	0.98	32.68	0	999.5		30.1	17.3	3.6	22.84	32.7	33.29
18	43.22	1.24	1.18	0.95	35.71	166	1237.4		32.9	16.84	3.94	22.89	28.86	30.37
19	45.14	1.29	1.25	0.97	39.18	0	1292.4		36.1	17.03	3.82	22.91	30.32	31.35
20	42.73	1.22	1.21	0.99	40.04	177	1223.2		36.9	17.3	3.61	22.98	32.73	33.11
21	48.86	1.4	1.41	1.01	46.95	0	1398.9		43.3	17.38	3.59	23.1	33.56	33.36
22	42.67	1.22	1.23	1.01	43.04	183	1221.6		39.7	17.55	3.42	23.12	35.24	35.04
23	53.02	1.52	1.51	0.99	52.99	0	1518.1		48.9	17.52	3.41	23.23	34.91	35.09
24	46.19	1.32	1.36	1.03	50.81	191	1322.5		46.9	17.82	3.2	23.27	38.42	37.38
25	45.95	1.32	1.33	1.01	47.76	0	1315.6		44.1	17.64	3.33	23.33	36.31	35.93
26	46.45	1.33	1.29	0.97	41.7	195	1329.8		38.5	17.15	3.72	23.32	31.36	32.2
27	63.63	1.82	1.82	1	55.96	0	1821.6		51.7	17.05	3.89	23.45	30.72	30.78
28	52.63	1.51	1.6	1.06	59.39	199	1506.9		54.9	17.87	3.22	23.56	39.41	37.16
29	55.62	1.59	1.69	1.06	61.09	0	1592.4		56.5	17.79	3.32	23.67	38.36	36.05
30	51.84	1.48	1.55	1.05	55.01	200	1484.1		50.9	17.69	3.37	23.76	37.07	35.47
31	59.84	1.71	1.84	1.07	65.35	0	1713.2		60.5	17.76	3.37	23.86	38.14	35.54
32	54.35	1.56	1.68	1.08	61.45	202	1555.9		56.9	17.87	3.27	23.88	39.5	36.6
33	58.18	1.67	1.78	1.07	65.73	0	1665.7		60.9	17.87	3.24	24	39.46	37
34	49.96	1.43	1.49	1.04	53.22	204	1430.4		49.3	17.71	3.34	23.98	37.2	35.79
35	63.4	1.82	1.91	1.05	63.55	0	1815.2		58.9	17.49	3.59	24.06	35.01	33.34
36	55.97	1.6	1.75	1.09	63.55	206	1602.4		58.9	17.87	3.29	24.07	39.66	36.38
37	58.2	1.67	1.81	1.09	65.23	0	1666.3		60.5	17.84	3.32	24.22	39.14	36.02
38	56.3	1.61	1.76	1.09	61.34	209	1611.9		56.9	17.74	3.44	24.22	38.06	34.78
39	62.72	1.8	1.98	1.1	66.92	0	1795.6		62.1	17.67	3.55	24.29	37.27	33.75
40	59.23	1.7	1.91	1.12	65.64	211	1695.8		60.9	17.78	3.48	24.28	38.71	34.44
41	58.49	1.67	1.91	1.14	66.47	0	1674.5		61.7	17.85	3.44	24.37	39.69	34.84

APPENDIX 4. 1.

(a) HEIGHT VELOCITY.

(b) HEIGHT PERCENTILES.

