Children's Sport - The Physiological Effects of a Season's Participation

A Masters Thesis

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DEDICATION

This thesis is dedicated to a very supportive and understanding family. I thank my mother and father, in particular for the strength of their belief in me and for their limitless care and love. I thank my sisters and their families for their continued encouragement and concern. Lastly, I dedicate this thesis to the memory of my grandfather whose sense of loyalty and commitment remains as an enormous source of inspiration in my life.

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CHAPTER 1

INTRODUCTION

More than ever before, Australians are being encouraged to be physically active and participate in sporting and recreational activities. The goal of striving for, or maintaining a feeling of 'fitness' through physical activity is very realistic for Australians of all ages. Young Australians in particular, have been a very large part of the explosive popularity of sports participation [Tables 1.1 and 1.2].

Table 1.1: National Sporting Associations Registrations
(Australian Sports Commission, 1988)

Year	Badminton	Basketball	Netball	Tennis
1987	14,000	172,825	361,507	555,000
1988	14,550	173,000	362,525	700,000

Table 1.2: Registered number of Junior Players in the State of Victoria for 1987-1988

	Badminton	Basketball	Netball	Tennis
'Junior'	Under 18	Under 20	Under 16	Under 18
	6,000	11,600	55,000	4,500

The Australian Sports Commission (1988) indicated that sporting participation numbers are increasing each year. A representative from the Victorian Tennis Association can be quoted as estimating that for every calendar month that passes, approximately one million people participate in the game of tennis in Australia. Table 1.2 provides substantial figures for registered Junior players in the State of Victoria alone. Although all these figures are impressive, they do not include school and non-affiliated associations. In spite of this the Victorian Netball Association has averaged a 5% gain in player registrations over the past few years.

Some professionals in physical education maintain that enjoyment and participation are, in themselves, the optimal value to be gained by children through playing sport. While factors such as skill development, attitude, game strategies and social interface may all contribute to the total development of children in sport, of equal importance is the quality of the sporting experience which can be offered from the physiological perspective. In a large number of popular sports the nature of the activities places the body under varying exercise and performance demands which physiologically could be either potentially beneficial, or conversely could be very stressful and potentially harmful. A physiological investigation of the quality of time spent by children in sport may provide answers to the following questions: What is the nature of the physiological stress incurred in sports participation by children? Does sports participation produce a training effect and how do the relative intensities of competitive games compare with practice situations? What, if any, are the physiological conditioning effects in children which can be associated with a season's participation in sport? Are the changes occurring in children who regularly participate in organised sporting activities similar to those children who do not regularly participate in organised sporting activities over the same period of time? While a sound body of research is available on the effects of controlled exercise or sports participation in adults (Saltin, 1987), there is little information on qualitative and quantitative measures of controlled exercise effects on children during sports participation. An investigation by Paterson et al., (1977) reported pre-adolescent children with mean exercise heart rate intensities in excess of 80 percent of maximal effort during ice-hockey games. Mc Ardle et al., (1971) investigated the heart rate intensities of competitive games of American female adult basketballers, aged 20 years. They reported that the competition heart rate intensities were substantially higher than those observed during more moderate practice sessions. The heart rate intensities during practice were so mild, that they were reported to be ineffective in contributing to a desired training state (Mc Ardle et al., 1971). Mosher et al., (1985) subjected pre-adolescent Canadian soccer players to 12 weeks of interval training. The experimental group who trained four times a week, were compared to control group of soccer players who were attending 'normal' training sessions for a similar number of sessions per week. When compared to their pre-program scores, the experimental group had improved significantly in their aerobic and anaerobic characteristics at the end of the 12 weeks. The changes in aerobic and anaerobic characteristics at the end of the same 12 weeks were non-significant in the control group. Mosher et al., (1985) recommended that fitness be a programmed objective and not to assume fitness would occur through practices and competition.

There exists a dearth of research on the quality of participation levels achieved by children playing sport in Australia. A recent policy statement on children and adolescents in sport by the Australian National Health and Medical Research Council reported that "It is important to establish the ages at which children are able to cope with physical and emotional stresses without being disadvantaged" (ACHPER, December 1988, p39.). Examination of the processes of physiological development throughout a season's involvement in a sport and determining the exercise intensities achieved during the practices and competition are potentially important forms of qualifying sporting experiences for children. Equally, this type of information can provide coaches, sporting associations and physical educators with valuable feedback on the outcomes of their respective performances.

RATIONALE

The rationale behind this study argues for investigations of children in sport to be conducted from a physiological perspective. It recognises the need for data to be collected on children in sports of their own choosing within the unique Australian environment. In so doing, it supports the need for Australian researchers to contribute to a better understanding of the fundamental physiological bases involved in a child's participation in sport. In addition to this, the rationale is also cognizant of the inherent risks associated with applying assumptions of performance or adaptation to the child which have only been validated in adults. It subsequently seeks to quantify and qualify several aspects of sporting experiences for children.

More specifically, the rationale argues for the need to qualify the intensities at which children are participating in popular sports in Australia today. The rationale also recognises the potential of an investigation which monitors performance and quantifies physiological profiles throughout a season's competition and commensurately provides feedback on the overall processes involved in sports participation to children, coaches, sporting associations and physical education professionals.

THE PURPOSE OF THE STUDY

The purpose of the study was two-fold:

(i) to investigate the relative exercise intensities of pre-adolescent children participating in competitive games and practices of basketball, badminton, netball and tennis.

(ii) to examine physiological, anthropometric and strength profiles of pre-adolescent children from the above mentioned sporting groups, as well as a control group, (who were not involved in organised sporting activities) over a period of three months corresponding to a season's participation in the sporting groups.

For the purpose of the study an assumption was made. This assumption was that under steady state incremental conditions the heart rate and oxygen uptake relationship is as linear in children as it is in adults.

LIMITATIONS

In conducting the study, the following limitations are recognised:

1. In research involving children over a period of time the main intervening variable for which little control can be gained is that of growth. Determining a distinction between normal growth factors and environmental influences is the challenge over which very few pediatric researchers have claimed victory. In reporting results of studies on children, Bar-Or (1983), recommends that changes are documented as occurring 'with', rather than 'because of' environmental influences.

2. The choice of sport by the child, the training conditions, or the environment in which the field participation occurred.

3. 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 protocol such as blood lactates or muscle biopsies were considered inappropriate.

4. A final limitation was imposed by the nature and quantity of tests performed by the subjects. Not all factors considered to influence performance were measured in the testing. The level of motivation and other psychological influences which may be important in performance were not assessed.

DELIMITATIONS

1. The study was delimited to four sports played by children in Australia; badminton, basketball, netball and tennis.

2. The number of subjects was restricted to group sizes of eight and the age of the subjects was selected by the stage of maturation within the range described by Tanner (1962) as pre-adolescent.

DEFINITION OF TERMS

The following definitions of terms were adopted for use during the study:

Anthropometric Measures.

These terms refer to body size, composition and structure measures:

Height (cm) - The linear size measure of the body.

Mass (kg) - The total body composition of a person.

Body Surface Area (m2) - An index of the total surface area of the body:(.00718 X [Mass (kg)$^{.425}$]) X [Ht. (cm)]$^{.725}$] (Du Bois)

Skinfold measurements - An indication of subcutaneous fat development at a specific site on the body.

Girth and Width Measurements - An indirect and relative measure of the extent of growth in muscularity and bone tissue at specified sites of the body.

Cardiorespiratory Function Measures.

This term refers to the measures adopted to reflect cardiovascular and respiratory function of the children in the study.

Maximal oxygen uptake (VO_2 max) - The maximal rate of oxygen utilized by a subject during a running treadmill test to volitional exhaustion. It is expressed in absolute terms ($l.min^{-1}$) and in relative terms, as a function of body weight ($ml.kg.^{-1}min.^{-1}$).

Submaximal oxygen uptake (Submax VO_2) - The rate of oxygen uptake at specific speeds which were less than the maximal speed during the process of the maximal run on the treadmill, expressed in absolute ($l.min.^{-1}$) or relative terms ($ml.kg.^{-1}min.^{-1}$).

Percent VO_2 max - The use of practice or competition heart rates values to predict the oxygen uptake in field situations estimated from the relationship of oxygen uptake and heart rate during a subject's maximal effort on the treadmill $\{Y = a + b(x)\}$.

Percent HR max (% HR max) - the mean rate of heart beats in a five minute period of participation in a practice or game situation, expressed relative to the absolute maximal heart rate obtained in the maximal effort treadmill run. Similarly the term maximal heart rate reserve [MHRR], refers to a formula which subtracts the resting heart rate from the given working heart rate.

Anaerobic function measures.

This term is used to define those characteristics associated with the anaerobic functions of the children in the study.

Peak Power - The value of highest mechanical output at any 5 second period of the 30 second Wingate test. It reflects the measurement of the ability of the limb muscles (in this case the leg muscles) to produce a high mechanical energy output in 30 seconds. It is expressed both in absolute (watts) or relative terms ($watts.kg^{-1}$).

Mean Power - The average power output during the 30 second test. It is a reflection of the limb muscles' (legs') ability to sustain extremely high power. It is expressed in absolute (watts) or relative terms (watts.kg.$^{-1}$).

Strength measures.

This term includes the characteristics of strength assessed isometrically and isokinetically in the children.

Isometric strength - This was assessed during the tests for grip strength and arm and shoulder strength. It is the type of muscular contraction which occurs when the muscle develops tension but does not change length. It is expressed in kilogram units.

Isokinetic strength - This is a description of the peak torque developed by a muscle group throughout its range of motion. In this study, the maximal contraction at the knee joint was tested at a constant speed of 60 degrees per second. Peak torque is expressed in absolute terms, as units of foot-pounds (ft.LBS.) or Newton metres (Nm), or relative to body weight (Nm.kg.$^{-1}$).

CHAPTER 2

REVIEW OF LITERATURE

The literature pertinent to the research problem is reviewed in this chapter. The review is categorised into the following sections:

(A) factors affecting responses occurring with conditioning in children, (B) growth, physical activity and heritability, (C) muscular strength and training in pre-adolescent children, (D) anaerobic characteristics of pre-adolescents, (E) body composition changes in pre-adolescent children and (F) heart rate responses to sports participation in children.

A. Factors affecting responses occurring with conditioning in children.

Conditioning responses in adults are relatively easier to quantify when compared to conditioning responses in children (Bar-Or 1983, Birrer and Levine, 1987, Astrand 1952, Ekbolm 1969). Many of the physiological changes which occur as a result of continuous exercise stresses in a conditioning program with adults, also occur during normal growth and developmental processes in the child; eg. increased maximal oxygen consumption (VO_2 max $l.min^{-1}$), increased stroke volume, increased cardiac output, improved muscular strength, higher maximal blood lactate levels (HLa), improved anaerobic performance, lower heart rates during submaximal workloads (HR submax $bts.min^{-1}$) and greater skill and/or mechanical efficiencies (Astrand and Rodahl, 1977; Bar-Or, 1983; Bell et al., 1980; Brown et al., 1972; Kobayashi et al., 1978 and Lawson et al., 1985).

Longitudinal studies are a constructive means of determining the nature of the relationship between growth and activity factors in children. Rutenfranz (1986), suggested that until recently, researchers conducting longitudinal studies on children ignored all other factors except growth and motor development. Rutenfranz (1986) identified the 1958 Medford Bay Growth Study as the first battery of measurements in pediatric testing to include a strength variable. The Prague Growth Study from 1961-1968 was recognised as the first longitudinal investigation on children which included aerobic maximal assessment. However Ruterfranz (1986) believed that the early testing methods were somewhat questionable. The modern advancement of longitudinal studies in children is accredited to the establishment of the European Group of Pediatric Work Physiology in 1968. This group was the first international body to apply and modify to pediatric populations, modern principles and practices of exercise physiology which had been established in adult-based research. According to Massicotte and Macnab (1974), a response pattern to physical activity

"...manifests itself in two ways: firstly by greater economy of the trained organism in response to a standard submaximal work; secondly, by the greater ability of the trained individual to perform more intensive work, since he has an increased functional capacity." Evidence of adaptations to physical activity using pre-pubertal children are reported in some of the recent longitudinal (> 6 months) research which have been summarised in Table 2.1.

The results from these longitudinal studies of normal, healthy children for durations of up to five years and over, reflect the difficulty of gaining significant differences associated with physical activity based programs when growth parallels activity (Cunningham et al., 1984, Koyabayashi et al., 1978, Shephard 1985). For example, Shephard (1985) monitored the effect of extra physical education classes on school children through the ages of 6 to 11 years. He reported a minor, non-significant advantage in the children exposed to extra classes in the assessment of VO_2 max, PWC_{170}, isometric muscle strength and field tests.

In pre-adolescent children, maximal aerobic capacity does not appear to have differed substantially over time in four out of the six studies which measured changes in relative maximal aerobic capacity [VO_2 max $ml.kg.^{-1}min.^{-1}$] (Cunningham et al., 1984, Daniels and Oldridge 1971, Kobayashi et al., 1978 and Shephard 1985). It must be noted that any comparison of these studies is difficult because of the differing research designs eg. Cunningham et al., (1984) studied changes between boys at different stages of maturation, Daniels and Oldridge (1971) and Kobayashi et al., (1978) examined changes within active boys and Shephard (1985) investigated changes which differed in the experimental group when compared to a control group.

Massicotte and Macnab (1974) suggested the "greater economy of the trained organism" is perhaps best determined by the results of submaximal testing data. As training programs were more often performed at submaximal intensity during training programs, it may be reasonable to expect that at the completion of the program, more changes would occur in submaximal data than in the maximal effort data. Significantly reduced submaximal VO_2 (associated with a greater efficiency of movement) was reported by Daniels and Oldridge (1971) in young runners. Reduced submaximal heart rates were reported by Mayers and Gutin (1979) on young adults. In general, however, non-significant changes in results from longitudinal studies were more often cited than significant changes in the measured variables at both the maximal and submaximal exercise levels.

The longitudinal studies in Table 2.1 emphasise the power of the growth factor and the extreme difficulty that researchers encounter in isolating effects of physical activity alone. The confounding nature of growth factors in the assessment of changes in physical activity in children is well demonstrated by Cunnin-

Table 2.1: Longitudinal Studies (6 Months) of Children Participating in Periods of Conditioning.

Authors, Yr. n, Age, Sex.	Specific Group	Nature Of Requirements	Major Results Conditioning
Ekbolm, 1969 n = 13, 11yrs males	School children - trained - untrained	45mins. x 2 phys.ed./wk x 6mths and 26mths	10% ↑ VO_2max ml.kg.-1min.-1 after 6 months 55% ↑ VO_2 max l.min.-1 after 26 months 54% ↑ in vital capacity
Daniels and Oldridge,1971 n = 14, 10-15yrs males	Distance runners	non-regulated running training over 22 months	∇ VO_2max ml.kg.-1min.-1 substantial changes only at submaximal level Δ ↓ submax VO_2ml.kg.-1min.-1 Δ ↓ performance time: running and implied higher efficiency
Hamilton and Andrew, 1976 n = 22, 10-12yrs males	Ice hockey players	2 practices + 2 games x 28 wks	∇ training effect in the pre-adolescent group ∇ change in heart rate and S.V. for any level of O_2 for pre-adolescent group
Koyayashi et al., 1978 n = 50, pre & post adolesc. males	School children	i) 5-6yrs study started from 9 or 13 ii) 2-3yrs from 14yrs	Δ ↑ aerobic power between 13-17 year old males only.
Mayer & Gutin 1979 n = 8, 8-11yrs males	Cross-country runners [elite]	normal training - 24-56km/wk or 70-120mins x 3-5/wk x 8-11mths	Δ ↓ submax. heart rate Δ ↓ RER submax. Δ ↑ VO_2 max ml.kg.-1min.-1 ∇ ↑ ht., mass, % body fat and heart rate maximum
Gilliam et al., 1983 n = 59, 6-7yrs males & females	Normal active children	CHD prevention program 25mins x 4/wk x 8mths eg. running, skipping & aerobic dance	Daily activity patterns improved as a result of the vigorous program Preliminary report found; i) girls did not voluntarily engage in highly intensive activities; ii) in 12 hours, heart rates reached > 160 bts.min^{-1} for 9.4mins. in girls and for 20.9mins. in boys
Cunningham et al.,1984(a) n = 62, 9-10yrs males	Normal active children early & late	6 yr. study: no specific program but engaged in recreational activities	VO_2 l.min^{-1} and stroke vol. of late maturers greater at each stage except during most rapid growth ∇ skinfolds ∇ VO_2max ml.kg.-1min.-1
Shephard 1985 8-11yrs males & females	School children	Phys. ed. classes + 1hr. endurance activites x 5/wk x 5yrs	Minor advantages in tests for VO_2max, PWC_{170}, isometric muscle strength, & field tests (eg. sit-ups, standing broad jumps, 50 yard sprint) No effect on growth

Δ significantly different 128M õ non-significantly different gham et al., (1984) who statistically determined that a strong variance in VO_2 max, had been accounted for by 'between group' growth factors accountability (31.7 to 50.3%). "Growth during the pre-pubescent period can be assumed to be linear but growth remains a complicating factor in extended studies of physical conditioning in children." (Lussier and Buskirk 1977).

According to Lussier and Buskirk (1977), shorter term studies (< 6 months) are preferrable to longer term studies in minimising the growth factors because they limit its potential intervention. Subsequently, shorter term studies may be expected to be more effective in producing significant differences when experimental and control groups are compared. In Table 2.2, five of the eight shorter term studies which cited the results of change in relative aerobic power (VO_2 max $ml.kg.^{-1}min^{-1}$) indicated substantial improvement over time (Brown et al., 1972, Eriksson 1972, Eriksson and Koch 1973, Lussier and Buskirk 1977, Massicotte and Macnab 1974). Additional evidence of "increased functional cardiorespiratory capacity" (Massicotte and Macnab 1974) is demonstrated in two studies; firstly, in a study by Geenan et al., (1981) who reported that there was a significant gain in the thickness of the left ventricular posterior wall of the heart in an experimental group of children following four months of increased physical education lessons, and secondly, in a study by Eriksson and Koch (1973) who reported a significant improvement in the cardiac output of young swimmers which was largely due to improved stroke volume.

In agreement with the nature of the studies in Table 2.1, the shorter term studies outlined in Table 2.2 again conducted training sessions which were more at a submaximal exercise level than at maximal levels. A decrease in relative submaximal VO_2 ($ml.kg.^{-1}min^{-1}$) was reported by Berg et al., (1985) in twenty young soccer players following nine weeks of training and competition. A significant reduction in submaximal constant work heart rates of children following participation in a physical activity program, was reported by Lussier and Buskirk (1977), Massicotte and Macnab (1974) and Yoshido et al., (1980). There is also evidence of improved submaximal results in studies which examined children's performance times in running tests (Berg et al., 1985, Mosher et al., 1985, Yoshido et al., 1980). Whilst many differences in physiological and performance characteristics are reported for children tested under submaximal conditions, discrepancy still exists between studies which are inconclusive and nonsignificant in their training results (Gilliam and Freedson 1980) and some studies which produced significant improvement (Elliott et al., 1984, Stewart and Gutin 1976 and Yoshido et al., 1980) in their training results.

In a review of the developmental aspects of maximal aerobic power of children, Krahenbuhl et al., (1985) drew attention to the number of studies which were conducted within a physical education setting at schools or pre-schools (Ekbolm 1969, Gilliam et al., 1983, Gilliam and Freedson 1980, Lange Anderson 1976,

Table 2.2: Shorter Term (6 Months) Longitudinal Studies of Children Participating in Periods of Conditioning

Authors, Yr. N, Age, Sex.	Specific Group	Nature Of Requirements	Major Results Conditioning
Brown Et Al., 1972 n = 12, 8-13yrs females	Cross-country runners	Running 4-5/wk x 6-12 wks	VO_2max ml.kg.-1min.-1 improved; 18% at 6 weeks and 26% at 12 weeks
Eriksson 1972 n = 12, 11-13yrs n = 5 " males	Normal active children "	1hr. x 3/wk x 4mths high intensity 30mins x 3/wk x 6wks(70% of VO_2max)	16% ↑ VO_2max ml.kg.-1min.-1 (similar to adults) PFK levels rose after 6wks from 40% to 70-75% of the level of sedentary male adults
Eriksson & Koch, 1973 n = 9, 11.7yrs males	Swimmers	1hr. x 3/wk x 4mths aerobic based activites	Δ ↑ cardiac output Δ VO_2max l.min.-1 due to ↑ in stroke vol. not in (a-v)O_2 difference
Massicotte & Macnab 1974 n = 36, 11-13yrs males	School children	12mins x 3/wk x 6wks 3 different HR zones;170-180, 150-160 and 130-140 bt.min	Δ ↓ submax HR by 12-16bts.min-1 Δ ↑ in WL to maintain HR Δ ↓ HLa submax. for the highest heart rate group only Δ ↑ VO_2max ml.kg.-1min.-1 for highest HR group only
Lussier & Buskirk 1977 n = 26, 8-12yrs males and females	School children	45mins x 4/wk x 12wks indoor running games & activities	Δ ↑ VO2max ml.kg.-1min.-1 Δ ↓ HR submax ∇ heart rate maximum Δ VE ∇ anthropometric data
Gilliam & Freedson,1980 n = 23, 7-9yrs males	School children	25mins x 4/wk x 12 weeks of moderate-high aerobic activity	∇ VO_2max ∇ body composition ∇ blood lipids
Yoshido et al., 1980 n = 57, 5yrs males and females	Kindergarten children	3 groups on running 1-5/wk x 14wks HR = 109-200bts.	∇ ↑ VO_2max ml.kg.-1min.-1 ∇ ↑ VO_2max l.min.-1 In group training 5/wk ↑ max running speed and ↓ submax. heart rate
Geenan et al., 1980 n = 79, 7yrs sex not cited	School children	25mins x 4/wk x 4mths "exercise"	Δ ↑ in left ventricular posterior wall Three months after the program, the left ventricular posterior wall returned to a ∇ compared to the control group.
Elliott et al., 1984 n = 16, 11.7yrs males & females	Elite tennis players	45mins x 3/wk x 10 wks of fitness training	Used elite players in both control & experimental groups ∇ VO2max ml.kg.-1min.-1 ∇ 40m sprint time ∇ flexibility Δ ↓ skinfolds Δ ↑ field performance tests

Table 2.2 cont'd.

Table 2.2 cont'd.

Berg et al., 1985 n=20, 11.8yrs males	Youth soccer training with 6th graders	75mins x 3/wk (2 training + 1 game) x 9wks	Δ ↓ VO_2 ml.kg.-1min.-1 at a given running speed ∇ VO_2max ml.kg.-1min.-1 ∇ peak knee torque ∇ flexibility
Mosher et al., 1985 n=23, 10-11yrs males	Soccer players	15-20mins x 3/wk x 12wks - interval training	Δ ↓ in mean performance of running test Δ ↑ in anaerobic speed test

Δ significantly different ∇ non-significantly different

Shephard 1985, Stewart and Gutin 1976). Krahenbuhl (1983) reported that, in general, school physical education programs (or the slight modifications that were made to them) were ineffective in improving maximal aerobic capacity. It was postulated that prior to puberty there is a lack of motivation for most children to excel in physical education. Krahenbuhl (1983) recommended that physical education programs which aim to improve maximal aerobic capacity should provide an enormous variation in the activities they offer and that closer attention needs to be paid to exercise prescription.

Whilst several children's conditioning research studies exist that report significant changes in variables such as aerobic power (Brown et al., 1972; Ekbolm, 1969, Eriksson, 1972; Eriksson and Koch, 1973), other studies report non-significant changes in children's aerobic power after conditioning (Berg et al., 1985, Gilliam and Freedson, 1980; Petray and Krahenbuhl, 1985; Yoshido et al., 1980). These and other discrepancies in results of conditioning programs with children are not only caused by intervening growth and developmental factors but also in the unstandardized nature of conditioning programs designed for children. Rowland (1985) critically analysed the aerobic responses of children to physical training in nine studies. He commented on the disregard for proper exercise prescription principles and a concomitant lack of training effects observed in the results of these studies. A closer scrutiny into the nature of the studies revealed serious weaknesses which may well have jeopardised the applicability of the results. These weaknesses included: wide ranges of ages, small sample numbers, the use of children whose ages were indicative of diverse developmental changes, discrepancies in the use of control groups of children and a lack of monitoring of the 'regular activities'. Rowland (1985) suggested that it would be reasonable to expect improvement following a training study with adult populations. He hypothesised that, improvement in children at the completion of a training study is often not apparent because of the comparatively high starting level of fitness and the lack of sensitivity of the measurement procedure. Since seven of the nine studies examined by Rowland (1985) are included in Tables 2.1 and 2.2, his analysis helps to explain the inconclusive nature within the summary of the results.

Cunningham et al., (1984b) support the observations of Rowland (1985) in that they discussed three concepts in work physiology and young children which contribute to an almost indivisible relationship between the effect of growth and physical activity. Firstly, Cunningham et al., (1984b) noted that there was a large discrepancy in age and size related characteristics among the different pre-adolescent populations cited in the literature. Secondly, the authors acknowledged that there is an inherently active habitual nature of all children (experimental and control) which may obscure any significant changes in experimental groups. Lastly, Cunningham and co-workers (1984b) drew attention to the fact that a review of the available literature indicated that there was a vast difference in maturational stages among children of the same chronological age.

Conditioning programs for adults as compared to children, are relatively easy to administer as children's attention span and motivational levels are substantially reduced when compared to adults (Bar-Or 1983). Imposing conditioning programs on children for sustained periods of time may decrease children's attraction to program maintenance a lot faster than adults. This may explain why most of the studies outlined in Table 2.1 have monitored children in field setting to which they are accustomed (Daniels and Oldridge 1971, Gilliam et al., 1983, Mayers and Gutin 1979 Kobayashi et al., 1978) or, as demonstrated by Table 2.2, have used specifically controlled programs for relatively shorter (< 6 months) periods of time (Elliott et al., 1984, Eriksson and Koch 1973, Eriksson 1972, Massicotte and Macnab 1974).

The results of adaptations to physical activity during growth in pre-adolescent children remain inconclusive. However it must be acknowledged that in producing changes much of the research highlights the fact that children have the potential to change during periods of enhanced activity. The magnitude and nature of these changes are clearly dependent on the quality of the exercise prescription and the research protocols.

Section summary

1. Conditioning responses in children are often masked by normal growth patterns.

2. Longitudinal studies (> 6 months) of physical activity during childhood have had limited success in producing significant training effects.

3. Shorter term studies (<6 months) provided substantial changes in submaximal data, but programs were unstandardized and results were inconsistent.

4. Discrepancies in results may be associated with weaknesses in research design and poor exercise prescription.

5. Although the summary of research remains inconclusive, the literature provides evidence of a potential for change in pre-adolescent children in association with enhanced periods of physical activity.

B. Growth, physical activity and heritability

The growth patterns of pre-adolescent children are particularly powerful and provide insight into the complexity of the nature of adaptations which occur with physical activity during childhood. Prior to adolescence, most growth patterns are linear in both boys and girls and reveal non-significant differences in their velocity and magnitude of characteristics such as mass, height, circumferences and diameters. In middle childhood, from eight to twelve years of age, the height of boys is slightly greater than girls but an earlier onset of adolescent growth spurts in girls, provides most girls with a superior height advantage at the age of twelve. In terms of body mass, by the age of ten years, a child has normally attained half of his/her adult mass (Shephard 1985). Although not significantly greater, the suprailiac skinfolds of girls as young as six years have reported to be thicker than boys of the same age (Parizkova 1964). A secular trend from 1850 to 1960 has seen the increase in subcutaneous fat tissue of children especially in the upper percentiles of measures of body mass (Tanner and Whitehouse 1962 and 1975, and Pate et al., 1985). In other words the 'overfat' children are becoming even more 'overfat'.

Meen and Oseid (1982) reviewed physiological reactions in relation to growth and development in children and adolescents. Meen and Oseid (1982) used the work of Tanner (1962) to describe the pre-adolescent years of boys and girls. The growth spurt commences in girls at approximately 10.5 years of age and peaks at 12 years with a growth rate in height of around 9 $cm.yr.^{-1}$. Boys begin their growth spurt approximately two years later (ie. approximately 12.5 years of age) and peak at around 14 years of age, having grown in height an average 10 $cm.yr.^{-1}$. A study by Marder et al., (1975) confirmed the relevance of these values from overseas, in relation to the adolescent growth spurt for Australian populations.

Many of the longitudinal comparisons of pre-adolescent children do not acknowledge the stage of maturation of the subjects (Cunningham et al., 1984b). Yet when a child's physical activity is assessed on absolute performances in chronological age groups, the advantages will appear to go to the early maturers.

The cardiorespiratory investigation of Cunningham et al., (1984b) reported significantly larger maximal aerobic capacity and stroke volume in the boys who were later maturers than the boys who were earlier maturers. In addition to this, when a child is undergoing a growth spurt, physical proportions can, at times appear awkward. Meen and Oseid (1982) attributed this phenomenon to a deficit in central nervous system adjustments to the new body changes. The authors (1982) suggested that the aforementioned "catch up" or "awkward" time can manifest a temporary stagnation or regression in sporting performance during these years. Weber et al., (1976) used 12 pairs of male monozygotic twins; 4 pair respectively aged 10, 13 and 16 years. It was noted that the 13 year old boys were undergoing a growth spurt (having grown at a rate of 8 cm per year). Weber et al., (1976) assigned one twin to be the "untrained" and the other twin to act as the control. The trained twin participated in a 10 week interval training program. Significant improvements in the trained twin were demonstrated in the 10 and 16 year old groups, but not in the 13 year old group. On the basis of the non-significant results in the 13 year old monozygotic twins, Weber et al., (1976) rejected the hypothesis found in earlier literature that increasing physical activity during the period of a growth spurt may be beneficial.

It is therefore pertinent to suggest that possibly the most successful attempts to isolate the influence of growth and hereditary from physical activity have been made in several studies similar to that of Weber et al., (1976) using monozygotic twins (Table 2.3). In 1971, Klissouras examined the aerobic power responses of 65 pairs of monozygotic twins aged between 7 and 13 years of age, who ran to exhaustion on a treadmill. The results of the research by Klissouras (1971) calculated the degree of variablility in three important physiological measures. In the changes in maximal oxygen uptake, genetic endowment accounted for 93.4% of the results, whilst in anaerobic power, 81.4% of the results could be accounted for genetically and the maximal heart rate values were 85.9% determined genetically.

Bouchard et al., (1986) investigated the effect of hereditary in the aerobic performance of brothers, dizygotic and monozygotic twins. The measured variables included; maximal aerobic capacity, maximal heart rate, maximal ventilation, maximal oxygen pulse and the work output during a ninety minute endurance test. The results supported previous research that monozygotic twins were most alike. The within pair estimate for genetic variance was significant for all variables except VO_2 max per kg. of fat free weight. The size of the genetic effect was estimated to be 40% for the relative VO_2 max, 50% for the heart rate maximal value, 60% for the oxygen pulse at maximal effort and the maximal ventilation. The highest genetic influence was reported as a 70% accountable variance in the 90 minute work output results. Bouchard et al., (1986) concluded that the genetic effect was significant in endurance events but that the heritability in the performance of maximal aerobic power was much less.

Table 2.3: Growth, Activity and Heritability Studies of Cross-sectional and Longitudinal Research.

Authors, Yr. N, Age, Sex.	Specific Group Requirements	Nature Of Conditioning	Major Results
Klissouras 1971 n = 50, 7-13yrs males	Monozygotic & dizygotic twins	cross-sectional study of max tests on a treadmill	Variability of the following revealed genetic determinations - VO_2 max 93.4% - Anaerobic capacity 81.4% - Heart rate max 85.9%
Weber et al., 1976 n = 24, 10-16yrs males	monozygotic twins	10wks of interval work - one twin trained & other acted as control	13yr. old twins reported to be going through growth spurt Δ ↑ VO_2max 10 & 16yr. olds ∇ ↑ VO_2max of 13 yr. olds Authors did not support the hypothesis that a growth spurt was a time for great improvement.
Prud'homme et al., 1983 n = 20, age & sex not cited	monozygotic twins	45mins x 4-5/wk x 20wks endurance training at 80% HR reserve	14% ↑ VO_2max 17% ↑ ventilatory threshold 74% of variance in VO_2max in in training effect was genotype dependent
Bouchard et al., 1984 cited in Bouchard & Lortie, 1984	siblings,77pr cousins, 83pr DZ.twins,59pr MZ.twins,58pr brothers and sisters, 54pr	resemblence of PWC170/kg.wt. cross-sectional study	Correlations between pairs: Adopted siblings r = -0.01 Unrelated siblings r = 0.09 First cousins r = 0.14 Brothers & sisters r = 0.24 Dizygotic twins r = 0.50 Monozygotic twins r = 0.60

Δ significantly different ∇ non-significantly different

Two of the most published researchers on the effects of heredity and performance, Bouchard and Lortie (1984); traced substrate availability and utilization in endurance training in monozygotic twins. These authors (1984) concluded that the sensitivity of stimulated lipolysis to endurance training regimes was largely genetically determined. Compounding this effect was also the authors' hypothesis that it was also important to identify whether subjects were high responders or low responders to endurance training. "One of the problems faced by sports scientists and coaches alike is that the sensitivity to endurance training is unpredictable for a given individual without data on past training experiences or genetic markers (as yet unavailable)." (Bouchard and Lortie 1984 p.58)

Bouchard and Lortie (1984) claimed that the "capacity to perform during prolonged exercise is a trainable property of the asymptomatic human organism" (Bouchard and Lortie 1984 p.59). What remained questionable to the authors (1984) was the extent of the effect of interactive factors of growth, heritability and activity. Table 2.3 discloses that not all twin studies have similar conclusions.

Again, there appears to be a need for standardization of sample sizes, methods and procedures in order to account for cross-sectional variances appearing in the available literature.

Section summary

1. Prior to puberty, growth is generally linear. Up until this stage, growth pattern differences between males and females appear to be largely non-significant.

2. Growth spurts begin in females at the average age of 10.5 years and begin two years later in males at approximately 12.5 years.

3. In studies where the participating children are at an age that a growth spurt is possible, there should be an acknowledgement of this development and attempts must be made to account for the magnitude of variation due to the intervening growth spurt.

4. Studies of monozygotic twins during childhood and adolescence indicated a potential masking of the training effect during periods of peak growth.

5. Variablity due to genetic endowment was reported to be significant in a number of results of maximal effort and endurance measures, with the exception of the maximal oxygen uptake.

6. Attempts to quantify the extent of heritability on growth and activity patterns have to date, been inconclusive.

In pediatric populations the term aerobic fitness is only one of the dimensions of fitness (Bar-Or 1987). The other fitness perspectives that need to be applied to children are; strength, muscular endurance, flexibility, anaerobic capacity and desirable body composition (Bar-Or 1987, Corbin 1987).

C. Muscular strength and training in pre-adolescent children

Until recently, very little information has been available on the effects of strength training in pre-adolescent children. Tanner (1962) claimed that adolescent muscle mass in either sex, does not increase significantly when compared to adults, because of the insufficient circulating androgens in adolescents. Androgens are chemical substances such as testosterone and androsterone which promote and stimulate male characteristics (including strength). Rohmert (1968) analysed the differences in strength between children and adults. In Rohmert's study (1968), the average age for the children and the adults was 8 and 28 years respectively. The two groups performed isometric strength training six times a week for three months. The author (1968) reported that in relative terms (strength/kg) strength gains occurring at the time of the program were not significantly different when children were compared to adults.

Ikai (1976) investigated muscular endurance training effects over five weeks in normally active children aged between 12 and 15 years of age. The nature of the training involved subjects working on an arm ergometer at one third of their maximal effort for six sessions in each of the five weeks. The muscular endurance training was associated with an estimated 48% increase in the blood flow through the muscles during the work performed by this adolescent population. The increase in muscle blood flow was only 4% in adults under the same conditions. The author (1976) believed that the results supported the hypothesis that endurance training was particularly effective in 12 to 15 year old adolescent children.

Up until the 1970's strength measurements for children were generally determined by gross motor and functional tests (Molnar and Alexander 1973) using dynamometers, cable tensiometers, strain gauges and spring scales (Malina 1975). Measurement of muscular strength in children became more sophistocated after a series of articles on the use of isokinetic devices with children (Alexander and Molnar 1973, Molnar and Alexander 1973 and Molnar et al., 1979). These articles documented the validation and reliability of isokinetic devices to ascertain the muscular strength of pre-adolescent populations. Molnar and Alexander (1973) investigated the muscular strength of the elbow and knee extensors and flexors in 25 males and 20 females aged between 7 and 15 years of age. From the results of their study, the authors (1973) emphasised four important findings; firstly, that compared to females of the same chronological age, pre-adolescent males were stronger in every test, secondly, that right-handed subjects were stronger on their dominant side that their non-dominant side, thirdly, that in the sample population of children aged between 7 and 15 years of age, compared to the upper extremities, there was a greater susceptablity to strength gain in the lower extremities, and lastly, that extensor muscles demonstrated greater strength gains than flexor muscles. These results were later confirmed in a corresponding study on a larger population of children (Alexander and Molnar 1973). Similar results were reported from a study using an adult population (Heywood et al., 1981).

In a later study, Molnar et al., (1979) published predictive and normative values for strength gains in pre-pubescent populations. Predictive values were recorded from actual scores and were computed using a multiple regression procedure which included the age, age squared, height and weight variables. Tabled percentile scores were highly specific in that the percentiles not only to referred to a particular sex, but also a particular age, weight, height and muscle group.

Subsequently the practice of predicting strength in populations of pre-adolescent children from the tables devised by Molnar et al., (1979) became very technical and not widely used.

In more recent literature, isokinetic devices have been selectively but successfully used as a training medium for strength training in children (Micheli 1985, National Strength and Conditioning Association 1985, Weltman et al., 1986, Servedio 1987, Rianes et al., 1988, Weltman et al., 1988, Young 1988) [Table 2.4]. In 1985, both Micheli and the North Amercian based National Strength and Conditioning Journal, published statements proclaiming the relative safety and suitability of weight training for pre-adolescent populations. Weltman et al., (1986) investigated the effectiveness and safety factors associated with the use of hydraulic resistance strength training with pre-adolescent males. The authors subjected 16 males (aged from 6 to 11 years) to a 45 minute workout 3 times a week for 14 weeks. Knee and elbow motions of flexion and extension were developed at 30 and 90 degrees per second (KIN COM). The mean concentric isokinetic strength increase per repetition improved by 18.5% to 36.6% for the 8 motions tested. Compared to the control group, the isokinetic strength and torque gains of the experimental group were significantly greater ($p < 0.05$). In addition to this, the experimental group, when compared to the control group recorded significant increases in their performance on the test for the vertical jump (10.4%), flexibility (8.4%) and VO_2 max (19.4%). Because the program had been conducted almost injury free during training, the authors concluded that they could support the hypothesis that hydraulic resistance equipment had been used effectively and safely with their population of pre-pubescent males. Weltman et al., (1986) also acknowledged the very limited application of the study in the light of the sophistication of the equipment and the fact that the tight program control had necessitated close supervision by highly trained specialists.

In another development of isokinetic devices with pre-adolescent children, Servedio et al., (1987) trained 6 males (mean age 11.9 years), 3 times a week for an 8 week strength training program using olympic style lifts (snatch, clean and jerk). An echocardiogram was used to assess cardiovascular function in this study. From the results of the echocardiogram, Servedio et al., (1987) determined that the experimental group when compared to the control group had significantly greater left ventricular end diastolic dimension and volume and associated this with a calculated increase in stroke volume and cardiac output in the weight training group over the duration of the program. The authors (1987) concluded that the major finding of their study had been an increase in the thickness of the cardiac diameter in the weight training group.

Table 2.4: Studies of Children Participating in Strength Training Programs

Authors, Yr. N, Age, Sex.	Specific Group Requirements	Nature Of Conditioning	Major Findings
Rhomert, 1968 n = 8 children n = 28 adults males	Normal active children and adults	Isometric strength training 6/wk x 3mths	Children before training were weaker than adults. Compared to the adults, the relative strength gains in the children were not significantly
Ikai, 1976 12-15yrs males	Normal active children	Muscular endurance activities on an arm ergometer, 3-6/wk x 5wks at 1/3 max.	Muscular endurance training was associated with a 48% ↑ in in the blood flow through the muscles during work. Training 3/wk was not as effective as training 6/wk for muscular endurance.
Sewall & Micheli, 1986 n = 10, 10yrs males &	Normal active children	Used isotonic thigh press machines for 9wks	Compared to matched controls, Δ strength gains No training injuries ∇ in flexibility of the experimental group
Weltman et al., 1986 n = 16, 6-11yrs males	Normal active children	8 motions; 45mins x 3/wk x 14wks - flexion & extension at knee & elbow at 30° & 90°-1 (KIN COM)	It studied effects of hydraulic resistance strength training in pre-adolescent children Mean concentric isokinetic strength increases by 18.5% to 36.6% Experimental group also increased significantly in: - vertical jump 10.4% - flexibility 8.4% - VO_2 max 19.4%
Raines et al., 1987 n = 18, 8.3yrs males	not cited	45min x 3/wk x 14wks using 6 settings on hydraulic resistance machines	Δ ↑ work output Δ ↑ in flexion Δ ↑ in vertical jump Warning that the study required highly qualified staff for supervision.
Servelio et al., 1987 n = 6, 11.9yrs males	Normal active children	3/wk x 8wks - Olympic style lifts eg. snatch, clean	Δ in shoulder flexion Δ in cardiac diameter ∇ in resting heart rate ∇ in body fat percentage ∇ in overall flexibility
Weltman et al., 1988 n = 27, 8.2yrs males	not cited	cross-sectional study: concentric strength in knee, shoulder, & elbow, in flexion & extension + 30° & 90°-1	Slightly higher strength in dominant limbs when compared to non-dominant limbs Δ ↑ strength in extension rather than flexion Greater torque at 30°-1 than than at 90°sec-1 Peak torque occurred within the the first 50% of the range of motion

Δ significantly different ∇ non-significantly different

Rianes et al., (1987) conducted a highly supervised and tightly controlled program for 18 males (aged 8.3 years). These children participated in 14 weeks of strength training which involved 35 minutes of exercise 3 times a week. The subjects had 6 resistance settings to move through, performing concentric exercise, on hydraulic resistance machines. On-going testing during the program included scintigraphic measurements to detect any damage to bone growth tissue and muscle. At the completion of the study, subjects were injury-free. In addition to this, the experimental group, when compared to the control group, had a significantly higher work output (ie. higher resistance settings reflecting greater strength gains from the program). Rianes et al., (1987) reinforced the impracticality of the study, again mainly because of the enormous degree of safety and technical supervision required in each training session. It was speculated that many field settings would not be able to supply such trained and intensive supervision.

A cross-sectional investigation of muscle strength adaptations in pre-adolescent children was conducted by Weltman et al., (1988). The authors investigated concentric strength in knee and elbow extremities using flexion and extension on the dominant and non-dominant sides. The adaptations observed at the completion of the investigation were that; the dominant side was only slightly stronger than the non-dominant side, significantly higher strength was evident in extension when compared to flexion, a higher torque was achieved at a slower speed of 30 degrees per second when compared to the torque achieved at 90 degrees per second, and finally, the peak torque occurred within the first 50% of the range of motion. Weltman et al., (1988) concluded that the pre-adolescent males had exhibited concentric isokinetic strength patterns at the knee, shoulder and hip joints that were very similar to adolescents' response patterns. The reasons for the similarities of responses to strength training in children and older population were outlined in an investigation by Bell et al., (1980). Bell et al., (1980) examined the nature of the muscle fibre type for the biopsies of 6 females and 5 males,with a mean age of 6.4 years. The children were all training in endurance based activities prior to the testing. Bell et al., (1980) reported that the muscle fibre types in these young endurance athletes contained approximately 60% of slow twitch fibres. The authors reported the results to be congruent with the findings from biopsies conducted on endurance based athletes in other studies where the subjects were adolescent and adults. The researchers further investigated the relative volume densities of the mitochondria and intracellular fluid in the samples from the 6 year old subjects. The resultant figures indicated that young children have an "equivalent or slightly greater capacity for oxidative metabolism than do sedentary adults." (Bell et al., 1980).

Relative strength is often expressed in terms of lean body mass (Heywood et al., 1986, Tabin et al., 1985). Tabin et al., (1985) hypothesised that lean body mass would correlate best with peak torque development. Mean peak quadracep force at 60 degrees per second obtained on a Cybex machine, was divided by the estimated lean body mass of the subjects. These ratios indicated that the children recorded scores (foot-pounds/lean body mass) which were approximately 70%. In the same study, post pubescent children recorded mean peak quadracep torque/lean body mass ratios which were 80% in the males and 90% in the females. The authors (1985) concluded that unless strength was recorded in relation to lean body mass, larger, leaner children would unfairly appear to be weak. Similar relative strength measures were used by Heywood et al., (1986) in a comparison of gender differences in strength. An accountable variance of 73% in both shoulder flexion and knee extension was explained by differences in lean body mass.

One of the skill-related aspects of health often associated with muscular strength is that of flexibility. There is a dearth of studies in the literature on the flexibility of growing children (Birrier and Levine 1987). The fact that bone grows much faster than tendons and that muscles stretch, leads to a child's body becoming relatively inflexible during the adolescent growth spurt (Kendall and Kendall 1948, Leighton 1956). Malina et al., (1976) suggested that following adolescence, flexibility increases in both sexes. The graphical presentation of a sit and reach test performed by over 8000 Australian school children aged between 7 and 15 years in 1985 appear to be in agreement with of the above statement on flexibility (ACHPER 1986).

Section summary

1. In absolute terms children have less strength than adults.

2. In relative terms, similar strength gains can be made by both children and adults.

3. Muscular endurance training can be reasonably effective in pediatric populations.

4. Isokinetic devices have been used effectively and safely to ascertain muscular strength in pre-pubescent children.

5. From isokinetic testing the following four characteristics have been confirmed in pre-adolescent children; (i) males were slightly stronger than females, (ii) dominant limbs were stronger than non-dominant limbs, (iii) lower extremities were more susceptible to strength gains than upper extremities (iv) and extensor muscles indicated greater strength gains than the flexor muscles.

6. Significant strength and torque gains have been reported to be associated with concentric isokinetic strength training programs (under strict supervision) in pre-adolescent populations.

7. When comparing the strength gains of different populations they may be preferably expressed per unit of lean body mass.