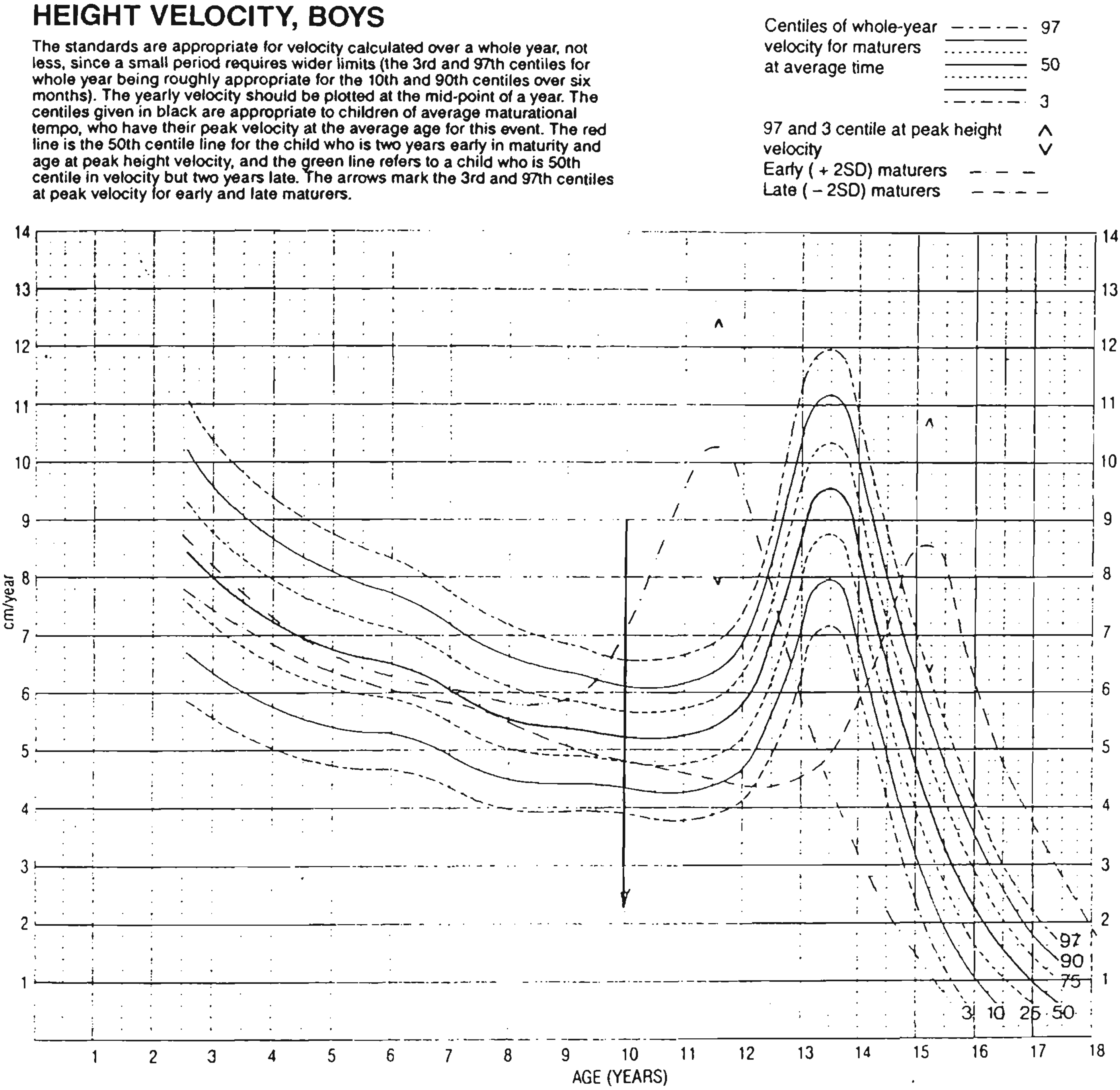
(c) WEIGHT PERCENTILES.

(d) BODY MASS INDEX.

HEIGHT VELOCITY.

HEIGHT VELOCITY, BOYS

The standards are appropriate for velocity calculated over a whole year, not less, since a small period requires wider limits (the 3rd and 97th centiles for whole year being roughly appropriate for the 10th and 90th centiles over six months). The yearly velocity should be plotted at the mid-point of a year. The centiles given in black are appropriate to children of average maturational tempo, who have their peak velocity at the average age for this event. The red line is the 50th centile line for the child who is two years early in maturity and age at peak height velocity, and the green line refers to a child who is 50th centile in velocity but two years late. The arrows mark the 3rd and 97th centiles at peak velocity for early and late maturers.