D. Anaerobic characteristics of pre-adolescent children

When Inbar and Bar-Or (1986) reviewed the anaerobic characteristics of children and adolescents, they acknowledged that there was a scarcity of literature. The anaerobic capacity research results to which they referred were recognised in the Margaria step running test (Margaria et al., 1966). Margaria et al., (1966) reported that there was an age-related incremental progression in anaerobic power, with children recording much less power in the explosive work output. Significant differences between children and adults were evident when results were expressed in both absolute and relative terms (peak power per kilogram of weight). Among the non-athletes the peak power per kilogram of weight score in 9 year old boys and girls was only some 60% of that of the 20 year old subjects (Margaria et al., 1966). Inbar and Bar-Or (1986) collected data from 300 subjects aged between 10 and 45 years. These subjects performed a 30 second supramaximal effort test by cycling or arm cranking. The relative mean power (watts per kilogram of body mass) in the arms of a 10 year old child was only 85% of the mean power achieved in adults. The mean power (watts per kilogram of body mass) in the legs of a 10 year old child was less than 70% of the mean power achieved by adults. The relative peak power (watts per kilogram of body mass) in the arms and legs of 10 year old children, in comparison to adults, was 60 and 70% respectively. In absolute terms in both the mean power and the peak power measures the 10 year old males displayed only 30% of the adult value in the legs and less than 30% of the adult power scores in the arms. The authors (1986) concluded that their results were similar to those reported by Margaria et al., (1966) in that anaerobic power output was linearly related to age. Peak power increased until approximately 30 years of age in the leg cycling task whilst in the arm cranking task it took until about 20 years of age to peak.

In an attempt to determine why children, when compared to adults, were significantly inferior in anaerobic capacity, Inbar and Bar-Or (1986) discussed a number of underlying mechanisms from the previous literature. Firstly, the authors (1986) identified the importance of a study in which children, when compared to adults, had lower resting and exercise glycogen levels (Eriksson and Saltin 1974). The same study however also noted that there were not any apparent differences in the ATP-PC levels in the two age groups. These results lead Inbar and Bar-Or (1986) to suggest that the inferior anaerobic capacity of children when compared to adults is more likely to be due to inadequacies in children's anaerobic glycolysis rather than their phosphagen system. Inbar and

Bar-Or (1986) also gave credence to the findings of Eriksson et al., (1972) which stated that following maximal effort muscle lactate was reported to be significantly lower in pre-adolescent boys than in young adults (11 $mmol.kg^{-1}$ and 17 $mmol.kg^{-1}$ respectively). In addition to this, when young males of 11 to 13 years were compared to 16 and 17 year old males, lower levels of the rate limiting enzyme in anaerobic glycolysis were obtained. More specifically, the younger subjects' activity level of phosphofructokinase prior to training was 8.4 $\mu mol^{-1}.g^{-1}.min^{-1}$ and increased to 15.4 $\mu mol^{-1}.g^{-1}.min^{-1}$ after 6 weeks of program participation. This final activity level was very close to adult values. Further postulations as to the causes of the reduced anaerobic capacity of children when compared to adults were also linked to lower testosterone levels and reduced lactate production observed in studies on animals (Krotiewski et al., 1980). Decreased levels of acidosis during maximal effort of children when compared to adults were also noted by Matejkova et al., (1980) and Von Ditter et al., (1977). The decreased acidosis level of children was associated with the possible mechanisms underlying the reduced anaerobic capacity of children by Inbar and Bar-Or (1986).

Macek, (1986) provided a detailed discussion of the literature available on the lower lactate production of children when compared to adults. Macek (1986) hypothesised that the lower lactate production in children may be the product of a number of systems. The author (1986) proposed that the work of Lehmann et al., (1981) had made an important contribution to the understanding of lower lactate concentrations in children. Lehmann (1981) established that there was significantly reduced sympathetic nervous activity in children when compared to adults during maximal effort. Sympathetic activity is associated with the vasoconstriction of vessels including those responsible for the removal of blood lactate from the muscle to the liver. Sympathetic activity consequently contributed to a greater ratio of lactate production to lactate removal. Macek (1986) hypothesised that "blood flow to the liver is consistently higher (in children) because of less vasoconstriction (due to reduced sympathetic activity) and thus the liver is able to remove the lactate from the blood at higher rates ..." (Macek 1986 p.6). To date, however the question of why differences exist in anaerobic capacity of children when compared to adults remains largely unresolved. Clearly, moral and ethical constraints in the nature of future research impairs its resolution.

Studies have attempted to explain differences in anaerobic performance in age groups by expressing data in relative rather than absolute terms. An investigation by Murphy et al., (1986) reported that for a population of adult males and females the substantial difference in results of mean power and peak power was decreased when the scores were expressed relative to a number of anthropometric units (ie. thigh volume, body weight and lean body mass). A similar investigation into the relative expression of anaerobic characteristics was published by Sargeant and Dolan (1986). The authors (1986) expressed concern that previous literature which had identified the anaerobic capacity of children as lower than adults when related to body mass and, or muscle mass, may have produced ambiguous results because the velocity of cycling of the children may not have been optimal. Sargeant and Dolan (1986) subjected 24 male and 16 female adults and 25 male children (whose age averaged 13.7 years) to a series of supramaximal effort tests at 3 or more velocities, in an attempt to determine the optimal velocity for maximal power production. In absolute terms, the male children were an average 36% less powerful than the adult males and only 3% less powerful than the adult females. When the results were calculated, relative to the size of active muscle mass, male and female adult differences disappeared. This result is similar to the aforementioned study by Murphy et al., (1986). However, when the results were expressed relative to body mass, there was a 17% superior score in power output of both adults groups when compared to the children. The authors (1986) therefore supported the previously observed differences in power output between children and adults and concluded that the differences were not associated with errors in measurement of optimal velocity for maximal power output. Sargeant and Dolan (1986) further hypothesised that the differences may well reflect children's immaturity in the nature of the sample of the muscle cross-sectional area. The authors (1986) suggested that in children, cross-sectional muscle samples must include the pennate and oblique orientation of fibers. They (1986) stated "...When longitudinal growth stops, the muscle fibers may continue to increase the fiber cross-sectional area, changing the angle of pennation and effective force production..... these values aren't reflected in assessment by leg volume, nor simple horizontal cross-sectional area of the thigh" (Sargeant and Dolan 1986 p.41). Thus, according to Sargeant and Dolan (1986), an error of relative measurement may still exist in anaerobic testing and analysis.

The role of maturation in anaerobic capacity was examined in a study by Paterson et al., (1981). The authors (1981) acknowledged the fact that the chronological age of children appeared to be largely insignificant in the prediction of anaerobic capacity of young children. Paterson et al., (1981) also recognised that a more accurate predictor may be that of maturation. They (1981) felt that early maturers appeared to demonstrate an advantage in size, strength and associated performances. Paterson et al., (1981) placed 19 boys from 11 to 15 years into early and late maturation groups from an investigation which was conducted over five years. Skeletal age was used to define early and late maturers. Subjects' anaerobic capacity was assessed from the amount of time that the children were able to run on a treadmill with a 20% grade at speeds ranging from 130m.min^{-1} to 190 m.min^{-1} (depending on the age of the child). Early maturers were reported to be taller by 8-12 cm and heavier by 4-7 kg than the late maturers. On the basis of previous research, Paterson et al., (1981) expected anaerobic capacity to improve proportionally with growth spurts. Anaerobic capacity did improve after peak height velocity when the groups were initially combined for analysis. However when each of the groups was examined separately, inconsistent increments were evident in the changes of anaerobic capacity for the same stage of growth in the early and late maturers. In addition to this non-significant differences were obtained between early and late maturers in the anaerobic capacity at each chronological age level. The authors concluded that development of anaerobic capacity was largely unrelated to the growth spurt differences of early and late maturing males aged from 11 to 15 years.

The question of the impact that training can have on children's anaerobic capacity is of importance to educators, coaches and other sporting professionals. Grodjinovsky et al., (1980) conducted research into the training effect on the anaerobic performance of children as measured by the Wingate Anaerobic Test. Grodjinovsky et al., (1980) used 50 young sixth grade males in a study of 6 weeks duration. The boys were divided into three groups; a control group, a treadmill group and a bicycle ergometer group. The boys who were assigned to run on the treadmill performed 3 X 40 metres sprints at an all out pace, followed by 3 X 150 metres sprints, again, at an all out pace in each session. The boys trained on the bicycle ergometer and had to perform 3 X 8 seconds all out bouts then 3 X 30 seconds all out rides. In the progress of the 6 weeks, the repetitions were increased. In the two training groups, the total anaerobic parameters was mildly, but significantly increased (3.5 - 5%) in both absolute and relative terms. A similar trend occurred in the peak anaerobic power of the two training groups at the completion of the study. The control group was reported to have non-significant changes in both total anaerobic mean and peak power. The authors (1981) concluded that the anaerobic parameters of children in the experimental groups had improved significantly in association with an intensively anaerobic conditioning regime.

Section summary

1. Compared to adults, children have reduced anaerobic characteristics in both absolute and relative terms.

2. The exact underlying mechanisms which may explain the reduced anaerobic characteristics of children remain unclear. Some of the popular hypoptheses include: lower glycolytic capacity, lower levels of the rate limiting enzyme in anaerobic glycolysis (phosphofructokinase), lower testerone levels and lower levels of acidosis. Additionally, children's lower lactate accumulation has been hypothesised to be associated with reduced sympathetic activity.

3. Expressing anaerobic characteristics in relative terms has an equalizing effect between male and females adult populations. Relative anaerobic characteristics of children compared to adults may need to be expressed in highly specific kinesiological units rather than normally accepted estimations of muscle mass.

4. Maturational differences and rates of maturation between children have a minimal effect on the result on the development of anaerobic performance characteristics.

5. Intensive anaerobic training has been associated with significant increases in the anaerobic mean and peak power output of children.

Body composition changes in pre-adolescent children related to growth and training

Most of the literature reviewed to date contains an element of body composition and its influence on performance and training programs. Body composition may be assessed indirectly through anthropometric data and may involve measurements of mass, height, breadths, girths, widths and soft tissue (skinfolds). Results from anthropmetric measurement have been used to estimate other elements of body composition, such as body fatness, lean body mass and bone density.

Skinfold measurements provide an estimate of the subcutaneous fat development at specific sites on the body. Parizkova (1964) discussed the results of a skinfold measurement comparison between pre-adolescent boys and girls. The total thickness of 10 skinfold sites in the 48 children was non-significant between the 7 year old boys and girls. Parizkova (1964) however also noted that there appeared to be a sex specific fat deposit site, despite the non-significant difference between the two sexes in that, there was a noticably higher thickness in the subcutaneous tissue in the hips of the girls. The sex difference in the body composition of children is well documented (Malina 1969, 1975, Parizkova 1963, 1979, Davies et al., 1972, Hensley et al., 1982, Seltzer and Mayer 1970 and Bar-Or 1983). In addition to this, Parizkova 1963, provided a wealth of early literature from the 1950's and 1960's which supported the relationship of greater proportions of lean body mass with high levels of activity.

The use of skinfolds, circumferences and diameter measurements as predictors of body density was investigated by Boileau et al., (1981). In an attempt to compare prediction equations across 2 samples of pre-adolescent population, Boileau and co-workers (1981), however reported significant differences in the groups' means and a significant difference in the prediction error of the measurement of body density. In a summary of the previous attempts to ascertain measurement of body fat from anthropometric and densiometric predictions, Johnston (1982) noted large statistical differences in correlation matrices and similarly large errors of estimates. The author (1982) suggested that future investigations should make use of anthropometrics directly, instead of confounding them in whole body composition equations.

It appears that avoiding estimations in measurement of body composition is not the only measurement problem. Malina (1975) expressed concern for measurement error in longitudinal studies such as training studies......"Growth increments can be quite small and technical errors in measurement can mask the true increment." (Malina 1975 p. 251). Du Rant and Linder (1981) stressed that "...once a skinfold measurement is obtained from a child, there still remains unresolved questions as to what the measurement actually means relative to the measurements of other children" (Du Rant and Linder 1981, p.35). From the available literature, it appears that measurements are best kept not only specific to the populations being tested, but more realistically, technically accurate body composition measures are probably most effective in intra-individual comparisons.

One example of effective use of skinfolds measurements was conducted by Parizkova and Poupa (1963). The body composition changes over 5 years were recorded in two groups of young female gymnasts. One of the groups trained continuously over the 5 years and the other group trained seasonally. The authors (1963) reported that while height and weight remained at a constant velocity, skinfold measurements fluctuated significantly in the seasonal group. Specifically, the skinfold measurements of the seasonal gymnasts significantly decreased during periods of intense physical training and increased when training discontinued with the resumption of training. Parizkova and Poupa (1963) postulated that "the lean body mass and depot fat are in a dynamic state of equilibrium, which relatively, rapidly and significantly reflects changes in energy output and balance.....".

The influence of body composition on the motor performance of children was investigated by Hensley et al., (1982). The authors (1982) acknowledged that similar studies in adult populations resulted in females being poorer performers than males at a given task, because of disadvantageous and greater levels of body fat. Hensley et al., (1982) used the sum of the tricep and subscapular sites as measures of body fat. With an average age of 9 years, 563 pre-pubescent children performed motor tests including; a vertical jump, a standing broad jump, pull-ups, a 40 yard dash and a 400 metre run. Hensley et al., (1982) reported significant differences between boys and girls in all tests. Although the boys were slightly taller and heavier than the girls, there was a non-significant difference in the sum of the 2 skinfolds between the 2 sexes. It was concluded that within the population of 9 year old children, the variation in performance because of body fatness was minimal.

Further support of the findings of Hensley et al., (1982) is evident in a study by Clarke and Vaccaro (1979) who examined the role that body composition plays in physical performance. The authors (1979) examined the effect of swimming training on the muscular performance and body compositon of children. The 13 girls and 2 boys aged between 9 and 12 years who participated in the study, were involved in swimming endurance training, 4 times a week for 7 months. When the trained group was compared to a carefully matched control group, significant differences were evident in muscular endurance. However the differences between the 2 groups in body composition and body strength were non-significant. It appeared that changes associated with training in these young swimmers were not effected by body composition. Perhaps because the nature of the swimming was endurance-based, there was insufficient intensity to produce any alterations to body composition.

The effectiveness of intense exercise in modifying the body composition of adults is well documented (Parizkova 1978, Leon et al., 1979, Wilcox 1982, Wilmore 1983, Pacey et al., 1986). Examples of adult studies using either untrained or overweight populations also emphasise the degree of effectiveness that training has on changing body composition. The nature and size of body composition change may also be commensurate with initial fitness level and the initial body composition.

Research also indicates that the body fat percentage is not markedly reduced in training of a moderate intensity (Thomas et al., 1984, Wilmore 1980). Wilmore (1983) reviewed body composition alterations with training and cited 55 studies from the literature, in which adults had been exposed to a wide variety of training programs. The studies ranged from 6 to 194 weeks, with duration of between 6 to 104 minutes and prescribed exercised for 3 to 6 sessions per week. The modes of exercise were very diverse. However, very few of these studies appear to have made any impact on body composition. The percentage of body fat losses for the 55 training studies averaged only 1.6%.

Changes in body composition were non-significant in the pre-adolescent children who participated in a 12 week endurance running training program conducted by Lussier and Buskirk (1977). The authors (1977) postulated that longer than 12 weeks would be needed in order to demonstrate a significant change in lean body mass. Another 12 weeks fitness program was conducted by Gilliam and Freedson (1980) using school children aged between 7 and 9 years. After 25 minutes of physical education lessons for 4 sessions a week, non-significant differences in body composition were reported between the experimental group and a control group. Thus, from the available literature, changes in body composition in normal, active children who trained over relatively short periods of time, appeared to be minimal. This is largely in agreement with the data on adults presented by Wilmore (1983).

The nature of the group being tested was observed to alter the results of training studies conducted with adults. This perspective appears to be supported in studies of children who begin training in an overweight state. Sprynarova and

Parizkova (1965) completed a research study on the changes in aerobic capacity and body composition in obese boys after a weight reduction program. Following 7 weeks at a recreational and therapeutic camp where 7 boys (11 years of age) walked and exercised daily, a significant decrease was obtained when the boys' pre-camp weights were compared with their weights at the end of the camp. The changes were of such a magnitude that there was an associated decrease in the relative aerobic capacity of the boys. In a similar study of overweight children participating in a specifically designed weight reduction camp, Whipp and Ruff (1971) reported a 9.2% weight loss after 6 weeks of restricted diet and vigorous daily activites such as swimmimg, volleyball, hiking and supervised calisthenics. But the results of the two aforementioned studies were difficult to interpret in the absence of a control group to act as a basis for comparison.

Moody et al., (1972) used a normal and overweight group of high school girls in an investigation into the effects that a jogging program had on the body composition. The authors (1972) selected 40 adolescent girls (aged 15 to 16 years) to participate in a 15 or optional 29 week elective program of walking, jogging and running. Compared to their pre-program body composition values, at the end of the program the overweight girls had significantly reduced in body weight and body fat. A corresponding increase in the body density and lean body mass occurred in overweight girls compared to the girls of normal weight. Concomitently the skinfold measurements of the overweight girls were also significantly reduced after the program. Non-significant changes were observed in the pre and post program weights of the control group. This result in the control group was unexpected by Moody et al., (1972). In fact four of the leaner girls in the control group actually gained in body mass. These results demonstrated "the complex relationship between exercise and body composition" and that exercise has some type of "mediating influence on appetite, food intake, basal energy levels and on the cellular metabolic processes which can lead to a substantial weight and fat loss in the obese, but a weight and fat gain in the lean" (Moody et al., 1972, p. 212).

The postulations made by Moody et al., (1972) are somewhat substantiated by Fidanza (1979) who investigated the association between nutrition and physical activity of 10 Italian children, aged between 6 and 10 years of age. From a food history assessment, a lifestyle survey and some anthropometric measures, more active children appeared to score better in several health related measures. It was found that the more highly active children had a larger muscle mass area. Fidanza (1979) reported a high correlation between nutritional status and the measures of muscle area of children. It was postulated that the measurement of muscle mass should be used in future research as an evaluative for both nutritional status and functional efficiency.

In summary, the results available on the effects of conditioning on body composition in pediatric populations, are inconclusive (Bar-Or 1983). Confounding these effects are the intervening variables of the role of diet, growth and maturation. Documented changes must therefore be accepted with reservations.

Section summary

1. Studies on the body composition of children have used body compostion measurement most effectively to assess intra-individual differences. Attempts to use normalized tables and prediction equations in determining "between group" and "within group" differences in body composition were generally unsuccessful.

2. Skinfold measurements in trained children have been observed to significantly fluctuate and reflect the state of training of the individual.

3. Body composition has been reported to make a minimal contribution to motor performance tasks in normal, healthy, pre-adolescent children.

4. Endurance-based training regimes appeared to be ineffective in significantly changing the body composition of normally active children.

5. Overweight children and adults who engaged in training programs were more likely to alter their body composition than leaner control groups.

6. The effect that a conditioning program has, on the body composition of pre-adolescent children is extremely complex.

F. Heart rate responses to sports participation in children.

Adult maximal effort heart rate responses are age-related. For example, it is generally accepted that there is a decrease in maximal heart rate with age. In children, only males demonstrated an age related relationship to the heart rate maximum. Young females' maximal heart rates appear to be independent of age and state of training (Astrand and Rodhal 1977). Submaximal work heart rate responses in children decrease with age. In both children and adults, decreased submaximal work heart rates may also indicate the state of training, independently of the heart rates recorded during maximal effort (Chausow et al., 1984, Fournier et al., 1985).

Pels et al, (1981) monitored the heart rate responses of pre-adolescent children during steady state, peak power output and recovery from exercise. The 66 children who participated in the study were aged between 6 and 7 years of age. The authors (1981) reported non-significant differences between boys and girls in peak power output heart rate responses. Significantly lower heart rates in the boys when compared to the girls were reported at rest, in steady-state exercise and during the first three minutes of a five minute recovery period. Pels et al., (1981) postulated that the lower heart rates in boys when compared to girls were associated with a difference in fitness levels. This suggestion was supported in the findings of Gilliam et al., (1981) who had in fact used largely the same population of children as Pels et al., (1981). Gilliam et al., (1981) had reported higher daily activity levels in boys than girls. More specifically, Gilliam et al., (1981) had examined 12 hours of physical activity in children between 8.00 am and 8.00 pm. They reported that in the 12 hour period, activity time where heart rates reached 160 $bts.min^{-1}$ for only 20.9 min. and 9.4 min. for the boys and girls, respectively. Gilliam et al., (1981) concluded that "Even though the children appear moderately active, they very seldom experience high intensity physical activity. Furthermore, the heart rate patterns showed that the boys are more physically active than the girls." Telemetred heart rate recording during physical activity is regarded as a more practical and a more reliable indication of the state of stress and intensity occurring in an individual than the palpation method (Mc Ardle et al., 1969). From the available literature, sporting studies where telemetred heart rates have been used have largely involved adult populations. Very few studies of younger populations have included telemetered heart rate recordings (Table 2.5). However, Saris (1986) recommended that the heart rate telemetry technique is possibily the best "in-field" measure of physical stress during activity in children.

Saris et al., (1977) described the design of a portable heart rate device which recorded the heart rates of children. The device used by Saris et al., (1977) was designed especially for children; its size and weight permitted freedom of movement, it had a quick and convenient printout procedure, it was able to monitor heart rates within a range of 35 and 225 $bts.min^{-1}$ and even above the presence of extraneous noise, produced reliable results. The authors (1977) found that their new device was in good agreement with other portable systems and most importantly the device did not interfere with normal daily activities. According to Saris et al., (1977), the use of previously devised telemetry systems with children was very limited because of the inconvenience of having to have the receiver within the vicinity of the subjects. Monitoring the daily physical activities of children for hours on end deemed the previous telemetry systems obtrusive. The main problems with the device used by Saris et al., (1977) were that firstly there was a lack of corresponding time registration of the heart rate readings and secondly, that there was an inability for permanent storage of the data. Saris et al., (1977) however suggested that for the purpose of their study, the 24 hour activity monitoring that they had completed in over 150 children, had demonstrated the device to be reliable practical and simple. Another system of a magnetic tape recording of heart impulses (Seliger et al., 1970) was suggested to be inappropriate with children because of its size, weight and inherent embarrassment when wearing the device.

Table 2.5: Summary of Methods Used to Quantify the Intensity of Training in Young Populations

Authors, Yr.	Nature of the Program	Intensity Measure
Goode et al., 1976	Physical education classes	Boys were taught to monitor their own pulse rate
Lussier & Buskirk, 1977	Indoor running program	Periodic checking of heart rates using a stethescope
Stewart & Gutin, 1976	Physical education classes	Random selection of boys to wear radio telemetry in each lesson
Paterson et al., 1977	Minor league ice-hockey games games at one minute intervals	Radio telemetry in one mid-semester
Saris et al., 1977	24 hous of natural activity in children	Newer telemetry device easy to use with reliable results in children during natural activity (but without memory function)
Gilliam et al., 1981	Daily physical	Holter monitoring system
Klausen et al., 1986	Physical education classes	Portable telemetry system with 30 second read out and a memory function

Klausen et al., (1986) monitored children's activity levels in physical education classes with the use of a light, portable heart rate device which was capable of 30 second readouts from a memory storage function. A simple time-motion analysis was also used in order to disregard those heart rate periods in which children were inactive. Klausen et al., (1986) also determined the maximal aerobic power of the children using a Monark bicycle ergometer. The authors (1986) noted a great diversity among the heart rate readings of children participating in the same lesson eg. one child had a mean heart rate of 164 bts. min^{-1} and another child had a recorded average heart rate of 107 $bts.min^{-1}$. The study also reported difficulty in determining the differences in activity heart rates between the sexes. Higher heart rates were reported in warm ups than in the rest of the lesson in older children (8th graders) when compared to younger children (6th graders). The time-motion analysis indicated that although the 8th graders, when compared to the 6th graders, spent less time preparing for the class, they were more often inactive in class and recorded much less time with a heart rate above 170 $bts.min.^{-1}$. Variations in heart rate responses may have occurred because of the different muscle masses employed in the physical education lessons. The authors (1986) concluded that "..the physical education lessons did not provide an activity level that was sufficient to improve the fitness of the children."

It appears somewhat ironic that high levels of activity are not commensurate with the level of intensity required to produce training effects. Vines (1988) quoted a study conducted by Armstrong where the heart rate responses were monitored in 500 children aged between 11 and 16 years of age. The subjects' heart rates were recorded in natural activity over 12 hours for 5 days. Less than 120 $bts.min^{-1}$ was classified as low intensity and above 160 $bts.min^{-1}$ as high intensity. None of the children's data fulfilled the established criteria for aerobic fitness improvement of approximately 20 minutes of high intensity activity 3 times per week. Only 6% of the boys, (and none of the girls), achieved even three high intensity levels of 10 minutes duration in one week. Armstrong (in Vines, 1988) then lowered the definition for high intensity to 140 $bts.min.^{-1}$. Again the results demonstrated that none of the observed children had participated in 3 sessions for the desired duration of a 20 minute session over the 5 days. When the lowered level for high intensity was applied to three sessions of at least 10 minutes duration for a week, the percentage of boys and girls who met this criteria was still remarkably low (34 and 3% respectively).

Relatively high heart rate intensities are reported in studies of responses during racket sports in adults. Friedman et al., (1984) reported consistent game intensities of 60-70% of predicted heart rate maximums (%HR max) during singles tennis games of middle aged men. In racket ball players, singles when compared to doubles, recorded significantly higher percentages of the maximal heart rate reserve (ie. 83% and 76% HR max reserve respectively) (Morgans et al., 1984). Squash players recorded high steady state heart rate plateaus within the first 10 minutes of play and thereafter revealed very minor fluctuations (Beaudin et al., 1978, Blanksby et al., 1973). Elliott et al., (1985) reported that the mean heart rate in competitive singles games of tennis of college-level players was 152 $bts.min.^{-1}$ (corresponding to approximately 80% HR max). The authors also noted significantly higher heart rates during the recovery periods between the rallies rather than in the rallies themselves. An additional significant difference was noted in the higher heart rates in serving than in receiving components of the game.

Mc Ardle et al., (1971) conducted a study into seasonal improvements in cardiorespiratory fitness in the basketball games of young college females. Significant changes in VO_2 max ($ml.kg.^{-1}min.^{-1}$) did not occur over the season although the mean game intensities were reported to be between 81% and 95% VO_2 max. Mc Ardle et al., (1971) postulated that non-significant fitness improvements occurred because, in contrast to the high game intensities, training sessions were only moderatley demanding. It was also suggested that heart rate intensities recorded in women's basketball reflected more of the emotional state of the player (eg. high pre-match heart rates) and, or the position played on the court, rather than direct aspects of play (Mc Ardle et al., 1971, Ramsey et al., 1971). Alexander et al., (1988) reported significant differences between the defenders and the forwards in the ice-hockey type game of ringette in females, aged 13-14 and 15-17 years. Mc Ardle et al., (1971) reported that within the same 6 player game of women's basketball, the averaged heart rates for guards was 154 bts.min.$^{-1}$. and the averaged heart rates for 'rover' type of player was 195 bts.min^{-1}. Thus it appears that heart rate indices can be immediately indicative on the nature of training, and competing and reflective of the long term effects of both.

There is a dearth of research studies specifically assessing the exercise intensities of children in sport using heart rate telemetry. Paterson et al., (1977) conducted a study on twenty-eight 10 year old boys from two different ice-hockey leagues ie. one league where the rules were quite stringent and competitive and the other league with more leniant, recreational type rules. The boys had their heart rates monitored during competition and the absolute mean heart rate was in excess on 180 bts.min.$^{-1}$ in all of the boys in both leagues. Mean "on-ice" exercise intensities for the competitive and recreational leagues were 81 and 89% of maximal aerobic power respectively. Strenuous near maximal bouts of play averaged three minutes duration. The study reported that there was a higher energy demand on the recreationally based league players than the competitive league players. In contrast to the recreationally based league, the competitive league was visibly faster, more skill efficient and players displayed a superior level of discipline. The combination of these observations was suggested as being highly related to the decreased aerobic intensity of the competitive league when compared to the recreational league (ie. the competitive league players were more efficient). Hanson (1968) used heart rate telemetry on North American Little League baseballers aged form 9 to 12 years and reported that the time spent by players being "physically active" in a one and one half to two hour competition, failed to promote any training effect in the children. The study concluded by questioning the value of the "very minor cardiovascular experience" of Little League baseballers, if it was replacing time that would normally be spent by children engaging in more active natural play activites.

Although these studies have provided some information on the effect of long-term exercise on children, they have little relevance to the Australian situation. The reviewed studies have been studies in which sports examined are largely unpopular with Australian children and are totally dissimilar to traditional Australian sports. It is apparent from the lack of published literature that there is a need for research to determine the imposed physiological stresses in sports in which children in Australia participate. Furthermore, there is a distinct dearth of literature which has examined the training effects of both game and practice situations over a full season.

Section summary

1. A wealth of literature is available on the heart rate intensity and training effects of adults participating in sports of a wide variety. There is a dearth of this type of literature available and applicable to children participating in sport in Australia.

2. There is a need to adopt portable heart rate devices to monitor children under the most inobstrusive circumstances and within environments which are largely familiar to them.

3. Low intensity heart rates in children have been recorded in normal physical education classes and natural playing conditions.

4. High intensity heart rates have been reported in pre-adolescent children playing games of ice-hockey. Little is known about the intensity of training and competitive conditions under which children participate in popular sports in Australia.

CHAPTER 3

METHODOLOGY

This chapter describes the research design, the subjects, the general and specific data-collection procedures under laboratory and field conditions and the statistical design treatment of the data.

a. Research Design

An 'observational' research design was employed in the study as the researcher neither manipulated nor experimentally controlled the independent variables of the study.

Forty children (males and females) from four different sports (badminton, basketball, netball and tennis) and a control group volunteered to serve as subjects for the study. The study required examining the subjects throughout a 12 week season's participation in the various sports. The following measurements were obtained on each subject at times corresponding to pre-season, mid-season and post season: selected anthropometric measures, a continuous grade incremental max VO_2 treadmill test, selected strength and flexibility measures and a cycling test for anaerobic characteristics. On at least two randomly selected occasions, heart rate and time analysis data were collected from subjects under competitive game and practice conditions. Three skills tests designed specifically for each sport, were administered at practice sessions at times which coincided with the three laboratory visits.

b. Description of subjects

The study involved forty children aged from 9 through to 13 years of age. There were four sporting groups and one control group. Children were assessed on a scale of biological maturation (Tanner, 1962). On a five point scale of maturation the average rating was two. Children of four or more on the scale were not included in the study. Eight pre-adolescent children were selected by state or district sporting associations as a representative sample of their junior players, ie. basketball, netball, tennis and badminton. Criteria for selection in each sport was that the children were regarded as well advanced competitors for their age and that they belonged to the same training group. The selection criteria for the control group accepted pre-adolescent children who engaged in normal school activities, including physical education, but excluded those children who had engaged in any systematic athletic conditioning in the preceeding twelve months. Informed medical consent was gained from the parents or guardians of the children after the nature of the study and any inherent risks had been fully explained to them..

c. General description of tests conducted in the laboratory

Within one week of the commencement of season's practices, the children came to the Exercise Physiology Laboratory at the Footscray Institute of Technology for a familiarization visit. Within the two following days, the children returned to the laboratory. During this session, the children's physiological profile was assessed. The battery of tests which was used in the physiological profile included aerobic capacity, anaerobic power and capacity, strength, flexibility and morphological measurements of skinfolds, mass, height, girths and widths.

d. Specific data collection procedures conducted in the laboratory

Aerobic capacity (VO_2 max) was assessed using a modification of the treadmill protocol established for children by Paterson et al., (1981). Each child performed a six minute warm up on the treadmill at a speed of 130 $m.min^{-1}$ and at 0% grade elevation. After the warm up, the child was prepared for on-line data collection and 3 minutes of resting data was monitored. The children then walked/jogged on the treadmill in a sequence of three minute continuous work bouts at 4 $kpm.hr^{-1}$, 6 $kpm.hr^{-1}$ and 8 $kpm.hr^{-1}$. At this point in the test 2.5% grade elevations were imposed every two minutes until volitional exhaustion. The usually accepted VO_2 max criterion of a plateau with increasing work settings, was considered inappropriate for use with children (Paterson et al., 1981). Volitional exhaustion points were therefore comparatively more difficult to judge than the practiced criterion with adults. The VO_2 tests were conducted using an on-line open-circuit spirometry system. Expired air volume was collected whilst the subect breathed through a Hans Rudolph 2 way valve connected to a Pneumatic digital spirometer. Sampled expired air was analysed for O_2 and CO_2 content by Applied Electrochemistry Analysers. Calibration of the analysers preceded each test (C.I.G. Melbourne, Analytical Grade Gas). An IBM PC linked via an A to D converter calculated the data directly from the preceding instrumentation.

Anaerobic characteristics were assessed using the Wingate test based on the protocol of Cumming, (1973) and Bar-Or, (1987). The tests were performed on a Monark bicycle ergometer, in which one pedal revolution equalled 6 metres at the perimeter at the flywheel. Standardized throughout the test were; the warm up, the nature of external motivation, the pedal crank length and the use of toe stirrups (Bar-Or, 1987). A warm up preceded each test by three minutes. It consisted of cycling at low intensity, and was interspersed by 4-5 all out practices of sprints for approximately 5 seconds to rehearse the testing resistance. Following the warm up there was a three minute rest before the commencement of the test. The test required the child to pedal for thirty seconds with an all out supramaximal effort against a resistance of $0.075kp.kg.^{-1}$. In order to record anaerobic capacity, there was a photointerrupter connected to the wheel of the Monark bicycle ergometer. The photointerrupter provided a pulse stream that had a frequency which was dependent on the revolution rate of the wheel. These pulses were converted into an analog signal and printed out from the computer. Subjects were instructed to avoid a "pacing effect" and maintain a supramaximal effort throughout the test. The data collected provided an indication of peak power which was calculated from the greatest mechanical output at any 5 second interval of the test. It also demonstrated mean power from the averaged mechanical output over the entire 30 seconds (Inbar and Bar-Or, 1986).

Anthropometric data collection included body mass, height, girths, widths and skinfolds. Body mass was assessed when subjects were seated on chair on the Sauter Electronic scales ($\pm$ 5 grams) model E1200. Subjects were barefooted and wore the tee shirts and shorts in which they performed their tests. The children were required to sit as stationary as possible and the mass was recorded to the nearsest 0.001 kg. Height was measured using a rigid metric measuring ruler, attached to a wall and a wooden set square. Subjects were barefooted. They were required to place their heels together and against the wall, with buttocks and head also touching the ruler. The children were requested to place hands on their hips and take a deep breath during the actual measurement. In accordance with the protocol used in the Australian Schools Fitness Study (1986), the head was raised gently by applying a lift on the mastoid process at the sides of the head. The set square was lowered to the head and pressed against the ruler on the wall. Height was recorded to the nearest 0.1 cm.

Girths of the appendicular skeleton were measured with a teflon anthropometric tape on the right side of the body. Three blind measurements were taken at each site to ensure measurement reliability and accuracy. The specific girth measurement sites were; the upper arm, the forearm, the waist, the hips, the thigh and the calf. The girth of the upper arm was recorded as the maximum circumference available when the right arm was flexed. The forearm circumference was measured on the right arm with the hand supinated. In taking the waist girth the tape was placed at the minimum circumference of the trunk waist. The tape was placed around the hips at the level of the greater trochanter. The thigh circumference was taken just below the gluteal furrow. Measurement of the calf circumference occurred over the maximal protusion of the gastrocnemius when the body mass was supported on the right leg.

Skeletal widths were measured at the shoulders, hips, elbow, knee and wrist using a Harpendon (UI-Uc) anthropometer. The width of the shoulders (biacromial) was measured as the distance between the lateral projection of the acromial processes. The hip (biiliocristal) width was taken as the distance between the lateral projections of the iliac crests. The elbow (humeral epicondylar) width was measured as the distance between the condyles of the humerus with the elbow flexed and hand supinated. The wrist width was the distance measured between the styloid process of the radius and the ulna. The knee (femoral biocondylar) width was recorded as the distance between the condyles of the femur with the knee flexed at a 90^{o} angle.

The following *skinfolds* were recorded at five sites on the right side of the body, using a set of Harpenden caliphers. The tricep skinfold was a vertical fold taken at the mid-point between the acromion and olecranon processes on the posterior side of the arm. The bicep skinfold was a vertical fold and was obtained midway between the acromion and the insertion of the biceps tendon. The subscapular skinfold was an oblique fold and was taken one centimetre below the inferior angle of the scapular. The mid-abdominal skinfold was a vertical fold which was taken one centimetre from the umbilicus. The suprailiac skinfold was an oblique fold and was measured from the top of the iliac crest on the mid-axillary line. All measurements were marked prior to the testing and were taken to the nearest 0.1 mm and the mean of three trials was the final score (Behnke and Wilmore, 1974).

Strength characteristics were assessed at three sites of the appendicular skeleton; the arms and shoulders, the wrist and the leg. Dominant and non-dominant grip strength were assessed using a Smedley's adjustable dynamometer (serial no. 68420). Scores were recorded to the nearest kilogram. During the grip strength test, the subjects stood erect, holding the dynamometer in one hand, at an oblique angle to the opposite shoulder. Three trials were conducted for each hand. Subjects were instructed to squeeze the dynamometer with a maximal effort. (Clarke, 1976 and Clarke and Munroe, (1970). The muscle groups of the arm and shoulder were similarly assessed using a push and pull shoulder dynamometer (serial no. 1620) The subjects were instructed to stand erect and hold the dynamometer with both hands, at the level of the nipples. The child was required to provide a maximal effort while firstly pulling outward, then secondly pushing inward on the dynamometer. Of three trials, the best score was recorded as the final score. Verbal encouragement was provided during the tests. Leg strength in each leg was assessed using a Cybex isokinetic dynamometer (Lumex Inc N.Y.). The child was seated in the Cybex chair and was secured with a seat belt and a strap to immobalise the thigh. With smaller children, it was necessary to use additional back support so that the the child was seated forward enough for the knee position to be correctly aligned. The fulcrum of the apparatus was aligned with the centre of the child's knee joint. The length of the lever arm was adjusted so that the child's foot rested comfortably in the foot plate. The child's ankle was strapped securely to the lever arm. The test began with the knee in 90^{0} flexion. The child was then instructed to complete three continuous knee extension-flexion sequences through a full range of motion at maximal effort. Three trails were conducted with the Cybex lever arm set at 60^{0} per second. A one minute rest period was allowed for recovery between each successive test. The peak torque achieved during flexion and extension was recorded from a graphical readout on a Cybex II Dual Chanel Recorder. For each leg, the results were recorded in absolute terms (ft.LBS.) and as the ratio of the hamstring to quadracep strength.

Flexibility was measured from three selected tests. They were used to assess the range of motion at three joints of the body. Trunk forward flexion was assessed using the sit and reach apparatus and protocol of Coonan and Dwyer (1983), and the Australian Schools Fitness Tests (1986). After three minutes of a stretching warm up, the child began the test seated on the floor with the legs fully extended and against the testing box. The child then reached forward as far as possible along a metre ruler attached to the box. The score was recorded when the furthest stretch was held for two seconds without bouncing or jerking. Hip flexion was measured with the use of the goniometer. The immovable and the movable arm of a goniometer were applied as closely as possible in line with the mechanical and functional axes of the right leg. The centre of the goniometer remained level with the greater trochanter of the head of the femur. The movable arm tracked the motion of the right leg as it was raised stretched up and over towards the body as far as possible. The movable arm recorded the degree of motion possible from the original, resting midline of the thigh. Lower back flexibility was assessed from a test devised by Weber (Mathews 1978) for lower back flexion/strength. The child lay prone on a firmly padded bench with the hands clasped behind the neck. An assistant tester held the child's ankles securely. The subject was encouraged to raise his/her chin as far up as possible from the bench. The distance between the lowest point of the mandible and the bench was measured to the nearest 0.1 cm. The best of three trials was recorded as the final score.

The battery of aforementioned tests was administered three times. The children visited the laboratory at the start of the season, 8 weeks into the season and within 5 days of the completion of the season of 12 weeks duration. Each testing period was conducted over two sessions which were not any more than 5 days apart. The anthropomertic, strength, flexibility and anaerobic tests were conducted on the first day and the aerobic capacity test was performed on the second day.

c. General description of tests conducted in the field.

In order to investigate the relative intensities of game stresses of children participating in the four selected sports, it was necessary to collect data in the field as well as the laboratory. Heart rate data was collected from all subjects in the sporting groups under both practice and field conditions. Specific skill tests were also conducted in field situations in an attempt to attain a gross estimate of skill performance changes that may have occurred over the season. In addition to this information, a time analysis of time spent actually 'being active' was also recorded.

d. Specific description of tests conducted in the field.

Practice and competitive game heart rates were monitored regularly throughout the season in order to determine both the stresses incurred by the heart and the corresponding exercise intensities. Data collection in the field involved the monitoring on heart rates from a Sports Tester PE-3000 Monitor (Polar Electro Ky). The monitor was initiated by the ECG signals of the heart being picked up from 2 electrodes in a belt which was worn by the subject in alignment with the subxiphoid and V5 positions. The ECG signal was sent via telemetry from the electrode belt to the microcomputer receiver worn as a wrist watch. Records of the actual heart rates were computed every 15 seconds over 20 minutes of activity and stored in a memory capacity in the wrist device. The memory was then recalled and printed out on a portable computer system (Sports Tester PE 3000 Training System and Printout). At the completion of each minute of activity in both games and practices, the nature of the preceding activity was annotated. A stop watch was also used to record the actual time spent being "active" in a game or practice session.

Skill tests were also conducted in the field. At time intervals corresponding to the start of the season, 8 weeks into the season and the completion of the season, specific performance skills in each sport were tested. These tests were designed after direct consultation with each of the four coaches and modifications to documented tests were often made as a result of this process.

The badminton tests were adapted from the Hicks Badminton Tests, (in Barrow and Mc Gee 1979). The first measurement was a long serve test. The purpose of this test was to measure the accuracy of the long high serve. Ten new cork-tipped shuttlecocks and a plastic sheet with target zones painted on it were required for this test. The target was attached to the right side of the intersection of the centre line and the base line. The examiner stood close to the target area to record the score. The player was instructed to stand in the right hand side on one half of thecourt and serve high and long into the target zone which was in the opposite right service court for singles games (Appendix A {1}). Ten warm up serves were provided and were followed by two minutes of rest before the actual serving shots were tested and recorded. The score was recorded as the numerical value of the area for which the shuttlecock first landed.

The clear shot test was designed to test a player's ability to return the shuttlecock quickly and successfully into a desirable area of the court. The required equipment was ten shuttlecocks and the division of one end of the court into target zones (Appendix A {2}). The player being tested stood in the half of the court which was opposite to the target, on the centre service line, 3.2 metres from the net. The "feeder" stood at the intersection of the short service line and the centre service line, on the same side of the net as the target. The setting up shot from the "feeder" had to be high and had to be going into the area beginning 4.1 metres from the net and extending to the base line. The "feeder" could hit randomly i.e.

to the left, right or middle of the court. To score points, the player had to return a clear shot into the target zone. Ten warm up shots were followed by two minutes rest before ten shots were scored. The areas A, B and C were scored 3, 4 and 5 respectively.

The third test was a test of the smash shot. The purpose of the test was to measure a player's ability to return a set up smash shot quickly and accurately into a desirable area of the court. Ten new corked-tipped shuttle cocks were used in the testing. Target zones can be observed in Appendix A {3}. The player being tested stood in the centre service line, 3.2 metres from the net. The "feeder" stood in the opposite and targeted side of the net at the intersection of the short service line and the centre service line. The setting up shot from the "feeder" had to be high and had to be going into the area beginning 4.1 metres from the net and extending to the baseline. The "feeder" could hit randomly to the left, right or middle of the court. To score points, the player had to return a smash shot into the target area. The examiner stood close to the target area. Ten warm up shots were provided and this was again followed by two minutes rest before the smash shots were scored and recorded. Areas diagrammed as A, B, C and D scored 3, 5, 4 and 1 respectively.

The basketball skills tests were adapted from the Harrison Basketball Battery (Barrow and Mc Gee 1979). The first test was a field goal test. The purpose of the test was to measure basketball field goal shooting ability under the stress of time. One basketball, one regulation goal ring and backboard and one stop watch were required for this test. The players were instructed to shoot the ball at the goal in any way, from any distance starting close under the goal. Ten practice shots were allowed, followed by a 2 minute rest. The player then was given two 30 seconds trials where one point was scored for each successful basket. The better of the 2 trials was counted as the player's final score.

The players were also given a speed pass test. The purpose of this test was to measure the speed of passing a basketball under the stress of time. The required equipment was a basketball and a line drawn 2.4 metres from the wall. The player was instructed to pass the ball using any pass, against the wall. The player had to remain behind the 2.4 metres line to throw and receive the ball. A warm up of ten throws was provided. Following a 2 minute rest the better score of two 30 second trials was recorded with one point being counted each time the ball hit the wall.

The final basketball test was a dribbling test. The purpose of the dribble test was to measure skill and speed of dribbling a basketball against the stress of time. The required equipment was a basketball, a stopwatch and 5 large witches caps. The lay out of the witches caps is presented in Appendix A {4}. The player was instructed to dribble the ball alternately passing to the right and to the left of the witches caps placed in a line 3 metres apart on a 12 metre course. The object was to pass as many witches caps as possible in 30 seconds time. Two trial runs were provided; one at walking pace and one at a jogging pace. This was followed by a two minute rest before the better score of two trials was recorded. One point was scored each time the midpoint of an obstacle was reached.

The netball tests were adapted from Plaisted (unpublished thesis, 1988). The first test was designed to test the accuracy of a one handed shoulder pass on the dominant and non-dominant sides of the body. The player stood 3 metres from a wall target, which was placed 57 centimetres from the ground. The target consisted of an inner circle (24.5 cm in diameter) and an outer circle (54 cm in diameter). Players were encouraged to aim for the centre of the target and to step forward with the opposite foot when using one arm to pass Two warm up shots were given for each arm. Scores ranged from 1 to 4; the score of 1 for a totally incorrect technique, the score of 2 for correct technique but a missed target, the score of 3 for correct technique and the outer circle and a score of 4 for correct technique and the inner circle.

Dodging (i.e. attacking) was assessed for accuracy against the stress of time. The player was required to dodge around 3 obstacles by pushing off from the outside of the outside foot as each obstacle was passed (Appendix A {5}). At the fourth obstacle, the player had to catch the ball that was thrown ahead by an assistant (using a one handed firm pass). At this point the player had to stop and was not allowed to step with the ball. Scoring ranged from 1 to 3. A score of 1 was recorded if all techniques were incorrect. A score of 2 was recorded if the player only dodged correctly and a score of 3 was recored for correct dodging, catching and landing techniques. Additionally, if the dodging skill was correctly executed the time taken to complete the task was noted as the final score.

The shooting goals test was designed to measure the accuracy of the players. Standing 1.5 metres from the goal post, the player had three shots at goal. The player was required to release the shot from head height or above. Two minutes rest followed 3 warm up shots. A score of one point was recorded for each successful goal.

The tennis tests were desgined specifically from a discussion with the district tennis co-ordinator for junior tennis squads. The serving test had a purpose of measuring the effective placement of the first service in tennis. The serve was delivered from the player's dominant side of the baseline of the court into the target zones created in the service area the opposite side of the court (Appendix A {6}). The target zone was a rectangular shape, bordered by a horizontal line one metre from the base of the service line, towards the centre of the court. Within the rectangle, there was a further division into three equal parts. Ten practice shots were required from each player. Three minutes was then provided as a recovery time. Ten serves were then scored and recorded. A score of 3 was given in the area closest to the centre line. A score of 2 was recorded for serves landing in the outer zone of the target area and a score of 1 was given to serves landing in the centre zone. The players were encouraged to approach each shot as a first service.