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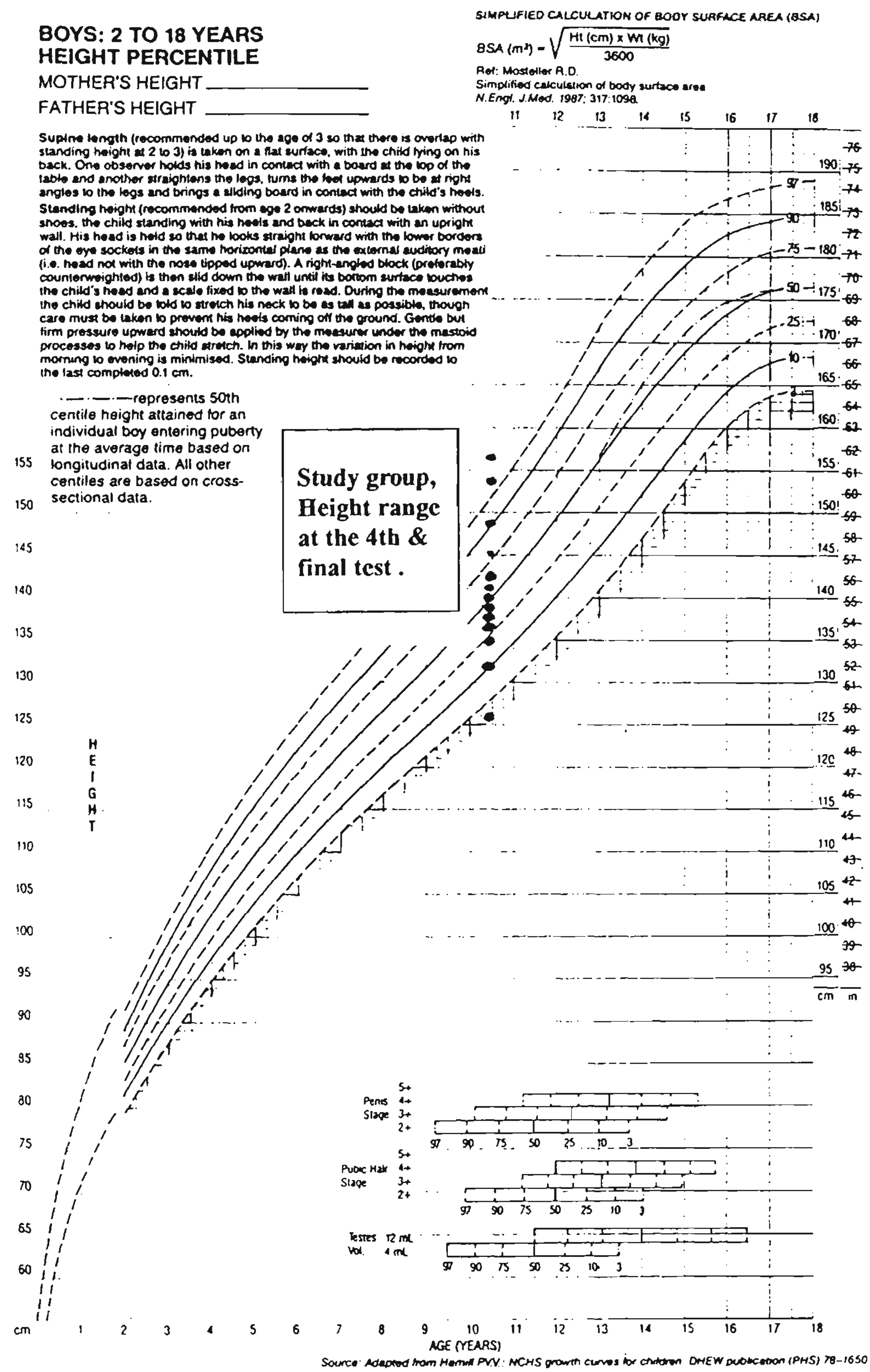
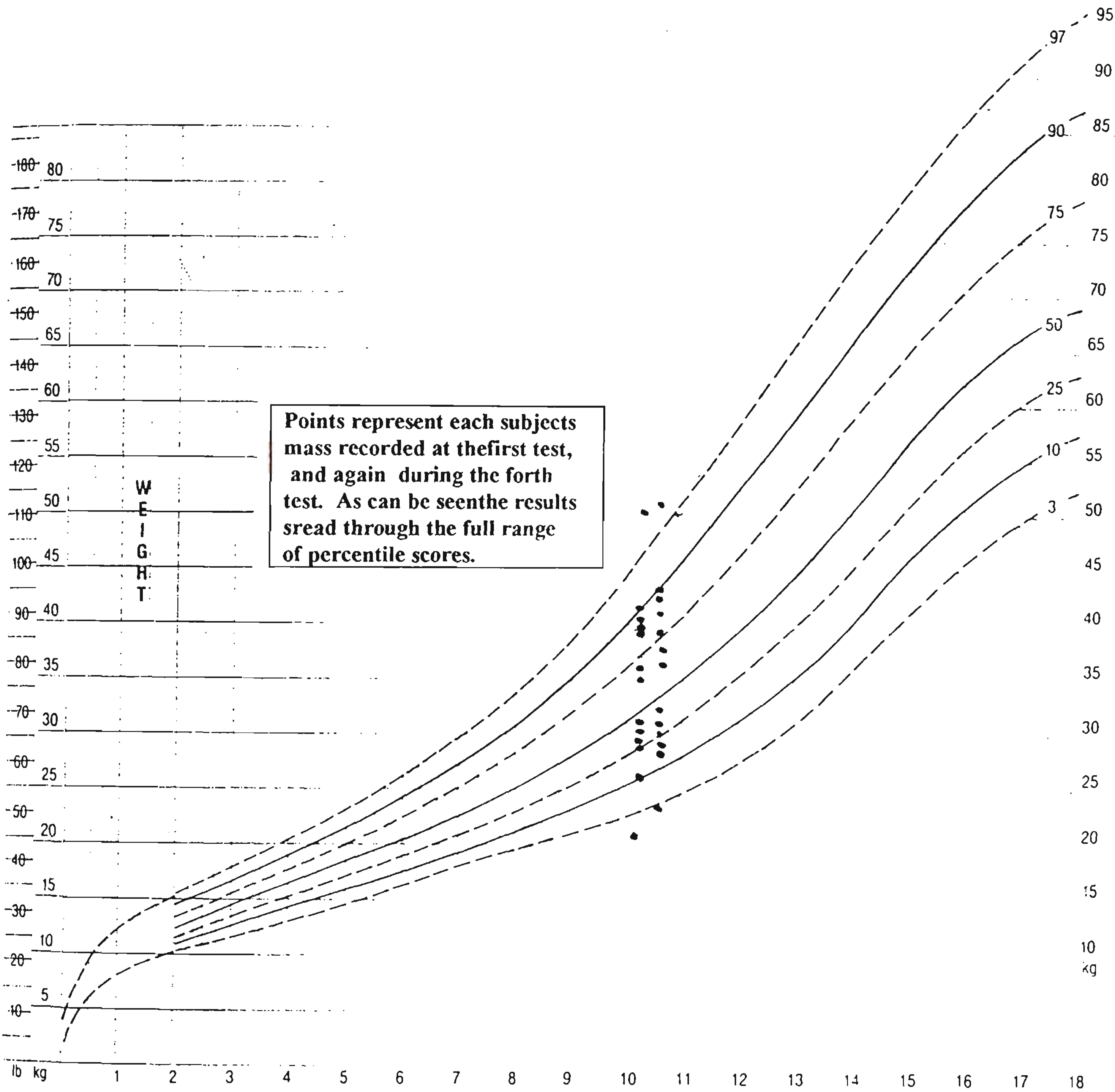
Data Source: Tanner J, Davis PSW. *Journal of Pediatrics* 1985:107