Forehand and backhand rally tests were devised to measure the placement skills of players into the far back corners of the singles court. Plastic targets with 4, quarter circles painted 1 metre apart were placed into the right angle made by the baseline and the singles sideline of the court (Appendix A {7}). A 'feeder' stood close to the net with a basket of tennis balls. The player stood approximately 1.5 metres in from the baseline and initially in the centre of the court. The player was instructed to return the set shot on the same side of the court to land in the target zone. Ten practices on both the forehand and the backhand side were given. This was followed each time by 3 minutes rest before ten scoring shots were attempted. Ten forehand shots preceded ten backhand shots. The feeder set the shot to the side of the player. The player was required to move from the centre of the court each time to the side of ball placement where he attempted to return it into the target zone at the other end of the court. Scoring 3 points meant that the ball landed inside the target's circle which was closest to the right angle of the baseline and the sideline. A score of 2 points was given when the ball bounced between the inner and the middle circle. A score of 1 point was recorded if the player's rally shot bounced between the middle circle and the outer circle.

e. Statistical design and treatment of data.

Analysis of various methods were used in three ways with the data collected. Firstly, to compare the data from the control group with the combined data from the four sporting groups, secondly to compare the data from each individual group with the data from the control group and thirdly to determine intra-group differences for each of the five groups over the season's duration.

The Biomedical Data Package (BMDP, 1985) was used to analyse the results. Both univariate and multivariate tests were conducted within a repeated measures design. One and two way analyses of variance were used to compare the difference in dependent variables between and within groups, with a repeated measure on the time factor. A one-way analysis of variance was used to determine if any significant differences existed within the individual groups comparisons over time. The risk of obtaining a type one error with univariate analysis is acknowledged ($p < 0.05$) (Keppel and Sautley, 1980).

In factorial design, the presence or absence of a significant interaction was an important issue. When an interaction was significant, an analysis for simple main effects was conducted. Simple main effects analysis consisted of the effects of the grouping variable (sport) being considered separately at each level of the season (i.e. pre-season, 8 weeks into the season and at the completion/12 week mark of the season).Whenever the interaction was insignificant, the focus of analysis became the main effects. The main effects analysis consisted of an examination of the effects that the grouping factor (i.e. sport) had over the season (time) on a given dependent variable. An insignificant interaction meant returning to the factorial design for two separate single factor analyses and that the variable need not be considered in the light of the combined effects of time and sporting group.

In addition to the aforementioned analysis the co-variate of weight was introduced into the analysis of the dependent variable of gross efficiency between groups and within groups over time. In so doing, there was an examination of the degree to which weight and efficiency varied together (co-varied) i.e. to check whether or not the magnitude of the changes in efficiency were similar to the magnitude of changes in weight, from the beginning of the season to the end of the season.

There was also a need to estimate VO_2 from the heart rates collected in the field. An assumption was made that the responses of children were similar to adults, ie. that there was a linear function underlying the relationship between oxygen uptake and heart rate during steady state incremental work on the treadmill. A prediction equation for each individual was determined from the laboratory data which was obtained closest to the time of their field data collection. This equation was used to determine the intensity at which the children were participating in practices and games over the season's duration. The data collected in the field was also treated statistically using univariate factorial analysis. This was conducted to determine whether or not there was a significant interaction between the sporting group's practice and competitive game intensities and the time of participation (i.e. time was divided into 5 minute intervals for the 20 minutes).

The alpha level of 0.05 was adopted for all statistical appraisal.

CHAPTER 4

RESULTS

The results will be presented in two major sections; laboratory data results and field data results. Under the laboratory data section, the following perspectives will be presented; descriptive data, maximal effort data, anthropometric girth data, anthropometric width data, skinfold data, upper body strength data, lower body strength data, anaerobic characteristics, and submaximal effort data. Whilst in the field data section, results will be described in terms of absolute and relative intensities of participation. The field data section also includes specific sports skills tests and an analysis of the fraction and percentage of time spent "being active" within the participation time.

Section A: Results of Laboratory Testing

1. Descriptive Data

The descriptive data of each group is provided in Tables 4.1 and 4.2 and in Appendix B (1 to 4). Table 4.1 contains the descriptive data from each individual group. Each group gained in body mass over the season's duration. The body mass changes over 12 week's data collection were significant in the basketball group (1.17 kg or 3.3%) and the tennis group (1.12 kg or 2.6%). Appendix B {1 to 4} indicates that changes in body mass over the season were non-significant when the control group was compared to individual sporting groups. Changes in the control group's body mass over the season, were also compared to a combination of the four sporting groups and were found to be non-significant (Table 4.2). When all five groups were examined, the mean gain in body mass over the season was 1.02 kg (2.4%). This gain was non-significant.

Height increased in all of the groups over the season with the exception of tennis. The magnitude of the growth which occurred in height, ranged from 0.68 cm (0.45%) in the tennis group to 2.51 cm (1.68%) in the control group (Table 4.1). A significant change occurred in height over the season in the analysis of the control group and the basketball group. The basketball group was significantly smaller in height than the control group. The simple main effects analysis which followed the significant interaction, identified a general significance of the influence of time in which changes in height between the control group and the basketball group were significantly different (Appendix B {2}). Non-significant differences were observed in height changes over the season when the control group was compared to a combination of all four sporting groups (Table 4.2). The mean height gain for all five groups over the 12 weeks of testing was a non-significant 1.68 cm (1.13%).

Table 4.1: Descriptive Data of all Five Groups of Pre-adolescents Over 12 Weeks

Group	Period	Mass (kg) X̄	(±S.D.)	Height (cm) X̄	(±S.D.)	Body Surface Area (m^2) X̄	(±S.D.)
Control	Pre	42.84	(14.22)	147.21	(8.85)	1.32	(0.25)
n = 8 males	8 weeks	43.51	(13.85)	148.93	(8.16)	1.33	(0.23)
11.25 yrs	Post	43.73	(13.67)	149.72	(9.12)	1.33	(0.23)
Badminton	Pre	43.13	(10.05)	149.63	(8.93)	1.33	(0.18)
n = 8 males	8 weeks	44.51	(10.03)	151.21	(3.03)	1.34	(0.19)
12.15 yrs	Post	44.41	(9.90)	151.80	(3.04)	1.36	(0.18)
Basketball	Pre	35.35*	(6.34)	140.55	(6.81)	1.18	(0.13)
n = 8 males	8 weeks	36.40	(6.93)	141.00	(7.03)	1.19	(0.14)
10.75 yrs	Post	36.53	(6.59)	141.86	(6.69)	1.20	(0.13)
Netball	Pre	40.21	(7.54)	143.32	(5.03)	1.25	(0.12)
n = 8 females	8 weeks	40.98	(7.25)	144.42	(4.26)	1.27	(0.12)
10.62 yrs	Post	40.86	(6.63)	145.05	(4.24)	1.27	(0.11)
Tennis	Pre	41.76*	(6.49)	152.58	(6.63)	1.33	(0.12)
n = 8 males	8 weeks	42.67	(6.45)	152.43	(7.20)	1.35	(0.11)
12.37 yrs	Post	42.88	(6.49)	153.26	(7.30)	1.35	(0.11)
Total Mean	Pre	40.66	(9.37)	146.66	(8.14)	1.28	(0.17)
	8 weeks	41.62	(9.30)	147.60	(8.22)	1.30	(0.16)
	Post	41.68	(9.10)	148.34	(8.21)	1.30	(0.16)

*significant differences within groups, $P < 0.05$

Table 4.2: Descriptive Data of the Combined Sports Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group X̄	(±S.D.)	Combined Sports Groups X̄	(±S.D.)	%	F Ratio
Age (yrs)		11.25	(1.03)	11.50	(1.34)	2.2	0.33
Mass (kg)	Pre	42.84	(14.22)	40.12	(7.95)	6.3	0.27
	8 weeks	43.51	(13.86)	41.14	(8.01)	4.9	0.22
	Post	43.71	(13.68)	41.17	(7.78)	5.9	0.16
Height (cm)	Pre	147.21	(8.85)	146.52	(8.09)	0.5	0.05
	8 weeks	148.93	(8.86)	147.27	(8.17)	1.1	0.23
	Post	149.72	(9.13)	147.99	(8.08)	0.5	0.24
Body surface area (m^2)	Pre	1.32	(0.25)	1.27	(0.15)	3.8	0.30
	8 Weeks	1.33	(0.23)	1.29	(0.15)	3.1	0.18
	Post	1.33	(0.23)	1.30	(0.15)	1.3	0.17

p* = probability of exceeding the F ratio when variances are assumed unequal

Body surface area changes over the season were significant in all within group analyses. The greatest change in body surface area occurred in the badminton group (0.03m^2, or 2.21%). The body surface area of the control group was 3.8% greater than the body surface area of the combined sporting groups at the start of the season, but only 2.3% greater than the sporting groups at the completion of the season. A non-significant 0.02m^2 (1.5%) gain in body surface area was reported over the season for all of the five groups.

A summary of the descriptive data indicates a homogeneous sample of pre-adolescent children. Generally non-significant differences were reported in between group comparisons of body mass, height and body surface area.

2. Maximal Effort Data

Within group comparisons in maximal aerobic consumption (ml.kg.$^{-1}$min^{-1}) over the season indicated significant improvement in the netball group only (3.5ml.kg.$^{-1}$min^{-1}, or 7.1%). During the season the control group and the tennis group recorded slight decreases in the VO_2 max (ml.kg.$^{-1}$min^{-1}), while the badminton, basketball and netball recorded slight gains in VO_2 max (ml.kg.$^{-1}$min^{-1}) [Table 4.3]. None of the individual groups differed significantly in VO_2 max (ml.kg.$^{-1}$min^{-1}) from the control group at any point in the season [Appendix B {5 to 8}]. At the start of the season the control group when compared to all four sporting groups had a 5.1% superior score in maximal aerobic fitness. By the end of the season this advantage had decreased to a mere 0.1% or 0.01 ml.kg.$^{-1}$min^{-1} [Table 4.4]. The mean gain in VO_2 max during the season for all 5 groups was a non-significant 0.36 ml.kg.$^{-1}$min^{-1} or 0.65%.

Heart rate at maximum effort (HR max) did not differ significantly in any of the groups during the season.Mean group HR max data ranged from 197 bts.min^{-1} (recorded as the mean HR max for the netballers at the start of the season) to 206 bts.min^{-1} (recorded as the mean HR max for the netballers 8 weeks into the season) [Table 4.3]. Non-significant differences were reported from a comparison of the HR max of the control group with each individual sporting group [Appendix B {5 to 8}]. Combined HR max data changes for all four groups when compared to the control group, differed by 0.05% at the start of the season to 0.001% at the completion of the season [Appendix B {5 to 8}]. The mean HR max gain for all 5 groups of pre-adolescent children was a non-significant 3 bts.min^{-1} (1.49%).

The respiratory exchange ratio obtained during maximal efforts (RER max) over the season changed non-significantly within all groups except badminton. A significant decrease of 0.10 (9.5%) in RER max occurred in the badminton group during the season [Table 4.3]. The comparison of the control group and the badminton group reported a significant interaction between their changes in the RER max over the season [Appendix B {5}]. Further analysis for simple main effects indicated that the significantly different period of testing occurred

Table 4.3: Maximal Effort Data Means of All Five Groups of Pre-adolescents Over 12 Weeks

Group	Period	VO_2 Max $ml.kg.^{-1}min^{-1}$ $\bar{X}$	(±S.D.)	Heart Rate Max $bts.min^{-1}$ $\bar{X}$	(±S.D.)	RER Max $\bar{X}$	(±S.D.)
Control	Pre	57.44	(11.43)	201	(10.44)	1.04	(0.09)
	8 weeks	57.15	(8.03)	204	(8.65)	0.98	(0.07)
	Post	55.47	(6.79)	201	(8.62)	1.04	(0.06)
Badminton	Pre	56.94	(4.32)	199	(6.67)	1.05*	(0.05)
	8 weeks	55.02	(8.33)	200	(8.64)	1.00	(0.05)
	Post	59.70	(5.01)	203	(8.19)	0.95	(0.03)
Basketball	Pre	55.82	(4.89)	201	(2.91)	0.97	(0.06)
	8 weeks	53.99	(6.58)	202	(6.06)	0.95	(0.02)
	Post	55.17	(5.54)	201	(5.14)	0.97	(0.10)
Netball	Pre	45.23*	(8.19)	197	(13.62)	1.00	(0.05)
	8 weeks	50.77	(8.47)	206	(7.60)	0.97	(0.04)
	Post	48.73	(7.67)	204	(7.89)	1.01	(0.06)
Tennis	Pre	60.02	(6.08)	201	(11.91)	1.06	(0.09)
	8 weeks	60.43	(4.95)	203	(13.89)	1.00	(0.05)
	Post	59.43	(5.89)	204	(13.92)	1.08	(0.05)
Total Mean	Pre	55.09	(8.72)	200	(9.52)	1.03	(0.08)
	8 weeks	55.56	(7.72)	203	(9.11)	0.98	(0.06)
	Post	55.45	(7.36)	203	(8.82)	1.01	(0.08)

* significant differences within groups $p < 0.05$

Table 4.4: Maximal Effort Data Means of the Combined Sports Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Combined Sports Group $\bar{X}$	(±S.D.)	%	F Ratio
VO_2 Max $ml.kg.^{-1}min.^{-1}$	Pre	57.44	(11.43)	54.51	(4.32)	5.1	0.47
	8 weeks	57.15	(8.03)	55.16	(7.71)	3.5	0.40
	Post	55.47	(6.97)	55.46	(7.56)	0.1	0.00
HR Max $bts.min.^{-1}$	Pre	200	(10.44)	201	(9.44)	0.05	0.12
	8 weeks	204	(8.65)	203	(9.34)	0.05	0.94
	Post	201	(8.62)	203	(8.97)	.001	0.26
RER Max	Pre	1.04	(0.09)	1.02	(0.07)	2.0	0.64
	8 weeks	0.98	(0.07)	0.98	(0.64)	0.0	0.00
	Post	1.04	(0.06)	1.00	(0.09)	3.9	2.24

p* = probability of exceeding the F ratio when variances are assumed unequal at the end of the season when the RER max of the control and badminton groups was 1.04 and 0.95 respectively (i.e. a difference of 8.7%). Changes in the RER max were non-significantly different when the control group was compared to a combination of all four sporting groups [Table 4.4]. There was a slight mean decrease of 0.02 (1.9%) in the RER max for all the groups throughout the season.

A summary of the data in the maximal effort tables again points to the homogenity of the groups participating in the study. Thus the between group differences in maximal aerobic potential were generally minimal.

3. Anthropometric girths data

Anthropometric data on the girths of the subjects are presented in Tables 4.5 and 4.6. Significant increases in the upper arm girths occurred within the badminton group (0.8 cm or 3.16%), the basketball group (0.56 cm or 2.33%) and the tennis group (1.03 cm or 4.14%) [Table 4.5]. The comparison of the upper arm girth of the individual sporting groups with the control group reported a significant interaction between the basketball group's and the control group's upper arm girths over the season [Appendix B {10}]. The simple main effects which followed, identified a general significance of the time factor over the season, between the magnitude of changes in the upper arm girth of the basketball and the control group. The upper arm girths of the control group did not differ signifanctly from a combination of all the sporting groups [Table 4.6]. The overall change in upper arm girths was a very marginal 0.01 cm for the season.

When changes in the forearm girths were examined within each group over the season, significant increases were reported in four of the five groups; control (0.84 cm or 3.7%), badminton (1.75 cm or 7.4%), netball (0.49 cm or 2.2%) and tennis (0.79 cm or 3.4%). Basketball was the only group without a significant gain in the forearm girth over the season [Table 4.5]. When changes in the forearm girth were compared between each individual sporting group and the control group, the only group which recorded significantly larger forearm girths than the control group was the badminton group. This difference was 6.3% at the 8 week testing period and had decreased to 5.7% at 12 weeks [Appendix B {9}]. Non-significant differences were reported in the forearm girths of the control group and a combination of all four sporting groups [Table 4.6]. When forearm girth changes over the season in all five groups were reported, there was an overall increase of 0.91 cm or 4.0%.

The abdominal girth increased in all groups. These changes were non-significant in all of the groups with the exception of the netball group. The mean abdominal girth for the netballers at the start of the season was 66.27 cm and completed the season at 69.4 cm (a 3.13 cm or 4.51% increase) [Table 4.5]. None of the sporting groups differed significantly in abdominal girths when compared individually to the control group [Appendix B {9 to 12}]. A combined group of

Table 4.5: Girth Measurements Profile of All Five Groups Of Pre-adolescents Over 12 Weeks

Group	Period	Upper Arm Girth (cm)		Forearm Girth (cm)		Abdomen Girth (cm)		Thigh Girth (cm)		Calf Girth (cm)	
		$\bar{X}$	(±S.D.)	$\bar{X}$	(±S.D.)	$\bar{X}$	(±S.D.)	$\bar{X}$	(±S.D.)	$\bar{X}$	(±S.D.)
Control	Pre	24.01	(4.0)	21.61★	(2.4)	69.11	(11.8)	45.43 ★	(8.4)	30.46	(4.3)
	8 weeks	24.29	(3.9)	22.05	(2.6)	69.43	(11.4)	44.16	(7.1)	30.65	(4.4)
	Post	24.00	(3.2)	22.45	(2.4)	69.74	(11.1)	46.03	(7.7)	31.10	(4.1)
Badminton	Pre	24.50 ★	(3.6)	22.00★	(2.8)	69.06	(7.6)	45.16 ★	(6.7)	30.25	(4.2)
	8 weeks	25.11	(3.4)	23.51	(2.9)	69.00	(6.1)	46.53	(5.5)	30.69	(4.1)
	Post	25.30	(3.2)	23.75	(2.9)	69.63	(6.1)	46.72	(5.7)	30.89	(4.0)
Basketball	Pre	23.51	(2.1)	21.06	(1.3)	64.31	(6.0)	43.12	(7.1)	28.62 ★	(2.8)
	8 weeks	23.55	(2.0)	21.52	(1.8)	64.96	(6.2)	43.43	(5.8)	28.65	(3.0)
	Post	24.07	(1.7)	21.76	(1.5)	65.85	(5.2)	46.65	(5.0)	29.61	(2.8)
Netball	Pre	23.83	(2.3)	21.51★	(1.2)	66.27 ★	(11.6)	45.93 ★	(4.6)	30.10 ★	(2.4)
	8 weeks	23.55	(2.0)	21.87	(1.3)	67.87	(9.5)	46.44	(3.6)	30.39	(2.6)
	Post	24.07	(1.7)	22.00	(1.3)	69.40	(9.1)	48.12	(4.4)	30.56	(2.5)
Tennis	Pre	23.83 ★	(2.3)	22.37★	(1.5)	67.38	(6.4)	44.20 ★	(4.2)	30.65 ★	(2.1)
	8 weeks	24.37	(2.5)	23.25	(1.7)	65.00	(14.0)	45.47	(4.9)	31.52	(2.0)
	Post	24.86	(2.5)	23.16	(1.9)	69.45	(6.9)	45.65	(4.9)	31.81	(2.0)
Total Mean	Pre	24.01	(4.0)	21.71	(1.9)	67.23	(8.7)	44.77	(6.1)	30.02	(3.2)
	8 weeks	24.29	(4.0)	22.44	(2.2)	66.25	(9.6)	44.21	(5.4)	30.38	(3.4)
	Post	24.00	(3.2)	22.62	(2.1)	68.81	(7.7)	46.04	(1.0)	31.10	(4.1)

★significant differences within groups, $P < 0.05$

the four sporting groups was reported to be non-significantly different from the control group in their changes of mean abdominal girth over the season [Table 4.6]. Overall a mean gain in abdominal girth for the five groups was a non-significant 1.58 cm (2.3%).

The thigh girths increased over the season significantly in four of the five groups. In the control, badminton, netball and tennis groups, the gain was 0.60cm (1.3%), 1.56 cm (3.3%), 2.19 cm (4.5%) and 1.45 cm (3.1%) respectively [Table 4.5]. When each sporting group's mean thigh girths changes over the season were compared to the control group's there was a significant interaction in three of the four analyses [Appendix B {9, 11 and 12}]. The comparison of the control group and the badminton group, the netball group and the tennis group all required simple main effects analysis. In each of these three analyses, the results of the simple main effects analysis indicated a general significance of the time factor on the magnitude of thigh girth changes observed in these three groups. A non-significant difference in thigh girth was reported in a comparison of the control group and a combination of all four sporting groups [Table 4.6]. A significant increase also occurred when all five groups were combined to examine thigh girth changes over time. The mean growth in the thigh girth of all five groups was a significant 1.27 cm (or 2.76%).

The calf girth increased significantly over the season in basketball (0.99 cm or 3.34%), netball (0.46 cm or 1.51%) and tennis (1.16 cm or 3.6%) [Table 4.5]. When each sporting group was compared individually to the control group, non-significant differences were observed [Appendix B {9 to 12}]. Similarly, when all four sporting groups, were combined together and compared to the control group, there was a non-significant difference in the changes in calf girths over the season [Table 4.6]. The five groups had a combined mean growth in their calf girth of a non-significant 1.08 cm (3.47%).

A summary of the anthropometric girth data results indicates significant girth increases; in the control group's forearm and thigh, in the badminton group's upper arm and calf, in the netball group's forearm, abdomen, thigh and calf and in the tennis's upper arm, forearm, thigh and calf. There appears to be considerable and consistent growth occurring in the girth measurements of all the pre-adolescent groups used in the study.

4. Anthropometric widths data

Width measurements began with the elbow. Basketball and netball players recorded significant increases in elbow width over the season (0.79 cm or 13.12% and 0.32 cm or 5.23% respectively) [Table 4.7]. There was a significant interaction in elbow width changes over the season when the basketball group was compared individually with the control group [Appendix B {14}]. The simple main effects which followed this finding, indicated that the significant changes in elbow widths between the two groups occurred at the start of the season (0.78

Table 4.6: Girth Measurements of the Combined Sports Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group X	(±S.D.)	Combined Sports Group X	(±S.D.)	%	F Ratio	P
Upper Arm (cm)	Pre	24.01	(3.96)	23.97	(2.53)	1.9	0.09	0.772
	8 weeks	24.28	(3.91)	23.96	(2.68)	1.4	0.05	0.826
	Post	24.00	(3.19)	24.40	(2.50)	1.7	0.11	0.747
Forearm (cm)	Pre	21.61	(2.39)	21.74	(1.83)	0.6	0.02	0.893
	8 weeks	22.05	(2.57)	22.54	(2.12)	3.2	0.25	0.629
	Post	22.40	(2.43)	22.67	(2.06)	1.2	0.05	0.819
Thigh (cm)	Pre	45.43	(8.37)	44.61	(5.61)	1.8	0.07	0.796
	8 weeks	44.16	(7.15)	45.47	(4.97)	2.9	0.24	0.637
	Post	46.04	(7.68)	46.04	(5.07)	0.0	0.00	1.00
Calf (cm)	Pre	30.46	(4.32)	29.91	(2.95)	1.9	0.12	0.739
	8 weeks	30.65	(4.45)	30.31	(3.08)	1.2	0.04	0.844
	Post	31.10	(4.12)	30.72	(2.88)	1.3	0.06	0.811
Abdomen (cm)	Pre	69.11	(11.48)	66.76	(7.97)	3.4	0.28	0.607
	8 weeks	69.43	(11.37)	66.71	(9.20)	4.0	0.40	0.545
	Post	69.73	(11.06)	68.58	(6.83)	1.7	0.08	0.785

p* = probability of exceeding the F ratio when variances are assumed unequal

cm or 12.9% difference). There was a non-significant difference in the elbow width of the control group when compared to the four sporting groups combined [Table 4.8]. When the five groups were analysed together for changes in elbow width over the season, there was a significant mean increase of 1.35 cm (5.58%).

None of the five groups were significantly different in the changes that occurred in the wrist widths over the season [Table 4.7]. Similarly when the changes in the mean wrist width of each group was compared to the control group, non-significant differences were apparent [Appendix B {13 to 16}]. There was a non-significant difference in changes in wrist width over the season when the control group was compared to a combination group of all the sporting groups [Table 4.8]. The five groups had a combined mean growth of 0.05 cm (0.98%) over the season.

Knee width increases were significant in the netball (0.33 cm or 3.5%) and the tennis (0.39 cm or 4.7%) groups [Table 4.7]. When the mean knee width changes were compared between individual sporting groups and the control group, there was a significant interaction in the netball and control groups' analysis [Appendix B {15}]. The simple main effects analysis indicated that changes in the knee width of these two groups were significantly different at the beginning of the season (ie. the knee width of the control group was 11.1% greater than the knee width of the netball group at the start of the season but the difference had been reduced to a non-significant 7.7% by the end of the season). An analysis of the knee width changes over the season in the control group and a group of the combined sporting activities indicated non-significant differences [Table

Table 4.7: Width Measurements of all Five Groups of Pre-adolescents Over 12 Weeks

Group	Period	Elbow Width (cm) $\bar{X}$	(±S.D.)	Wrist Width (cm) $\bar{X}$	(±S.D.)	Knee Width (cm) $\bar{X}$	(±S.D.)	Shoulder Width (cm) $\bar{X}$	(±S.D.)	Hip Width (cm) $\bar{X}$	(±S.D.)
Control	Pre	6.01	(0.5)	5.20	(0.5)	8.77	(1.0)	32.81 ★	(2.8)	23.73	(3.3)
	8 weeks	6.31	(0.6)	5.17	(0.4)	8.60	(0.8)	33.10	(2.8)	22.77	(2.1)
	Post	6.25	(0.5)	5.29	(0.5)	8.87	(0.8)	33.73	(3.0)	23.00	(2.2)
Badminton	Pre	6.22	(0.8)	5.17	(0.1)	8.72	(0.8)	33.83 ★	(1.6)	22.75 ★	(1.4)
	8 weeks	6.34	(0.3)	5.22	(0.2)	8.70	(0.7)	34.26	(0.5)	23.28	(1.2)
	Post	6.42	(0.4)	5.26	(0.1)	8.86	(0.7)	34.47	(1.7)	23.41	(1.2)
Basketball	Pre	5.23 ★	(0.2)	4.75	(0.2)	8.55	(0.3)	31.39	(1.5)	21.45	(1.2)
	8 weeks	5.87	(0.1)	4.89	(0.2)	8.55	(0.3)	31.61	(1.9)	21.66	(1.2)
	Post	6.02	(0.1)	4.84	(0.3)	8.57	(0.4)	31.81	(2.0)	22.04	(1.2)
Netball	Pre	5.80 ★	(0.3)	4.92	(0.3)	7.80 ★	(0.4)	32.46 ★	(2.3)	23.27	(2.9)
	8 weeks	5.85	(0.3)	4.94	(0.2)	8.16	(0.4)	33.26	(2.3)	23.15	(2.4)
	Post	6.12	(0.3)	4.91	(0.3)	8.19	(0.3)	33.62	(2.1)	23.12	(2.0)
Tennis	Pre	6.35	(0.4)	5.27	(0.2)	8.86 ★	(0.4)	33.46 ★	(1.5)	23.75 ★	(1.0)
	8 weeks	6.57	(0.3)	5.19	(0.3)	8.99	(0.4)	33.26	(1.6)	24.07	(1.1)
	Post	6.55	(0.1)	5.26	(0.3)	9.19	(0.3)	33.62	(1.8)	24.21	(1.0)
Total Mean	Pre	5.92 ★	(0.7)	5.06	(0.4)	8.54 ★	(0.7)	32.79	(1.9)	22.99 ★	(2.2)
	8 weeks	6.19	(0.4)	5.08	(0.4)	8.50	(0.6)	33.09	(1.8)	22.99	(1.2)
	Post	6.27	(0.4)	5.11	(0.4)	8.73	(0.4)	33.45	(2.1)	23.16	(1.6)

★ significant differences within groups $P < 0.05$

4.8]. The overall five groups' analysis also produced a significant change. The mean growth in knee width for the five groups over the season was 0.19 cm or 2.18%.

Table 4.8: Width Measurements Profile of the Combined Sports Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group X	(±S.D.)	Combined Sports Groups X	(±S.D.)	%	F Ratio	P
Elbow (cm)	Pre	6.01	(0.50)	5.90	(0.71)	1.9	0.25	0.623
	8 weeks	6.31	(0.61)	6.16	(0.45)	2.4	0.44	0.525
	Post	6.25	(0.53)	6.28	(0.39)	0.5	0.02	0.880
Wrist (cm)	Pre	5.20	(0.53)	5.03	(0.32)	3.3	0.75	0.412
	8 weeks	5.17	(0.46)	5.06	(0.33)	2.2	0.44	0.522
	Post	5.29	(0.47)	5.07	(0.38)	4.2	1.49	0.254
Knee (cm)	Pre	8.77	(1.00)	8.48	(0.64)	3.4	0.61	0.458
	8 weeks	8.60	(0.83)	8.52	(0.60)	1.0	0.06	0.815
	Post	8.87	(0.79)	8.65	(0.61)	2.5	0.55	0.478
Shoulder (cm)	Pre	32.81	(2.85)	32.79	(1.92)	0.1	0.00	0.982
	8 weeks	33.10	(2.81)	33.36	(2.09)	0.8	0.06	0.812
	Post	33.75	(2.98)	33.68	(2.18)	0.3	0.00	0.952
Hip (cm)	Pre	23.73	(3.33)	22.81	(1.92)	3.9	0.57	0.471
	8 weeks	22.77	(2.11)	23.04	(1.74)	1.2	0.11	0.746
	Post	23.00	(2.16)	23.20	(1.54)	0.9	0.06	0.813

p* = probability of exceeding the F ratio when variances are assumed unequal

Significant increases in shoulder width over the season occurred in four of the five groups [Table 4.7]. These differences were apparent in the control group (0.92 cm or 2.7%), the badminton group (6.4 cm or 1.8%), the netball group (1.16cm or 3.4%) and the tennis group (0.16 cm or 0.47%). None of the individual sporting groups had significantly different shoulder width changes during the season, when each was compared to the control group [Appendix B {13 to 16}]. A similar non-significant difference in shoulder width changes was reported when the control group was compared to the combined sporting groups [Table 4.8]. The mean increase in shoulder width over the season was a non-significant 0.66 cm or 1.97%.

Significant increases in hip widths over the season, were observed within the badminton group (0.66 cm or 2.8%) and the tennis group (0.46 cm or 1.9%) [Table 4.7]. Significant interactions were present in three of the sporting groups when compared individually to the control group [Appendix B {13 to 16}]. The simple main effects analyses which consequently followed may be summarised as indicating that the basketball group and the badminton group had changes in hip width which were significantly influenced by time. Conversly, the tennis group when compared to the control group had consistently superior hip widths over the season at each of the testing sessions. All four sporting groups were

Table 4.9: Skinfold Measurements of All Five Groups of Pre-adolescents Over 12 Weeks

Group	Period	Biceps (mm) $\bar{X}$	(±S.D.)	Triceps (mm) $\bar{X}$	(±S.D.)	Subscapula (mm) $\bar{X}$	(±S.D.)	Mid-abdomen (mm) $\bar{X}$	(±S.D.)	Suprailiac (mm) $\bar{X}$	(±S.D.)	Sum Of 5 (mm) $\bar{X}$	(±S.D.)
Control	Pre	9.86★	(5)	13.26★	(6)	12.92	(10)	16.27	(11)	13.72★	(10)	66.05★	(39)
	8 wks	7.52	(4)	11.99	(6)	11.61	(9)	16.21	(12)	10.41	(7)	57.75	(36)
	Post	6.35	(4)	11.42	(6)	8.86	(5)	14.62	(11)	9.81	(7)	51.07	(32)
Badminton	Pre	8.29★	(3)	14.57	(4)	7.25	(2)	13.45	(9)	7.81★	(7)	53.37	(25)
	8 wks	7.61	(3)	14.87	(5)	7.40	(3)	13.79	(10)	8.92	(6)	52.60	(26)
	Post	6.92	(2)	13.51	(4)	7.76	(2)	13.34	(9)	8.02	(5)	49.56	(21)
Basketball	Pre	6.80★	(3)	10.57	(2)	6.90	(2)	10.07	(5)	5.86	(2)	40.21	(13)
	8 wks	6.17	(3)	11.41	(4)	6.82	(3)	10.80	(7)	5.89	(3)	41.10	(18)
	Post	5.89	(3)	11.22	(4)	8.15	(6)	10.26	(7)	5.62	(3)	41.15	(21)
Netball	Pre	8.35★	(3)	13.64	(5)	10.96	(6)	14.69	(7)	10.24	(5)	57.87	(23)
	8 wks	7.37	(3)	13.31	(4)	11.72	(6)	16.30	(9)	9.91	(5)	58.62	(28)
	Post	7.49	(3)	13.24	(4)	11.56	(5)	15.47	(8)	10.96	(5)	58.74	(24)
Tennis	Pre	6.11	(5)	11.66	(6)	7.28★	(5)	9.04	(9)	5.77	(4)	39.87	(28)
	8 wks	6.14	(5)	12.04	(8)	6.75	(4)	10.30	(9)	6.60	(6)	41.82	(31)
	Post	6.77	(4)	12.09	(7)	7.40	(5)	10.59	(10)	7.77	(7)	44.62	(32)
Total	Pre	7.88★	(4)	12.74	(5)	9.06	(6)	12.70	(8)	9.08★	(7)	51.47	(28)
	8 wks	6.96	(3)	12.72	(6)	8.86	(6)	13.48	(9)	8.34	(6)	50.38	(28)
	Post	6.68	(3)	12.30	(5)	8.75	(5)	12.86	(9)	8.44	(6)	49.03	(26)

★ significant differences within groups, $P < 0.05$

combined and compared to the control group and non-significant differences in changes in the hip widths were reported. When the five groups were combined, the mean hip width increase was a significant 0.17 cm or 0.73%.

Table 4.10: Skinfold Measurements Profile of the Combined Sports Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group X	(±S.D.)	Combined Sports Groups X	(±S.D.)	%	F ratio	P
Biceps (mm)	Pre	9.86	(4.72)	7.34	(3.43)	25.6	1.94	0.197
	8 weeks	7.52	(4.19)	6.82	(3.23)	9.4	0.19	0.670
	Post	6.35	(3.99)	6.77	(2.97)	6.2	0.08	0.787
Triceps (mm)	Pre	13.26	(5.66)	12.61	(4.66)	4.9	0.09	0.770
	8 weeks	11.99	(6.30)	12.91	(5.70)	7.2	0.14	0.714
	Post	11.42	(6.03)	12.52	(4.71)	8.8	0.23	0.644
Subscapula (mm)	Pre	12.92	(10.33)	8.10	(4.28)	37.4	1.67	0.232
	8 weeks	11.61	(9.05)	8.17	(4.39)	29.7	1.09	0.327
	Post	8.86	(5.08)	8.72	(4.72)	1.6	0.01	0.944
Suprailiac (mm)	Pre	13.72	(9.65)	7.92	(5.09)	42.3	2.71	0.139
	8 weeks	10.41	(7.23)	7.83	(5.38)	24.8	0.90	0.369
	Post	9.81	(6.78)	8.10	(5.22)	17.5	0.45	0.521
Mid-abdomen (mm)	Pre	16.27	(10.70)	11.81	(7.54)	27.5	1.24	0.295
	8 weeks	16.21	(12.06)	12.80	(8.60)	21.1	0.57	0.470
	Post	14.62	(10.91)	12.42	(8.47)	15.1	0.28	0.606
Sum of 5 (mm)	Pre	66.05	(38.89)	47.83	(23.83)	27.6	1.61	0.240
	8 weeks	57.75	(36.16)	48.54	(26.06)	16.0	0.46	0.515
	Post	51.07	(31.87)	48.52	(24.77)	5.0	0.04	0.837

p* = probability of exceeding the F ratio when group variances are assumed unequal

A summary of the results of the significant changes in the width measurements indicates that the control group increased at the shoulder, the badminton increased at the shoulder and the hip, the netball group increased at the elbow, knee and shoulder and the tennis group increased in widths at the knee, hip and shoulder. None of the groups changed significantly in wrist width over the season.

5. Anthropometric skinfold measurements

Each one of the five groups' biceps skinfold changed significantly over time [Table 4.9]. Four of the groups'skinfold measurements at the bicep decreased significantly during the season; control (3.51 mm or 35.5%), badminton (1.37 mm or 16.52%), basketball (0.91 mm or 13.38%) and netball (0.86mm or 10.29%). There was a significant increase in the bicep skinfold of the tennis group over the season (0.66 mm or 9.7%). Three significant interactions were observed when the individual sporting groups were analysed individually with the control group for differences in the changes of the biceps skinfold over the season [Appendix B {17 to 20}]. Simple main effects analyses indicated that in the basketball and netball groups, significant differences in biceps skinfolds occurred with a general and significant effect of time (without any one specific testing period having greater changes between groups than other testing points). In the comparison of the tennis group and the control group, the simple main effects analysis indicated a significant difference in bicep skinfolds at the start of the season (i.e. a 38% greater mean score in the control when compared to the tennis group). The comparison of all four sporting groups to the control group demonstrated a non-significant difference in the changes of bicep skinfolds over the season [Table 4.10]. When all five groups data were combined there was a significant decrease accompanying a 1.2 mm (or 15.2%) change in the bicep skinfold measurements over the season.

Tricep skinfold measurements changed significantly in only the control group (ie. a 1.84 mm or 13.87% difference between the start and the end of the season [Table 4.9]. The tricep skinfolds of the individual sports and the control group reported two significant interactions [Appendix B {18 and 20}]. The basketball and the control group analysis reported a significant interaction in changes which occurred in the tricep skinfolds over time. The simple main effects computations failed to statistically recognise a specific point in time for these changes to have differed. There was however a 20.3% decrease in the tricep skinfolds of the basketball group when compared to the control group at the start of the season. Similarly, a non-specific influence of time for these changes in skinfolds to occur were reported following a significant interaction between the control and the tennis group. Although not statistically acknowledged, there was a 12.1% greater mean score of triceps skinfolds in the control group than the tennis group at the start of the season. Non-significant differences in tricep skinfolds were reported when a comparison of changes in the control group was compared to a combination of all four sporting groups [Table 4.10]. For all five groups, there was a mean decrease in tricep skinfolds of 0.44 mm or 3.34% over the season.

Subscapular skinfolds altered significantly only in the tennis group over the season (ie. a 0.12 mm or 1.65% decrease) [Table 4.9]. None of the individual sporting groups differed significantly over the season from the control group [Appendix B {17 to 20}]. When all four sporting groups' subscapular skinfold changes were combined for a comparison with the control group, the difference was non-significant over time [Table 4.10]. There was a mean subscapular decrease of 0.31 mm or 3.42% for all five groups of pre-adolescent children over the 12 weeks investigation.

Mid-abdominal skinfolds altered non-significantly in all five groups [Table 4.9]. Non-significant changes over the season were reported from comparison of the mid-abdominal skinfolds of the control group with the individual sporting groups [Appendix B {17 to 20]. Similarly non-significant differences were observed in the changes occurring in the mid-abdominal skinfolds of the control group and the combination of all four sporting groups [Table 4.10]. When all five groups were analysed together, there was a non-significant mean decrease in mid-abdominal skinfold of 0.16 mm or 1.24% over the season.

Suprailiac skinfold changes over the season were significant in the control group (a decrease of 3.91 mm or 28.49%) and the badminton group (a decrease of 0.21 mm or 2.61%) [Table 4.9]. In the comparison of each sporting group, individually with the control group there were three significant interactions (ie. in the analyses involving basketball, netball and tennis) [Appendix B {18 to 20}]. The results of the simple main effects analysis indicated pre-season differences between groups in suprailiac skinfolds to be of a significant magnitude in basketball and tennis groups when compared to the control group (ie the basketball and tennis groups recorded suprailiac skinfolds of 57.37% and 48.0% respectively less than the control in the pre-season tests. The simple main effects which analysed changes over time of the suprailiac skinfolds of the netball group when compared to the control group, failed to demonstrate the significant influence of time in the season. There was however a 25.4% difference observed between the netball and control groups in the pre-season testing values. The combined four sporting groups were non-significantly different from the control group in changes in the suprailiac skinfolds over the season [Table 4.10]. When the five groups data were analysed collectively, there was a significant change over the season in which there had been a 0.64 mm or 7.04% mean decrease in suprailiac skinfold measurements.

Only the control group recorded a significant within group decrease in the sum of the 5 skinfolds over the season (14.98 mm or 22.67%) [Table 4.9]. When each sporting group's sum of the 5 skinfolds was compared to the control group, significant interactions were reported in the basketball, netball and tennis groups [Appendix B {18 to 20}]. The simple main effects in which each of these three comparisons were made with the control group indicated a general difference of time between the groups' sum of 5 skinfolds over the season. Non-significant changes in the sum of the 5 skinfolds over time were reported from the comparison between the combined four sporting groups and the control group [Table 4.10]. There was a non-significant mean decrease (2.44 mm or 4.7%) in the sum of the 5 skinfolds over the 12 weeks testing period when all five groups were analysed together.

A summary of the skinfold measurement changes over the season indicated the greatest number of significant decreases occurring in the control group (biceps, triceps, suprailiac, and the sum of the five skinfolds). The control group was observed to carry the largest skinfolds when compared to the other four groups. The magnitude of the difference between the control and the four sporting groups was generally greatest at the start of the season. The badminton group decreased their skinfolds at two sites (biceps and suprailiac). The basketball and netball groups had decreased significantly at one site only (biceps). The tennis group was the only group to increase significantly at both the bicep and the subscapular sites.

6. Upper body strength

Changes over the season in the strength of the upper body are summarised in Tables 4.11 and 4.12 and Appendix B {21 to 28}. Dominant handgrip changes over the season were significant in the basketball group (an increase of 0.13 kg or 2.19%), the netball group (a decrease of 6.87 kg or 35.93%) and the tennis group (an increase of 3.13 kg or 15.65%) [Table 4.11]. When each sporting group was compared individually to the control group, the changes in the dominant grip strength of the analysis involving the netball group produced a significant interaction [Appendix B {23}]. The simple main effects analysis of the changes in dominant grip strength of the netball and control group indicated that the period of greatest difference was the 8 week testing session. At this time the control group was 37.5% stronger than the netball group. When the dominant grip strength scores were expressed relative to body weight, the comparison of individual sporting groups to the control group, indicated the presence of two significant interactions [Appendix B {27 and 28}]. The changes in relative dominant grip strength between the netball and the control group were again significant at the 8 week mark of the season. The changes in relative dominant grip strength between the tennis group and the control group were significant at the end of the season. At this point the tennis group had a 23.5% advantage in relative grip strength when compared to the control group. When the dominant grip strength scores of all four sporting groups were combined for a comparison with the control group, the difference was non-significant [Table 4.12]. The five groups recorded an overall slight decrease in dominant grip strength of 0.95 kg over the season.

Non-dominant grip strength over the 12 week season altered significantly in the same three groups that had experienced significant changes in the results of dominant grip strength [Table 4.11]. There was a significant within-group increase in the non-dominant grip strength changes in the basketball group (3.5 kg or 22.58%) and the tennis group (2.42 kg or 13.36%). There was a significant decrease over the season in the non-dominant strength of the netballers (3.56 kg or 20.87%). Individual sporting group comparisons with the control groups for changes in non-dominant grip strength over the season indicated three significant interactions [Appendix B {22 to 24}]. In the simple main effects analysis of the non-dominant grip strength of the basketballers, there was a significant difference between the groups at the 8 week testing period (a 16.1% advantage to the control group). The simple main effects analysis of the non-dominant grip strength of the netball players and the control group reported that the significant changes between the groups occurred specifically at the 8 weeks testing period and the post season testing period (ie. a 28.3% and 17.3% respectively, were the advantages in the grip strength of the control group). The simple main efffects

Table 4.11: Upper Body Strength Profile of All Five Groups of Pre-adolescents Over 12 Weeks

Group	Period	Dominant Hand Grip (Kg)		Non-dominant Hand Grip (Kg)		Arm & Shoulder Push (Kg)		Arm & Shoulder Pull (Kg)	
		$\bar{X}$	(±S.D.)	$\bar{X}$	(±S.D.)	$\bar{X}$	(±S.D.)	$\bar{X}$	(±S.D.)
Control	Pre	16.54	(3.30)	15.19	(3.15)	10.25	(6.15)	9.94	(4.39)
	8 weeks	17.37	(4.93)	16.37	(4.13)	10.62	(6.48)	8.62	(3.65)
	Post	15.12	(2.10)	16.31	(3.33)	12.50	(10.94)	11.62	(7.29)
Badminton	Pre	19.25	(4.60)	15.44	(6.25)	15.50	(4.86)	12.06	(4.37)
	8 weeks	17.85	(6.60)	17.44	(6.13)	16.50	(7.17)	13.56	(4.00)
	Post	19.37	(5.60)	18.37	(4.27)	17.87	(5.36)	14.50	(6.80)
Basketball	Pre	13.87★	(3.44)	12.00★	(3.45)	8.31	(2.99)	6.56	(2.60)
	8 weeks	12.00	(2.07)	13.75	(3.15)	7.81	(3.12)	6.37	(2.87)
	Post	14.18	(1.18)	15.50	(2.98)	7.37	(3.10)	7.75	(3.01)
Netball	Pre	19.12★	(2.76)	17.06★	(1.72)	5.00★	(3.77)	3.81	(2.20)
	8 weeks	10.87	(1.35)	11.75	(2.81)	10.87	(3.45)	7.06	(2.29)
	Post	12.25	(1.49)	13.15	(2.20)	11.87	(3.46)	8.84	(3.16)
Tennis	Pre	16.87★	(4.08)	15.69★	(5.28)	14.12★	(5.19)	12.19	(7.15)
	8 weeks	19.62	(3.67)	16.99	(4.77)	12.50	(5.09)	11.87	(6.61)
	Post	20.00	(3.07)	18.11	(3.83)	15.56	(5.80)	12.31	(7.14)
Total Mean	Pre	17.13	(2.20)	15.07	(1.86)	8.91★	(5.39)	10.64	(5.92)
	8 weeks	15.54	(3.36)	15.26	(2.42)	9.50	(4.90)	11.66	(5.80)
	Post	16.18	(3.36)	16.35	(2.00)	11.00	(6.04)	13.04	(7.04)

★ significant differences within groups, $P < 0.05$

Table 4.12: Upper Body Strength Profile of the Combined Sports Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group X	(±S.D.)	Combined Sports Groups X	(±S.D.)	%	F Ratio	P
Dominant	Pre	16.54	(3.33)	17.28	(4.23)	4.3	0.28	0.603
Hand Grip	8 weeks	17.37	(4.93)	15.09	(5.35)	13.2	1.32	0.272
(kg)	Post	15.12	(2.10)	16.45	(4.67)	8.1	1.43	0.242
Non-dominant	Pre	15.19	(3.15)	15.05	(9.70)	1.0	0.01	0.921
Hand Grip	8 weeks	16.37	(4.13)	14.98	(4.83)	8.5	0.68	0.426
(kg)	Post	16.31	(3.30)	16.37	(3.83)	0.4	0.00	0.966
Arm and	Pre	10.25	(6.15)	10.73	(5.96)	4.5	0.04	0.845
Shoulder	8 weeks	10.62	(6.48)	11.92	(5.70)	11.0	0.27	0.616
Push (kg)	Post	12.50	(10.94)	13.17	(5.94)	5.1	0.03	0.871
Arm and	Pre	9.94	(4.39)	8.67	(5.65)	12.8	0.48	0.499
Shoulder	8 weeks	8.62	(3.65)	9.72	(5.20)	11.4	0.48	0.500
Pull (kg)	Post	11.62	(7.29)	10.85	(5.81)	6.7	0.08	0.786

p* = probability of exceeding the F ratio when variances are assumed unequal

analysis on the non-dominant grip strength means of the tennis and the control groups indicated a significant 10% advantage in favour of the tennis groups compared to the control group at the post season testing. When the non-dominant grip strength was expressed in relation to body mass, and individual sporting groups were compared to the control group, there was a significant interaction between the the badminton group and the control group [Appendix B {25}]. The simple main effects analysis of the changes in the non-dominant grip strength of the two groups revealed an overall significance of the time factor, rather than any one specific testing time being significantly different from others. There was a non-significant difference in the non-dominant grip strength changes over the season in an analysis that compared the control group with all four sporting groups combined [Table 12]. The five groups had a non-significant mean gain in non-dominant grip strength of 1.28 kg or 7.8% over the season.

Arm and shoulder push strength over the season increased significantly in the netball group (6.87 kg or 57.88%) and the tennis group (1.44 kg or 9.25%) [Table 4.11]. When each sporting group was compared separately to the control group, there was a significant decrease in the changes in the arm and shoulder push strength of the analysis involving the netball group [Appendix B {23}]. The simple main effects analysis pointed to a general difference over time. However there was a statistically non-significant 51.3% advantage in the pre-season arm and shoulder push strength tests of the (male) control group when compared to the (female) netball players. The magnitude of the advantages that the arm and shoulder push strength had demonstrated at the start of the season had reduced to 5.1% by the end of the season. When the arm and shoulder push strength was expressed in relation to body mass, and an analysis of the individual sporting groups were compared to the control group, there was again a significant interaction between the results of the netball group when compared to the control group [Appendix B {27}]. The simple main effects analysis recognised the 51.1% difference between the two groups at the start of the season as significant. All four sporting groups when compared to the control group had non-significant changes in their arm and shoulder push strength over time [Table 4.12]. There was a mean increase of 2.09 kg or 19% over the season's duration. In the course of these gains the differences between the groups created a significant improvement.

Changes in the arm and shoulder pull strength over the season improved significantly only in the netball group (5.03 kg or 56.9%) [Table 4.11]. When the arm and shoulder pull strength changes over the season were analysed for differences, comparisons of the control group and individual sporting groups, produced a significant interaction between the netball and the control group [Appendix B {23}]. The simple main effects analysis identifed the 61.7% advantage in the arm and shoulder pull strength of the control group when compared to the netball group as significant at the start of the season. A similar interaction and point of time's significance was reported when the arm and shoulder strength was expressed in relation to body mass [Appendix B {27}]. Non-significant differences in changes of arm and shoulder pull strength were evident when the control group was compared to the combination of all four sporting groups [Table 4.12]. There was a non-significant increment in arm and shoulder strength (2.4 kg or 18.4%) for all five groups over the season.

A summary of the results from the testing for upper body strength over the season reported non-significant changes in the control group and the badminton groups. Basketballers improved in dominant and non-dominant grip strength. Netballers changed in all four aspects of the testing; decreasing in grip strength and increasing in arm and shoulder strength tests. Generally netballers appeared consistently less powerful in their upper body strength, while the tennis and badminton groups were consistently superior in all four tests of upper body strength over the season.

7. Lower body strength

The results from the lower body strength data are presented in Tables 4.13 and 4.14 and Appendix B {29 to 36}. A significant within group change in right quadricep peak torque was reported in two groups [Table 4.13]. The badminton group's mean right quadricep peak torque decreased significantly over the season (6.25ft. LBS. or 8.28%). The netball group also decreased in their mean peak torque of the right quadricep over the season (1.62ft. LBS. or 2.69%). These decreases are hypothesised to be associated with the technical servicing of the Cybex machine which occurred within the same week as the 8 week testing period for the badminton and netball groups in the study. Changes in the right quadricep peak torque which occurred over the season were analysed in comparisons between the control group and individual sporting groups [Appendix B {29 to 32}]. There was a significant interaction in the changes in right quadricep peak torque over the season when the control group was compared with the basketball group. The simple main effects analysis identified the 8 weeks testing period as the point at which the two groups differed significantly in their responses (30.7%). Significant changes in right quadricep peak torque were also evident between the badminton and the control group when the data was expressed relative to body mass [Appendix B {33}]. The simple main effects analysis of the relative peak torque in the right quadricep in the badminton and control groups indicated a general rather than specific influence of the time factor. When combined, the four sporting groups did not differ significantly from the control group in the changes that took place over the season [Table 4.14]. The five groups decreased by 2.3ft. LBS in their right quadracep's peak torque over the season. Again it is suggested that the decreased strength is more likely to be associated with technical error rather than a physiological regression.

Left quadricep peak torque within group changes were significant in three sports [Table 4.13]. Over the season, there was a significant decrease of 2.37ft. LBS. (or 4.13%) in the basketball group, a 1.0ft.LB. (or 1.60%) decrease in the netball group and a 4.13ft. LBS. (or 5.74%) increase in the tennis group in the left quadricep peak torque. The lower results of the 8 week tests for the basketball and netball groups may explain why such small differences would be significant. In basketball, the mean left quadricep peak torque was 57.37ft. LBS at the start of the season. The 8 weeks mean left quadricep peak torque decreased to 43.37ft. LBS and the 12 weeks mean torque had returned to 55.0ft. LBS. Similarly, the netball group began the season with a mean left quadricep peak torque of 60.50ft. LBS. At the 8 week mark of the season, this value had decreased to 53.37ft. LBS. and by the end of the season the value had returned to 59.5ft. LBS. Technical difficulties are postulated to be more related to this pattern of results than physiological differences, once again because of the timing of a service on the Cybex (II) machine. An analysis of individual sporting groups compared to the control group produced a significant interaction in the changes in the left quadricep peak torque between the basketball group and the control group [Appendix B {30}]. The simple main effects analysis identified as significant, the 8 weeks and 12 weeks testing periods. At these specific points in time the control group was 32.1% and 18.7% (respectively) stronger in the left quadricep peak torque than the basketball group. Individual sporting groups were also compared to the control group when the left quadricep peak torque was expressed relative to body mass [Appendix B {33 to 36}]. In these analyses, two significant interactions were reported. The basketball group's relative left quadricep peak torque differed from the control group's at the 8 weeks testing period. The changes in the relative left quadricep peak torque of the tennis group when compared to the control group were significantly but generally influenced by time. A combination of the four sporting groups did not differ significantly from the control group [Table 4.14]. The five groups averaged an overall decrease in left quadricep peak torque of 0.65ft. LBS or 0.9%. This slight decrease however was part of the significant decrease which had occurred in the between group chan-

Table 4.13: Lower Body Strength Profile of All Five Groups of Pre-adolescents Over 12 Weeks

Group	Period	Right Quad Peak Torque (ft.LBS.) X̄	(±S.D.)	Left Quad Peak Torque (ft.LBS.) X̄	(±S.D.)	Right Ham'g Peak Torque (ft.LBS.) X̄	(±S.D.)	Left Ham'g Peak Torque (ft.LBS.) X̄	(±S.D.)	Right H/q Ratio (%) X̄	(±S.D.)	Left H/q Ratio (%) X̄	(±S.D.)
Control	Pre	69.37	(15)	70.25	(13)	55.62	(12)	52.12	(14)	80.80	(11)	73.60	(11)
	8 wks	68.62	(12)	66.75	(11)	53.50	(8)	48.37	(11)	78.41	(7)	74.49	(17)
	Post	67.87	(13)	67.62	(18)	51.25	(13)	48.75	(9)	74.41	(8)	73.97	(13)
Badminton	Pre	75.50 *	(21)	73.00	(21)	50.62	(15)	48.00	(12)	68.17	(15)	66.19 *	(12)
	8 wks	65.62	(24)	66.25	(21)	47.12	(12)	48.87	(14)	73.22	(13)	75.04	(10)
	Post	69.87	(22)	71.62	(20)	52.62	(5)	53.00	(15)	77.93	(10)	74.73	(8)
Basketball	Pre	57.87	(3)	57.37 *	(11)	37.00	(13)	37.87	(12)	62.74	(14)	66.54 *	(13)
	8 wks	47.62	(3)	45.37	(9)	33.62	(6)	31.62	(7)	72.69	(15)	71.77	(17)
	Post	58.50	(3)	59.50	(4)	42.25	(5)	39.12	(9)	65.24	(18)	62.32	(19)
Netball	Pre	60.12 *	(2)	60.50 *	(3)	39.25	(11)	37.12	(11)	72.86	(10)	66.21	(16)
	8 wks	54.37	(2)	53.37	(5)	37.12	(9)	35.00	(9)	66.40	(13)	66.68	(19)
	Post	58.50	(3)	59.50	(4)	42.25	(5)	39.12	(9)	65.24	(18)	62.32	(18)
Tennis	Pre	73.12	(18)	67.87 *	(15)	49.87	(15)	47.25	(16)	63.82	(21)	63.44 *	(18)
	8 wks	75.00	(17)	73.75	(17)	46.37	(15)	44.87	(14)	67.79	(13)	68.76	(19)
	Post	72.50	(17)	72.00	(15)	46.12	(16)	47.62	(16)	61.29	(18)	61.29	(19)
Total Mean	Pre	67.20 *	(16)	65.80 *	(15)	46.47	(14)	44.47	(14)	69.68	(15)	67.20	(14)
	8 wks	62.25	(17)	61.10	(17)	43.55	(12)	41.75	(13)	71.72	(13)	70.95	(16)
	Post	64.82	(16)	65.15	(14)	45.80	(13)	45.27	(13)	68.80	(15)	68.82	(16)

* significant differences within groups, $P < 0.05$

ges in left quadricep peak torque at the 8 week and 12 week testing periods. Again, the significant overall decrease is suggested to be due to technical difficulties rather than physiological fluctuations.

Within group analysis of the right hamstring peak torque provided non-significant differences in all of the groups [Table 4.13]. When the changes in the right hamstring peak torque were analysed for differences between the control group and individual sporting groups, non-significant differences were reported [Appendix B {29 to 32}]. When the changes in right hamstring peak torque were expressed in relation to body mass there was a significant interaction in the analysis involving the netball group and the control group [Appendix B {35}. The simple main effects analysis indicated that the specific times which contributed to the significant differences between the groups were at the start and 8 week mark of the season. When expressed in relation to right hamstring peak torque these differences represented a 28.6% and a 30.2% advantage to the control group when compared to the netball group respectively. When all four sporting groups were combined for a comparison with the control group, the sporting groups' right hamstring peak torque was significantly less at both the start and 8 week mark of the season [i.e. 19.5% at the start of the season and 23.4% by the 8 week mark of the season] [Table 4.14]. For all five groups, there was an overall change in the right hamstring peak torque of a non-significant 0.67ft. LBS or 1.4%.

Within group differences were non-significant when the changes in the left hamstring peak torque over the season were examined [Table 4.13]. Similar non-significant differences were reported when individual sporting groups were compared to the control group in absolute terms and in relation to the body mass [Appendix B {29 to 36}]. When the changes in the left hamstring peak torque were compared to the changes in a combined sporting group, again there were non-significant differences [Table 4.14]. In a similar response to the movement pattern of the right hamstring peak torque, the left hamstring peak torque was greatest in the control group and smallest in the basketball and netball groups. Left hamstring peak torque insignificantly increased in the five groups by a mean 0.8ft. LBS (or 1.77%) over the season.

Another measure of lower body strength was the ratio between the peak torque scores of the hamstrings and the quadraceps muscle groups. Non-significant changes occurred in the within groups analysis conducted on the hamstring to quadraceps strength ratio in the right leg [Table 4.13]. The individual sporting group's comparison to the control group reported a significant interaction in the changes that occurred in the right leg hamstring to quadricep strength ratio between the badminton group and the control group [Appendix B {29}]. The simple main effects analysis reported a general and significant influence of the time factor, rather than a specific point of testing at which the changes in the right leg hamstring to quadraceps ratio were more markedly different than others. When the four sporting groups were combined together to compare the

Table 4.14: Lower Body Strength Profile of the Combined Sports Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group X	(±S.D.)	Combined Sports Groups X	(±S.D.)	%	F Ratio	P
Right Quads Peak Torque (ft.lbs.)	Pre	69.37	(14.57)	66.66	(16.06)	4.0	0.21	0.652
	8 weeks	68.62	(12.06)	60.66	(18.29)	11.6	2.22	0.156
	Post	67.87	(12.99)	64.06	(16.56)	5.7	0.49	0.496
Left Quads Peak Torque (ft.lbs)	Pre	70.25	(13.36)	64.69	(15.06)	8.0	1.05	0.325
	8 weeks	66.75	(10.70)	59.69	(17.59)	10.6	2.08	0.166
	Post	67.62	(11.72)	64.53	(14.72)	4.6	0.40	0.538
Right Hams'g Peak (ft.lbs.)	Pre	55.62	(11.99)	44.79	(14.31)	19.5	5.36	0.037*
	8 weeks	53.50	(7.98)	41.06	(12.14)	23.4	12.30	0.003*
	Post	51.25	(13.30)	44.43	(13.18)	17.4	1.69	0.221
Left Hams'g Peak (ft.lbs.)	Pre	52.12	(13.98)	42.56	(13.31)	18.4	3.05	0.111
	8 weeks	48.37	(11.48)	40.09	(13.14)	17.2	3.14	0.102
	Post	48.75	(9.45)	44.41	(13.47)	9.9	1.12	0.307
H/Q Ratio Right Leg (%)	Pre	80.80	(11.26)	66.90	(15.17)	17.2	8.39	0.012*
	8 weeks	78.40	(6.83)	70.05	(13.16)	10.3	6.22	0.021*
	Post	74.10	(7.87)	67.48	(16.64)	9.0	2.68	0.115
H/Q Ratio Left Leg (%)	Pre	73.61	(11.03)	65.60	(14.52)	10.9	2.96	0.107
	8 weeks	73.50	(16.53)	70.31	(16.25)	4.6	0.24	0.635
	Post	73.97	(12.75)	67.53	(16.87)	8.9	1.42	0.253

p* = probability of exceeding the F ratio when variances are assumed unequal.

changes in the right leg's ratio of hamstrings to quadricep strength, significant differences were reported at both the pre-season and the 8 weeks testing times. The magnitude of these changes were 17.2% and 10.3% (respectively), with the advantage going to the control group. At the completion of the season the difference in the five groups' right leg hamstring to quadricep ratio remained virtually unchanged.

The left leg ratio of the peak torque of the hamstrings and quadraceps reported three significant within-group changes [Table 4.13]. The badminton group's left legs' hamstrings to quadraceps strength ratio over the season improved by 8.54%. Similarly, the left legs' hamstrings to quadraceps strength ratio over the season improved by a significant 4.59% in the basketball group. There was a significant decrease of 1.5% in the left legs' hamstrings to quadraceps strength ratio in the tennis group. The comparison of changes in the left legs' hamstrings to quadraceps ratio between individual sporting groups and the control group were all non-significant [Appendix B {29 to 32}]. When the four sporting groups were combined for a comparison with the control group, there was a non-significant difference in the changes of the left legs' hamstrings to quadraceps strength ratio over the season [Table 4.14]. All five groups had a mean non-significant gain in the left legs' hamstring to quadraceps strength ratio of 1.62%.

A summary of the results of the measurements of lower leg strength revealed that the control group was the only group in which non-significant changes occurred during the 12 weeks investigation. It is important to note that the control group had relatively higher levels of lower body strength when compared to the basketball and netball groups throughout the season. In addition to this, the control group also maintained the highest level of hamstrings to quadricep ratio in both the right and left legs when compared to the four other groups. When the results that were related to the time at which technical servicing was conducted, were disregarded, very few improvements in lower body strength can be reported. These improvements occurred in the left quadricep peak torque of the the tennis group and in the left leg's hamstrings to quadricep strength ratio in the badminton, basketball and tennis groups.

8. Flexibility (and strength) data.

The results of the flexibility tests are summarised in Tables 4.15 and 4.16 and in Appendix B {37 to 40}. The sit and reach test produced results in four groups which indicated significant improvement over time [Table 4.15]. These improvements occurred in the control group (2.20 cm), the badminton group (3.44 cm), the netball group (3.21 cm) and the tennis group (6.07cm). Individual sporting group comparisons with the control group indicated a significant interaction in the changes occurring in the sit and reach scores of the tennis and the control groups [Appendix B {40}]. Simple main effects acknowledged a general and significant influence of time in the results of the sit and reach test between the control and the tennis groups over the season. In addition to this, the control group when compared to the tennis group, appeared to have consistently greater flexibility in the sit and reach test throughout the season. When all four groups were combined for a comparison with the control group, there was a non-significant difference in the changes of the sit and reach mean scores over the season [Table 4.16]. Overall, the five groups mean gain in sit and reach flexibility scores over the season was 2.13 cm.

Flexibility scores from the test for the angle of leg extension at the hip, indicated significant improvements in all five groups over the season's duration [Table 4.15]. The magnitude of increase in the angle of hip extension for the control, badminton, basketball, netball and tennis groups were 16.56^{o} (18.53%), 18.25^{o} (17.98%), 10.56^{o} (11.91%), 18.25^{o} (16.57%) and 15.63^{o} (15.84%) respectively. There were non-significant differences in the analysis of the hip angle extension changes over the time between each sporting group and the control group [Appendix B {37 to 40}]. A significant but slight difference was identified in the changes in hip extension angle over time of the control group and the combination of all four sporting groups [Table 4.16]. The mean overall gain in the angle of leg extension at the hip over the season was a non-significant 15.85^{o} or 16.23%.

Table 4.15: Flexibility Profile of All Five Groups of Pre-adolescents Over 12 Weeks

Group	Period	Sit and Reach (cm) X	(±S.D.)	Angle of Hip Ext'n (degrees) X	(±S.D.)	Lower Back Ext'n (cm) X	(±S.D.)
Control	Pre	-2.06*	(7.72)	72.81 *	(16.22)	33.00	(8.91)
	8 weeks	-3.00	(6.99)	90.25	(8.31)	37.57	(9.95)
	Post	0.19	(8.52)	89.37	(11.38)	36.75	(9.79)
Badminton	Pre	-5.32*	(12.30)	83.25 *	(8.68)	36.87	(11.18)
	8 weeks	-4.82	(11.60)	94.81	(14.35)	40.64	(7.13)
	Post	-1.88	(8.96)	101.50	(14.58)	41.15	(6.29)
Basketball	Pre	-3.19	(3.18)	78.12 *	(14.46)	26.87	(7.89)
	8 weeks	-3.44	(4.84)	88.62	(11.31)	30.25	(8.85)
	Post	-2.50	(4.90)	88.68	(7.52)	30.63	(9.36)
Netball	Pre	2.75*	(7.27)	91.87 *	(13.44)	34.62 *	(7.30)
	8 weeks	4.65	(7.60)	102.87	(13.06)	39.90	(6.29)
	Post	5.96	(8.21)	110.12	(13.48)	43.21	(9.71)
Tennis	Pre	-8.38*	(3.74)	83.06 *	(4.27)	33.94	(12.00)
	8 weeks	-4.75	(3.55)	93.62	(3.80)	41.04	(9.95)
	Post	-2.31	(3.36)	98.69	(3.35)	41.12	(9.71)
Total Mean	Pre	-3.24	(9.12)	81.82	(14.07)	33.06*	(9.73)
	8 weeks	-2.27	(8.85)	94.03	(12.20)	37.88	(9.07)
	Post	-1.11	(8.40)	97.67	(13.64)	38.57	(9.12)

*significant differences within groups, $P < 0.05$

Table 4.16: Flexibility Profile of the Combined Sports Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group X	(±S.D.)	Combined Sports Group X	(±S.D.)	%	F Ratio	P
Sit and Reach (cm)	Pre	-2.06	(7.72)	-3.53	(9.52)	41.7	0.21	0.654
	8 weeks	-3.00	(8.53)	-2.08	(9.35)	31.7	0.09	0.763
	Post	0.19	(8.62)	0.181	(8.50)	4.8	0.01	0.915
Hip Extension angle (degrees)	Pre	72.81	(16.22)	84.08	(12.78)	13.5	3.34	0.10
	8 weeks	90.25	(8.31)	94.98	(12.92)	5.0	1.62	0.221
	Post	89.37	(11.38)	99.75	(13.41)	10.5	4.91	0.047
Lower Back extension (cm)	Pre	33.00	(8.90)	33.08	(10.06)	0.3	0.00	0.983
	8 weeks	37.52	(9.95)	37.96	(9.01)	1.1	0.01	0.92
	Post	36.75	(9.79)	39.03	(9.06)	5.9	0.36	0.56

p* = probability of exceeding the F ratio when variances are assumed unequal

The third test in flexibility was also an indication of the strength of the muscles in the lower back. The ability to lift the lower back up as high as possible produced within group changes of significant magnitude in the netball group only (8.59 cm or 19.88% improvement) [Table 4.15]. A non-significant difference in the changes occurring in the lower back flexibility over the season occurred when the control group was compared to the four sporting groups individually [Appendix B {37 to 40}] and when all four sporting groups were combined together [Table 4.16]. A significant improvement was present when an analysis was conducted on the changes occurring in the lower back flexibility and strength of all five groups over the season.

A summary of the results of the three flexibility tests indicated the superiority of the female netball group in each of the areas. The netball group improved significantly in all three aspects of flexibility. Three groups; the control, badminton and tennis significantly increased their flexibility at two out of the three ranges of motion assessed. Basketball players improved significantly only in the test of the angle of leg extension at the hip.

9. Anaerobic charactersitics

The anaerobic characteristics of the pre-adolescent children tested are summarised in Tables 4.17 and 4.18 and Appendix {41 to 44}. Within group peak power over the season improved significantly in the three male sporting groups [Table 4.17]. Significant improvements in peak power were 113.54 watts (34.38%) in badminton players, 55.16 watts (22.62%) in basketball players, and 59.73 watts (19.64%) in tennis players. Significant interactions were found in a comparison made of the separate male sporting groups with the control group [Appendix B {41, 42 and 44}]. The results of the simple main effects from the badminton and control groups indicated a general significance of the influence of time in the peak power efforts. There was however initially a 23.7% advantage to the control group at the start of the season. By the 8 week and 12 week testing periods the advantage had swung to the badminton group where their advantage had become 24.4% and 26.7%, respectively. The simple main effects analysis of the peak power changes over the season between the basketball groups and the control group, indicated that the pre-season tests results had influenced the significant difference. Pre-season test results demonstrated a 33.6% advantage to the control group. By the end of the season, the basketball group had a 0.7% advantage over the control group. The simple main effects analysis of the peak power changes over the season, between the tennis group and the control group, identified changes at the 8 week testing period as significant. At 8 weeks there was a 29.79% advantage to the peak power of the tennis group when compared to the control group. All four sporting groups were non-significantly different from the control group in changes of peak power over the season [Table 4.18]. When all five groups were analysed together, there was a mean significant improvement of 39.18 watts or 14.32% over the season.

The time taken to reach peak power produced non-significant differences in all forms of analyses i.e., within group, individual sporting groups compared to the control, combined sporting groups compared to the control and all five groups [Table 4.17 and 4.18 and Appendix B {41 to 44}]. The badminton group arrived

Table 4.17: Anaerobic Characteristics Profile of all Five Groups of Pre-adolescents Over 12 Weeks

Group	Period	Peak Power (watts)		Time To Peak (seconds)		Mean Power (watts)		Relative Peak Power (Watts/kg)	
		X	(±S.D.)	X	(±S.D.)	X	(±S.D.)	X̄	(±S.D.)
Control	Pre	283.85	(111.4)	10.37	(3.96)	221.55	(31.47)	6.57	(1.00)
	8 weeks	212.97	(65.97)	10.22	(4.27)	167.42	(26.62)	5.14	(2.00)
	Post	242.19	(96.97)	11.11	(7.10)	195.72	(25.91)	5.57	(1.67)
Badminton	Pre	216.62*	(108.01)	7.21	(1.41)	159.42 *	(92.38)	4.86 *	(1.61)
	8 weeks	281.40	(81.44)	9.12	(7.41)	224.82	(63.03)	6.27	(0.64)
	Post	330.16	(93.79)	8.92	(1.67)	265.45	(73.39)	7.36	(0.64)
Basketball	Pre	188.71*	(35.61)	10.16	(2.80)	145.45 *	(37.20)	5.41 *	(0.89)
	8 weeks	199.03	(56.85)	9.76	(2.37)	160.57	(49.14)	5.38	(0.90)
	Post	246.95	(50.43)	10.95	(6.56)	196.42	(37.80)	6.60	(0.59)
Netball	Pre	236.80	(39.32)	9.10	(1.79)	190.12	(27.58)	5.79	(0.37)
	8 weeks	241.72	(44.82)	9.29	(1.63)	196.52	(30.88)	5.94	(0.90)
	Post	246.95	(50.43)	10.91	(4.29)	201.67	(27.78)	5.99	(0.90)
Tennis	Pre	244.24*	(50.06)	10.47	(4.36)	195.78*	(36.86)	5.85	(0.84)
	8 weeks	302.80	(57.92)	9.08	(2.40)	248.36	(41.96)	7.10	(0.94)
	Post	303.97	(53.42)	10.64	(5.21)	248.01	(38.50)	7.14	(1.06)
Total Mean	Pre	234.35*	(79.27)	9.46	(3.18)	182.48*	(10.41)	5.70	(1.12)
	8 weeks	247.59	(71.49)	9.50	(4.02)	199.54	(9.64)	5.97	(1.30)
	Post	273.43	(77.83)	10.51	(5.11)	221.46	(9.32)	6.53	(1.20)

*significant differences within groups, $P < 0.05$

Table 4.18: Anaerobic Characteristics Profile of the Combined Sports Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group X̄	(±S.D.)	Combined Sports Groups X̄	(±S.D.)	%	F Ratio	P
Peak Power (watts)	Pre	283.85	(111.37)	221.85	(65.66)	21.9	2.28	0.169
	8 weeks	212.97	(65.97)	256.24	(71.14)	16.9	2.67	0.131
	Post	242.19	(96.96)	281.24	(71.99)	13.9	1.14	0.313
Time To Peak (sec)	Pre	10.37	(3.96)	9.24	(2.99)	10.9	0.58	0.467
	8 weeks	10.22	(4.22)	9.32	(4.01)	8.1	0.30	0.598
	Post	11.11	(7.10)	10.36	(4.62)	6.8	0.08	0.782
Mean Power (watts)	Pre	221.55	(89.00)	172.69	(56.31)	22.1	2.19	0.177
	8 weeks	167.42	(72.47)	207.57	(56.24)	19.4	2.13	0.178
	Post	195.72	(73.29)	227.89	(54.31)	14.2	1.35	0.274
Relative Peak Power (watts/kg)	Pre	6.57	(1.07)	5.48	(1.05)	16.6	7.37	0.020
	8 weeks	5.14	(2.00)	6.17	(1.00)	16.7	1.99	0.196
	Post	5.58	(1.67)	6.72	(0.95)	17.6	3.81	0.087

p* = probability of exceeding the F ratio when variances are assumed unequal

at their peak consistently quicker than the other groups (i.e., between 7 and 9 seconds). The overall pattern for the five groups demonstrated a slight increase in the time to reach peak power of 1.5 seconds over the season.

The mean of power attained in the 30 second anaerobic capacity test revealed three significant within-group improvements in the three male sporting groups [Table 4.17]. These improvements in mean power occurred in the badminton group by 106.03 watts (or 39.94%), the basketball group by 50.97 watts (or 25.94%) and the tennis group by 52.23 watts (or 21.05%). The comparisons of the individual sporting groups and the control group's changes in mean peak power over the season, resulted in significant interactions between the control and each of the three male sporting groups [Appendix B {41, 42 and 45}]. The simple main effects analysis of the badminton and the control group's changes in mean peak power indicated that the time factor had a general and significant influence. The simple main effects analysis of the basketball and the control group's response to mean peak power, indicated that the pre-season scores contributed to significant changes between the groups. The results of the pre-season difference between basketball and the control groups quantified the difference as 28.1% in favour of the control group. The simple main effects analysis of the tennis and the control groups' changes in mean peak power, identified the 8 week testing period as that time which had produced a significant difference between the groups. At this time the tennis group diplayed a 32.6% advantage over the control group in mean power accumulated during the test. There was a non-significant difference between the changes occurring in mean peak power over the season when an analysis was made using the control group and the combined four sporting groups [Table 4.18]. When all five groups were computed together a significant improvement was present. The overall gain in mean peak power was 38.98 watts (or 17.60%) for all of the five groups when combined. In order to account for discrepancies in body mass among subjects, peak power was expressed relative to body mass (watts.kg.$^{-1}$). Two groups recorded significant within-group gains in peak power per kg. [Table 4.17]. The badminton group gained a significant 2.5 watts.kg.$^{-1}$ (or 33.96%) and the basketball group gained a significant 1.19 watts.kg.$^{-1}$ (or 18.03%) over the season. Three significant interactions were reported in the comparison of changes in watts.kg.$^{-1}$mean scores over the season between the badminton and the control group and the basketball and the control group [Appendix B {41, 42 and 43}]. The simple main effects analysis revealed one of the significant interactions between the badminton and the control group was related to the changes at the start and end of the season. At the start of the season, the control group had a 26.1% advantage in their relative peak power scores over the badminton group. Conversley, at the end of the season, there was a 24.2% advantage in relative peak power to the badminton group (Appendix B {41}). The other significant interaction occurred between the basketball group and the control group. The simple main effects analysis recognised the start of the season testing period as the time when between groups differences were of a significant magnitude. At the start of the season, there was 26.1% advantage to the control group when compared to the basketball group (Appendix B {42}). This difference did not however continue into the season. A third significant interaction occurred over the season between the tennis and the control groups' changes in peak power in watts.kg. $^{-1}$. The simple main effects analysis indicated that the significant differences in changes in relative peak power between the tennis and control groups had occurred at the 8 and 12 week testing periods. At these times, there was a 27.7% and 21.5% (respectively) advantage to the tennis group, when compared to the control group (Appendix B {43}). A significant difference also occurred at the preseason testing period when all four groups were combined for a comparison with the control group [Table 4.18]. This difference was represented by a 16.6% advantage in the relative peak power to the control group when compared to the other four sporting groups. This advantage to the control group was removed as the season progressed. When all five groups combined for analysis there was an overall improvement of 0.83 watts.kg^{-1} (or 12.71%). This difference was part of a significant influence of time in the changes of relative peak power which occurred at the 8 and 12 week testing times.

A summary of the anaerobic characteristics presented non-significant changes in each of the measures within the control and netball groups. The badminton and basketball groups changed significantly in absolute and relative peak power and in mean power. The tennis group improved significantly in peak power and mean power. Overall the anaerobic characteristics appeared strongest in the control group at the start of the season. However each of the male sporting groups had matched or surpassed most of the anaerobic characteristics of the control group by the end of the season's participation.

10. Submaximal effort data

The submaximal effort data for the five groups of the pre-adolescent children has been summarised in Tables 4.19 and 4.20 and in Appendix B {45 to 48}. Within group changes in the submaximal oxygen upatake at 4 k.p.h. were non-significant in all groups [Table 4.19]. Individual sporting group's comparisons and a combined sporting group's comparison with the control group, again supported non-significant changes in oxygen uptake at 4 k.p.h. [Table 4.20 and Appendix B {45 to 48}]. The overall change over the season was a mere 0.46 $ml.kg.^{-1}min.^{-1}$ at 4 k.p.h..

The oxygen uptake at 6 k.p.h. changed significantly over the season in two within-group comparisons [Table 4.19]. A change occurred in the netball group which demonstrated a significant 0.94 $ml.kg.^{-1}min.^{-1}$ (or 3.4%) increase over the season. The tennis group's significant difference occurred over the three testing periods with a start of the season oxygen uptake mean score at 6 k.p.h. of 27.24 $ml.kg.^{-1}min.^{-1}$, an 8 week mean score of 29.08 $ml.kg.^{-1}min.^{-1}$ and an end of season score of 27.72 $ml.kg.^{-1}min.^{-1}$. Non-significant differences in oxygen uptake at 6 k.p.h. occurred over the season between the individual sporting groups and the control group. [Appendix B {45 to 48}. A slight, significant increase in the post season testing occurred in the comparison between the control group and the combined sporting groups. [Table 4.20]. When all five groups were examined, there was a significant differences between the groups' scores. There was a slight

Table 4.19: Submaximal Effort Data Of All Five Groups Of Pre-adolescents Over 12 Weeks

Group	Period	VO_2 4 Km $ml.kg.^{1-}min^{-1}$ $\bar{X}$	(±S.D.)	VO_2 6 Km $ml.kg.^{-1}min^{-1}$ $\bar{X}$	(±S.D.)	VO_2 8 Km $ml.kg.^{-1}min^{-1}$ $\bar{X}$	(±S.D.)
Control	Pre	16.57	(2.80)	25.05	(5.68)	33.85	(4.87)
	8 weeks	17.80	(1.59)	26.46	(3.91)	40.08	(3.69)
	Post	16.44	(3.77)	24.14	(2.99)	39.00	(3.14)
Badminton	Pre	15.52	(4.09)	27.44	(4.57)	42.87	(2.97)
	8 weeks	17.30	(3.35)	25.79	(3.85)	39.00	(4.53)
	Post	16.73	(1.67)	25.99	(2.59)	38.98	(3.95))
Basketball	Pre	19.74	(2.71)	34.73	(4.25)	43.32	(2.72)
	8 weeks	19.29	(2.10)	30.28	(3.42)	43.42	(2.53)
	Post	20.07	(2.66)	29.72	(3.69)	42.56	(3.03)
Netball	Pre	16.57	(1.61)	26.64 ✱	(2.92)	37.86	(3.00)
	8 weeks	17.07	(2.78)	26.28	(3.58)	38.72	(3.25)
	Post	17.55	(2.07)	27.58	(3.39)	39.57	(5.09)
Tennis	Pre	18.40	(2.59)	27.24 ✱	(2.47)	37.86	(2.06)
	8 weeks	18.55	(2.07)	29.08	(3.15)	40.46	(4.63)
	Post	17.95	(1.82)	27.72	(2.40)	39.58	(3.39)
Total Mean	Pre	17.35	(3.12)	28.02 ✱	(5.27)	40.15	(3.95)
	8 weeks	18.00	(2.47)	27.58	(3.85)	40.34	(3.99)
	Post	17.81	(2.72)	27.03	(3.45)	39.94	(3.84)

✱ significant differences within groups, $P < 0.05$

overall decrease the oxygen uptake at 6 k.p.h. for all five groups over the season (0.99 $ml.kg.^{-1}min^{-1}$ or 3.53%). Although statistically significant, a difference of 0.99 $ml.kg.^{-1}min.^{-1}$ was not considered to be physiologically significant.

Submaximal oxygen uptake scores at 8 k.p.h. changed non-significantly over the season in all five groups [Table 4.19]. Changes in oxygen uptake at 8 k.p.h. over the season were also non-significant when the control group was compared to individual sporting groups and a combined sporting group [Table 4.20 and Appendix B {45 to 48}]. All five groups oxygen uptake at 8 k.p.h. decreased slightly over the season (0.21 $ml.kg.^{-1}min.^{-1}$ or 0.52%). This difference was non-significant.

Table 4.20: Submaximal Effort Data of the Combined Sports Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Combined Sports Group $\bar{X}$	(±S.D.)	%	F Ratio	P
VO_2	Pre	16.57	(2.80)	17.56	(3.21)	5.7	0.74	0.407
($ml.kg.^{-1}min^{-1}$)	8 weeks	17.81	(1.59)	18.05	(2.67)	1.4	0.11	0.740
4km	Post	16.44	(3.79)	18.15	(2.33)	9.5	1.49	0.257
VO_2	Pre	25.05	(5.68)	28.76	(4.99)	12.9	2.87	0.121
($ml.kg.^{-1}min^{-1}$)	8 weeks	26.46	(3.91)	27.86	(3.84)	5.1	0.83	0.383
6km	Post	24.14	(2.99)	27.75	(3.21)	13.1	9.09	0.011
VO_2	Pre	38.85	(4.87)	40.48	(3.71)	4.1	0.78	0.401
($ml.kg.^{-1}min^{-1}$)	8 Weeks	40.08	(3.69)	40.40	(4.12)	0.8	0.05	0.834
8km	Post	39.00	(3.14)	40.17	(4.01)	3.0	0.79	0.390

p* = probability of exceeding the F ratio when the variances are assumed unequal

A summary of the submaximal effort results indicated that data remained largely stable over the season. Very few between group changes in oxygen uptake at 4, 6 and 8 k.p.h. in efficiency occurred during the season. This result may suggest that either, the nature of participation was not intense enough to induce an effect submaximally or, submaximal oxygen uptake and inferred efficiency changes may not occur in studies of the relatively short duration of 12 weeks.

Section B: Field Testing Results

1 and 2. Descriptive and maximal effort profiles.

The data collected in the field situation included a larger population in each of the four groups than was sampled in the aforementioned laboratory results [Tables 4.21 and 4.22]. As well as the children involved in extensive laboratory testing, an additional number of other children from the same clubs were included in the field testing and a smaller range of laboratory tests. The children who were added to each group also conformed to the previously stated conditions for inclusion. The sample still remained homogeneous [Tables 4.21 and

4.22]. Non-significant differences were produced from analysis of both the descriptive data for age, body mass and height and maximal effort data for VO_2 max ($ml.kg^{-1}min^{-1}$), heart rate max and respiratory exchange ratio at maximal effort.

Table 4.21: Descriptive Data of the Sporting Groups Used in the Field Data Collection

Sport	N	Age X	(yrs) (±S.D.)	Mass X	(kg) (±S.D.)	Height (cm) X	(±S.D.)
Badminton	13	11.69	(1.03)	40.43	(9.20)	147.83	(8.24)
Basketball	13	11.00	(1.22)	39.98	(8.59)	145.75	(11.00)
Netball	13	10.84	(0.69)	40.42	(6.28)	145.98	(4.50)
Tennis	13	13.53	(5.32)	41.46	(5.76)	150.68	(7.89)

p* = probability level between groups $p < 0.05$

Table 4.22: Maximal Effort Data of the Sporting Groups Used in Field Data Collection

Sport	N	Vo2 Max ($ml.kg.^{-1}min.^{-1}$) X	(±S.D.)	Heart Rate Max ($bts.min^{-1}$) X	(±S.D.)	RER Max X	(±S.D.)
Badminton	13	56.06	(4.76)	203	(7.42)	1.03	(0.07)
Basketball	13	54.88	(4.08)	201	(3.49)	0.97	(0.04)
Netball	13	49.80	(8.04)	203	(7.91)	1.01	(0.45)
Tennis	13	58.57	(5.04)	201	(10.25)	1.08	(0.07)

p* = probability level between groups $p < 0.05$

3. Absolute heart rate intensities.

Data which was used to gather field intensity was collected using a portable heart rate monitoring system for approximately 20 minutes of activity, several times during the season, in both practice and game situations. Table 4.23 presents the absolute heart rate values averaged in five minute intervals over 20 minutes. Absolute heart rates ($bts.min^{-1}$) in practice and game situations did not differ significantly in the basketball group. However, overall significant differences were evident in the practice and competitive games situations for the netball and tennis groups. In additon to the overall difference in the badminton group, there was a significant difference in the changes of absloute heart rates in the games and practice situations. The simple main effects analysis indicated that the difference in heart rates was not occurring in the first five minute interval of the practice and game situations. There was a significant difference in the changes of heart rates which occurred in the remainder of the five minute intervals monitored under the two conditions of practices and games. When the absloute

Table 4.23: Absolute Heart Rate Data of the Sporting Groups During Competitive Games and Practice Situations

Sport	Period (min.s)	Practice X	(±S.D.)	Games X	(±S.D.)	Difference	% Diff.
Badminton	1-5	149	(11.12)	157	(12.69)	8.0	5.10
	6-10	143	(12.66)	175	(12.62)	32.0	18.29*
	11-15	149	(15.73)	176	(14.25)	27.0	15.34*
	16-20	155	(12.26)	172	(17.16)	17.0	9.88*
Basketball	1-5	145	(16.30)	153	(18.08)	8.0	5.23
	6-10	158	(10.68)	170	(19.91)	12.0	7.06
	11-15	173	(14.08)	157	(23.95)	16.0	9.25
	16-20	153	(13.62)	157	(23.36)	4.0	4.55
Netball	1-5	137	(16.55)	155	(20.85)	18.0	11.61*
	6-10	146	(20.35)	170	(20.93)	24.0	14.12*
	11-15	147	(14.79)	176	(22.71)	29.0	16.48*
	16-20	146	(14.88)	172	(23.34)	26.0	15.12*
Tennis	1-5	129	(17.12)	153	(16.84)	24.0	15.69*
	6-10	134	(13.54)	165	(19.84)	31.0	18.79*
	11-15	137	(13.93)	164	(20.05)	27.0	16.46*
	16-20	141	(11.97)	165	(21.97)	24.0	14.55*
Total Mean	1-5	140	(15.27)	154	(17.11)	14.0	9.09*
	6-10	145	(14.30)	170	(18.32)	25.0	14.71*
	11-15	151	(14.63)	168	(20.24)	17.0	10.21*
	16-20	149	(13.18)	166	(21.45)	17.0	10.24*
Combined Mean of 20 minutes		145	(16.14)	165	(1.46)	19.32	11.72*

p* = probability level between groups p <.05

heart rate data from the four sporting groups were combined there was an overall significant difference between the mean heart rate of the practice situation (145.5 bts.min^{-1}) and the competitive game situation (164.8 bts.min^{-1})

4. Relative Heart Rate Intensities (%HR max).

On court absolute heart rate data was combined with the maximal heart rates (HR max) obtained in the laboratory testing to express the relative percentage of HR max

$$\frac{\text{Absolute Heart Rates on Court X Heart Rate Maximums}}{100}$$

Table 4.24 indicates all of the sporting groups produced a significantly different heart rate percentage (%HR) in the competitive game and practice conditions. The time factor was again significant only in the badminton group. Badminton players had %HRs which were significantly different at all of the five minute intervals of the 20 minutes of activity, except for the first five minutes. The dif-

Table 4.24: Relative Heart Rate Intensity Data of the Sporting Groups During Competitive Games and Practice Situations

Sport	Period (min.s)	Practice $\bar{X}$	Practice (±S.D.)	Games $\bar{X}$	Games (±S.D.)	Difference	% Diff.
Badminton	1-5	72.91	(6.19)	75.88	(5.89)	2.97	3.91
	6-10	69.96	(5.84)	85.13	(5.66)	15.17	17.80*
	11-15	72.35	(6.83)	84.14	(8.24)	11.79	14.01*
	16-20	76.13	(7.06)	85.29	(7.03)	9.16	10.74*
Basketball	1-5	69.57	(7.59)	77.51	(8.16)	7.94	10.24*
	6-10	77.44	(5.60)	83.82	(10.13)	6.38	7.61*
	11-15	76.48	(6.28)	81.01	(9.28)	4.53	5.59*
	16-20	76.15	(7.07)	75.68	(14.37)	0.47	0.62*
Netball	1-5	65.52	(8.42)	75.57	(10.18)	10.05	13.30*
	6-10	70.04	(8.49)	83.01	(9.01)	12.97	15.62*
	11-15	71.62	(6.61)	85.71	(10.08)	14.09	16.44*
	16-20	70.62	(6.69)	83.76	(10.72)	13.14	15.69*
Tennis	1-5	63.75	(9.93)	74.83	(5.66)	11.08	14.81*
	6-10	66.08	(8.05)	80.35	(6.67	14.27	17.76*
	11-15	67.61	(7.53)	79.60	(6.57)	11.99	15.06*
	16-20	69.50	(6.83)	80.11	(7.49)	10.61	13.24*
Total Mean	1-5	67.93	(8.03)	75.94	(7.47)	8.01	10.55*
	6-10	70.88	(6.99)	83.07	(7.86)	12.10	14.67*
	11-15	72.01	(6.81)	82.61	(8.54)	10.60	12.83*
	16-20	73.10	(6.91)	81.21	(9.90)	9.01	9.99*
Combined Mean of 20 minutes		70.98	(8.06)	80.71	(9.21)	9.73	12.06*

p* = probability level within groups $p < 0.05$

ference between game and practice conditions for all four sporting groups was a significant 10% (i.e. the mean %HR for games was approximately 80% and the mean %HR for practice situations was 70%).

5. Relative Percentage of Maximal Oxygen Uptake (%VO_2 max)

From the known heart rates responses collected in the field data and the assumed linear response of heart rate and oxygen uptake recorded in the laboratory situation, a regression analysis was used to predict %VO_2 max. Overall significant differences in %VO_2 max in practice and game situations were evident in netball and tennis groups, but not in the basketball group [Table 4.25]. The analysis of the %VO_2 max data in practice and competitive game situations for the badminton group produced a significant interaction. Simple main effects analysis of these results indicated that significant differences were evident in the %VO_2 max responses of the game and practice situations at all 5 minute intervals except for the first 5 minutes of participation. There was also a significant interaction present when the data from all four groups were combined for an analysis of the between group changes in %VO_2 max under the practice and competitive game conditions over time. The simple main effects analysis recognised significant differences in every one of the four five-minute intervals in

Table 4.25: Relative Percentages of Maximal Oxygen Uptake (VO_2 Max) of the Sporting Groups During Competitive Games and Practice Situations

Sport	Period (min.s)	Practice $\bar{X}$	(±S.D.)	Games $\bar{X}$	(±S.D.)	Difference	% Diff.
Badminton	1-5	59.26	(9.80)	63.30	(8.73)	4.04	6.38
	6-10	53.85	(9.03)	77.97	(7.81)	24.12	30.93*
	11-15	58.47	(10.34)	79.58	(12.17)	21.11	26.53*
	16-20	67.03	(12.37)	79.96	(14.69)	12.93	16.17
Basketball	1-5	49.05	(18.78)	61.11	(13.82)	12.06	19.73
	6-10	59.96	(9.22)	71.08	(17.13)	11.12	15.64
	11-15	61.94	(9.12)	63.13	(20.07)	1.19	1.88
	16-20	55.10	(11.80)	61.55	(22.36)	6.45	10.48
Netball	1-5	46.05	(14.98)	58.99	(15.11)	12.94	21.94*
	6-10	50.56	(14.06)	75.26	(15.06)	24.70	32.82*
	11-15	50.35	(16.08)	77.83	(15.50)	27.48	35.31*
	16-20	52.07	(16.46)	71.63	(18.44)	19.56	27.31*
Tennis	1-5	43.32	(18.03)	59.95	(9.25)	16.63	27.74*
	6-10	47.67	(13.27)	68.12	(7.97)	20.45	30.02*
	11-15	50.45	(13.82)	68.16	(8.18)	20.49	25.98*
	16-20	52.55	(13.27)	68.44	(10.11)	15.89	23.22*
Total Mean	1-5	49.42	(15.39)	60.84	(11.73)	11.42	18.77*
	6-10	53.01	(11.39)	73.11	(11.99)	20.10	27.49*
	11-15	55.30	(12.34)	72.17	(13.98)	16.87	23.38*
	16-20	56.68	(13.47)	70.39	(16.40)	13.71	19.48*
Combined Mean 20 minutes		53.60	(14.38)	69.13	(15.53)		22.46*

p* = probability level within groups $p < 0.05$

which %VO_2 max values were compared. It may be suggested therefore that practice and game conditions over five minute intervals in the 20 minutes of activity that was monitored, were consistently and significantly different in their estimated response of %VO_2 max.