HEIGHT PERCENTILES.

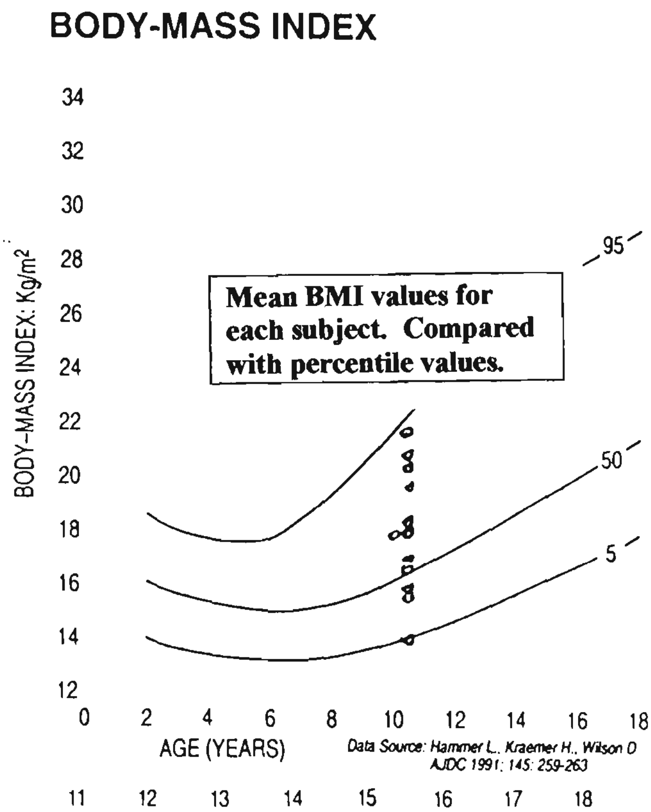


WEIGHT PERCENTILES.



Source: Adapted from Hamill P.V.V.: NCHS growth curves for children. DHEW publication (PHS) 78-1

BODY MASS INDEX.



APPENDIX 4. 2.

SUBJECT COMPLIANCE AND RECORD OF THE FREQUENCY OF USE OF POLAR HEART RATE MONITORS BY THE SUBJECTS DURING TRAINING STUDY.

APPENDIX. 4. 2.

ATTENDANCE DURING TRAINING SESSIONS AND POLAR USE.

GROUP. 1. FIRST TRAINING GROUP.

SUBJECT	1	6	2	3	7	4	5
27/04/94	*	*		*			*
29/04/94	*		*		AB	*	*
2/05/94	*	*		*	*		*
4/05/94	*	*			*	*	*
6/05/94	*	*	*	*			*
9/05/94	*	*	*	*		*	
11/05/94		*	*	*	AB	*	*
13/05/94		*	*	*	AB	*	*
16/05/94			*		*		*
18/05/94		*		*	*	*	*
20/05/94	*	*	*	*	*	*	
23/05/94	*	*		*	*		
25/05/94	*	*	*	*	AB	*	*
27/05/94		*	*	*		*	*
30/05/94		*	*	*	*	*	*
1/06/94	*	*	AB	*	*	*	*
3/06/94	*	*	AB	*	*	*	*
6/06/94		*	*	*	*	*	*
8/06/94	*		*	*	*	*	*
10/06/94		*	AB	*	*	*	*
Total number of times a polar HR monitor was used for each subject	12	17	12	17	12	15	17

* THE A'STERISK INDICATES WHEN THE SUBJECT WAS WEARING A POLAR HEART RATE MONITOR DURING TRAINING.

APPENDIX. 4. 2.

ATTENDANCE DURING TRAINING SESSIONS AND POLAR USE.

SECOND TRAINING PROGRAM.

SUBJECT	12	8	10	13	9	11
10/10/94	*	*	AB		*	*
11/10/94	*	*	*	*	*	
13/10/94	*	*	*	*		*
17/10/94	*	*	AB	*	*	AB
18/10/94	*		*	*	*	*
20/10/94	*	*	*		*	*
24/10/94	AB	AB	*	*	*	AB
25/10/94		*	*	*	*	AB
27/10/94	*	*	*		*	AB
31/10/94	*	*	AB		*	*
3/11/94		*	*	*	*	*
7/11/94	*	*	*		*	*
8/11/94	*	*	*	*		*
10/11/94		*	*	*	*	*
14/11/94	*	*	*		*	*
15/11/94	*	*	*	AB	*	*
17/11/94	*	*	*	*	*	*
21/11/94	*	*	*	AB	*	*
22/11/94	*	*	*	AB	*	*
24/11/94	*	*	*	*		*
28/11/94	*	*	*		*	*
29/11/94	*	*	AB	AB		*
1/12/94	*	*	*	*	*	
6/12/94		*	*		*	*
8/12/94	*			*	*	*
Total number of times a polar HR monitor was used for each subject	20	22	20	13	21	19