6. Skill Tests in Specific Sports

Field data testing for the skills tests designed to monitor specific skills in each sport have been summarised in Tables 4.26 to 4.29. The badminton players improved significantly in the test for the smash shot [Table 4.26]. The magnitude of the significance in this test over the season was 17.71%, which was a 24.23% improvement. Non-significant changes over the season occurred in the serving and overhead clear tests.

Table 4.27 presents the basketball skill tests results. The basketball players improved significantly (by 10.08%) over the season in a test for the number of passes made in 30 seconds. There was a significant improvement in the scores of the dribbling test. Although the basketball players improved in their test for goal shooting by 1.49 goals, this difference was not significant.

Table 4.26: Specific Skills Test Results of the Badminton Group Over 12 Weeks

Skill	Period	Mean ($\bar{x}$)	(+ S.D.)	% Δ Pre Vs Post
Serving (%)	Pre	25.50	9.59	
	8 weeks	22.12	8.10	
	Post	23.00	8.80	
				9.8
Overhead Clear (%)	Pre	77.00	2.56	
	8 weeks	81.50	3.66	
	Post	82.12	5.86	
				6.3
Smash (%)	Pre	55.50	13.89	
	8 weeks	66.00	14.26	
	Post	73.25	10.69	
				24.23*

* significant differences within groups, $P < 0.05$

Table 4.27: Specific Skills Test Results Of The Basketball Group Over 12 Weeks

Skill	Period	Mean ($\bar{x}$)	(+ S.D.)	% Δ Pre Vs Post
Number of Passes in 30 Seconds	Pre	21.25	5.47	
	8 weeks	25.00	5.63	
	Post	23.87	6.92	
				10.08
Number of Objects Passed During Dribbling	Pre	16.87	3.18	
	8 weeks	18.50	2.98	
	Post	19.12	3.94	
				11.77
Number of Goals Shot in 30 Seconds	Pre	4.75	2.37	
	8 weeks	5.12	4.05	
	Post	6.25	3.45	
				24.00*

* significant differences within groups, $P < 0.05$

Table 4.28 contains the results from the skills tests of the netball players over the season. A significant decrease occurred in the time the girls took to dodge around a set course. This decrease was 1.7 seconds or 26.4%. Although the netballers improved their accuracy by 12.5%, non-significant changes were reported in a throwing accuracy test. Similarly, whilst the netballers scores for goal shooting improved in accuracy from 41.5% to 45.75%, this change over the season was non-significant.

Table 4.28: Specific Skills Test Results of the Netball Group Over 12 Weeks

Skill	Period	Mean ($\bar{x}$)	(+ S.D.)	% Δ Pre vs Post
Throwing at Target (%)	Pre	66.87	11.44	
	8 weeks	76.25	14.18	
	Post	79.37	9.19	
				15.75
Dodging (time in seconds)	Pre	6.44	0.17	
	8 weeks	5.51	0.19	
	Post	4.74	0.18	
				26.40 *
Goal Shooting (%)	Pre	41.50	15.09	
	8 weeks	37.25	11.66	
	Post	45.75	13.94	
				9.29

* significant differences within groups, $P < 0.05$

The three tennis skills tests produced improvements but none of the these changed significantly over the season [Table 4.29]. Tests for serving improved by 15.21%, forehand rallies improved by 24.30% and backhand rallies improved by 19.43%.

Table 4.29: Specific Skills Test Results of the Tennis Group Over 12 Weeks

Skill	Period	Mean ($\bar{X}$)	($\pm$ S.D.)	% Δ Pre vs Post
Serving (%)	Pre	16.00	10.97	
	8 weeks	12.25	12.99	
	Post	18.85	12.03	
				15.21
Forehand Rally (%)	Pre	10.50	10.32	
	8 weeks	16.00	8.96	
	Post	13.87	8.94	
				24.30 *
Backhand Rally (%)	Pre	10.37	9.93	
	8 weeks	11.00	10.03	
	Post	12.87	4.52	
				19.43

* significant differences within groups, $P < 0.05$

In summary, the changes in skills over the season were very minimal. Three of the sports; badminton, basketball and netball improved in one of the three tests administered. The tennis group recorded better scores in their three tests, but the improvement was insufficient to produce a significant difference.

7. *Analysis of the percentage of time spent being "active".*

Table 4.30 presents the analysis of participation time spent being "active". The analyses were determined from 20 minutes of monitoring in both practice and competitive game situations. From the summary of "activity" times, badminton players appear to have the most similar scores with regard to practice and game conditions (i.e 6.55 and 7.03 minutes respectively). "Activity" times in practice and game conditions in the other three sports of basketball, netball and tennis differed by 1.97 minutes, 1.85 minutes and 1.92 minutes respectively. In general, all times spent being active were less during practice than game situations. Less than one quarter of the 20 minutes monitored was spent being "active" during netball and tennis practices. Game situations in these two sports indicated that approximately one third of the 20 minutes was spent being "active" (33.67% and 31.60% respectively). Although the basketball players were actually substituted from the court during games, their mean activity time for 20 minutes of participation was the highest of all four sports (X = 8.72 min.s or 41.36%).

Table 4.30: Percentages of 'Active' Time from the Sporting Groups During Competitive Games and Practice Situations

Sport	Competitive Games				Practices			
	Actual Time (from 20 mins)		%		Actual Time (from 20 mins)		%	
	$\bar{X}$	(±S.D.)	$\bar{X}$	(±S.D.)	$\bar{X}$	(±S.D.)	$\bar{X}$	(±S.D.)
Badminton	7.03	(2.16)	35.15	(11.83)	6.55	(2.47)	32.7	(13.09)
Basketball	8.27	(2.11)	41.36	(10.56)	6.30	(1.58)	31.64	(7.85)
Netball	6.73	(2.87)	33.67	(14.37)	4.88	(1.56)	24.40	(7.83)
Tennis	6.32	(0.71)	31.60	(3.56)	4.40	(1.65)	22.02	(8.26)

CHAPTER 5

DISCUSSION, SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Increasing numbers of pre-adolescent children are playing sport in Australia. However most of the literature examining the physiological perspectives of children in sport is from overseas. In an attempt to qualify the nature of physiological changes in children who participate in sport, 5 groups of pre-adolescents were assessed over a 12 week season of sporting involvement. The groups (control, badminton, basketball, netball and tennis) were assessed for physiological variables in the Human Performance Laboratory on three occasions (at the start of the season, 8 weeks into the season and at the 12 week mark which was the completion of the season). In addition to this, the study aimed to quantify the intensity of participation through heart rate monitoring and time analysis under competitive games and practice conditions. Specific skill performance tests in the field corresponded to the three laboratory visits.

(a) Descriptive data

The descriptive data in this study are an indication of two important findings; firstly, the compounding effect of growth among the pre-adolescent population and secondly the homogeneity of the selected sample. The percentage change in height for the combined sporting group was 0.9% (or 1.47 cm) and 1.6% (or 2.5 cm) for the control group. A comparison was made with studies of similar duration involving children of a compatible chronological age. The rate of change in growth was more than that observed by Berg et al., (1985) in young soccer players after 9 weeks of training (0.4%) but less than the height gain measured in a study by Eriksson et al., 1973 (1.8% or 2.8 cm in a 6 week study). The rate of growth in height of the children in the present study was however similar to the results of Gilliam and Freedson (1980) (1.1% or 1.6 cm). The present study's growth rate was also in agreement with the findings of Elliott et al., (1984) whose experimental group of Australian elite pre-adolescent tennis players grew 1.01 cm (or 0.7%) and whose control group of elite tennis players grew 1.7 cm (1.1%) in ten weeks.

Non-significant between group differences were reported in growth rates of body mass. The experimental groups gained in body mass at a rate of 1.05 kg (or 2.53%) and the control group gained a mean 0.89 kg (or 1.9%) over the season. Children in the present study gained in body mass at a rate that was more than that observed in two previous studies; firstly in the research by Stewart and Gutin (1976), there was a 1.23% gain in children aged between 10-12 years after an eight week conditioning program and secondly, in a study by Berg et al., (1984) there was a 0.7% body mass increase after 9 weeks of soccer training in boys aged 11.8 years. Two other studies from the literature which involved shorter term conditioning studies, in pre-adolescent children, reported gains in body mass which were less than the present studies. In these two 12 week studies by Gilliam and Freedson (1980) and Brown et al., (1972), the body mass gains were 4.3% and 3.2% respectively. The results of body mass gain in the present study were in agreement with a 2.4% mass gain reported after 4 months of swimming training (Eriksson and Koch, 1973). The results of the present study were also similar to the body mass gains of 3.03% and 2.4% of the experimental and control group of elite adolescent tennis players (Elliott et al., 1984).

During the season there was a significant interaction between the height gains of the control group and the basketball group. These two groups grew 2.51 cm and 1.31 cm respectively. It is suggested that the rate of growth between the two groups differed because the control group were older (mean age, 11.25 years) than the basketball group (mean age, 10.75 years) and therefore may have been closer to peak height velocity.

(b) Maximal effort data

In the present study changes in maximal effort data were minimal over the season. The nature of the conditioning program appears to be critical to the significance of changes in the aerobic effects in subjects (Table 5.1). In the study by Eriksson (1972), the high intensity work performed for 3 1-hour sessions per week over 4 months by 11-13 year old males resulted in a highly significant improvement in aerobic capacity. Subjects in the present study reported participating in their sport 3-4 times a week. But often the overall quality of observed sessions was not categorised as high intensity. In addition to this, only 1-2 sessions a week were monitored. The quality of work output in the sessions which were not monitored remains uncertain. Subsequently, it may be suggested that the intensity of the participation in sport by children in the present study may not have been high enough to produce significant improvement. It should also be noted that the pre-season mean VO_2max ($ml.kg.^{-1}min.^{-1}$ was comparatively higher (55.09 $ml.kg.^{-1}min.^{-1}$) than that of the experimental group of Eriksson (1972) who had a mean pre-season VO_2max of 41.83 $ml.kg.^{-1}min.^{-1}$. Similarly the 12 year old females who participated in a 12 weeks' running program which was conducted by Brown et al., (1972) began the program with a VO_2 max of 49.17 $ml.kg.^{-1}min.^{-1}$. Whereas the lower starting point values for VO_2 max would appear to account for the significant gains that were observed in these two groups, it is suggested that the four male groups in the present study (including the control group) maintained a high level of aerobic power throughout the entire study. Any improvement in aerobic capacity of the boys in the present study would have required a great deal of highly intensive training. In addition to this Massicotte and Macnab (1974), suggested that performance changes are more likely to reflect the training protocol. Since all of the participation in the present study occurred relatively submaximally [mean 80% HR max in competitive games and a mean 70% HR max in practice situations], changes over shorter periods of time would be more likely to occur in variables other than maximal effort data.

Table 5.1: Training Changes in VO_2 Max ($ml.kg.^{-1}min.^{-1}$) of Children in Short Term Studies

Authors & Yr.	Age Group yrs	Percent Change in VO_2 Max ml.kg.-1min.-1	Duration of Study [weeks]	Type of Training
Brown et al., [1972]	8-13	26	12	Unstandardised Running Training
Eriksson [1972]	11-13	11	16	High Intensity Cycling etc.
Massicotte & macnab [1974]	11-13	--	6	Highest Heart Rate Group (170-180bts)
Lussier & buskirk [1977]	8-12	7	12	Running & Vigorous activities
Stewart & Gutin [1976]	10-12	No Change	8	Phys. Ed. Classes Games
Gilliam & Freedson [1980]	7-9	No Change	12	Physical Fitness Classes
Berg et al., [1985]	11.8	No Change		Soccer Training
Elliott et al., [1984]	11.7	No Change	10	Physical Fitness in Tennis Training
Present Study	11.4	No Change	12	Specific Sports Training

(c) Anthropometric profiles

The anthroprometric data included skinfold, girths and widths. The data were reported in direct terms (i.e. mm and cm). The use of formulas for body compositions estimates of percentage body fat in young populations has been reported to be subject to some question as to validity of underlying assumptions, techniques and direct applicability (Wilmore and McNamara, 1974, Lohman et al., 1975 and Lohman et al., 1984). Wherever a prediction equation for body density and percent body fat has been developed, its value appears to be limited to the population in which it was devised and the validity of such equations to children has certainly been challenged (Flint et al., 1977, Pollock et al., 1975 and Boileau et al., 1981). Johnston (1982) recommended that anthropometrics were best used directly rather than as a part of a prediction formula. Thus in the present study anthropometric data have been reported directly and data comparisons have been restricted to other studies reporting direct measures.

(i) Skinfold measurements

The fact that all groups except tennis decreased in their skinfold measurements at one or more sites may be related to the timing of the study. The study commenced at the start of the school year. Prior to this, there had been a six week vacation, in which limited training or competitive games had been experienced by any of the groups. Within the tennis groups, there was an overall slight increase in skinfolds. In a table of average thickness of skinfolds, Shephard (1982) displayed the results of children of incremental ages. The greatest gain in children's skinfolds occurred between the ages of 11 and 12 years of age i.e. when 10 years of age, the mean sum of ten skinfolds was 6.7 mm and when aged 11-12 years of age, the mean sum of ten skinfolds had increased to 8.0 mm. Since the tennis group in the present study were among the oldest group of participating subjects (with a mean age of 12.4 years of age), the increase in skinfolds over the season could have been associated with normal growth processes (Payne and Issacs 1987 p.172).

It must also be stated that although the control group was the only group to decrease in skinfolds over the 12 weeks, they had entered the study with the highest values. It is postulated that their return to school in February may have put some restriction on their caloric intake and also enhanced their energy output in terms of physical education classes, recesses and lunch breaks and other school sporting activities. The change in the control group's normal lifestyle could therefore be associated with decreased skinfolds over this particular period of time.

The tennis group from the present study can be compared to the tennis group profiled by Carlson and Cera (1984):

Table 5.2: A Comparison of Young Tennis Players' Skinfold Measurements

Skinfold Site (mm)	Carlson & Cera (1984)		Present Study - Tennis Group Pre-season		Post season	
Triceps	8.45	(±2.30)	11.66	(±6.37)	12.09	(± 6.51)
Biceps	4.50	(±0.72)	6.11	(±4.56)	6.77	(± 4.29)
Sub-scapular	8.25	(±1.27)	7.28	(±5.00)	7.40	(± 4.55)
Iliac Crest	8.70	(±1.70)	5.77	(±4.00)	7.77	(± 6.91)
Mid-abdomen	11.60	(±3.63)	9.04	(±8.67)	10.59	(±10.34)

[$\bar{X}$ (±S.D.)]

In the upper arm skinfold data, the present group appeared to have increased layers of adipose tissue when compared to the elite tennis players assessed by Carlson and Cera (1984). The three skinfolds on the trunk sites were slightly less in the present study's tennis group and this may be explained by the younger age of these participants (i.e. 12.37 yrs) than the tennis players (16.8 yrs.) tested by Carlson and Cera (1984)[Table 5.2].

(ii) Girths and Widths

The mean girths and widths of the children in the present study are compared to the results of children of a similar age from Canada (Ross et al., 1980):

Table 5.3: Comparison of Girths and Widths of Pre-adolescent Children.

Widths & Girths [mm]	Ross et al., 1980 Skaters	Prototype	Present Study - All 5 Groups Pre-season	Post Season
WIDTHS				
Hips	21.50 (±2.50)	23.12 (±2.53)	22.99 (±2.25)	23.16 (±1.65)
Elbow	5.51 (±0.35)	5.75 (±0.42)	5.92 (±0.67)	6.27 (±0.47)
Knee	8.10 (±0.54)	8.46 (±0.53)	8.54 (±0.73)	8.73 (±0.37)
GIRTHS				
Thigh	44.40 (±5.10)	45.89 (±5.24)	44.76 (±6.14)	46.63 (±0.94)
Calf	27.90 (±1.90)	29.55 (±3.14)	30.0 (±3.21	30.79 (±3.11)
Upper Arm (flexed)	21.30 (±0.30)	23.59 (±2.68)	24.01 (±3.95	24.00 (±3.18)

[$\bar{X}$ (±S.D.)]

The extent of on-going growth patterns was observed in Tables 4.5 to 4.8. In these tables, each of the groups demonstrated at least one significant within-group growth pattern in both girth and width measurements. From the published data, it would certainly appear that the growth patterns in the present study are normal for active children (Ross et al., 1980 Shephard 1982, Carlson and Cera, 1984). The results of the anthropometric data revealed that the changes in the girths, widths and skinfold measurements in the sporting groups which, when compared to the control group, were largely non-significant. This finding is in agreement with a study by Bloomfield et al., 1985. The authors presented profiles of young Australian swimmers, tennis players and non-competitors.

They reported non-significant differences among physical size, body composition and flexibility of the three groups. "It would appear that at this pre-adolescent stage of development, physical size, body shape, body composition and flexibility are not discriminating factors for high or low levels of performance...." (Bloomfield et al., 1985, p22.)

(d) Strength and Flexibility

(i) Upper body strength

Significant improvements in strength measurements in the upper body were reported in three of the four sporting group i.e. basketball, netball and tennis [Table 4.4]. The badminton group did not improve significantly over the season. However, the badminton players recorded the highest initial values in arm and shoulder push and pull strength tests at the start of the season and maintained these levels throughout the season. The control group did not improve significantly in upper body strength over the 12 weeks. Children participating in the sporting groups in the present study may be associated with a superior quality of upper body strength characteristics, when comparison is made with the control group.

Comparative data on the changes occurring in upper body strength of children over a period of time were difficult to obtain. However, the gains in grip strength of the tennis players have been able to be compared to the changes observed in the elite Australian pre-adolescent tennis players assessed by Elliott et al., (1984):

Table 5.4: Comparison of the Grip Strength of Pre-adolescent Children.

Author & Year	Grip Strength [-kgf]	Control Pre $\bar{X}$	Control Post (±S.D.)	Experimental Pre $\bar{X}$	Experimental Post (±S.D.)
Elliott et al., (1984)	Dominant	22.5 (±3.5)	24.3 (±4.3)	23.6 (±3.7)	25.5 (±2.5)
Aged 11.7yrs 10 weeks	Non-dominant	19.6 (±3.5)	22.5 (±3.5)	19.8 (±3.4)	22.1 (±4.1)
Present Study's Tennis Players	Dominant	16.54 (±3.3)	15.12 (±2.1)	16.87 (±4.08)	20.00* (±3.07)
Aged 12.4 Yrs 12 weeks	Non-dominant	15.19 (±3.1)	16.31 (±3.3)	15.69 (±5.3)	18.11 (±3.83)

* p.05

The table demonstrates a consistently superior standard of grip strength in the elite tennis players in the study of Elliott et al., (1984) when compared to the tennis group in the present study. However the percentage of change in the grip strength over the season in the present study's tennis players indicated a greater level of improvement than the tennis players conditioned by Elliott et al., (1984) i.e. 7.5% and 15.7% in the experimental groups of the respective studies in dominant grip strength and 10.5% and 13.4% improvements in the non-dominant grip strength of the respective groups.

(ii) Lower Body Strength

In studies where improvements have occurred in the lower body strength of pre-adolescent children, the nature of conditioning has been specific to the strengthening of these muscle groups (Sewall and Micheli, 1986, Servelio et al., 1987, Weltman et al., 1986, Raines et al., 1987 and Weltman et al., 1988). There have been non-significant strength gains in other studies where strength was included in a battery of tests, but not specifically conditioned during a testing period. For example, there was a non-significant gain in the peak knee torque in a soccer training study by Berg et al., (1985) and a non-significant gain in isometric muscle strength in a longitudinal study on effects of extra physical education classes on children by Shephard (1985).

Similarly, in the present study no specific leg strength conditioning was attempted and the only significant absolute gain in leg strength occurred in the left quadracep peak torque of the tennis group. In the right and left peak torque of the quadriceps and hamstrings of other groups, non-significant changes were reported over the season. However significant intra-group increases were observed in the basketball and badminton groups in the strength measured as the left hamstring to quadriceps ratio. But generally, the greatest and most consistent scores in hamstrings to quadriceps ratios were recorded from the control group. Two explanations are suggested for the pre-season superior hamstrings to quadriceps ratio of the control group; firstly, it may be hypothesised that the natural play activities of the control group developed a more even balance in the quadriceps to hamstring ratios when compared to the sporting groups, or secondly, it may alternatively be suggested that there was an initial imbalance in the practices of the sporting groups at the start of the season which tended to favour the strengthening of the quadriceps rather than the hamstring muscle group. It was interesting to note that the difference in hamstring to quadracep ratio between the sporting groups and the control group was non-significant by the end of the season.

Table 5.5: Comparison of Lower Body Leg Strength of Pre-adolescent Trained And Untrained Children In Australia.

	Isokinetic Torque (ft.LBS.)	
	Peak Torque Quadraceps	Peak Torque Hamstrings
TELFORD et al., 1986		
Trained Little Athletes		
males	47.27	31.34
females	50.29	32.74
Inactive controls		
males	45.57	26.10
females	47.27	27.06
PRESENT STUDY		
Badminton males	69.25	52.64
Basketball males	56.60	36.75
Netball females	58.50	42.25
Tennis males	72.50	46.12
Active controls males	67.87	51.25

Table 5.5 compares children in the present study with a profile of Australian Little Athletes (Telford et al., 1986). The peak torque in the quadriceps and hamstrings of the children in the present study was slightly higher than the trained children in the study by Telford et al., 1986. In the previous study (Telford et al., 1986) the females' leg strength was greater than the males. Data in the present study did not support this finding. It may be suggested however that the nature of conditioning for the Little Athletics females was more specific than the leg strengthening experiences provided for the netballers in the present study. Any comparison of the control groups from the two studies in Table 5.5 would however be invalid because of the differing nature of the groups (i.e. inactive and active). The comparatively good leg strength of the active control males from the present study when compared to their contemporary sporting peers, is very favourable, and suggests that sporting participation is not the only way in which young males may develop acceptable levels of leg strength.

(iii) Flexibility

Flexibility improvements were significant for almost all of the 5 groups in the sit and reach test and the test for the angle of hip extension. The only group to record a significant improvement in the test for lower back strength and flexibility was the female netball group. In agreement with the findings of the Australian Health and Fitness Survey (1986), the pre-adolescent females had superior flexibility in each of the three tests. Not only did they start the season with relatively higher levels of flexibility, but they were also able to improve in each aspect of flexibility testing throughout the season. Flexibility improvements were not significant in the study by Berg et al., (1985) where males aged 11.8 years participated in soccer training over a period of 9 weeks. Similarly, non-significant improvements in flexibility were observed after 9 weeks of isotonic strength training in males aged 10 years (Sewall and Micheli, 1986). In a later isokinetic strength training study, Weltman et al., (1987) included substantial amounts of flexibilty in the 14 week program with males aged between 6 and 11 years of age. Flexibility was reported to have improved a significant 8.4% at the end of the program.

In the present study, the observed practice and game sessions of the badminton and tennis groups, flexibility was an integral part of the warm up. In netball and basketball flexibility training was non-existent. The results however indicate that all groups improved in flexibility. These results are difficult to explain. Additionally, it should be acknowledged that in the light of very few of the males in the present study being able to stretch beyond their toes, more flexibility should be encouraged in game and practice situations. For example, the tennis group's flexibility in the sit and reach test (-8.38 to -2.31 cm over the season) was substantially less than the reported results of the sit and reach test (3.1 cm to 2.9 cm) performed by the elite tennis players over 10 weeks in the study by Elliott et al., (1984).

(e) Anaerobic characteristics

According to Inbar and Bar-Or (1986) the Wingate anaerobic capacity test which the children in the present study performed, reflects in subjects, the ability of a limbs' muscles to produce a high mechanical energy output peak power, and the averaged amount of sustained energy output. Margaria (1966), reported an age related incremental progression in anaerobic power. The results of the present study support Margaria's (1966) research. For example, at the completion of the season the peak power of the 10.75 year old basketballers was 243.87 watts whereas, the peak power mean for the tennis group aged 12.4 years was 303.97 watts at the end of the season. In the present study, however the percentage gain in peak power over the season for basketball and tennis was 22 and 19.65% respectively. The control group actually decreased 14.49% in peak power over the same period of time. This loss is difficult to explain. When compared to the peak power of chronologically age-matched children in other studies (Inbar and Bar-Or 1986, and Sargeant and Dolan 1986), the children in the present study appear to be considerably weaker in their peak power and their mean power output. It is suggested that the resistance of 0.075 $kp.kg.^{-1}$ was too easy for these children and that a greater resistance setting criteria (e.g. 0.5 $kp.kg.^{-1}$) would have promoted more powerful outputs. The force suggested in the original Wingate test was 0.075 $kp.kg.^{-1}$when a Monark bicycle was used. In 1987, Bar-Or published a review of the Wingate anaerobic test. He (1987) suggested that the optimisation of force depended on the training, age and body weight of the subjects. Bar-Or (1987) concluded that the issue of optimal force remained unsolved. Since all children in the present study were given a standardized force, the correct optimal resistance may not have been provided.

Blimke et al., (1986) conducted a study where anaerobic power was expressed as $watts.kg.^{-1}$ and tabled the values for boys and girls aged between 8 and 14 years of age. The 10 year old girls averaged 7.85 $watts.kg.^{-1}$, the 10 year old boys averaged 8 $watts.kg.^{-1}$ and the 11 year old boys averaged 9 $watts.kg.^{-1}$. Once again the approximate means of the relative peak power in the present study were less than those reported in the literature e.g. 10 year old female netballers, 10 year old male basketballers and 11 year old male badminton players scored an average 5.99, 6.60 and 7.36 $watts.kg.^{-1}$ respectively.

Significant improvement in the results of the Wingate test was reported by Grodjinovsky et al., (1980) after 6 weeks of an interval-based cycling program. The comparisons of the results from the present study with other documented anaerobic characteristics of pre-adolescent children have been made difficult in the light of the force resistance discrepancies. Nevertheless, within the present study, the male sporting groups all improved significantly in their mean power and peak power over the season. The badminton and basketball groups also improved significantly in their peak power when it was expressed relatively, in $watts.kg.^{-1}$. There was an absence of significant improvement in the female netball group and the control group. It is postulated that significant improvements in anaerobic characteristics of the male sporting groups are a reflection of the specific nature of their practice and competitive conditions. The boys in badminton, basketball and tennis groups were all given the opportunity for high intensity explosive work in at least some proportion of each training session [Appendix C {1 to 4}]. But the frequency of the explosive work in the the training sessions of the netball group was substantially less in the other sporting groups. Overall, the observed significant improvements in the anaerobic capacity of the male sporting groups in the present study, are suggested to reflect one of the advantages associated with a season's participation in sporting activities where anaerobic demands are often practised.

(f) Field data

(i) Intensity of participation

The American College of Sports Medicine (1978) published the recommendations for adequate exercise quality for healthy adults. Their recommended intensity was between 60 and 90% of maximal heart rate reserve [MHRR] or between 50 and 85% VO_2 max. Table 5.6 provides only a sample of the wealth of available literature on the intensity at which adults participate in physical activity. The sports chosen are those that closely resemble the sports in the present study.

Table 5.6: Intensity of Sports Participation in Adults.

Author & Yr.	Activity	Absolute Heart Rate [$bts.min^{-1}$]	% Heart Rate . Max
Beaudin et al., 1978	Squash	155	77
Morgans et al., [1984]	Racquetball - singles - doubles	 161 145	 83 {MHRR} 67 {MHRR}
Elliott et al., [1985]	Tennis - singles	152	80
Morgans et al., [1987)	Tennis - singles	154	61 {MHRR}

{MHRR = Maximal Heart Rate Reserve}

Limited attempts have been made to quantify the intensity at which children participate in physical activity, but the literature that is available has been summarised in the following table:

Table 5.7: Intensity of Children Participating in Physical Activity

Author & Yr.	Subjects	Activity & Intensity	Results
Eriksson [1972]	School Children	High Intensity Aerobic Activity	6% in VO_2 Max [$l.min^{-1}$]
Eriksson & Koch [1972]	Swimmers	85-90% VO_2 Max	Sig. Improvement in VO_2 MAX.
Massicotte & Macnab [1974]	School Children	3 Groups 170-180 $bts.min^{-1}$ 150-160 $bts.min^{-1}$ 130-140 $bts.min^{-1}$	Most Significant Changes Occurred in Highest HR Group

Table 5.7 cont'd.

Table 5.7 cont'd.

Stewart & Gutin [1976]	School Children	Trained at 90% HR Max	No Change - VO_2Max Significant Change in Sub-max Work Hrs
Gilliam & Freedson [1980]	School Children	Mean Hr For Exp'l Group = 165 $bts.min^{-1}$	No Change in Anthropometric Data

Massicotte and Macnab (1974) exercised males aged 11-13 years, at the three intensities (tabled above) and reported improvements in maximal and sub-maximal efforts only in those children who worked at the highest intensity. Significant maximal aerobic effort increases were also reported in a study by Eriksson and Koch (1973) where young swimmers exercised at an estimated 85-90% of VO_2 max. Heart rates of children in the present study were not consistently within the high intensity zones.

Table 5.8 presents a summary of the game and practice data (Tables 23, 24 and 25). An analysis of the practices and games demonstrated that the mean absolute heart rates were significantly lower in practice situations than in competitive games, in badminton, netball and tennis.

Table 5.8: Mean Practice and Competitive Game Intensities of Children Participating in Four Sports

Sport	Absolute Heart Rates [$bts.min^{-1}$]		% Heart Rate Max.		% VO_2 Max	
	Practice	Games	Practice	Games	Practice	Games
Badminton	149 * [± 4.89]	170 [±8.83]	72.83 * [±2.50]	82.61 [±4.51]	59.65 * [±5.46]	75.20 [±7.98]
Basketball	157 [±11.78]	159 [±7.41]	74.91 * [±3.61]	79.50 [±3.62]	56.51 [±5.74]	64.21 [±4.65]
Netball	144 * [± 4.69]	168 [±9.17]	69.45 * [±2.70]	82.01 [±4.44]	49.75 * [±2.58]	70.92 [±8.35]
Tennis	135 * [± 5.05]	162 [±5.86]	66.73 * [±2.40]	78.72 [±2.13]	48.49 * [±3.99]	66.16 [±4.15]

* significant difference (p.05) [$\bar{X}$ (±S.D.)]

The sport with the highest mean game absolute heart rate was badminton (170 $bts.min^{-1}$) and the sport with the lowest mean game absolute heart rate was basketball (159 $bts.min^{-1}$). Since basketball was comparatively lower in absolute heart rates than any of the other groups, it is not surprising that the mean basketball game absolute heart rate data (159 $bts.min^{-1}$) was not significantly different from the mean absolute practice heart rate data (157 $bts.min^{-1}$). It is suggested that although the heart rate on court data for basketball was quite high, the mean of the game was considerably lower than expected because of the number of substitutions, and stops and starts that were included in the collection of the game data. None of the four sports had mean absolute or relative heart rates which could be considered as high as those reported by Paterson et al., (1977) in young players of ice-hockey [Table 5.9]. But the present results are similar to those reported in the young players of another ice-based game called ringette [Alexander et al., (1988)]

Table 5.9: Intensity of Children Participating in Competitive Games of Sport

Author & Yr.	Sport	Mean Absolute Heart Rate ($bts.min^{-1}$)		Mean % Heart Rate	
Paterson et al., [1977]	Ice-Hockey 2 Leagues	182.4	[±3.1]	92.3	[±4.0]
		187.7	[±3.3]	94.7	[±1.2]
Alexander et al.,	Ringette				
	Standard;			[predicted max]	
	centre	162.4	[±2.2]	78.48	
	forward	155.6	[±7.4]	75.67	
	defence	153.8	[±2.1]	74.32	
	Zoneless				
	centre	161.6	[±1.7]	78.07	
	forward	161.4	[±1.6]	77.97	
	defence	160.6	[±1.8]	77.57	
PRESENT STUDY	Badminton	170	[±8.83]	82.61	[±4.51]
	Basketball	159	[±7.41]	79.50	[±3.62]
	Netball	168	[±9.71]	82.01	[±4.44]
	Tennis	162	[±5.86]	78.72	[±2.13]

[$\bar{X}$ ±S.D.]

When the intensity of the four sports' competitive games data in the present study was examined, each sport apppeared to be within the range recommended by the ACSM (1978) for development of aerobic fitness i.e. between 50 and 85% VO_2 max.

The use of the relative percentage of maximal oxygen consumption (%VO_2 max) was based on the assumption that children were similar to adults in their reponse to incremental exercise. It was assumed both age groups have a linear relationship among heart rate, oxygen uptake and work load. But this relationship may not necessarily be similar in the two populations (Saris 1986). In addition to this, Katch et al., (1978), concluded that relative percent values were not indicative of an often associated and predicted metabolic acidosis. In other words, information on the relative percentage of heart rate maximum was not consistent with the state of metabolic acidosis which appeared to vary significantly among individuals. Without invasive studies, which are very difficult to justify in pre-adolescent subjects, we can only estimate whether or not young children are being given a training stimulus. When the term exercise intensity is expressed as a relative percentage of maximal effort in the children in this study, it therefore must be recognised as a general reference and is not used as a precise indicator of exercise demands.

Mc Ardle et al., (1971) reported relatively high game intensities in adult female basketballers during a season of college matches (81-95% HR max). Despite these high game intensities, a non-significant improvement occurred in the basketballers' aerobic capacity over the season. The authors (1971) postulated that increased aerobic capacity had not occurred because the practice sessions were of a substantially lower intensity and required a smaller work ouput. Similarly, in the present study, non-significant changes in aerobic capacity were reported over the season. It was also reported that significantly lower intensitites were present in 3 of the 4 sports when the intensity of practice sessions was compared to competitive game situations. It is suggested that although game intensities were of sufficient intensity, for aerobic improvement to occur over the season, training sessions were not replicating those stresses (Table 5.9) and may have contributed to a lack of improvement in this variable. It must also be acknowledged that while the difference between game and practice conditions in badminton was significantly different, the section of training sessions which was monitored, was generally the first half hour of a one and one half hour practice. This meant that what was normally monitored was the warm up and individual skill drills. If the last half hour of training had been monitored then the results may have been different in that this was the period in which the highly intense anaerobic based work was conducted. Although elements of high intensity were present in each practice session attended for all sports (with the exception of netball), the intensity was not generally sufficient in matching the stresses of game conditions.

A comparison of practice and game intensities, was used as another measure of the quality of intensity of participation. This was an analysis of the actual time spent being active. Table 5.10 cites activity values reported largely in adult studies and indicates some diversity of results.

Table 5.10 Summary Of Previous Studies Where The Percentage Of Time Spent Being Active has Been Recorded

Author & Yr.	Sport	Total Playing Time	% Activity Time
Seiger et aL., [1973]	Tennis	10 min.s	41.1
Paterson ct al., [1977]	Junior Ice-hockey	45 min.s	42.2
Beaudin ct al., [1978]	Squash	45 min.,	58.0

Table 5.10 cont'd.

Table 5.10 cont'd.

Misner et al., [1980]	Tennis	45 min.s	23.6
Docherty [1982]	Tennis	30 min.s	16.7
Elliott et al., [1985]	Tennis	60 min.s	23.6
Morgans et al., [1984]	Racquetball	60 min.s	44.9 singles 60.0 doubles
Present Study	4 Sports	20 min.s	33

Elliott et al., (1985) alluded to the problem of discrepancies among playing and environmental conditions in any between study comparisons of activity times of the same sports. According to Elliott et al,. (1985), comparisons, must acknowledge the anomalies that exist in intervening variables such as playing time, court surfaces, skill level of opponents etc. Even when allowances are made for different playing conditions, the 'active' times of participation, the children participating in competitive games in the present study compare poorly with those reported in the preceeding table. Percentages of activity in practice times of the children in each sport were only slightly less than the game percentages of activity times. The low activity time levels of the children in the present study are in agreement the study conducted by Klausen et al., (1986). In this study the authors (1986) reported that less than 20% of the total time was spent with absolute heart rates greater than 150 $bts.min.^{-1}$ within physical education classes of young children. The authors concluded that the level of activity in these classes was insufficient in improving the fitness level of the children.

Non-significant changes in many cardiorespiratory variables in the present study may have been a result of poor exercise prescription. Although the frequency and duration of participation in sport among the children was adequate to provide a potential training stimulus, the intensity of the total commitment to the sport may be questioned. Heart rates may have been relatively high during games but in terms of activity times, participation levels were poor. It is not known whether these low activity levels are atypical of other forms of sports participation in young populations in Australia.

Conversely, non-significant changes in many variables may not have occurred because of inadequate participation intensities. Many of the children in the present study began the study with comparatively high levels of fitness. Improvement therefore may have been more difficult to attain. The high fitness levels of the control group must also be acknowledged. Significant levels of difference between the control group and the sporting groups were perhaps also made harder to ascertain because of the high initial levels of the control group. Non-sporting subjects in adult studies are likely to be more sedentary than a non-sporting group drawn from a child-based sample population. Since an active control group was selected for the present study a limited number of significant differences in cardiorespiratory data may be associated with the nature of the control group.

SUMMARY AND CONCLUSIONS

Summary of results

The descriptive data of the five groups of pre-adolescent children demonstrated within group homogeneity population. It should be noted that the basketball group was younger and smaller, the netball group was female, and the control groups were fatter. In the laboratory testing there was substantial evidence of the amount of growth occurring in all five groups in this particular age (X 11.4 yrs) of children from the concomitant gains in body mass, height, girths and widths. These growth patterns are consistent with other studies in the literature where growth has been monitored over a similar amount of time.

Skinfold measurements indicated slight decreases in three of the four sporting groups, with a slight gain in the tennis group. The individual skinfold sites of the tennis group were compared to a group of age-matched elite level tennis players and were reported to be substantially higher in the present group. The sum of the five skinfolds did not alter significantly in any of the four sporting groups over the season. The only significant difference occurred in the sum of the five skinfolds of the control group. It is hypothesised that this may have been associated with the timing of the study. The three month testing program began at the end of summer vacation and the start of the academic year. This period could have meant the end of somewhat unrestricted eating patterns and simultaneously instigated the return of regular activity in curriculum and informal playground activities for the control group. There was an absence of significant improvement in the upper body strength characteristics of the control group over the 12 week testing period. However the basketball and tennis group improved significantly in their grip strength. It should also be noted that the badminton group maintained the highest level of grip strength among all the groups throughout the season. Although the netballers began their season with substantially lower arm and shoulder push and pull strength, they improved significantly over the 12 weeks. Very few changes were recorded in the lower body strength of the quadriceps and hamstrings over the season in any of the groups. However it is interesting to note that when compared to the four sporting groups combined, the control group had a significantly superior hamstrings to quadriceps ratio at the start of the season. This finding may be associated with an imbalance in the pre-training state of the sporting groups in that the quadriceps were much stronger than the hamstrings or it may be that the unorganised activities in which the control group engaged, provided a more natural balance in leg strength.

Flexibilty was consistently superior throughout the season in the female netballers. Although some improvements in flexibilty were evident in the male groups, there was a disturbingly small range of motion in the trunk forward flexion test of sit and reach among male participants. Flexibility work needed to be addressed more seriously in the young male subjects.

The male sporting groups investigated in this study improved significantly in their anaerobic measurements of peak power and mean power over the season. Elements of anaerobic activity were reported in both the competitive game and practice situations of these groups. There was an absence of anaerobic type activities among the netball group. The changes in anaerobic power of the netball group and the control group were non-significant. It was concluded that the significant improvement in anaerobic capacity of the male sporting groups was associated with the nature of their competitive game and training conditions.

Field data collection of heart rates demonstrated that the game and training situations were being played at an intensity which had the potential to be used as a training stimulus. The impact of the training stimulus was significantly less in the practice situations than the game situations in all of the sports except basketball. In other words, from the results of the study, improvements are recommended in exercise prescription of training programs for children in sport. All components of fitness should be included and seriously applied within the nature of the sport. Intensity levels at training may be altered in order to replicate the stresses of the game.

CONCLUSIONS

1. Physiological advantages do exist in pre-adolescent children who participate in sport over time.

The five groups involved in the study were largely homogeneous in their descriptive and maximal effort data. In spite of these similarities significant differences were present in a number of variables when comparisons of the sporting groups were made with the active control group.

The first significant difference which was of interest was the finding that the control group had larger skinfold measurements. This could be associated with an advantage in leaness that the male sporting groups had over the control group. There were also significant improvements in some of the strength measurements over the season. In the left leg's mean quadriceps to hamstrings ratio, two of the sporting groups displayed significant improvement. Three of the sporting groups also gained significantly in upper body strength when compared to the control group. Thirdly the anaerobic characteristics of the male sporting groups improved significantly over the season when compared to the male control group.

The control group must be accredited with comparatively high levels of aerobic, anaerobic and strength characteristics. Being active children, the control group not only participated well in school based activities, but also reported playing many hours of unorganised activities out of school hours. Thus by selecting active rather than sedentary children for the control group, significant differences between the control and the sporting groups were harder to identify.

The anthropometric profile also highlighted the substantial amount of growth occurring in these children in terms of height, body mass, girths and widths. In addition to this, a number of authors (Bar-Or 1985, Brooks and Fahey 1985, Inbar and Bar-Or 1986 and Birrer and Levine 1987) have indicated that there are growth related increments in aerobic and anaerobic capacity and strength and flexibility. Any significant changes in children must occur over and above those occurring naturally in growth processes. Even when significant differences are reported between groups of children, difficulties still exist in determining the accountability and percentage of variance due to hereditary, growth and conditioning. Claims of changes resultant from training are acceptable only in well controlled adult populations. In children, changes which occur in the process of a training study, are better acknowledged as occurring in association with (rather than as a result of) conditioning programs (Bar-Or 1983).

2. Within group changes often reflected the nature of the conditioning imposed by the sport and more importantly, by the coach.

Improvements in upper body arm and shoulder strength in basketball, tennis and netball players may be a reflection of the demand imposed by their chosen sport. The badminton group however did not improve in upper body strength. This may be due to a comparatively higher starting level in all four assessments of upper body strength.

Minute by minute records of activities were documented during training sessions. Each of the training sessions observed at the tennis, badminton and basketball venues, had some elements of anaerobic activity in them e.g. rebounding drills in basketball, smashing drills in badminton and serving drills in tennis. In badminton practice sessions, in particular, the coach attempted to replicate game stressess by including a section of drill sequences which involved a 1 to 1 ratio of work and recovery. The absence of anaerobic improvement in the netball group may also be a reflection of training in that their training sessions were very low in intensity and more often than not consisted of an hour of low work output practice games.

3. In agreement with previous studies, the intensity at which children were participating in sport was adequate in providing the potential for a training effect.

Recommendations have been made which state that adults exercising between 50 and 85% VO_2 max were potentially undergoing an endurance training effect. In applying this guideline of intensity to the children in the present study, it can be reported that participation in all of competitive games and most of the practices, was supplying children with a potential training effect. Heart rate data of the control group was not recorded during their unorganised play activities, so it is difficult to postulate whether or not this training effect was a unique experience to the sporting groups.

4. Competitive game stresses were generally significantly greater than those imposed in practice sessions.

In badminton, netball and tennis physiological game stresses were not being matched in practice sessions. In basketball players, the mean stresses under competitive games and practice conditions were similar. One possible explanation for the similar responses to the two conditions in the basketball players is that the mean basketball game heart rates were lowered considerably by the inclusion of data coinciding with substitution, time outs and stops and starts for referees' decisions. Thus, the overall effect of all the interruptions to play was a lower competitive game heart rate mean in basketball players than in any of the other more continuous sports. In the other three sports some evidence of high intensity activity was present in each of the observed practice sessions (with exception of netball), yet the averaged 5 minute heart rate was significantly lower than those obtained under competitive game situations.

5. The nature of practices in children's sport may necessarily have to differ from that of adults.

It is however recoginsed that training at junior levels of sport requires principles of skill, discipline and social understanding. The goals of the coach, the children and their sport may necessitate the emphasis being placed on components other than those with a physiological basis. In this case, supplementary programs may be necessary. These programs may include additional off-court work to supplement and match the physiological stresses of game play. Alternatively, it may be possible to have coaches and coaching associations design programs that emphasise greater physiological stresses within the actual practice time.

RECOMMENDATIONS

The recommendations from the study will be made in two catagories. These categories are the specific and the general recommendations.

(a) Specific Recommendations

1. The first recommendation is to continue the present investigation with the same subjects as they advance into adolescence. A detailed profile of this nature has not been conducted on children playing sport in Australia. A longitudinal study of this nature would provide continuous and specific feedback to the coaches over time and would provide potenitial benefits beyond the scope of the present subjects.

2. It would also be recommended that several more control groups of children be included. A control group of active pre-adolescent females who do not engage in organised sport would enhance the appropriateness of comparisons. Comparisons in the present study between the male control and the female netball group were compounded by the gender/lifestyle differences in many of the variables. Another consideration is the inclusion of control groups of children who participate in sport in competitive games only. It is expected that any resultant differences between children who participate in games only would be a greater reflection of the effectiveness of training.

3. It is also recommended that sports based training programs continue to be encouraged, but that they include specific training for the aerobic and anaerobic demands of competitive situations. Careful analysis of current games demands may result in changes being made to training regimes. Alternatively, children participating in sports where training priorities do not centre on physiological principles, may require their coaches to prescribe fitness programs to be completed outside of participation hours.

4. It is recommended that specific training programs be designed to provide the opportunity for these children to continue to develop their strength, anaerobic capacity and flexibility through sports participation. If elements of these general fitness components were included, coaches, children and parents would be able to monitor any changes that occur with the process of sports participation. Rewards of the process of fitness in sports participation are deemed to be of greater lasting and intrinsic value than those rewards which only concentrate on the product/outcome of competitive participation (Corbin, 1988), such as premierships or best and fairest awards.