*** THE A'STERISK INDICATES WHEN THE SUBJECT WAS WEARING A POLAR HEART RATE MONITOR DURING TRAINING.**

APPENDIX 5. 1.

ACTIVITY LEVELS OF THE SUBJECT.

SUBJECTIVE EVALUATION- BASED ON,

(PARENTAL REPORT . TEACHER REPORT. & PHYSICAL ACTIVITY INTERVIEWS WITH THE SUBJECTS.)

A SUBJECTIVE EVALUATION OF THE ACTIVITY LEVELS OF THE SUBJECTS, AT SCHOOL AND DURING ACTIVITY PROGRAMS IN THE LOCAL COMMUNITY.

The parents of the boys in the study were requested to outline the activity involvement approximating the weeks prior to the study and during the study period. In addition the children were interviewed, during the study, about the activities they were involved in to establish the frequency, duration of participation, and a subjective interpretation of the intensity of the activity. This is a brief summary of the findings.

School physical education and sport programs provided on average, two sessions per week. The focus was generally on skill and not fitness. The intensity of these programs was not comparable with the workloads used in the present study. This was supported by observation of selected school PE and sport sessions, and reports from the subject in relation to the school program. Subjects involves in cross county running did practice for 4 weeks prior to competition, twice a week for approximately 20 minutes around the school grounds and the adjacent park.

SUBJECT. 1. Minimal activity outside of school. Short bike rides with mum on the weekends. No involvement with any sporting groups.

SUBJECT. 2. Participates in the school cross country. Competes in Little Athletics, on weekends and trains once a week. Very active at home. Very conscientious, if asked for a max effort that what he will do. An active child. Small in stature and had a very small sum of skinfold.

SUBJECT. 3. Enjoys basketball. Not very active. Overweight, was the first to find the vending machine providing potato chips. Often had money to use in the vending machine. Did lose fatty tissue during the training period and also improved in a number of his test results during the program.

SUBJECT. 4. A very capable young boy, very active. Through out the training program was able to maintain a very high work output. Runs in the school cross country team. Plays basketball twice a week. Little athletics once a week. Quite active. Displayed only minimal changes in VO_2 at VT breakpoint and VO_2 at VT as a percentage of peak VO_2, through out the training period.

SUBJECT. 5. Plays basketball twice a week. No other activity. Likes to sit a round and talk. When motivated he can produce an above average performance.

SUBJECT. 6. A soccer player, trains twice a week. Is a natural in most sports. Quite active.

SUBJECT. 7. Inactive. No sporting interests outside of the school. Was possibly the hardest to motivate during the study.

SUBJECT. 8. A very gifted performer. Plays basketball, baseball each week also trains for both sports. Very motivated very competitive. Slight build and maintained a minimal skinfold total through out the study

SUBJECT. 9. Also very active. Did not display the same endurance capabilities during the training period as some of the other boys. Motivated. Plays and trains in both baseball and basketball.

SUBJECT. 10. Not very active. A big fellow. Enjoys basketball, plays only does not train.

SUBJECT. 11. Involved in gymnastics. Very capable endurance performer, worked at extremely high levels during the training period. Did improve his VT metabolic data as a result of the training. For a number of reasons was not able to participate in organised activities outside of school. Casual activity level was high. Genetic potential may be very high.

SUBJECT. 12. Not very active. Very involved in music and does not have a lot of time for organised physical activity outside of school time. Gave 100 percent effort and enjoyed the physical activity during the study period.

SUBJECT. 13. Tends to try many activities, but does not persist. Active but at a low intensity.