(b) General Recommendations

1. The first general recommendation is to continue investigations into physiological nature of conditioning responses in pre-adolescent sporting populations. In this way, exercise prescription can be designed specifically to enhance the physiological advantages in children who participate in sport in Australia.

2. Secondly, the results of the present study would be complimented by conduct of more broadly based longitudinal studies into the physiological effect of children participating in sport such as the five year project undertaken in England (Vines, 1988).

3. Lastly it is recommended that there be a large scale promotion of information obtained in this and future studies of a similar nature to enhance the quality of coaching in sport and the quality of the sporting experience for the child.

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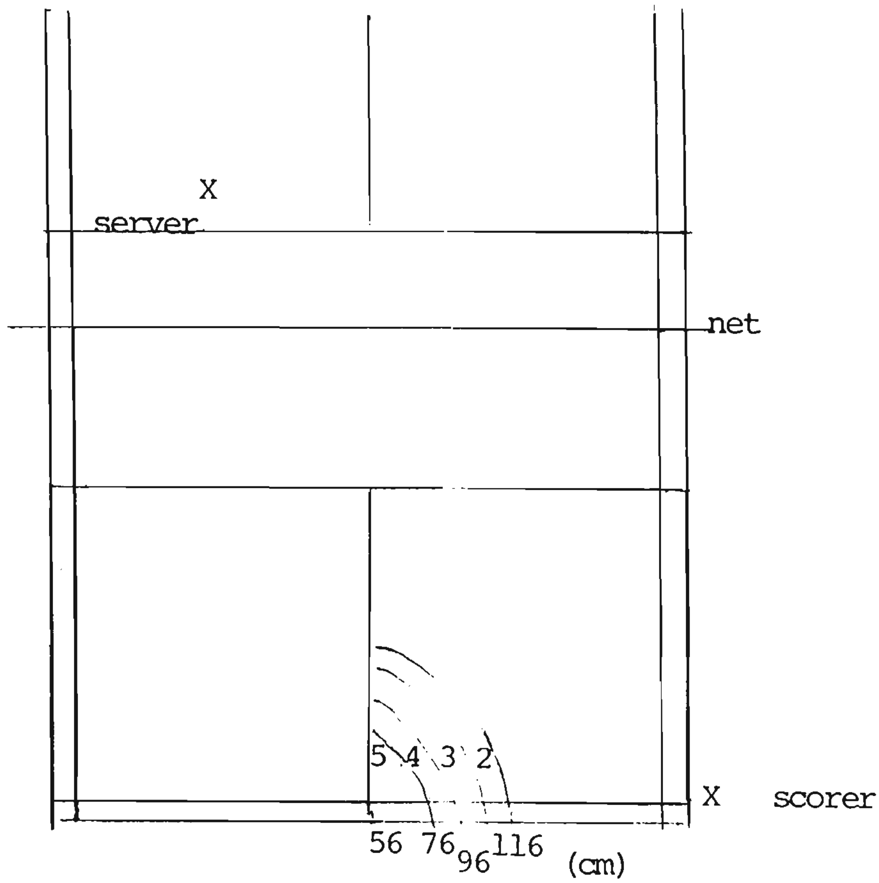
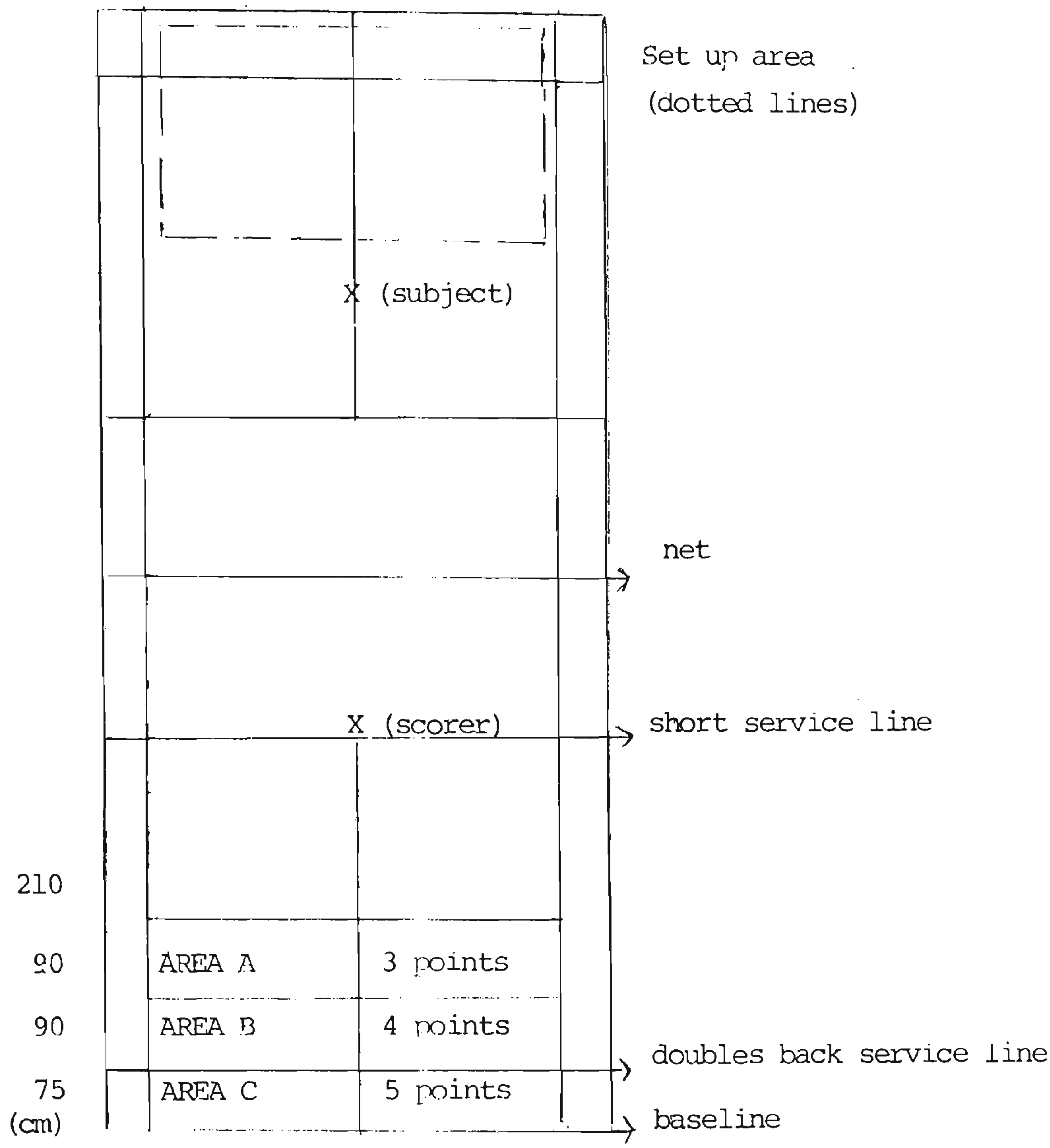
APPENDIX A

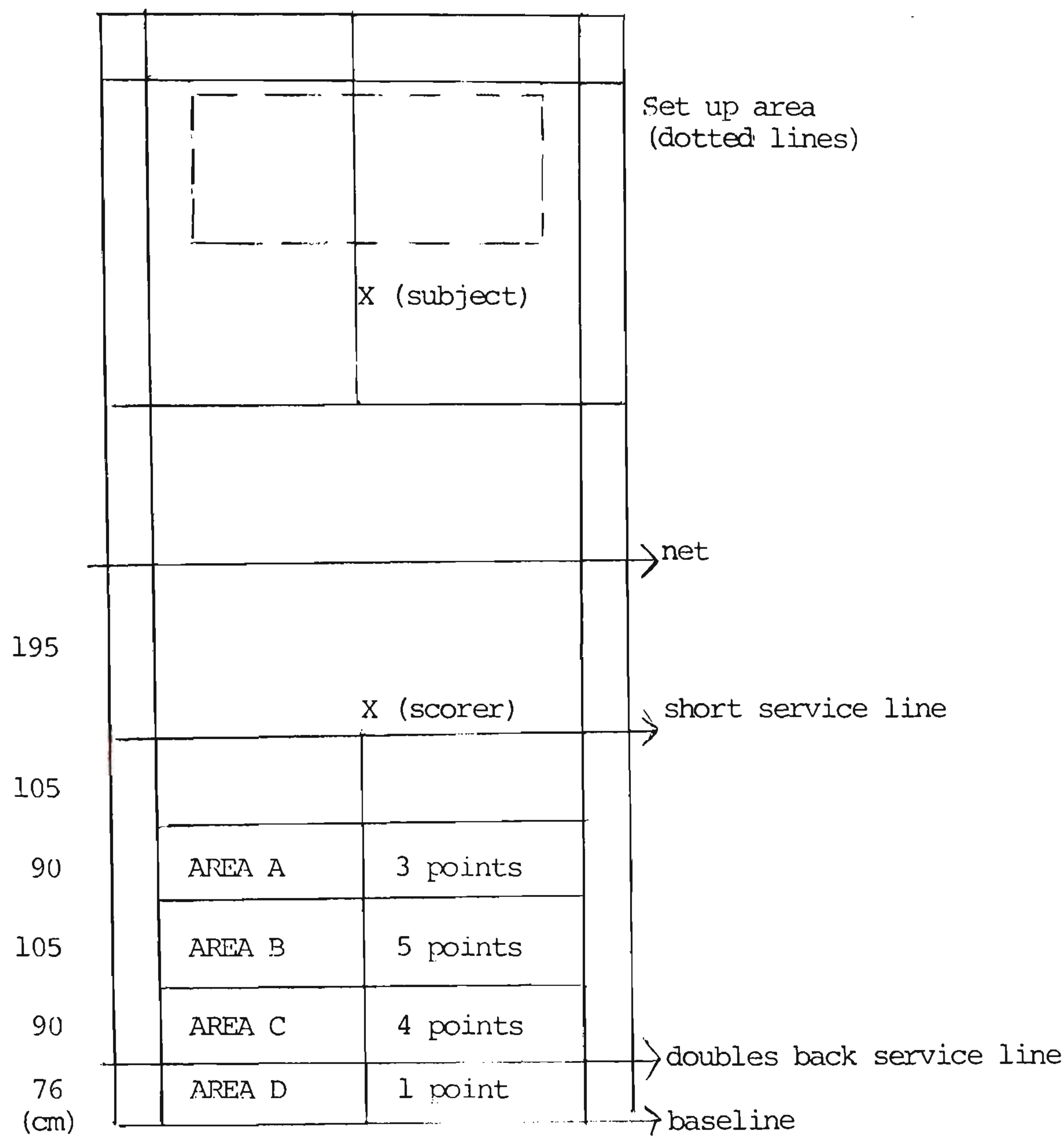
APPENDIX A (1): Scoring system for long service test in badminton



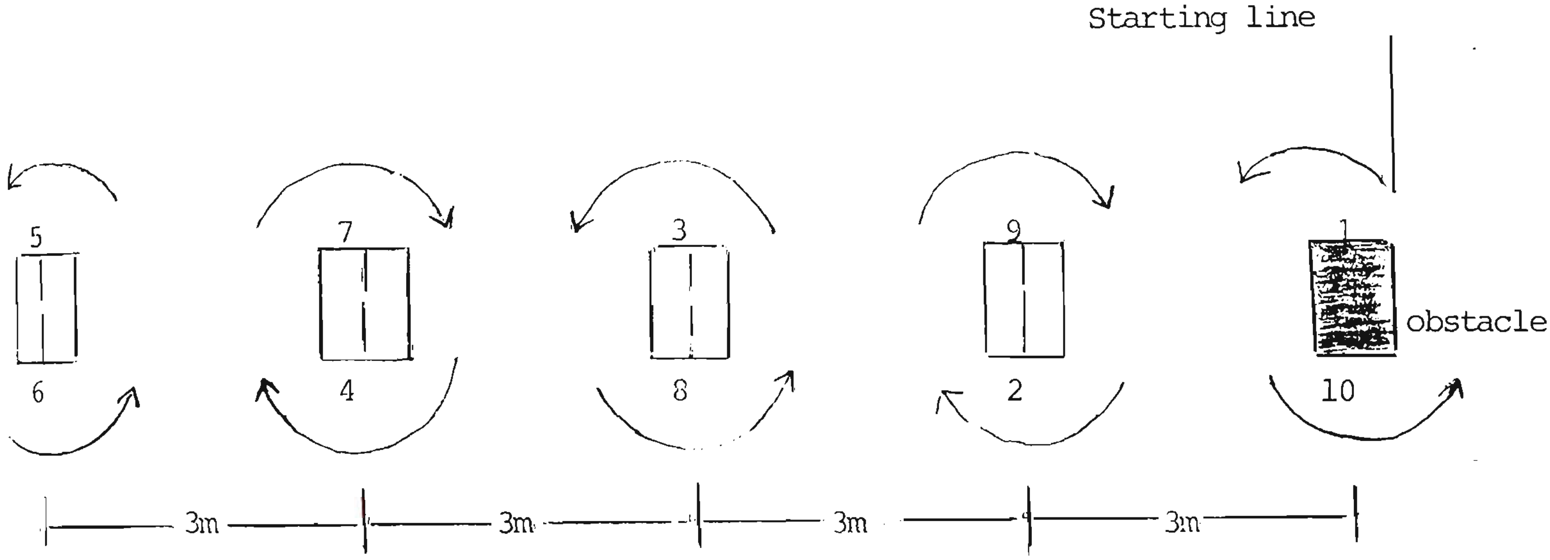
APPENDIX A (2): Scoring shot system for clearing shot test in badminton



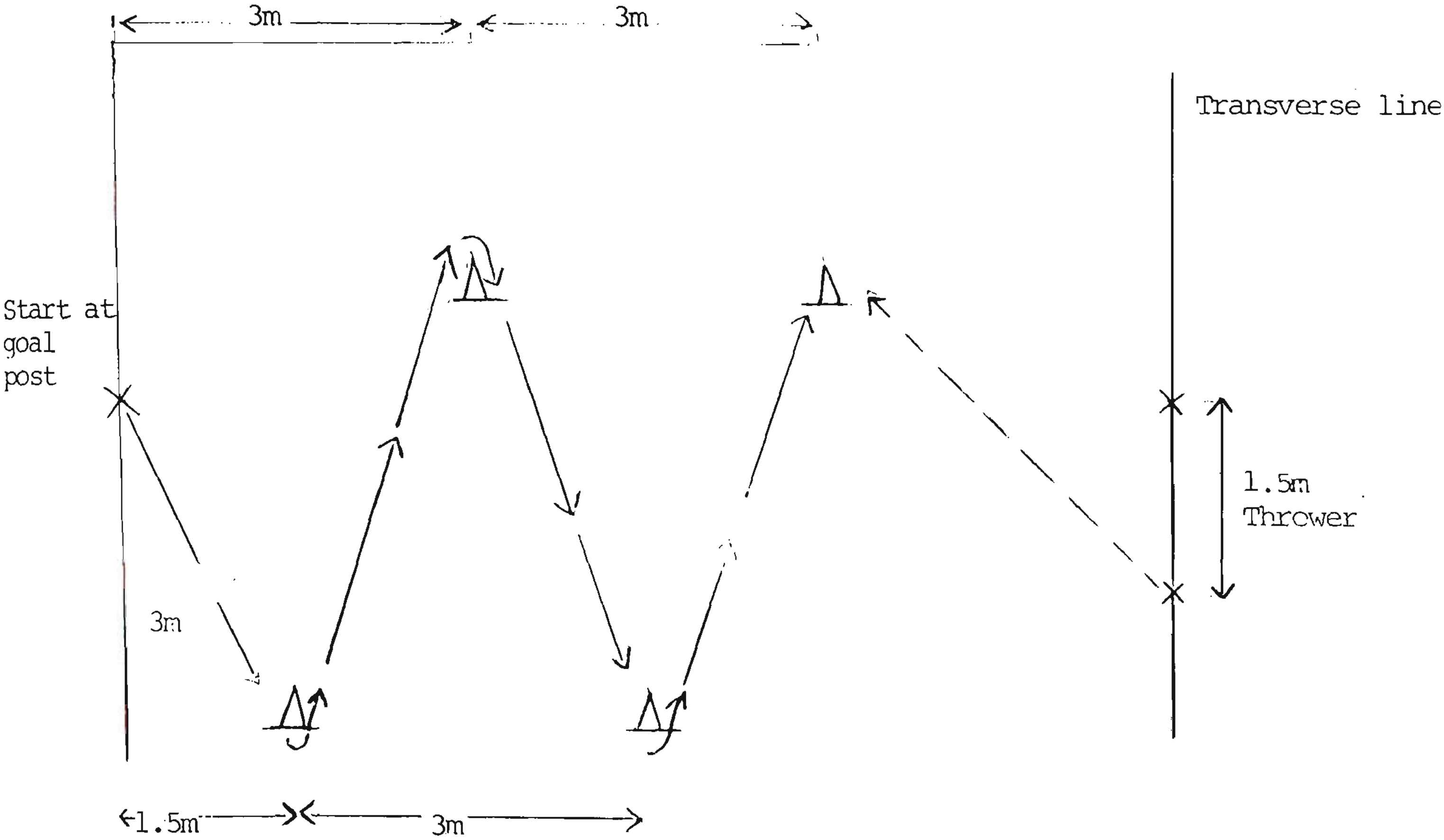
APPENDIX A (3): Scoring system for smash shot test in badminton



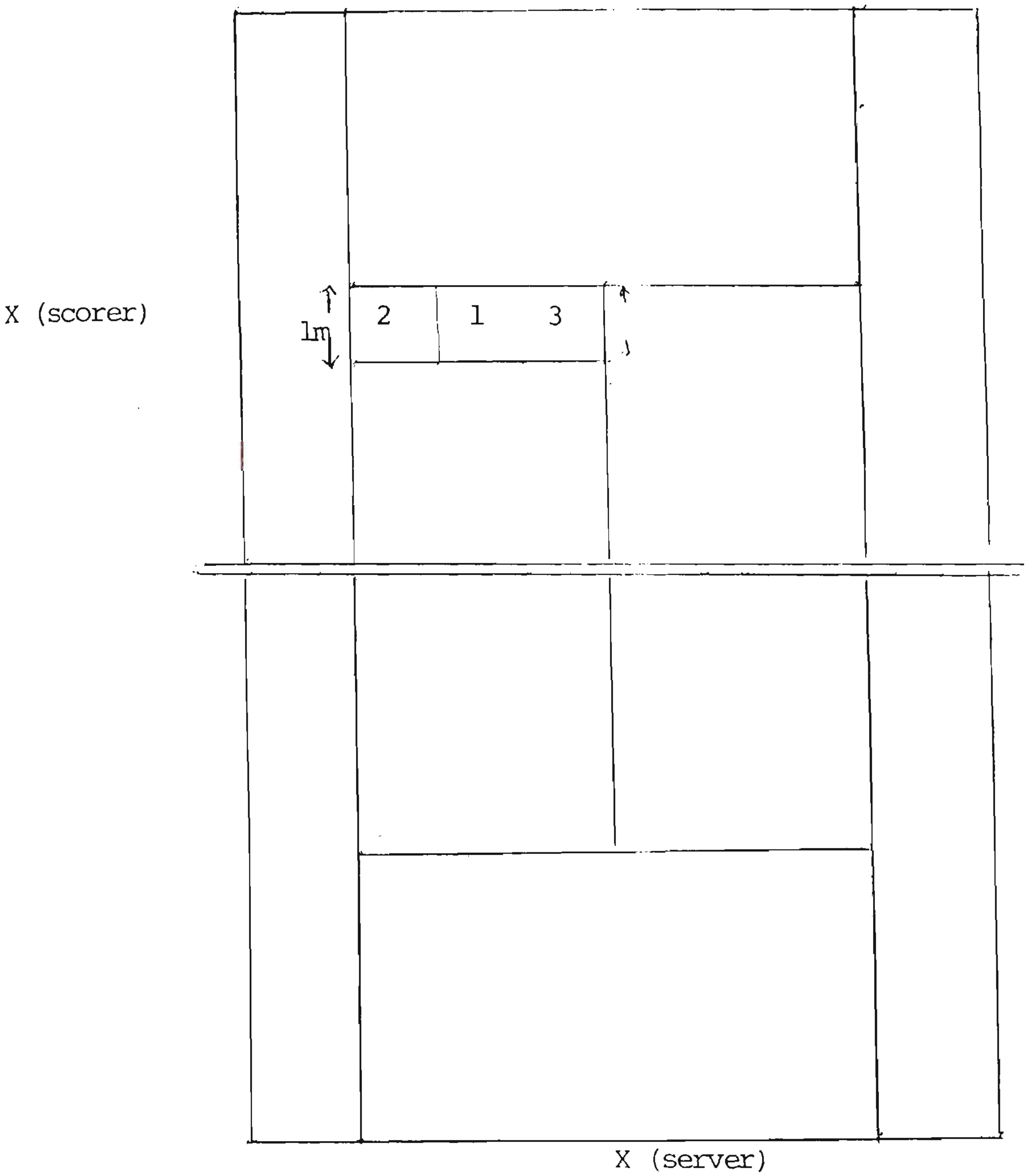
APPENDIX A (4): Dimensions for timing of the dribbling test in basketball



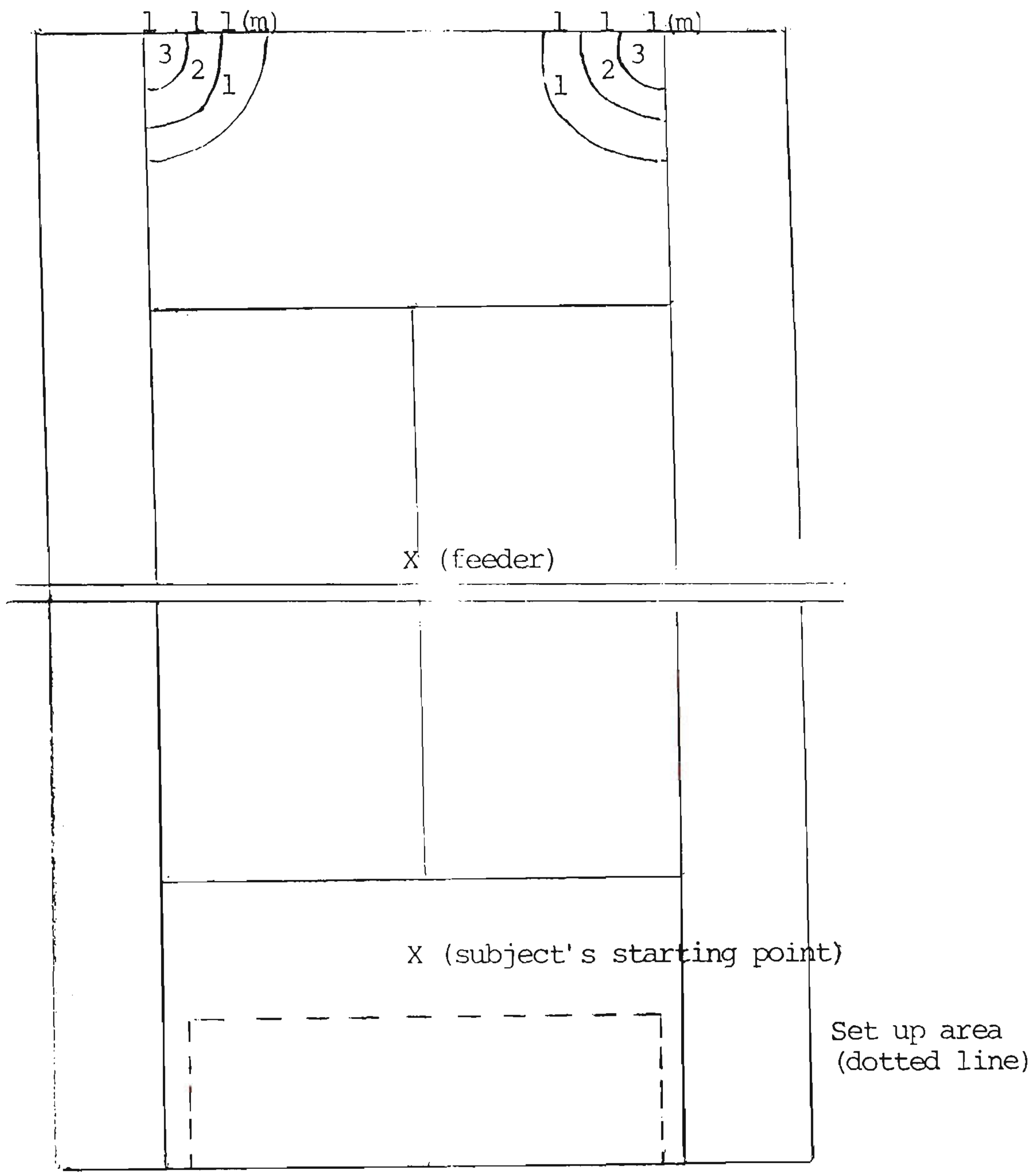
APPENDIX A (5): Dimensions for the timing of the dodging test for netball



APPENDIX A (6): Scoring system for tennis service test (right handed players)



APPENDIX A (7): Scoring system for forehand and backhand test in tennis



APPENDIX B

APPENDIX B [1]

Comparison of the Descriptive Data of the Badminton Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group X	(±S.D.)	Badminton Group X	(±S.D.)	%	F Ratio	P
Age (yrs)	11.25	(1.03)	12.5	(1.12)	10.0	2.62	0.128	
Mass	Pre	42.84	(14.22)	43.13	(10.05)	0.7		
(kg)	8 weeks	43.51	(13.84)	44.51	(10.03)	2.3	1.02	0.374
	Post	43.71	(13.68)	44.41	(9.90)	1.6		
Height	Pre	147.21	(8.85)	149.63	(8.93)	1.7		
(cm)	8 weeks	148.93	(8.86)	151.21	(3.03)	1.6		
	Post	149.72	(9.13)	151.80	(3.04)	1.4	0.35	0.711
Body Surface	Pre	1.32	(0.25)	1.33	(0.18)	0.8		
area	8 weeks	1.33	(0.23)	1.34	(0.19)	0.8	1.90	0.169
(m^2)	Post	1.33	(0.23)	1.36	(0.18)	2.3		

p* = probability level between means $p < 0.05$

APPENDIX B [2]

Comparison of the Descriptive Data of the Basketball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Basketball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Age (yrs)	11.25	(1.03)	10.75	(1.48)	8.9	0.6	10.448	
Mass	Pre	42.84	(14.22)	35.35	(6.34)	17.5		
(kg)	8 weeks	43.51	(13.86)	36.40	(6.93)	16.4	0.43	0.654
	Post	43.71	(13.68)	36.53	(6.59)	16.5		
Height	Pre	147.21	(8.85)	140.55	(6.81)	4.6		
(cm)	8 weeks	148.93	(8.86)	141.00	(7.03)	5.4	5.59	0.009*
	Post	149.72	(9.13)	141.86	(6.69)	5.3		
Body	Pre	1.32	(0.25)	1.18	(0.13)	10.7		
Surface	8 weeks	1.33	(0.23)	1.19	(0.14)	10.6	0.34	0.712
Area (m^2)	Post	1.33	(0.23)	1.20	(0.13)	9.8		

p* = probability level beween means $p < 0.05$

APPENDIX B [3]

Comparison of the Descriptive Data of the Netball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Netball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Age (yrs)		11.25	(1.03)	10.62	(0.74)	5.4	1.91	0.187
Mass (kg)	Pre	42.84	(14.22)	40.21	(7.54)	6.2		
	8 weeks	43.51	(13.86)	40.98	(7.25)	5.9	0.21	0.811
	Post	43.71	(13.68)	40.86	(6.63)	6.6		
Height (cm)	Pre	147.21	(8.85)	143.32	(4.03)	2.7		
	8 weeks	148.93	(8.86)	144.42	(4.26)	3.3	1.60	0.219
	Post	149.72	(9.13)	145.05	(4.24)	3.2		
Body Surface Area (m^2)	Pre	1.32	(0.25)	1.25	(0.12)	5.4		
	8 weeks	1.33	(0.23)	1.27	(0.12)	4.6	0.46	0.636
	Post	1.33	(0.23)	1.27	(0.11)	4.6		

p* = probability level between means $p < 0.05$

APPENDIX B [4]

Comparison of the Descriptive Data of the Tennis Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Tennis Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Age (yrs)		11.25	(1.03)	12.37	(0.93)	9.1	6.48	0.056
Mass (kg)	Pre	42.84	(14.22)	47.76	(6.49)	2.6		
	8 weeks	43.51	(13.86)	42.67	(6.45)	2.0	0.16	0.852
	Post	43.71	(13.68)	42.88	(6.49)	1.9		
Height (cm)	Pre	147.21	(8.85)	152.58	(6.63)	3.6		
	8 weeks	148.93	(8.86)	152.43	(7.20)	2.3		
	Post	149.72	(9.13)	153.26	(7.30)	2.5		
Body Surface Area (m^2)	Pre	1.32	(0.25)	1.33	(0.12)	0.8		
	8 weeks	1.33	(0.23)	1.35	(0.11)	1.5	0.47	0.632
	Post	1.33	(0.23)	1.35	(0.11)	1.5		

p* = probability level between means $p < 0.05$

APPENDIX B [5]

Comparison of the Maximal Effort Data of the Badminton and the Control group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Badminton Group $\bar{X}$	(±S.D.)	%	F Ratio	P
VO_2 Max ($ml.kg.^{-1}min.^{-1}$)	Pre	57.44	(11.43)	56.94	(4.32)	0.9		
	8 weeks	57.15	(8.03)	55.02	(8.33)	3.8	2.35	0.114
	Post	55.47	(6.97)	59.70	(5.01)	7.1		
HR Max ($bts.min^{-1}$)	Pre	200	(10.44)	199	(6.67)	0.5		
	8 weeks	204	(8.65)	200	(8.64)	2.0	2.00	0.155
	Post	201	(8.62)	203	(8.19)	1.0		
RER Max	Pre	1.04	(0.09)	1.05	(0.05)	1.0		
	8 weeks	0.98	(0.07)	1.00	(0.05)	2.0	5.20	0.012*
	Post	1.04	(0.06)	0.95	(0.03)	8.7		

p* = probability level between means $p < 0.05$

APPENDIX B [6]

Comparison of the Maximal Effort Data of the Basketball and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Basketball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
VO_2 Max ($ml.kg.^{-1}min.^{-1}$)	Pre	57.44	(11.43)	55.82	(4.49)	2.1		
	8 weeks	57.15	(8.03)	53.99	(6.58)	5.6	0.45	0.641
	Post	55.47	(6.97)	55.17	(5.54)	0.6		
HR Max ($bts. min^{-1}$)	Pre	2.00	(10.44)	2.01	(2.91)	0.5		
	8 weeks	2.04	(8.65)	2.02	(6.06)	1.0	0.22	0.808
	Post	2.01	(8.62)	2.01	(5.14)	0.0		
RER Max	Pre	1.04	(0.09)	0.97	(0.06)	6.8		
	8 weeks	0.98	(0.07)	0.95	(0.02)	3.1	0.66	0.526
	Post	1.04	(0.06)	0.97	(0.10)	6.8		

p* = probability level between means $p < 0.05$

APPENDIX B [7]

Comparison of the Maximal Effort Data of the Netball and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Netball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
VO_2 Max	Pre	57.44	(11.43)	45.23	(8.19)	21.3		
($ml.kg.^{-1}min.^{-1}$)	8 weeks	57.15	(8.03)	50.77	(8.47)	11.2	2.66	0.087
	Post	55.47	(6.97)	48.73	(7.67)	12.2		
HR Max	Pre	2.00	(10.44)	1.97	(13.62)	1.5		
($bts.min^{-1}$)	8 weeks	2.04	(8.65)	2.06	(7.60)	1.0	1.29	0.290
	Post	2.01	(8.62)	2.04	(7.89)	1.5		
RER Max	Pre	1.04	(0.09)	1.00	(0.05)	3.9		
	8 weeks	0.98	(0.07)	0.97	(0.04)	1.1	0.53	0.593
	Post	1.04	(0.06)	1.01	(0.06)	2.9		

p* = probability level between means $p < 0.05$

APPENDIX B [8]

Comparison of the Maximal Effort Data of the Tennis and the Control Group Over 12 Weeks

Dependent variable	Period Group	Control Group $\bar{X}$	(±S.D.)	Tennis $\bar{X}$	(±S.D.)	%	F Ratio	P
VO_2 Max	Pre	57.44	(11.43)	60.02	(6.08)	4.3		
($ml.kg.^{-1}min.^{-1}$)	8 weeks	57.15	(8.03)	60.54	(4.95)	5.5	0.09	0.913
	Post	55.47	(6.97)	59.43	(5.89)	6.7		
HR Max	Pre	2.00	(10.44)	2.01	(11.91)	0.5		
($bts.min^{-1}$)	8 weeks	2.04	(8.65)	2.03	(13.89)	0.5	0.65	0.531
	Post	2.01	(8.62)	2.04	(13.92)	1.5		
RER Max	Pre	1.04	(0.09)	1.06	(0.09)	1.9		
	8 weeks	0.98	(0.07)	1.00	(0.10)	2.0	0.12	0.890
	Post	1.04	(0.06)	1.08	(0.05)	3.8		

p* = probability level between means $p < 0.05$

APPENDIX B [9]

Comparison of the Girth Measurements of the Badminton Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Badminton Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Upper Arm	Pre	24.01	(3.96)	24.50	(3.58)	2.0		
(cm)	8 weeks	24.28	(3.91)	25.11	(3.40)	3.5	3.20	0.055
	Post	24.00	(3.19)	25.30	(3.24)	5.2		
Forearm	Pre	21.61	(2.39)	22.00	(2.83)	1.18		
(cm)	8 weeks	22.05	(2.57)	23.51	(2.95)	6.3		
	Post	22.40	(2.43)	23.75	(2.91)	5.7	3.73	0.037*
Thigh	Pre	45.43	(8.37)	45.16	(6.74)	0.6		
(cm)	8 weeks	44.16	(7.15)	46.53	(5.54)	5.1	6.83	0.004*
	Post	46.04	(7.68)	46.72	(5.73)	1.5		
Calf	Pre	30.46	(4.32)	30.25	(4.21)	0.7		
(cm)	8 weeks	30.65	(4.45)	30.69	(4.13)	0.2	0.22	0.801
	Post	31.10	(4.12)	30.89	(3.99)	0.7		
Abdomen	Pre	69.11	(11.48)	69.06	(7.58)	0.1		
(cm)	8 weeks	69.43	(11.37)	69.00	(6.06)	0.7	0.09	0.918
	Post	69.73	(11.06)	69.63	(6.07)	0.2		

* = probability level between means $p < 0.05$

APPENDIX B [10]

Comparison of the Girth Measurements of the Basketball Group and the Control Group over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Basketball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Upper Arm (cm)	Pre	24.01	(3.96)	23.51	(2.07)	2.1		
	8 weeks	24.28	(3.91)	23.55	(1.97)	3.1	3.40	0.047*
	Post	24.00	(3.19)	24.07	(1.71)	0.3		
Forearm (cm)	Pre	21.61	(2.39)	21.06	(1.35)	2.6		
	8 weeks	22.05	(2.57)	21.52	(1.80)	2.5	0.05	0.947
	Post	22.40	(2.43)	21.76	(1.48)	2.9		
Thigh (cm)	Pre	45.43	(8.37)	43.12	(7.08)	5.1		
	8 weeks	44.16	(7.15)	43.43	(5.84)	1.7	1.59	0.223
	Post	46.04	(7.68)	46.65	(5.01)	1.4		
Calf (cm)	Pre	30.46	(4.32)	28.62	(2.82)	6.1		
	8 weeks	30.65	(4.49)	28.65	(3.02)	6.6	1.31	0.286
	Post	31.10	(4.12)	29.61	(2.82)	4.8		
Abdomen (cm)	Pre	69.11	(11.48)	64.31	(5.96)	7.0		
	8 weeks	69.43	(11.37)	64.96	(6.24)	6.5	0.61	0.549
	Post	69.73	(11.06)	65.85	(5.24)	5.6		

p* = probability level between means $p < 0.05$

APPENDIX B [11]

Comparison of the Girth Measurements of the Netball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Netball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Upper Arm (cm)	Pre	24.01	(3.96)	23.83	(2.31)	0.8		
	8 weeks	24.28	(3.91)	23.55	(1.97)	3.1	2.10	0.141
	Post	24.00	(3.19)	24.07	(1.71)	0.3		
Forearm (cm)	Pre	21.61	(2.39)	21.51	(1.25)	0.5		
	8 weeks	22.05	(2.57)	21.87	(1.26)	0.9	0.72	0.494
	Post	22.40	(2.43)	22.00	(1.27)	1.8		
Thigh (cm)	Pre	45.43	(8.37)	45.93	(4.59)	1.1		
	8 weeks	44.16	(7.15)	46.44	(3.65)	5.0	3.85	0.033*
	Post	46.04	(7.68)	48.12	(4.41)	4.4		
Calf (cm)	Pre	30.46	(4.32)	30.10	(2.39)	1.2		
	8 weeks	30.65	(4.49)	30.39	(2.60)	0.9	0.24	0.741
	Post	31.10	(4.12)	30.56	(2.49)	1.8		
Abdomen (cm)	Pre	69.11	(11.48)	66.27	(11.5)	4.2		
	8 weeks	69.43	(11.37)	67.87	(9.47)	1.2	3.02	0.065
	Post	69.73	(11.06)	69.40	(9.11)	0.5		

p* = probability level between means $p < 0.05$

APPENDIX B [12]

Comparison of the Girth Measurements of the Tennis Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Tennis Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Upper Arm	Pre	24.01	(3.96)	24.01	(3.96)	0.0		
(cm)	8 weeks	24.28	(3.91)	24.29	(3.91)	0.1	2.91	0.71
	Post	24.00	(3.19)	24.00	(3.19)	0.0		
Forearm	Pre	21.61	(2.39)	21.71	(1.92)	0.5		
(cm)	8 weeks	22.05	(2.57)	22.44	(2.19)	1.8	1.41	0.261
	Post	22.40	(2.43)	22.62	(2.11)	1.0		
Thigh	Pre	45.43	(8.37)	44.20	(4.22)	2.8		
(cm)	8 weeks	44.16	(7.15)	45.47	(4.92)	2.9	6.67	0.004*
	Post	46.04	(7.68)	45.65	(4.88)	0.9		
Calf	Pre	30.46	(4.32)	30.65	(2.12)	0.7		
(cm)	8 weeks	30.65	(4.49)	31.52	(2.04)	2.8	2.47	0.103
	Post	31.10	(4.12)	31.81	(1.96)	2.3		
Abdomen	Pre	69.11	(11.48)	67.23	(8.75)	2.8		
(cm)	8 weeks	69.43	(11.37)	67.25	(9.58)	3.2	0.93	0.408
	Post	69.73	(11.06)	68.81	(7.70)	1.4		

p* = probability level between means $p < 0.05$

APPENDIX B [13]

Comparison of the Width Measurements of the Badminton Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Badminton Group $\bar{X}$	(±S.D.)	%	FRatio	P
Elbow	Pre	6.01	(0.50)	6.22	(0.83)	3.4		
(cm)	8 weeks	6.31	(0.61)	6.34	(0.34)	0.5	0.32	0.729
	Post	6.25	(0.53)	6.42	(0.44)	2.7		
Wrist	Pre	5.20	(0.53)	5.17	(0.08)	1.0		
(cm)	8 weeks	5.17	(0.46)	5.22	(0.16)	1.0	0.27	0.765
	Post	5.29	(0.47)	5.26	(0.15)	0.6		
Knee	Pre	8.77	(1.00)	8.72	(0.77)	0.6		
(cm)	8 weeks	8.60	(0.83)	8.70	(0.75)	1.2	0.24	0.780
	Post	8.87	(0.79)	8.86	(0.74)	0.2		
Shoulder	Pre	32.81	(2.85)	33.83	(1.58)	3.1		
(cm)	8 weeks	33.10	(2.81)	34.26	(0.52)	3.4	0.77	0.471
	Post	33.75	(2.98)	34.47	(1.75)	2.1		
Hip	Pre	23.73	(3.33)	22.75	(1.40)	4.2		
(cm)	8 weeks	22.77	(2.11)	23.28	(1.20)	2.2	6.00	0.007*
	Post	23.00	(2.16)	23.41	(1.23)	1.8		

p* = probability level between means $p < 0.05$

APPENDIX B [14]

Comparison of the Width Measurements of the Basketball Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Basketball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Elbow	Pre	6.01	(0.50)	5.23	(0.22)	13.0		
(cm)	8 weeks	6.31	(0.61)	5.87	(0.11)	7.0	4.10	0.027*
	Post	6.25	(0.53)	6.02	(0.10)	3.7		
Wrist	Pre	5.20	(0.53)	4.75	(0.23)	8.7		
(cm)	8 weeks	5.17	(0.46)	4.89	(0.22)	7.6	1.47	0.225
	Post	5.29	(0.47)	4.84	(0.34)	8.6		
Knee	Pre	8.77	(1.00)	8.55	(0.30)	2.6		
(cm)	8 weeks	8.60	(0.83)	8.55	(0.33)	4.1	0.95	0.401
	Post	8.87	(0.79)	8.57	(0.39)	5.7		
Shoulder	Pre	32.81	(2.85)	31.39	(1.49)	4.4		
(cm)	8 weeks	33.10	(2.81)	31.61	(1.92)	4.6	0.66	0.523
	Post	33.75	(2.98)	31.81	(1.99)	5.8		
Hip	Pre	23.73	(3.33)	21.45	(1.22)	9.7		
(cm)	8 weeks	22.77	(2.11)	21.66	(1.21)	4.9	4.46	0.021*
	Post	23.00	(2.16)	22.04	(1.19)	4.2		

p* = probability level between means $p < 0.05$

APPENDIX B [15]

Comparison of the Width Measurements of the Netball Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Netball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Elbow (cm)	Pre	6.01	(0.50)	5.80	(0.33)	3.5		
	8 weeks	6.31	(0.61)	5.85	(0.35)	7.3	1.92	0.165
	Post	6.25	(0.53)	6.12	(0.30)	2.1		
Wrist (cm)	Pre	5.20	(0.53)	4.92	(0.29)	5.4		
	8 weeks	5.17	(0.46)	4.49	(0.22)	4.5	1.08	0.352
	Post	5.29	(0.47)	4.91	(0.26)	7.2		
Knee (cm)	Pre	8.77	(1.00)	7.80	(0.43)	11.1		
	8 weeks	8.60	(0.83)	8.16	(0.43)	5.2		
	Post	8.87	(0.79)	8.19	(0.35)	7.7	3.68	0.038 *(pre,post)
Shoulder (cm)	Pre	32.81	(2.85)	32.46	(2.27)	1.1		
	8 weeks	33.10	(2.81)	33.26	(2.33)	0.5	0.73	0.491
	Post	33.75	(2.98)	33.62	(2.09)	0.4		
Hip (cm)	Pre	23.73	(3.33)	23.27	(2.89)	2.0		
	8 weeks	22.77	(2.11)	23.15	(2.41)	1.7	1.17	0.325
	Post	23.00	(2.16)	23.12	(1.96)	0.6		

p* = probability level between means $p < 0.05$

APPENDIX B [16]

Comparison of the Width Measurements of the Tennis Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Tennis Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Elbow	Pre	6.01	(0.50)	6.35	(0.43)	5.4		
(cm)	8 weeks	6.31	(0.61)	6.57	(0.34)	6.0	0.10	0.901
	Post	6.25	(0.53)	6.55	(0.11)	4.6		
Wrist	Pre	5.20	(0.53)	5.27	(0.24)	1.4		
(cm)	8 weeks	5.17	(0.46)	5.19	(0.29)	0.4	0.53	0.592
	Post	5.29	(0.47)	5.26	(0.31)	0.6		
Knee	Pre	8.77	(1.00)	8.86	(0.43)	1.1		
(cm)	8 weeks	8.60	(0.83)	8.99	(0.44)	4.4	1.21	0.313
	Post	8.87	(0.79)	9.19	(0.35)	3.5		
Shoulder	Pre	32.81	(2.85)	33.46	(1.50)	2.0		
(cm)	8 weeks	33.10	(2.81)	33.26	(1.62)	0.5	0.97	0.390
	Post	33.75	(2.98)	33.62	(1.85)	0.4		
Hip	Pre	23.73	(3.33)	23.75	(1.05)	0.1		
(cm)	8 weeks	22.77	(2.11)	24.07	(1.11)	5.5	5.78	0.008*
	Post	23.00	(2.16)	24.21	(1.01)	5.0		

p* = probability level between means $p < 0.05$

APPENDIX B [17]

Comparison of the Skinfold Measurements of the Badminton Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\overline{X}$	(±S.D.)	Badminton Group $\overline{X}$	(±S.D.)	%	F Ratio	P
Biceps (mm)	Pre	9.86	(4.72)	8.29	(3.48)	16.0		
	8 weeks	7.52	(4.19)	7.61	(2.79)	1.2	2.79	0.079
	Post	6.35	(3.99)	6.92	(2.23)	8.3		
Triceps (mm)	Pre	13.26	(5.66)	14.57	(4.23)	9.0		
	8 weeks	11.99	(6.30)	14.87	(5.25)	19.4	1.93	0.164
	Post	11.42	(6.03)	13.51	(3.64)	15.5		
Subscapula (mm)	Pre	12.92	(10.33)	7.25	(2.22)	43.9		
	8 weeks	11.61	(9.05)	7.40	(2.61)	36.3	1.96	0.159
	Post	8.86	(5.08)	7.76	(2.22)	12.5		
Suprailiac (mm)	Pre	13.72	(9.65)	7.81	(7.07)	43.1		
	8 weeks	10.41	(7.23)	8.92	(6.53)	14.4	1.71	0.199
	Post	9.81	(6.78)	8.02	(4.78)	18.3		
Mid-abdomen (mm)	Pre	16.27	(10.70)	13.45	(8.81)	17.4		
	8 weeks	16.21	(12.06)	13.79	(9.65)	15.0	0.48	0.623
	Post	14.62	(10.91)	13.34	(9.45)	8.8		
Sum of 5 (mm)	Pre	66.05	(38.89)	53.37	(25.00)	19.2		
	8 weeks	57.75	(36.16)	52.60	(26.29)	9.0	2.29	0.112
	Post	51.07	(31.87)	49.56	(21.55)	3.0		

p* = probability level between means $p < 0.05$

APPENDIX B [18]

Comparison of the Skinfold Measurements of the Basketball Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Basketball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Biceps (mm)	Pre	9.86	(4.72)	6.80	(2.52)	31.9		
	8 weeks	7.52	(4.19)	6.17	(2.63)	18.0	4.50	0.020*
	Post	6.35	(3.99)	5.89	(2.67)	7.3		
Triceps (mm)	Pre	13.26	(5.66)	10.57	(2.33)	20.3		
	8 weeks	11.99	(6.30)	11.41	(4.36)	4.9	4.52	0.020*
	Post	11.42	(6.03)	11.22	(4.19)	1.8		
Subscapula (mm)	Pre	12.92	(10.33)	6.90	(2.30)	46.6		
	8 weeks	11.61	(9.05)	6.82	(2.51)	41.3		
	Post	8.86	(5.08)	8.15	(6.23)	8.1		
Suprailiac (mm)	Pre	13.72	(9.65)	5.86	(2.43)	57.3		
	8 weeks	10.41	(7.23)	5.89	(3.42)	43.5	4.54	0.020*
	Post	9.81	(6.78)	5.62	(2.55)	42.8		
Mid-abdomen (mm)	Pre	16.27	(10.70)	10.07	(4.98)	38.2		
	8 weeks	16.21	(12.06)	10.80	(6.57)	33.4	0.76	0.475
	Post	14.62	(10.91)	0.26	(6.52)	29.9		
Sum of 5 (mm)	Pre	66.05	(38.89)	40.21	(13.22)	39.2		
	8 weeks	67.75	(36.16)	41.10	(18.50)	28.9	4.29	0.023*
	Post	51.07	(31.84)	41.15	(21.19)	29.5		

p* = probability level between means $p < 0.05$

APPENDIX B [19]

Comparison of the Skinfold Measurements of the Netball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group X̄	(±S.D.)	Netball Group X̄	(±S.D.)	%	F Ratio	P
Biceps (mm)	Pre	9.86	(4.72)	8.35	(2.94)	15.4		
	8 weeks	7.52	(4.19)	7.37	(2.90)	2.0		
	Post	6.35	(3.99)	7.49	(2.64)	15.3	4.93	0.015*
Triceps (mm)	Pre	13.26	(5.66)	13.64	(4.55)	2.8		
	8 weeks	11.99	(6.30)	13.31	(4.36)	10.0	1.54	0.232
	Post	11.42	(6.03)	13.24	(4.19)	1318		
Subscapula (mm)	Pre	12.92	(10.33)	10.96	(5.78)	15.2		
	8 weeks	11.61	(9.05)	11.72	(5.93)	1.0	1.81	0.183
	Post	8.86	(5.08)	11.56	(4.63)	23.4		
Suprailiac (mm)	Pre	13.72	(9.65)	10.24	(4.75)	25.4		
	8 weeks	10.41	(7.23)	9.91	(5.38)	4.9		
	Post	9.81	(6.78)	10.96	(5.22)	10.5	4.47	0.021*
Mid-abdomen (mm)	Pre	16.27	(10.70)	14.69	(7.04)	9.8		
	8 weeks	16.21	(12.06)	16.30	(9.91)	0.6	1.20	0.317
	Post	14.62	(10.91)	15.47	(7.98)	5.5		
Sum of 5 (mm)	Pre	66.05	(38.89)	57.87	(23.49)	12.4		
	8 weeks	67.75	(36.16)	58.62	(27.83)	1.5	4.35	0.023*
	Post	51.07	(31.87)	56.74	(23.64)	5.0		

p* = probability level between $p < 0.05$

APPENDIX B [20]

Comparison of the Skinfold Measurements of the Tennis Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Tennis Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Biceps (mm)	Pre	9.86	(4.72)	6.11	(4.56)	38.1		
	8 weeks	7.52	(4.19)	6.14	(4.57)	18.4	12.17	0.000*
	Post	6.35	(3.99)	6.77	(4.29)	6.3		*(pre)
Triceps (mm)	Pre	13.26	(5.66)	11.66	(6.37)	12.1		
	8 weeks	11.99	(6.30)	12.04	(7.54)	0.5	5.82	0.008*
	Post	11.42	(6.03)	12.09	(6.51)	5.6		
Subscapula (mm)	Pre	12.92	(10.33)	10.96	(5.78)	15.2		
	8 weeks	11.61	(9.05)	11.72	(5.93)	1.0	1.78	0.187
	Post	8.86	(5.08)	11.56	(4.63)	13.6		
Suprailiac (mm)	Pre	13.72	(9.65)	5.77	(4.00)	48.0		
	8 weeks	10.41	(7.23)	6.60	(5.72)	36.4	8.17	0.002*
	Post	9.81	(6.78)	7.77	(6.91)	20.8		
Mid-abdomen (mm)	Pre	16.27	(10.70)	9.04	(8.67)	44.5		
	8 weeks	16.21	(12.06)	10.30	(9.25)	36.5	1.51	0.238
	Post	14.62	(10.91)	10.59	(10.34)	27.6		
Sum of 5 (mm)	Pre	66.05	(38.89)	39.87	(27.95)	39.7		
	8 weeks	57.75	(36.16)	41.82	(30.83)	27.6	7.41	0.003*
	Post	51.07	(31.87)	44.62	(32.16)	12.7		

p* = probability level between means $p < 0.05$

APPENDIX B [21]

Comparison of the Upper Body Strength Profile of the Badminton Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Badminton Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Dominant	Pre	16.54	(3.33)	14.25	(4.60)	14.1		
Hand Grip	8 weeks	17.37	(4.93)	17.85	(6.60)	2.7	0.49	0.619
(-Kgf)	Post	15.12	(2.10)	19.37	(5.60)	22.0		
Non-dominant	Pre	15.19	(3.15)	15.44	(6.25)	1.7		
Hand Grip	8 weeks	16.37	(4.13)	17.44	(6.13)	6.2	2.16	0.134
(-Kgf)	Post	16.31	(3.30)	18.37	(4.27)	17.3		
Arm and	Pre	10.25	(6.15)	15.50	(4.86)	33.9		
Shoulder	8 weeks	10.62	(6.48)	16.50	(7.17)	35.7	0.04	0.964
Push (-Kgf)	Post	12.50	(10.94)	17.87	(5.36)	30.1		
Arm and	Pre	9.94	(4.39)	12.06	(4.37)	17.6		
Shoulder	8 weeks	8.62	(3.65)	13.56	(4.00)	36.5	0.99	0.383
Pull (-Kgf)	Post	11.62	(7.29)	14.50	(6.80)	19.9		

p* = probability level between means $p < 0.05$

APPENDIX B [22]

Comparison of the Upper Body Strength Profile of the Basketball Group And The Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Basketball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Dominant	Pre	16.54	(3.33)	13.87	(3.44)	16.2		
hand Grip	8 weeks	17.37	(4.93)	12.00	(2.07)	31.0	0.49	0.619
(-Kgf)	Post	15.12	(2.10)	14.18	(1.18)	6.3		
Non-dominant	Pre	15.19	(3.15)	12.00	(3.45)	21.1		
hand Grip	8 weeks	16.37	(4.13)	13.75	(3.15)	16.1	4.12	0.027*
(-Kgf)	Post	16.31	(3.30)	15.50	(2.98)	5.0		(8wks)
Arm and	Pre	10.25	(6.15)	8.31	(2.99)	9.0		
Shoulder	8 weeks	10.62	(6.48)	7.81	(3.12)	26.5	1.60	0.220
Push (-Kgf)	Post	12.50	(10.94)	7.37	(3.10)	41.1		
Arm and	Pre	9.94	(4.39)	6.56	(2.60)	34.1		
Sahoulder	8 weeks	8.62	(3.65)	6.37	(2.87)	26.2	0.48	0.623
Pull (-Kgf)	Post	11.62	(7.29)	7.75	(3.01)	33.4		

p* = probability level between means $p < 0.05$

APPENDIX B [23]

Comparison of the Upper Body Strength Profile of the Netball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Netball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Dominant	Pre	16.54	(3.33)	19.12	(2.76)	13.5		
Hand Grip	8 weeks	17.37	(4.93)	10.87	(1.36)	37.5	7.76	0.002*
(-Kgf)	Post	15.12	(2.10)	12.25	(1.49)	19.0		
Non-dominant	Pre	15.19	(3.15)	17.06	(1.72)	11.0		
hand Grip	8 weeks	16.37	(4.13)	11.75	(2.81)	28.3	17.38	0.000*
(-Kgf)	Post	16.31	(3.30)	13.50	(2.20)	17.3		(8 wks and post)
Arm and	Pre	10.25	(6.15)	5.00	(3.77)	51.3		
Shoulder	8 weeks	10.62	(6.48)	10.87	(3.48)	2.3	4.54	0.020*
Push (-Kgf)	Post	12.50	(10.94)	11.87	(3.46)	5.1		
Arm and	Pre	9.94	(4.39)	3.81	(2.20)	61.7		
Shoulder	8 weeks	8.62	(3.65)	7.06	(2.29)	18.1	3.50	0.044*
Pull (-Kgf)	Post	11.62	(7.29)	8.84	(3.16)	24.0		(pre)

p* = probability level between means $p < 0.05$

APPENDIX B [24]

Comparison of the Upper Body Strength Profile of the Tennis Group And The Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	($\pm$S.D.)	Tennis Group $\bar{X}$	($\pm$S.D.)	%	F Ratio	P
Dominant	Pre	16.54	(3.33)	16.87	(4.08)	2.0		
Hand Grip	8 weeks	17.37	(4.93)	19.62	(3.67)	11.5		
(-Kgf)	Post	15.12	(2.10)	20.00	(3.07)	24.4	0.44	0.649
Non-dominant	Pre	15.19	(3.15)	15.69	(5.28)	3.2		
hand Grip	8 weeks	16.37	(4.13)	16.99	(4.77)	3.7	3.72	0.037* (post)
(-Kgf)	Post	16.31	(3.30)	18.11	(3.83)	10.0		
Arm and	Pre	10.25	(6.15)	14.12	(5.19)	27.5		
Shoulder	8 weeks	10.62	(6.48)	12.50	(5.09)	15.1	0.52	0.598
Push (-Kgf)	Post	12.50	(10.96)	15.56	(5.80)	19.7		
Arm and	Pre	9.94	(4.39)	12.19	(7.15)	18.5		
Shoulder	8 Weeks	8.62	(3.65)	11.87	(6.61)	27.4	0.86	0.432
pull (-Kgf)	Post	11.62	(7.29)	12.31	(7.14)	5.7		

p* = probability level between means $p < 0.05$

APPENDIX B [25]

Comparison of the Relative Upper Body Strength Profile of the Badminton Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Period X̄	(±S.D.)	Badminton Group X̄	(±S.D.)	%	F Ratio	P
Dominant	Pre	41.19	(11.92)	44.84	(5.60)	8.2		
Grip/WT	8 weeks	40.78	(8.60)	39.70	(9.95)	2.7	1.71	0.199
(%)	Post	36.34	(7.28)	43.51	(6.72)	16.5		
Non-dominant	Pre	38.00	(11.44)	43.62	(8.63)	12.9		
Grip/WT	8 weeks	38.82	(7.84)	28.89	(6.41)	25.6	6.57	0.004*
(%)	Post	38.77	(7.30)	33.37	(5.08)	14.0		
Arm and	Pre	24.04	(10.00)	37.07	(12.92)	35.2		
Shoulder	8 weeks	23.91	(9.59)	36.76	(13.01)	35.0	0.00	0.997
Push/WT (%)	Post	27.19	(14.70)	39.86	(8.29)	31.8		
Arm and	Pre	23.15	(8.08)	27.38	(4.75)	23.5		
Shoulder	8 weeks	19.67	(6.63)	30.44	(4.93)	35.4	0.82	0.449
Pull/WT (%)	Post	25.77	(11.54)	33.26	(15.47)	22.6		

p* = probability level between means $p < 0.05$

APPPENDIX B [26]

Comparison of the Relative Upper Body Strength Profile of the Basketball Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group X̄	(±S.D.)	Basketball Group X̄	(±S.D.)	%	F Ratio	P
Dominant Grip/WT (%)	Pre	41.19	(11.92)	39.19	(5.95)	4.9		
	8 weeks	40.78	(8.60)	33.56	(4.70)	17.8	3.24	0.054
	Post	36.34	(7.28)	39.50	(5.94)	8.0		
Non-dominant Grip/WT (%)	Pre	38.00	(11.44)	33.78	(8.32)	11.2		
	8 weeks	38.82	(7.84)	38.41	(8.66)	1.1	2.41	0.108
	Post	38.77	(7.30)	42.57	(6.03)	9.0		
Arm and Shoulder Push/WT (%)	Pre	24.04	(10.00)	23.29	(6.91)	3.2		
	8 weeks	3.91	(9.59)	21.50	(6.78)	10.1	1.61	0.2184
	Post	27.19	(14.70)	19.90	(7.16)	26.9		
Arm and Shoulder Pull/WT (%)	Pre	23.15	(8.08)	18.77	(6.75)	19.0		
	8 weeks	19.67	(6.63)	17.08	(5.54)	13.2	0.20	0.823
	Post	25.77	(11.54)	20.99	(6.49)	18.6		

p* = probability level between means $p < 0.05$

APPENDIX B [27]

Comparison of the Relative Body Strength Profile of the Netball and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Netball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Dominant	Pre	41.19	(11.92)	48.50	(7.84)	15.1		
Grip/WT	8 weeks	40.78	(8.64)	27.40	(6.57)	22.9	14.77	0.000*
(%)	Post	36.34	(7.28)	30.74	(6.54)	15.5		
Non-dominant	Pre	38.00	(11.44)	36.27	(9.49)	4.6		
Grip/WT	8 weeks	38.82	(7.84)	38.70	(7.78)	0.4	1.02	0.37
(%)	Post	38.77	(7.30)	40.18	(6.02)	3.6		
Arm and	Pre	24.04	(10.00)	11.77	(6.96)	51.1		
Shoulder	8 weeks	23.91	(9.59)	26.40	(5.93)	9.5	7.94	0.005
Push/WT (%)	Post	27.19	(14.70)	29.35	(8.07)	7.4		
Arm and	Pre	23.15	(8.08)	9.62	(5.55)	58.5		
Shoulder	8 weeks	19.67	(6.63)	17.62	(8.19)	10.5	4.76	0.016* (pre)
Pull/WT (%)	Post	25.77	(11.54)	21.48	(6.28)	16.7		

p* = probability level between means $p < 0.05$

APPENDIX B [29]

Comparison of the Lower Body Strength Profile of the Badminton Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Badminton Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Right Quads	Pre	69.37	(14.57)	75.50	(20.71)	8.2		
Peak Torque	8 weeks	68.62	(12.06)	65.62	(24.01)	4.4	2.81	0.077
(ft.LBS.)	Post	67.87	(12.99)	69.25	(22.37)	2.0		
Left Quads	Pre	70.25	(13.36)	73.00	(21.49)	3.8		
Peak Torque	8 weeks	66.75	(10.70)	66.25	(20.57)	0.8	0.68	0.516
(ft.LBS.)	Post	67.62	(11.72)	71.62	(19.55)	5.6		
Right Hams'gs	Pre	55.62	(11.99)	50.62	(14.98)	9.0		
Peak Torque	8 Weeks	53.50	(7.98)	47.12)	(12.40)	12.0	2.65	0.088
(ft.LBS.)	Post	51.25	(13.30)	52.62	(14.64)	2.7		
Left Hams'gs	Pre	52.12	(13.98)	48.00	(11.53)	8.0		
Peak Torque	8 weeks	48.37	(11.48)	48.87	(13.88)	1.1	2.53	0.098
(ft.LBS.)	Post	48.75	(9.45)	53.00	(14.17)	8.1		
H/Q Ratio	Pre	80.80	(11.26)	68.17	(14.53)	15.7		
Right Leg	8 weeks	78.40	(6.83)	73.22	(12.76)	6.7	3.78	0.035*
(%)	Post	74.10	(7.87)	77.93	(10.13)	5.0		
H/Q Ratio	Pre	73.61	(11.00)	66.19	(12.04)	10.1		
Left Leg	8 weeks	73.50	(16.53)	75.04	(9.98)	2.1	1.61	0.218
(%)	Post	73.97	(12.73)	74.73	(8.12)	1.1		

p* = probability level between means $p < 0.05$

APPENDIX B [30]

Comparison of the Lower Body Strength Profile of the Basketball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.	Basketball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Right Quads	Pre	69.37	(14.57)	57.87 (3.16)16.6				
Peak Torque	8 weeks	68.62	(12.06)	47.62	(3.42)	30.7	6.04	0.007*
(ft.LBS.)	Post	67.87	(12.99)	56.00	(4.20)	17.5		
Left Quads	Pre	70.25	(13.36)	57.32	(11.36)	18.5		
Peak Torque	8weeks	66.75	(10.70)	45.37	(9.05)	32.1	5.18	0.012*
(ft.LBS.)	Post	67.62	(11.72)	55.00	(9.72)	18.7		
Right Hams'GS	Pre	55.62	(11.99)	37.00	(13.07)	33.5		
Peak Torque	8 weeks	53.50	(7.98)	33.62	(6.34)	37.2	0.69	0.51
(ft.LBS)	Post	51.25	(13.30)	36.75	(14.00)	28.3		
Left Hams'GS	Pre	52.12	(13.98)	37.87	(12.17)	27.4		
Peak Torque	8 weeks	48.37	(11.48)	31.62	(7.30)	34.7	0.92	0.411
(ft.LBS.)	Post	48.75	(9.45)	37.87	(9.84)	22.4		
H/Q Ratio	Pre	80.80	(11.26)	62.74	(14.39)	22.4		
Right Leg	8 Weeks	78.40	(6.83)	72.69	(15.01)	7.3	1.32	0.282
(%)	Post	74.10	(7.87)	65.43	(17.60)	11.8		
H/Q Ratio	Pre	37.61	(11.03)	66.54	(12.92)	9.7		
left leg	8 weeks	73.50	(16.53)	70.77	(17.32)	3.8	0.14	0.871
(%)	Post	73.97	(12.73)	71.13	(18.27)	3.9		

p* = probability level between means $p < 0.05$

APPENDIX B [31]

Comparison of the Lower Body Strength Profile of the Netball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Netball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Right Quads	Pre	69.37	(14.57)	60.12	(1.91)	13.4		
Peak Torque	8 weeks	68.62	(12.06)	54.37	(2.01)	20.8	1.34	0.278
(ft.LBS.)	Post	67.87	(12.99)	58.50	(2.52)	13.9		
Left Quads	Pre	70.25	13.36)	60.50	(3.42)	13.9		
Peak Torque	8 weeks	66.75	(10.70)	53.37	(4.53)	20.1	1.40	0.243
(ft.LBS.)	Post	67.62	(11.72)	59.50	(3.85)	12.1		
Right Hams'gs	Pre	55.62	(11.99)	39.25	(11.27)	29.5		
Peak Torque	8 weeks	53.50	(7.98)	37.12	(9.33)	30.7	2.19	0.131
(ft.LBS.)	Post	51.25	(13.30)	42.25	(4.80)	13.6		
Left Hams'gs	Pre	52.12	(13.98)	37.12	(11.63)	28.8		
Peak Torque	8 weeks	48.37	(11.48)	35.00	(9.25)	27.7	0.87	0.430
(ft.LBS.)	Post	48.75	(9.45)	39.12	(8.76)	19.8		
H/Q Ratio	Pre	80.80	(11.26)	72.86	)9.78)	9.9		
Right Leg	8 weeks	78.40	(6.83)	66.40	(12.60)	15.4	0.18	0.830
(%)	Post	74.10	(7.87)	65.24	(7.52)	12.0		
H/Q Ratio	Pre	73.61	(11.00)	66.24	(16.20)	10.1		
Left Leg	8 weeks	73.50	(16.53)	66.68	(19.18)	9.3	0.22	0.806
(%)	Post	73.97	(12.73)	62.32	(18.46)	15.8		

p* = probability level between means $p < 0.05$

APPENDIX B [32]

Comparison of the Lower Body Strength Profile of the Tennis Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Tennis Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Right Quads	Pre	69.37	(14.57)	73.12	(18.16)	5.2		
Peak Torque	8 weeks	68.62	(12.06)	75.00	(16.64)	8.6	0.31	0.739
(ft.LBS.)	Post	67.87	(12.99)	72.50	(17.31)	7.4		
Left Quads	Pre	70.25	(13.36)	67.87	(15.16)	3.4		
Peak Torque	8 weeks	66.75	(10.70)	73.75	(17.03)	9.5	5.04	0.013
(ft.LBS.)	Post	67.62	(11.72)	72.00	(14.63)	6.1		
Right Hams'gs	Pre	55.62	(11.99)	49.87	(14.60)	10.4		
Peak Torque	8 weeks	53.50	(7.98)	46.37	(14.72)	13.4	0.8	0.839
(ft.LBS.)	Post	51.25	(13.30)	46.12	(16.07)	10.1		
Left Hams'gs	Pre	52.12	(13.98)	47.25	(15.84)	9.4		
Peak Torque	8 weeks	48.37	(11.48)	44.87	(14.45)	7.3	0.51	0.607
(ft.LBS.)	Post	48.75	(9.45)	47.62	(15.89)	2.4		
H/Q Ratio	Pre	80.80	(11.26)	63.82	(20.79)	21.1		
Right Leg	8 weeks	78.40	(6.83)	67.79	(13.41)	23.6	0.64	0.53
(%)	Post	74.10	(7.87)	61.29	(18.10)	27.3		
H/Q Ratio	Pre	73.61	(11.03)	63.44	(18.24)	13.9		
Left Leg	8 weeks	73.50	(16.53)	68.76	(18.93)	6.5	0.70	0.505
(%)	Post	73.97	(12.73)	61.94	(19.47)	16.3		

p^* = probability level between means $p < 0.05$

APPENDIX B [33]

Comparison of the Relative Lower Body Strength Profile of the Badminton Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group X	(±S.D.)	Badminton Group X̄	(±S.D.)	%	F Ratio	P
Right Quads	Pre	23.49	(5.09)	24.15	(2.82)	2.8		
Peak	8 weeks	22.87	(4.99)	20.23	(4.84)	1.6	3.67	0.0396*
Torque/WT (%)	Post	22.42	(4.96)	21.29	(3.26)	5.1		
Left Quads	Pre	23.76	(4.98)	23.22	(3.30)	2.3		
Peak	8 weeks	22.48	(5.98)	20.54	(1.43)	9.7	0.89	0.4206
Torque/WT (%)	Post	22.46	(5.52)	22.25	(2.84)	1.0		
Right Hams'gs	Pre	18.66	(3.38)	16.26	(3.32)	12.9		
Peak	8 weeks	17.87	(3.84)	14.90	(3.23)	16.7	2.71	0.084
Torque/WT (%)	Post	16.48	(1.78)	16.44	(2.58)	0.3		
Left Hams'gs	Pre	17.16	(2.47)	12.64	(2.72)	26.4		
Peak	8 weeks	15.81	(2.93)	11.92	(3.22)	24.7	0.82	0.449
Torque/WT (%)	Post	15.87	(1.81)	13.30	(2.73)	16.2		

p* = probability level between means $p < 0.05$

APPENDIX B [34]

Comparison of the Relative Lower Body Strength Profile of the Basketball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Basketball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Right Quads	Pre	23.49	(5.09)	22.73	(1.08)	3.3		
Peak	8 weeks	22.87	(4.99)	18.12	(1.93)	10.8	11.27	0.000*
Torque/WT (%)	Post	22.42	(4.96)	21.12	(1.33)	5.8		(8 wks)
Left Quads	Pre	23.76	(4.98)	22.39	(1.29)	5.8		
Peak	8 weeks	22.48	(5.98)	17.39	(2.75)	22.7	0.95	0.000
Torque/WT (%)	Post	22.46	(5.52)	20.88	(1.59)	7.1		(8 wks)
Right Hams'gs	Pre	18.66	(3.38)	14.28)	(3.52)	23.5		
Peak	8 weeks	17.87	(3.87)	13.00	(2.67)	27.3	0.92	0.412
Torque/WT (%)	Post	16.48	(1.78)	14.04	(4.20)	14.9		
Left Hams'gs	Pre	17.16	(2.47)	14.63	(3.19)	14.8		
Peak	8 weeks	15.81	(2.93)	12.04	(1.83)	23.9	1.03	0.369
Torque/WT (%)	Post	15.87	(1.81)	14.65	(4.37)	7.7		

p^* = probability level between means $p < 0.05$

APPENDIX B [35]

Comparison of the Relative Lower Body Strength Profile of the Netball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Netball Groups $\bar{X}$	(±S.D.)	%	F Ratio	P
Right Quads	Pre	23.49	(5.08)	21.16	(3.58)	10.0		
Peak	8 weeks	22.87	(4.99)	18.74	(3.16)	18.1	1.66	0.208
Torque/WT (%)	Post	22.42	(4.90)	20.13	(3.21)	10.3		
Left Quads	Pre	23.76	(4.98)	21.30	(3.27)	10.4		
Peak	8 weeks	22.48	(5.98)	18.52	(3.69)	17.7	2.45	0.104
Torque/WT (%)	Post	22.46	(5.52)	20.60	(3.52)	8.3		
Right Hams'gs	Pre	18.66	(3.38)	13.33	(2.28)	28.6		
Peak	8 weeks	17.87	(3.87)	12.49	(2.28)	30.2	3.40	0.047* (pre,8wks)
Torque/WT (%)	Post	16.48	(1.78)	14.55	(2.51)	11.8		
Left Hams'gs	Pre	17.16	(2.47)	15.87	(4.20)	7.6		
Peak	8 weeks	15.81	(2.93)	15.11	(1.91)	4.5	0.82	0.429
Torque/WT (%)	Post	15.87	(1.81)	16.60	(2.56)	4.4		

p* = probability level between means $p < 0.05$

APPENDIX B [36]

Comparison of the Relative Lower Body Strength Profile of the Tennis Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Tennis Group $\bar{X}$	(±S.D.)	%	F Ratio	P
Right Quads	Pre	23.49	(5.09)	24.25	(4.93)	3.2		
Peak	8 weeks	22.87	(4.99)	24.44	(4.98)	6.5	1.45	0.253
Torque/WT (%)	Post	22.42	(4.96)	23.58	(5.81)	5.0		
Left Quads	Pre	23.76	(4.98)	22.56	(4.34)	5.1		
Peak	8 weeks	22.48	(5.98)	23.98	(4.83)	6.3	4.47	0.020*
Torque/WT (%)	Post	22.46	(5.52)	23.40	(4.49)	4.1		
Right Hams'gs	Pre	18.65	(3.38)	16.59)	(4.87)	11.1		
Peak	8 weeks	17.87	(3.87)	14.88	(4.38)	6.8	0.49	0.616
Torque/WT (%)	Post	16.48	(1.78)	14.62	(4.63)	11.3		
Left Hams'gs	Pre	17.16	(2.47)	15.68	(5.17)	8.7		
Peak	8 weeks	15.81	(2.93)	14.53	(4.67)	8.1	0.25	0.783
Torque/WT (%)	Post	15.87	(1.81)	15.21	(4.85)	4.2		

p* = probability level between means $p < 0.05$

APPENDIX B [37]

Comparison of the Flexibility Profile of the Badminton Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Badminton Group $\bar{X}$	(±S.D.)	% Δ	F Ratio	P
Sit & Reach	Pre	-2.06	(7.72)	-5.32	(12.30)	61.3		
(cm)	8 weeks	-3.00	(8.53)	-4.82	(11.60)	37.8	0.46	0.637
	Post	0.19	(8.52)	-1.88	(8.96)	89.9		
Hip Extension	Pre	72.81	(16.22)	83.25	(8.68)	12.6		
Angle	8 weeks	90.25	(8.31)	94.81	(14.35)	4.9	1.12	0.339
(degrees)	Post	89.37	(11.38)	101.50	(14.58)	12.0		
Lower Back	Pre	33.00	(8.90)	36.87	(11.81)	10.5		
Extension	8 weeks	37.57	(9.95)	40.64	(7.13)	7.6	0.06	0.943
(cm)	Post	36.75	(9.79)	41.15	(6.29)	10.7		

p* = probability between groups $p < 0.05$

APPENDIX B [38]

Comparison of the Flexibility Profile of the Basketball Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group $\bar{X}$	(±S.D.)	Basketball Group $\bar{X}$	(±S.D.)	% Δ	F Ratio	P
Sit & Reach	Pre	-2.06	(7.72)	-3.19	(3.81)	35.5		
(cm)	8 weeks	-3.00	(9.53)	-3.44	(4.84)	12.8	0.66	0.525
	Post	0.19	(8.52)	-2.50	(4.90)	92.4		
Hip Extension	Pre	72.81	(16.22)	78.12	(14.46)	6.8		
angle	8 Weeks	90.25	(8.31)	88.62	(11.31)	1.9	0.91	0.414
(degrees)	Post	89.37	(11.38)	88.68	(7.52)	0.8		
Lower Back	Pre	33.00	(8.90)	26.87	(7.89)	18.6		
Extension	8 weeks	37.57	(9.95)	30.25	(8.85)	19.5	0.07	0.929
(cm)	Post	36.75	(9.79)	30.63	(9.36)	16.7		

p* = probability level between means $p < 0.05$

APPENDIX B [39]

Comparison of the Flexibility Profile of the Netball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group X̄	(±S.D.)	Netball Group X̄	(±S.D.)	% Δ	F Ratio	P
Sit & Reach (cm)	Pre	-2.06	(7.72)	2.75	(7.27)	25.1		
	8 weeks	-3.00	(8.53)	4.65	(7.60)	35.5	2.79	0.078
	Post	0.19	(8.52)	5.96	(8.21)	96.9		
Hip Extension Angle (degrees)	Pre	72.81	(16.22)	91.87	(13.44)	20.8		
	8 Weeks	90.25	(8.31)	102.87	(13.06)	12.3	1.15	0.332
	Post	89.37	(11.38)	110.12	(13.48)	18.9		
Lower Back Extension (cm)	Pre	33.00	(8.90)	34.62	(7.30)	4.7		
	8 weeks	37.57	(9.95)	39.90	(6.29)	5.9	1.09	0.350
	Post	36.75	(9.79)	43.21	(5.57)	15.0		

p* = probability level between means p < 0.05

APPENDIX B [40]

Comparison of the Flexibility Profile of the Tennis Group and the Control Group Over 12 Weeks

Dependent variable	Period	Control Group X̄	(±S.D.)	Tennis Group X̄	(±S.D.)	% Δ	F Ratio	P
Sit & Reach (cm)	Pre	-2.06	(7.72)	-8.38	(3.74)	75.5		
	8 Weeks	-3.00	(8.53)	-4.75	(3.55)	36.9	4.53	0.020*
	Post	0.19	(8.52)	-2.31	(3.36)	91.8		
Hip Extension Angle degrees)	Pre	72.81	(16.22)	83.06	(4.27)	12.4		
	8 Weeks	90.25	(8.31)	93.62	(3.80)	3.6	1.00	0.380
	Post	89.37	(11.38)	98.69	(3.35)	9.5		
Lower Back Extension (cm)	Pre	33.00	(8.90)	33.94	(12.00)	2.8		
	8 Weeks	37.57	(9.95)	41.04	(9.95)	8.5	0.51	0.606
	Post	36.75	(9.79)	41.12	(9.71)	10.7		

p* = probability level between means p < 0.05

APPENDIX B [41]

Comparison of the Anaerobic Characteristics Profile of the Badminton Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	($\pm$S.D.)	Badminton Group $\bar{X}$	($\pm$S.D.)	% Δ	F Ratio	P
Peak Power (watts)	Pre	283.85	(111.37)	216.62	(108.01)	23.7		
	8 Weeks	212.97	(65.97)	281.40	(81.44)	24.4	10.53	0.000*
	Post	242.19	(96.96)	330.16	(93.79)	26.7		
Time To peak (seconds)	Pre	10.37	(3.96)	7.21	(1.41)	30.5		
	8 Weeks	10.22	(4.27)	9.12	(7.41)	10.8	0.25	0.784
	Post	11.11	(7.10)	8.92	(1.67)	19.8		
Mean Power (watts)	Pre	221.55	(89.00)	159.42	(92.38)	28.1		
	8 Weeks	167.42	(72.47)	224.82	(63.03)	25.6	11.11	0.000*
	Post	195.72	(7.329)	265.45	(73.39)	26.3		
Watts/kg	Pre	6.57	(1.00)	4.86	(1.61)	26.1		
	8 Weeks	5.14	(2.00)	6.27	(0.62)	18.1	10.64	0.000*
	Post	5.58	(1.67)	7.36	(0.64)	24.2		(pre,post)

p* = probability level between means $p < 0.05$

APPENDIX B [42]

Comparison of the Anaerobic Characteristics Profile of Basketball and the Control Group

Dependent Variable	Period	Control Group X̄	(±S.D.)	Basketball Group X̄	(±S.D.)	% Δ	F Ratio	P
Peak Power (watts)	Pre	283.85	(111.37)	188.71	(35.61)	33.6		
	8 Weeks	212.97	(65.97)	199.03	(56.85)	6.6	4.25	0.024*
	Post	242.19	(96.96)	243.87	(49.87)	0.7		(pre)
Time To Peak (seconds)	Pre	10.37	(3.96)	7.21	(1.41)	30.5		
	8 Weeks	10.22	(4.27)	9.12	(7.41)	10.8	0.01	0.995
	Post	11.11	(7.10)	8.92	(1.67)	19.8		
Mean Power (watts)	Pre	221.55	(89.00)	159.42	(92.38)	28.1		
	8 weeks	167.42	(72.47)	224.82	(63.03)	25.6	3.90	0.032*
	Post	195.72	(73.29)	265.45)	73.39)	26.3		
Watts/kg	Pre	6.57	(1.03)	4.86	(1.61)	26.1		
	8 weeks	5.14	(2.00)	6.27	(0.62)	18.1	3.83	0.033*
	Post	5.58	(1.67)	7.36	(0.64)	24.2		(pre)

p* = probability level between means $p < 0.05$

APPENDIX B [43]

Comparison of the Anaerobic Characteristics Profile of the Netball Group and the Control Group

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Netball Group $\bar{X}$	(±S.D.)	% Δ	F Ratio	P
Peak Power (watts)	Pre	283.85	(111.37)	188.71	(35.61)	33.6		
	8 weeks	212.97	(65.97)	199.03	(56.85)	6.6	2.55	0.096
	Post	242.19	(96.96)	243.87	(49.87)	0.7		
Time To Peak (seconds)	Pre	10.37	(3.96)	10.16	(2.80)	2.1		
	8 Weeks	10.22	(4.27)	9.76	(2.73)	4.6	0.10	0.907
	Post	11.11	(7.10)	10.95	(6.56)	1.5		
Mean Power (watts)	Pre	221.55	(89.00)	145.45	(37.20)	34.4		
	8 Weeks	167.42	(72.47)	160.57	(49.14)	4.1	2.50	0.100
	Post	195.72	(73.29)	196.42	(37.80)	0.4		
Watts/kg	Pre	6.57	(1.00)	5.41	(0.89)	17.7		
	8 weeks	5.14	(2.00)	5.38	(0.90)	4.5	3.19	0.074
	Post	5.58	(1.67)	6.60	(0.59)	15.5		

p^* = probability level between means $p < 0.05$

APPENDIX B [44]

Comparison of the Anaerobic Charactersitics Profile of the Tennis Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Tennis Group $\bar{X}$	(±S.D.)	% Δ	F Ratio	P
Peak Power (watts)	Pre	283.85	(111.37)	244.24	(50.06)	14.0		
	8 weeks	212.97	(65.97)	302.80	(57.92)	29.7	8.09	0.002*
	Post	242.19	(96.96)	303.97	(53.42)	20.4		(8 wks)
Time To Peak (seconds)	Pre	10.37	(3.96)	10.47	(4.36)	1.0		
	8 weeks	10.22	(4.27)	9.08	(2.40)	11.2	0.09	0.910
	Post	11.11	(7.10)	10.64	(5.21)	4.3		
Mean Power (watts)	Pre	221.55	(89.00)	195.78	(36.86)	11.7		
	8 weeks	167.42	(72.47)	248.36	(41.96)	32.6	8.00	0.002*
	Post	195.72	(73.29)	248.01	(38.50)	21.1		
Watts/kg	Pre	6.57	(1.00)	5.86	(0.84)	10.9		
	8 weeks	5.14	(2.00)	7.10	(0.94)	27.7	7.64	0.002*
	Post	5.58	(1.67)	7.14	(1.06)	21.5		(8 wks, post)

p* = probability level between means $p < 0.05$

APPENDIX B [45]

Comparison of the Submaximal Effort Data of the Badminton Group and the Control Group

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Badminton Group $\bar{X}$	(±S.D.)	% Δ	F Ratio	P
VO_2	Pre	16.57	(2.80)	15.52	(4.09)	6.4		
$ml.kg.^{-1}min^{-1}$	8 weeks	17.81	(1.59)	17.30	(3.55)	2.9	0.23	0.795
4 km	Post	16.44	(3.79)	16.73	(1.67)	1.8		
VO_2	Pre	25.05	(5.68)	27.44	(4.57)	8.8		
$ml.kg.^{-1}min^{-1}$	8 weeks	26.46	(3.91)	25.79	(3.85)	2.6	0.89	0.421
6 km	Post	24.14	(2.99)	25.99	(2.59)	7.2		
VO_2	Pre	38.85	(4.87)	42.87	(2.72)	9.4		
$ml.kg.^{-1}min^{-1}$	8 weeks	40.08	(3.69)	43.42	(2.53)	7.7	2.34	0.115
8 km	Post	39.00	(3.14)	42.56	(3.03)	8.4		

p^* = probability level between means $p < 0.05$

APPENDIX B [46]

Comparison of the Submaximal Effort Data of the Basketball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	($\pm$S.D.)	Basketball Group $\bar{X}$	($\pm$S.D.)	% Δ	F Ratio	P
VO_2	Pre	16.57	(2.80)	19.74	(2.71)	16.1		
$ml.kg.^{-1}min^{-1}$	8 weeks	17.81	(1.59)	19.29	(2.10)	7.7	0.61	0.550
4 km	Post	16.44	(3.79)	20.07	(2.66)	18.1		
VO_2	Pre	25.05	(5.68)	34.73	(4.25)	27.9		
$ml.kg.^{-1}min^{-1}$	8 weeks	26.46	(3.91)	30.28	(3.42)	12.7	2.84	0.075
6 km	Post	24.14	(2.99)	29.72	(3.69)	18.8		
VO_2	Pre	38.85	(4.87)	43.32	(2.72)	10.4		
$ml.kg.^{-1}min^{-1}$	8 weeks	40.08	(3.69)	43.42	(2.53)	7.7	0.14	0.870
8 km	Post	39.00	(3.14)	42.56	(3.03)	8.4		
Efficiency	Pre	45.50	(4.35)	41.27	(5.60)	9.3		
%	Post	45.56	(3.76)	41.94	(2.79)	8.0	0.09	0.768

p* = probability level between means $p < 0.05$

APPENDIX B [47]

Comparison of the Submaximal Effort Data of the Netball Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Netball Group $\bar{X}$	(±S.D.)	%	F Ratio	P
VO2	Pre	16.57	(2.80)	16.57	(1.61)	0.0		
$l.kg.^{-1}min^{-1}$	8 weeks	17.81	(1.59)	17.07	(2.78)	4.2	0.76	0.476
4 km	Post	16.44	(3.79)	17.55	(2.07)	6.4		
VO2	Pre	25.05	(5.68)	26.64	(2.92)	6.0		
$ml.kg.^{-1}min^{-1}$	8 weeks	26.46	(3.91)	26.28	(3.58)	0.7	1.72	0.198
6 km	Post	24.14	(2.99)	27.58	(3.39)	12.5		
VO2	Pre	38.85	(4.87)	27.24	(2.47)	29.9		
$ml.kg.^{-1}min^{-1}$	8 weeks	40.08	(3.69)	29.08	(3.15)	27.5	0.34	0.714
8 km	Post	39.00	(3.14)	27.72	(2.40)	29.0		

p^* = probability level between means $p < 0.05$

APPENDIX B [48]

Comparison of the Submaximal Effort Data of the Tennis Group and the Control Group Over 12 Weeks

Dependent Variable	Period	Control Group $\bar{X}$	(±S.D.)	Tennis Group $\bar{X}$	(±S.D).	%	F Ratio	P
VO_2	Pre	16.52	(2.80)	18.40	(2.59)	10.0		
$ml.kg.^{-1}min^{-1}$	8 weeks	17.81	(1.59)	18.55	(2.07)	4.0	0.19	0.831
4 km	Post	16.44	(3.79)	17.95	(1.82)	8.5		
VO_2	Pre	25.05	(5.68)	27.24	(2.47)	8.1		
$ml.kg.^{-1}min^{-1}$	8 weeks	26.46	(3.91)	29.08	(3.15)	8.1	0.25	0.780
6 km	Post	24.14	(2.99)	27.72	(2.40)	13.0		
VO_2	Pre	38.85	(4.87)	37.86	(2.06)	2.6		
$ml.kg.^{-1}min^{-1}$	8 weeks	40.08	(3.69)	40.46	(4.63)	1.0	0.74	0.982
8 km	Post	39.00	(3.14)	39.58	(3.39)	1.5		

p* = probability level between means $p < 0.05$

APPENDIX C

APPENDIX C {1}

Practice Activities and Their Intensities for Badminton

High Intensity 160-180 bts.min.$^{-1}$	Moderate Intensity 140-160 bts.min.$^{-1}$	Low Intensity Below 140 bts.min.$^{-1}$
*agility drills	*active recovery	*waiting turn
*net drills	*doubles practice	*explanations
*'pointing' drill		*tactics discussions
*overhead drill		*feeding to others
*clear, drop drill		*stretching
*smashing drill		
*one minute sequences		
*singles drill; clear net, lift etc.		
*foot work sequences		

APPENDIX C {2}

Practice Activities and Their Intensities for Basketball

High Intensity 160-180 bts.min.$^{-1}$	Moderate Intensity 140-160 bts.min.$^{-1}$	Low Intensity Below 140 bts.min.$^{-1}$
*defence drill	*2-1-2 drill	*organisation/discipline
*lay-ups drill	*run through drill	* walk through drills
*rebound drill	*dribbling drill	*demonstrations
*practice game	*shooting drill	*game discussion
*dribbling full court court	*full court defence drills	*undefended shooting for goals practice
*pass & shuffle	*dribble & throw relay relay	
	*3 man weave full court relay	

APPENDIX C {3}

Practice Activitities and Their Intensities for Netball

High Intensity 160-180 bts.min.$^{-1}$	Moderate Intensity 140-160 bts.min.$^{-1}$	Low Intensity Below 140 bts.min.$^{-1}$
*half court game	*systems drill	*shooting goal practice
*1 on 2 drill	*warm up run drill	*stretching
*attacking drill	*full court practice	*passing practices
*defending drill	*defending goals drill	*organisation
*dodging drill	*toss-up practices	*demonstrations
*3 on 3 drill		*umpiring prac. matches

APPENDIX C {4}

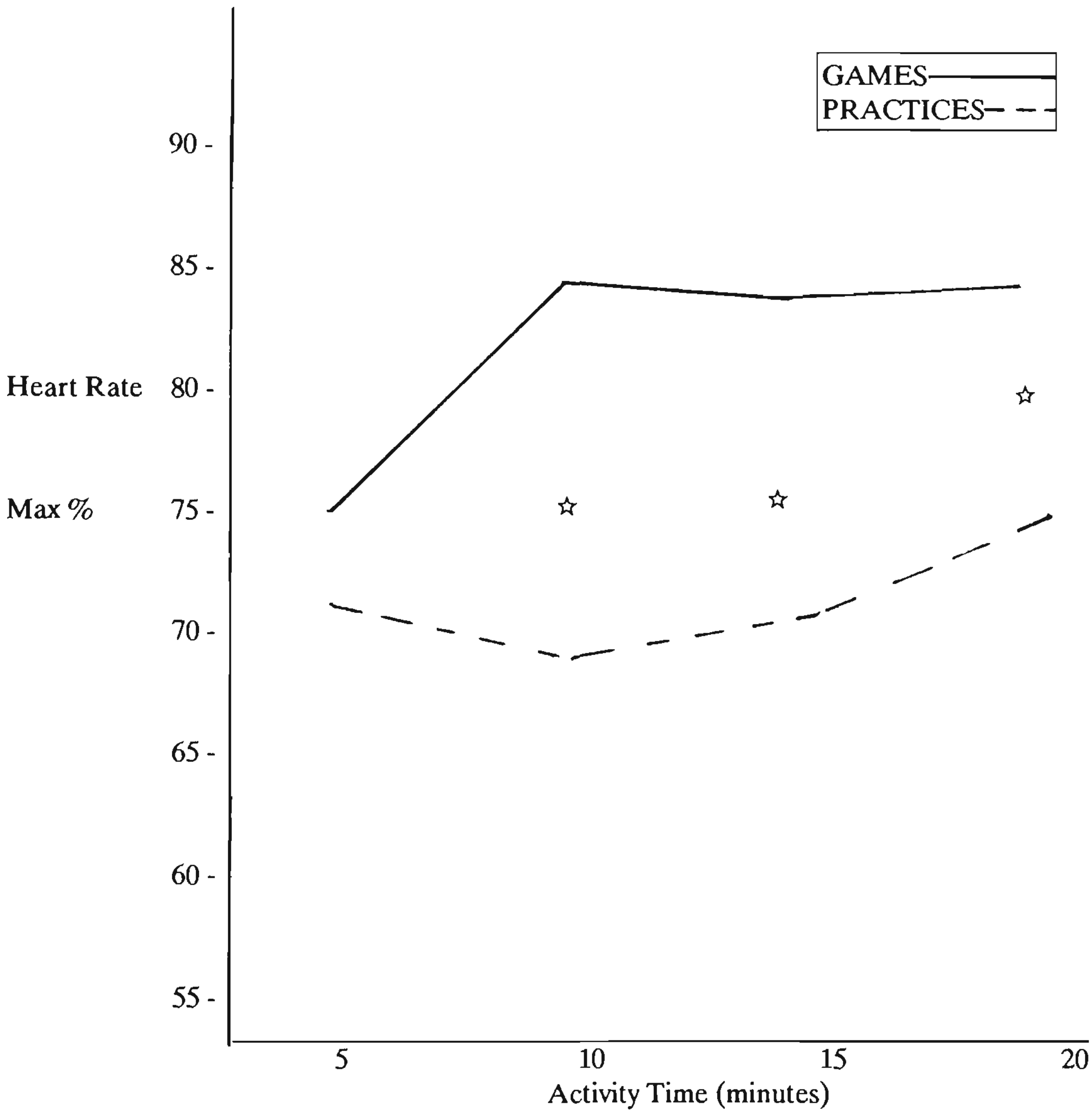
Practice Activitities and Their Intensities for Tennis

High Intensity 160-180 bts.min^{-1}	Moderate Intensity 140-150 bts.min.$^{-1}$	Low Intensity Below 140 bts.min.$^{-1}$
*serve and volley	*forehand drill	*waiting turn
*sequence starting	*5 shot rally drill	*explanations
with a cross-court	*warm up hits	*recovery during an
backhand drive	*back court rallies	elimination game
*volley drill	*serving practice	
*back court to volley at net	*alternate hitting drill	
*volley and smash	*receiving service to	
*3 on 3 survival game	play out shots	

APPENDIX D

APPENDIX D {1}

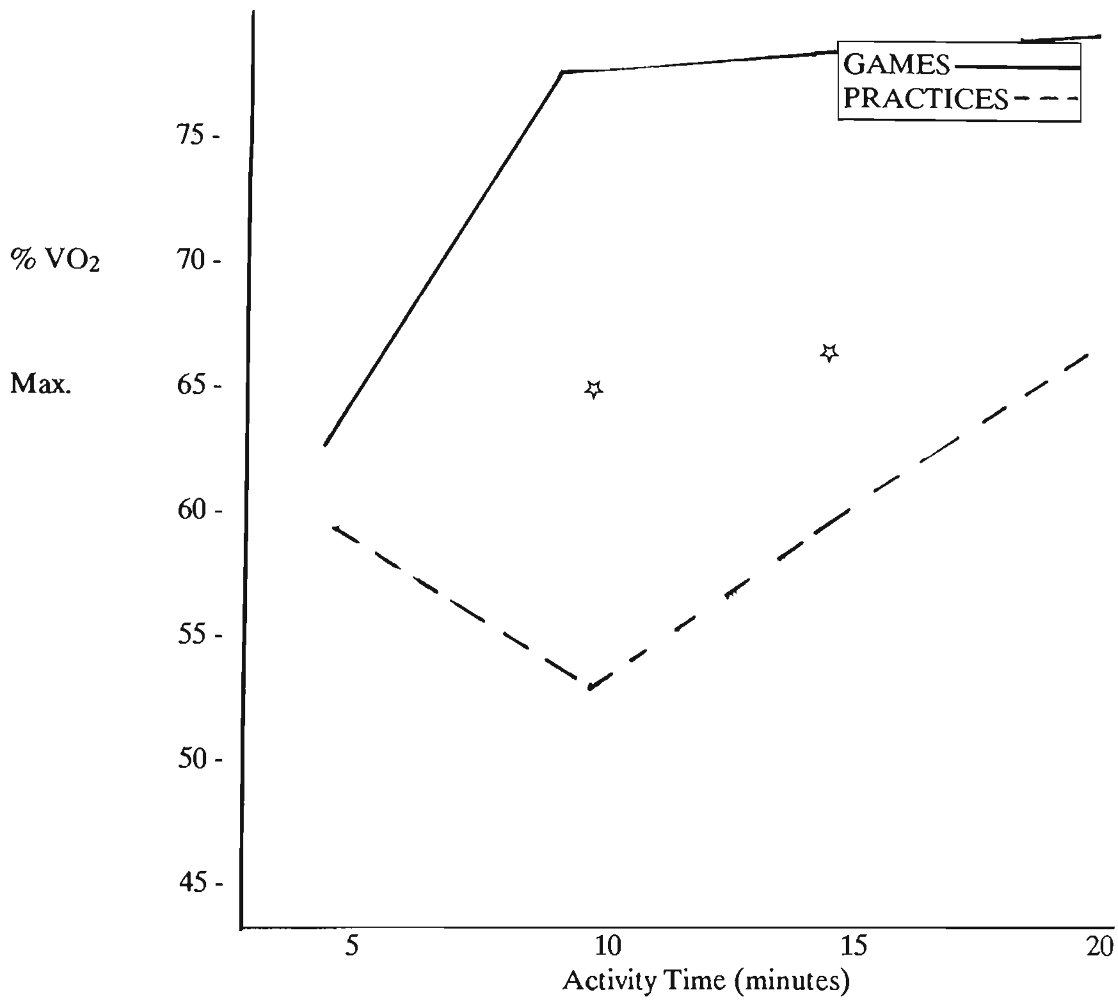
Graph (b): Mean Percentage of Maximal Heart Rate During Competitive Games and Practices of Badminton.



p☆ probability level < 0.05

APPENDIX D {1}

Graph (c): Mean Percentage of VO_2 Max During Competitive Games and Practices of Badminton

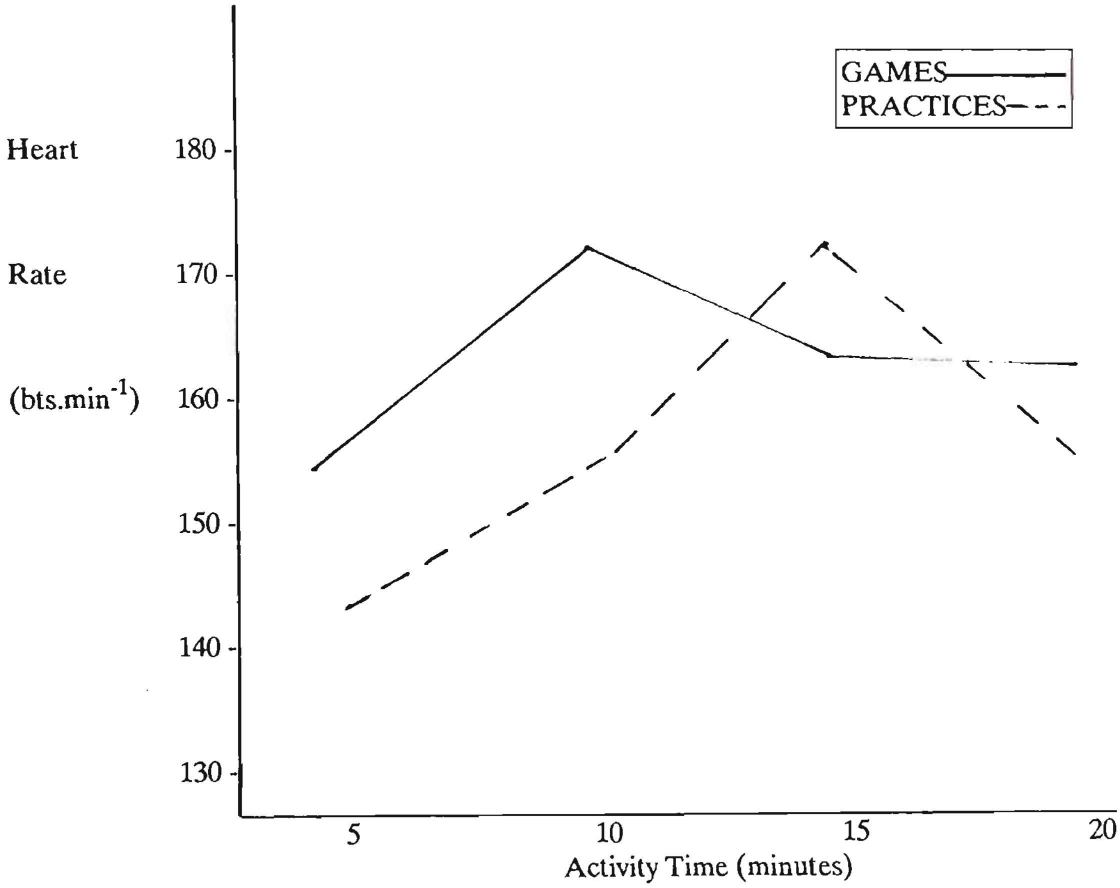


p☆probability level < 0.05

APPENDIX D {2}

Graphs of the Intensity at Which Pre-adolescent Basketball Players were Participating in Competitive Games and Practices

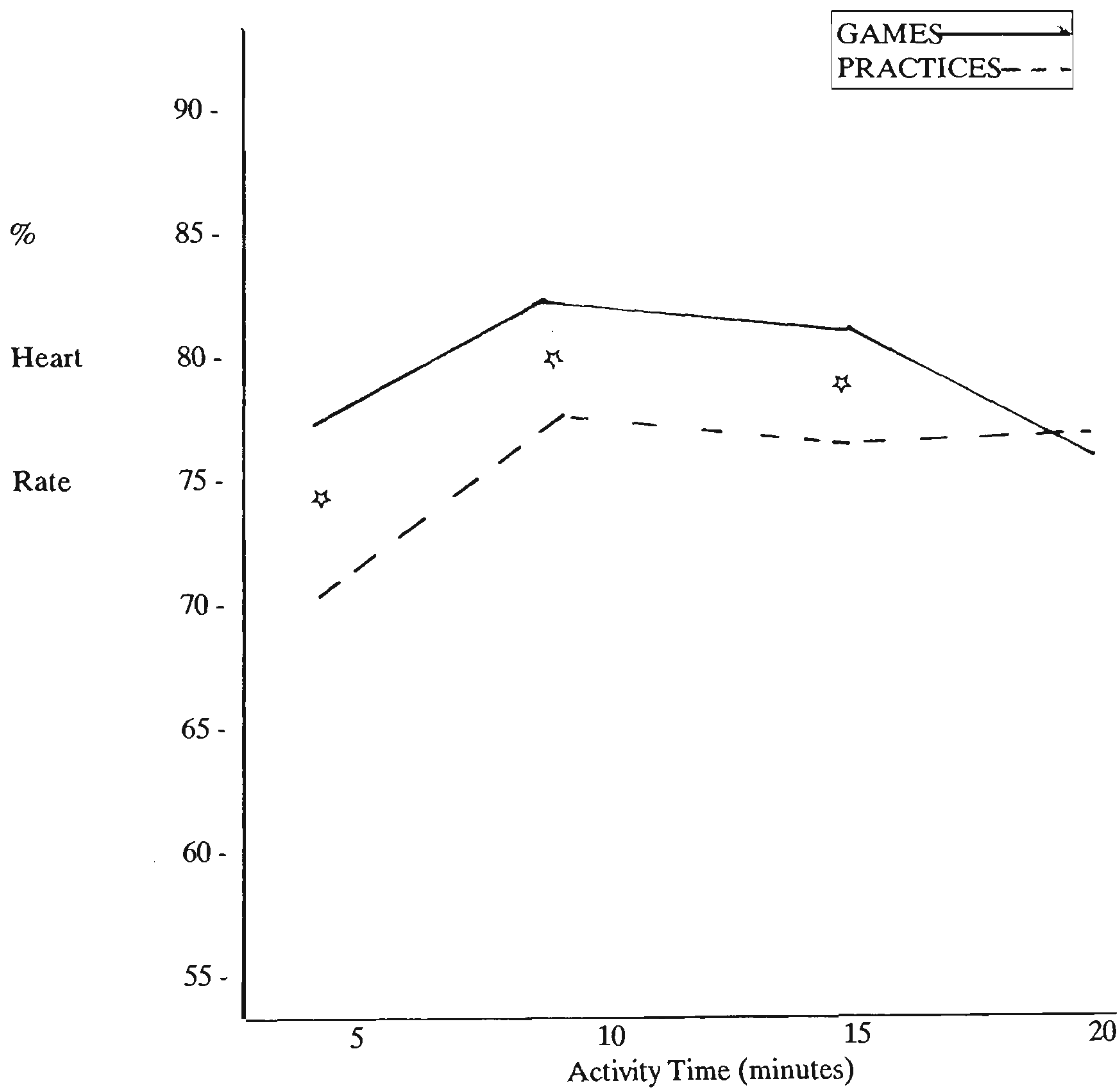
Graph (a): Mean Absolute Heart Rates During Competitive Games and Practices of Basketball.



p* probability level < 0.05

APPENDIX D {2}

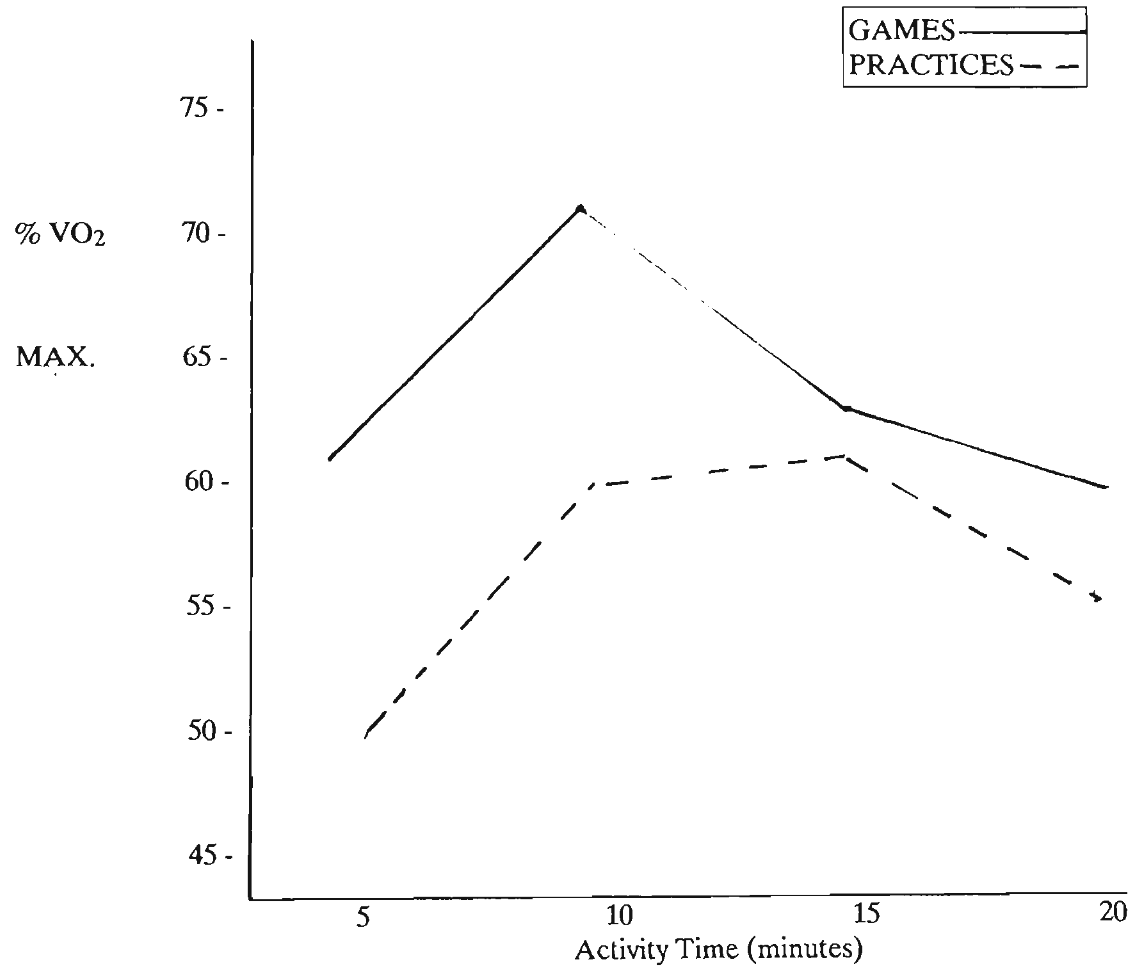
Graph (b): Mean Percentage of Maximal Heart Rate During Competitive Games And Practices Of Basketball.



p✩ probability level < 0.05

APPENDIX D {2}

Graph (c): Mean Percentage of VO_2 Max During Competitive Games and Practices of Basketball.

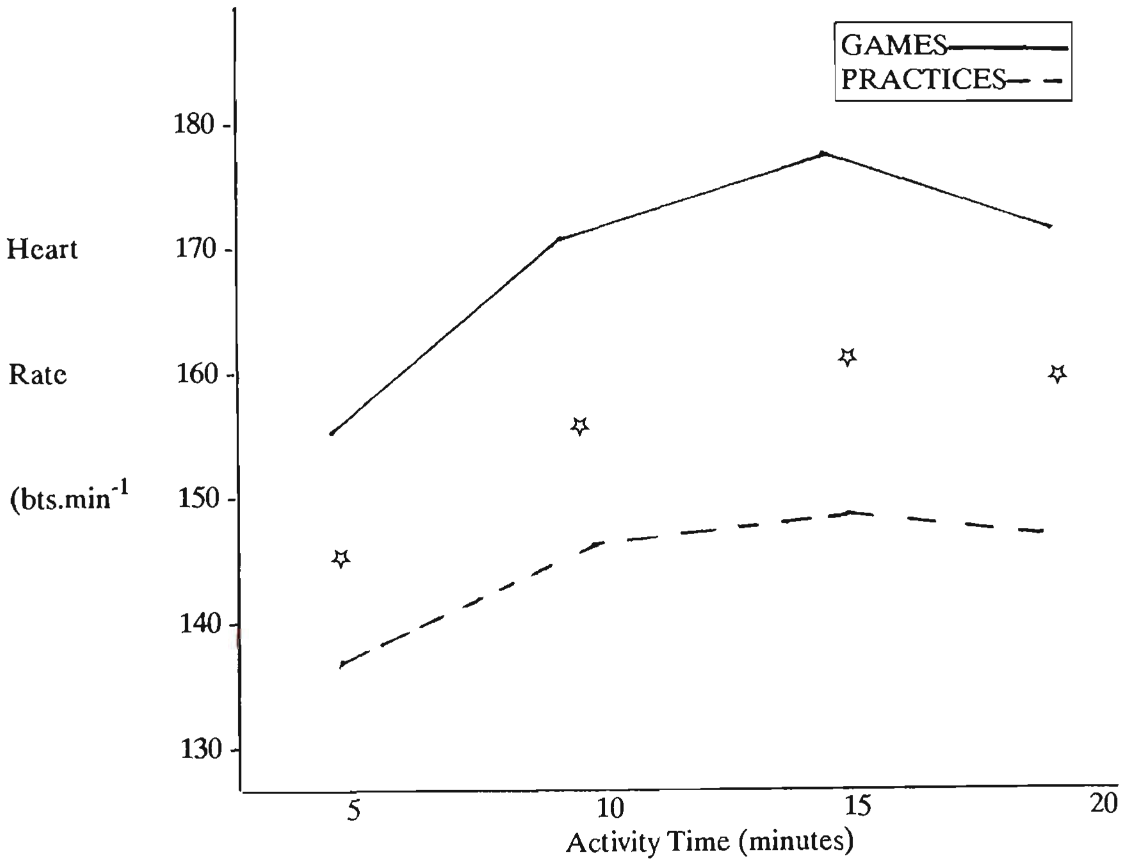


p* probability level < 0.05

APPENDIX D {3}

Graphs of the Intensity at which Pre-adolescent Netball Players were Participating In Competitive Games And Practices

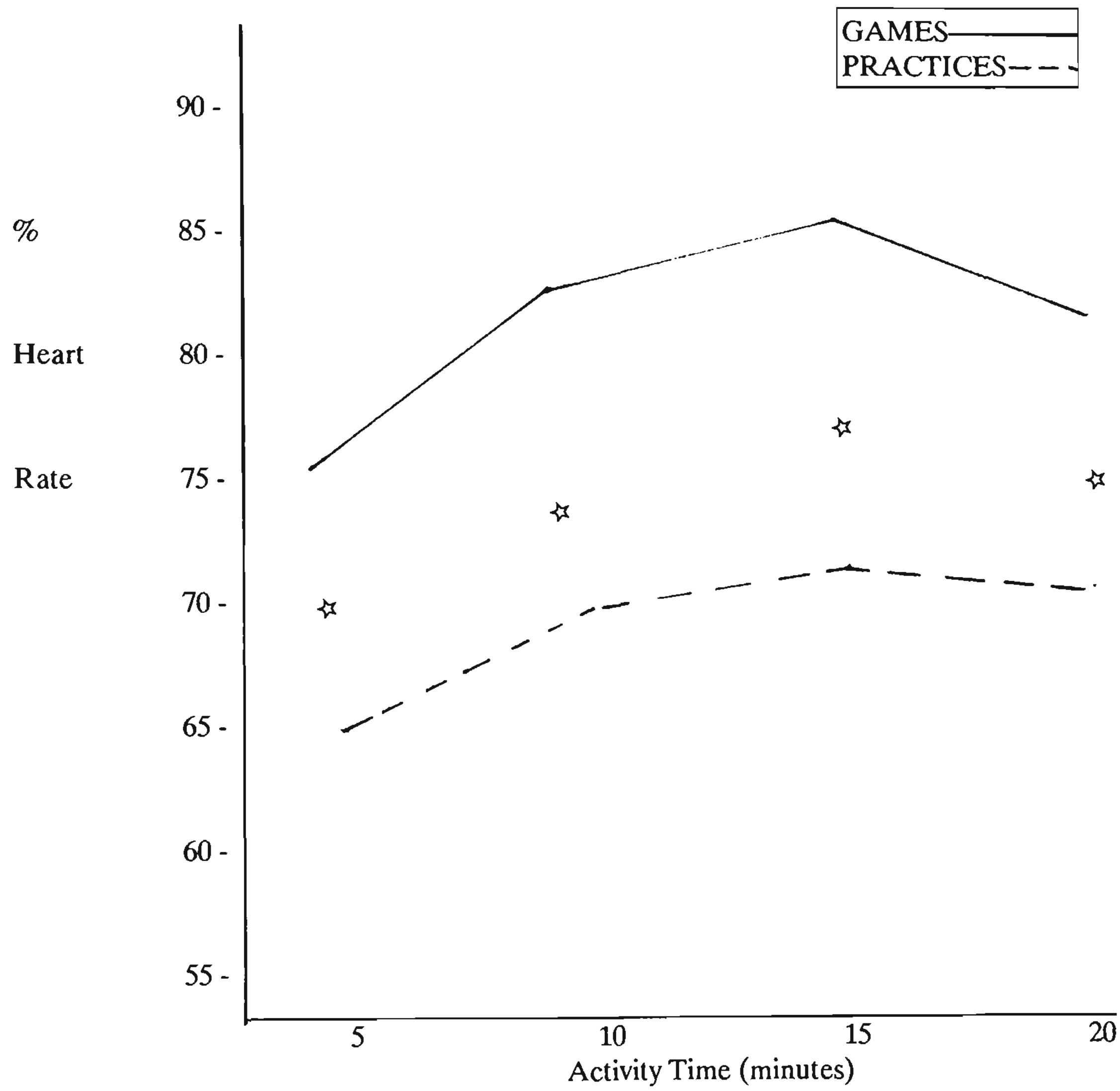
Graph (a): Mean Absolute Heart Rates During Competitive Games and Practices Of Netball



p☆probability level < 0.05

APPENDIX D {3}

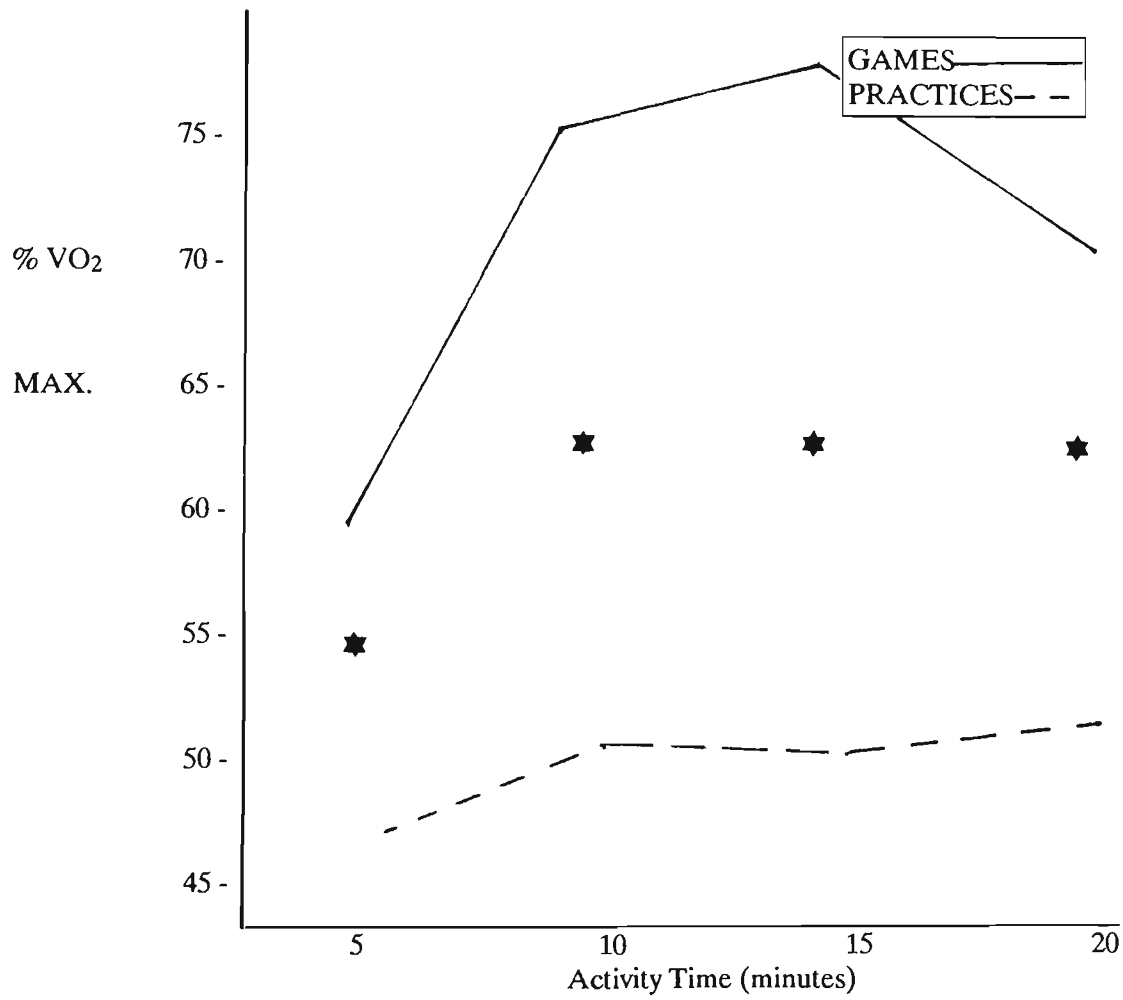
Graph (b): Mean Percentage of Maximal Heart Rate During Competitive Games And Practices Of Netball



p☆ probability level < 0.05

APPENDIX D {3}

Graph (c): Mean Percentage of VO_2 Max During Competitive Games and Practices Of Netball.

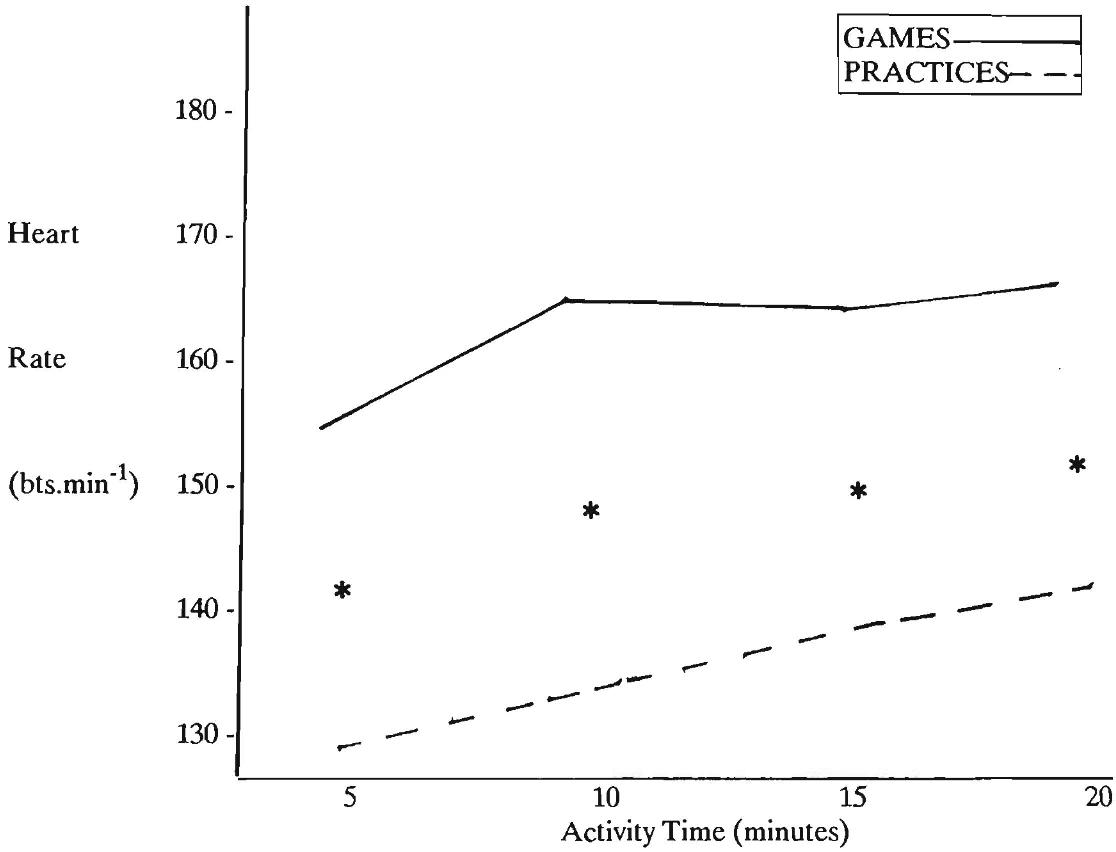


p* probability level < 0.05

APPENDIX D {4}

Graphs of the Intensity at which Pre-adolescent Tennis Players were Participating In Competitive Games and Practices.

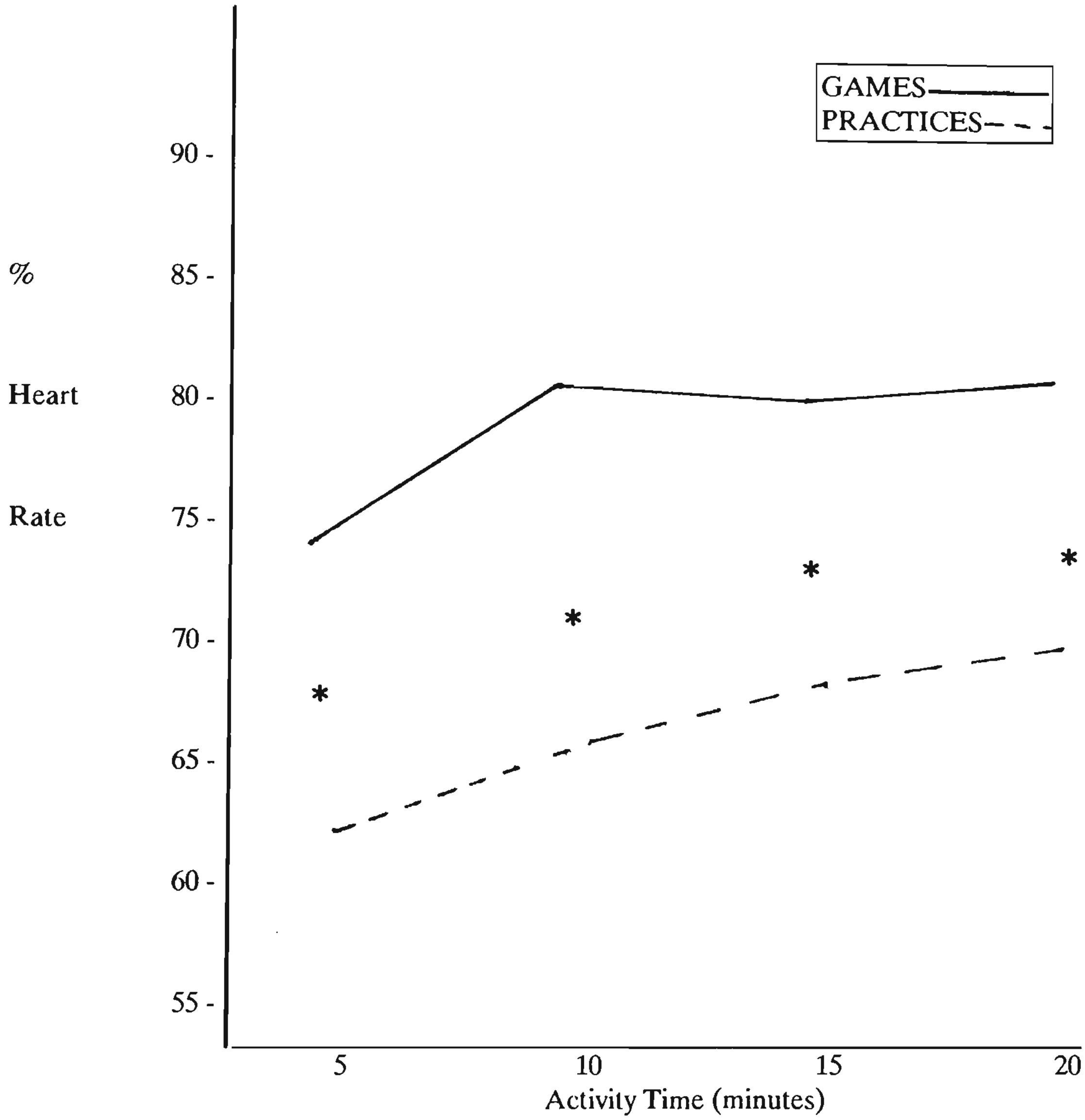
Graph (a): Mean Absolute Heart Rates During Competitive Games and Practices of Tennis



p* probability level < 0.05

APPENDIX D {4}

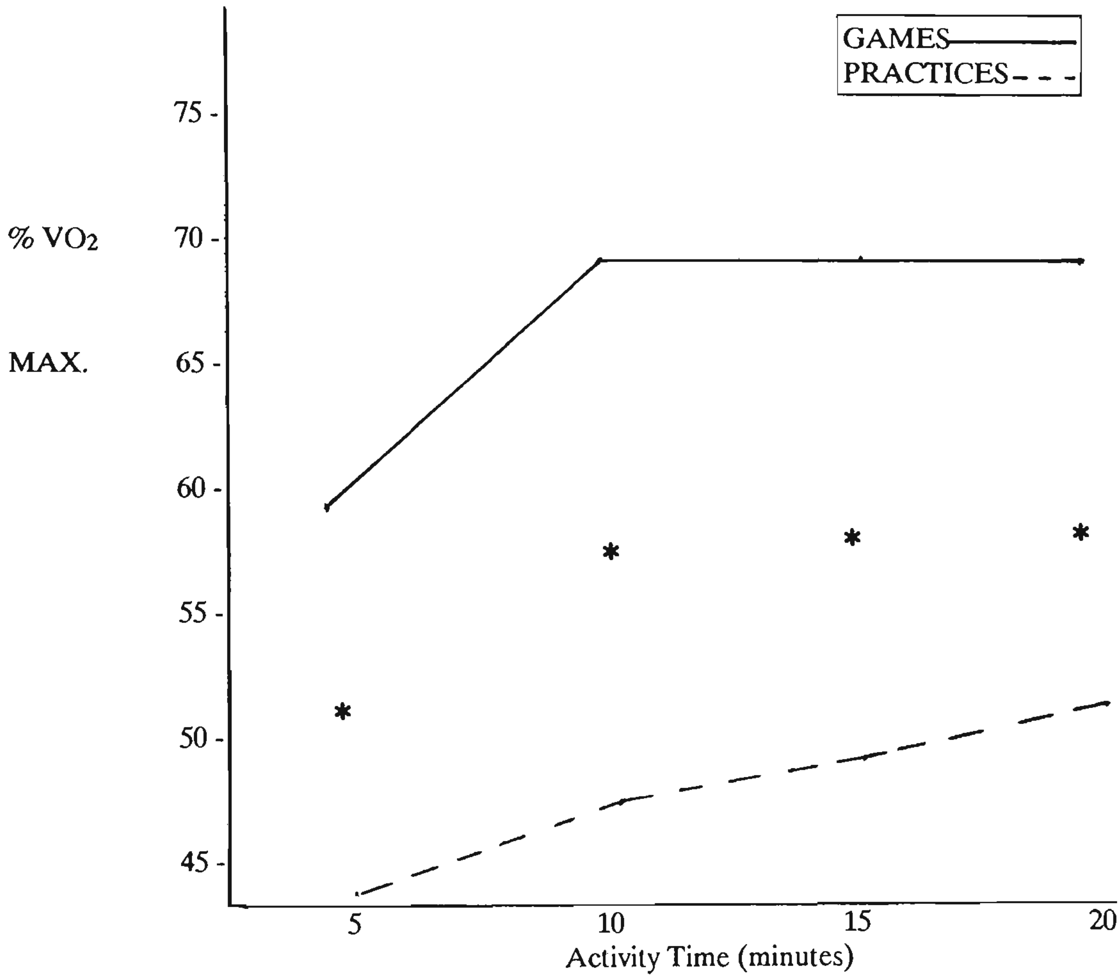
Graph (b): Mean Percentage of Maximal Heart Rate During Competitive Games and Practices of Tennis



p* probability level < 0.05

APPENDIX D {4}

Graph (c): Mean Percentage of VO_2 Max During Competitive Games and Practices of Tennis

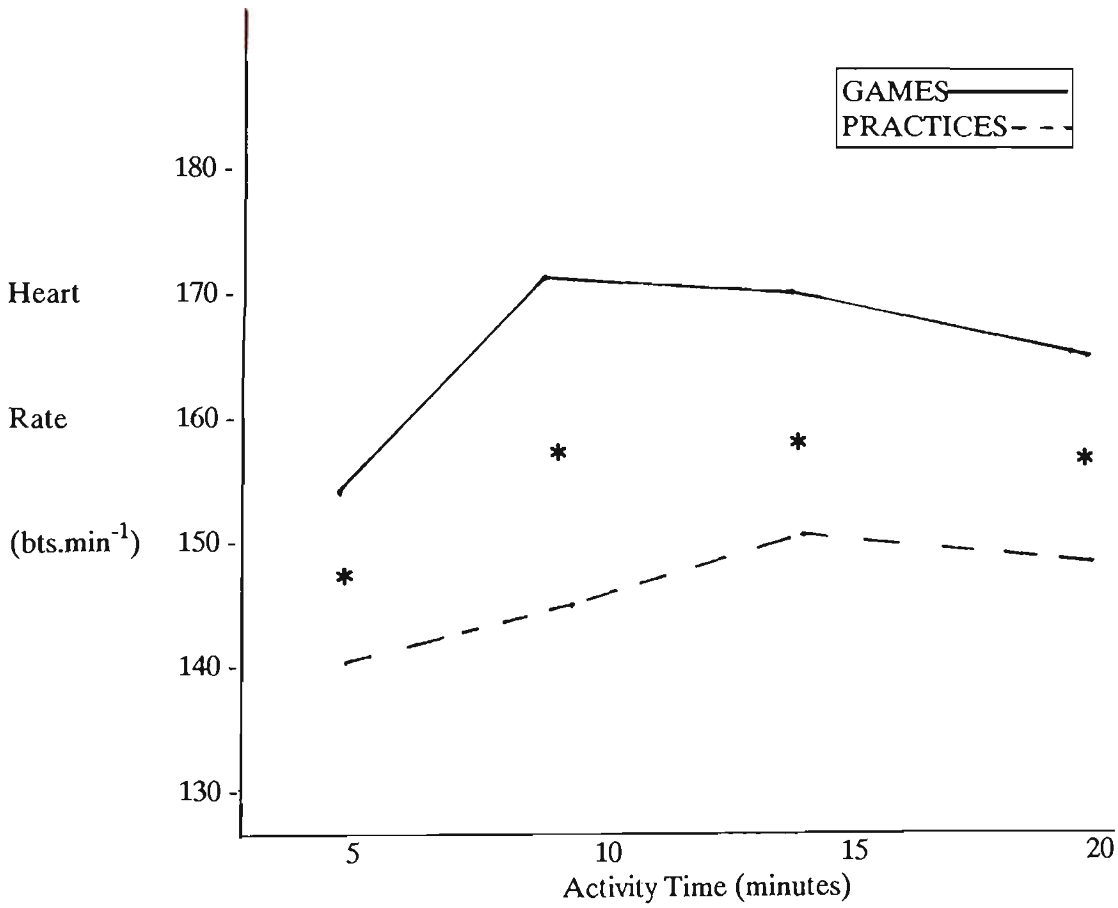


p* probability level < 0.05

APPENDIX D {5}

Graphs of the Intensity at which Pre-adolescents in All Four Sports Were Participating In Competitive Games and Practices.

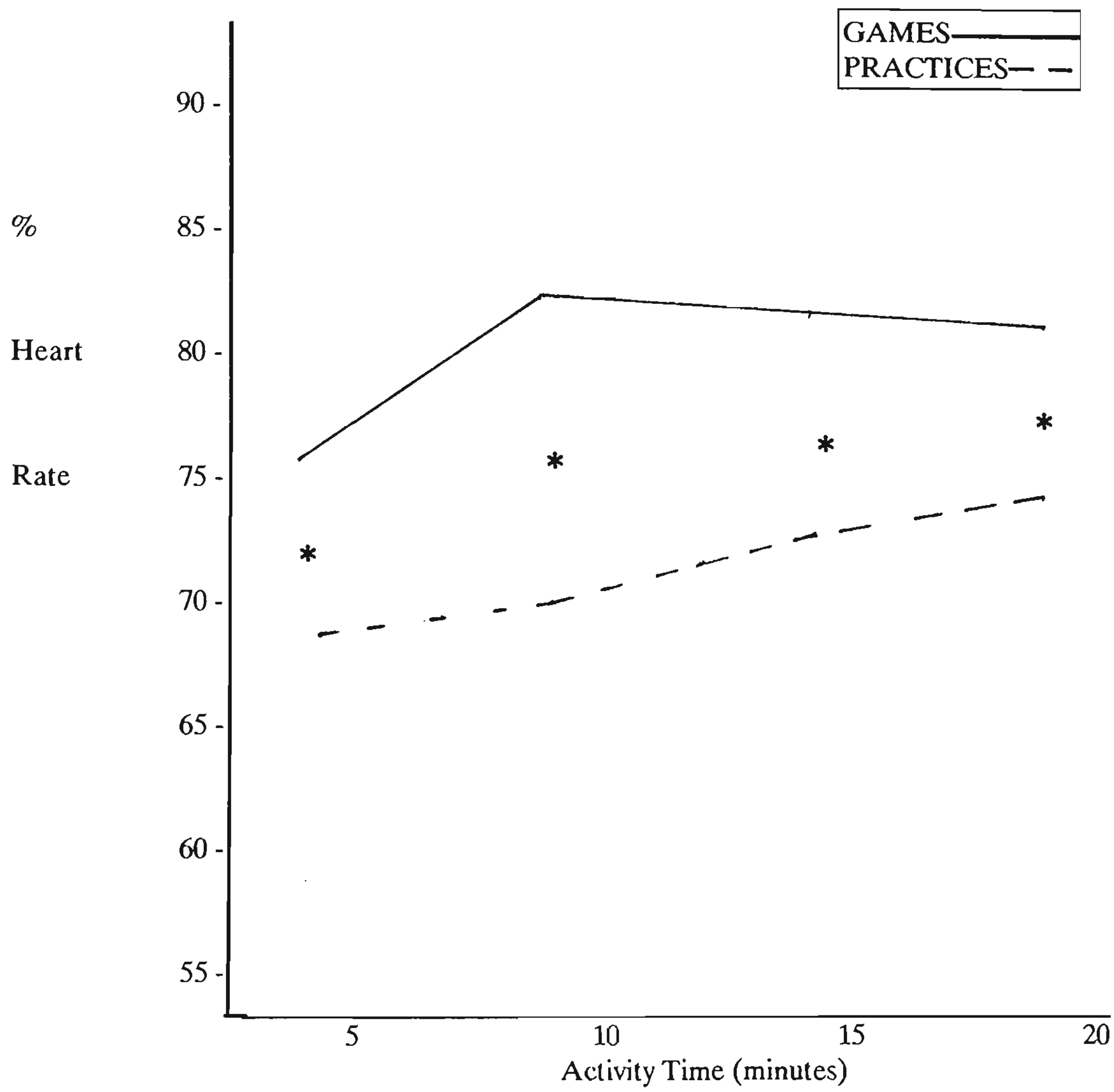
Graph (a): Mean Absolute Heart Rates During Competitve Games and Practices of all Four Sport Combined.



p* probability level < 0.05

APPENDIX D {5}

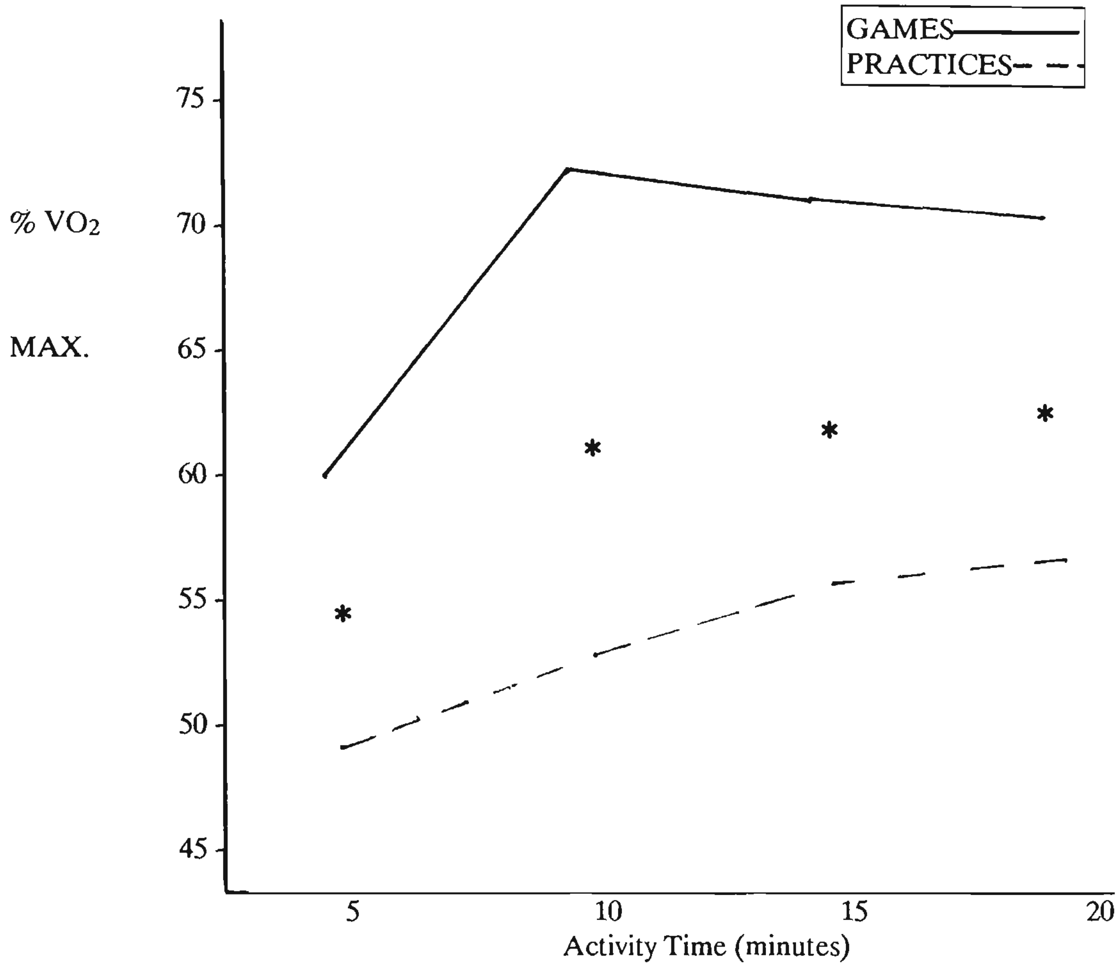
Graph (b): Mean Percentage of Maximal Heart Rate During Competitive Games And Practices Of All Four Sports Combined.



p* probability level < 0.05

APPENDIX D {5}

Graph (c): Mean Percentage of VO_2 Max During Competitive Games and Practices of all Four Sports Combined.



p* probability level < 0.05