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ANTHROPOMETRIC AND MATURATIONAL ASSESSMENT OF FEMALE GYMNASTS FROM VARYING PERFORMANCE LEVELS

by

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ABSTRACT

Sixty-nine Canadian female gymnasts ages 11.5 to 18.0 years, from varying ability levels (National Elite = Group 1, Pre-National Elite = Group 2, Competitive = Group 3, Recreational = Group 4), were studied to determine relationships between performance and maturity, and between performance and anthropometric characteristics. It was hypothesized that there would be significant maturational and anthropometric differences among the ability groups.

Skeletal age in reference to chronological age differences, among the ability groups, were assessed using analysis of variance, while differences in the incidence of menarche were assessed using chi-square analysis. Anthropometric differences were assessed using multivariate and univariate analysis of covariance, with chronological age as the covariate.

At a level of significance of $p < .01$, and using preplanned orthogonal contrasts of Group 1 + 2 + 3 vs Group 4, Group 1 + 2 vs Group 3, and Group 1 vs Group 2, both of the maturational and all five of the anthropometric hypotheses were partially supported, with the following significant differences noted:

Highly skilled gymnasts, in comparison to lesser skilled gymnasts (Group 1 + 2 + 3 vs Group 4, and Group 1 + 2 vs Group 3), were maturationally delayed both skeletally and menarcheally. Anthropometrically, they were shorter in trunk length; smaller in triceps, suprailiac, abdominal, front thigh, and medial calf skinfolds; smaller in proportional fat mass;

and larger in proportional muscle mass. In addition, highly skilled gymnasts (Group 1 + 2 + 3), in comparison to recreational gymnasts (Group 4), were smaller in bi-epicondylar femur width, thigh girth, and subscapular skinfold. As well, elite gymnasts (Group 1 + 2), in comparison to lesser skilled competitive gymnasts (Group 3), were smaller in sitting height and larger in proportional skeletal mass.

National elite gymnasts (Group 1), in comparison to pre-national elite gymnasts (Group 2), were not maturationally different, skeletally or menarcheally. Anthropometrically, they were shorter in trunk length, longer in thigh length, and smaller in anterior-posterior chest depth.

The significant maturational differences noted among the ability groups were considered to be related to gymnastic performance, with higher skilled gymnasts being developmentally less mature than lesser skilled gymnasts.

The significant anthropometric differences noted among the ability groups were considered to be related to gymnastic performance. More specifically, these differences were considered to be of biomechanical importance, and reflections of differences in activity level. As well, it was suggested that these anthropometric differences were associated with maturational differences.

The results of the maturational and anthropometric assessments indicated that there may be a relationship between gymnastic performance and maturity, and between gymnastic performance and anthropometric characteristics. It was proposed that further analysis of the anthropometric parameters, with respect to proportional assessment, would be necessary before anthropometric characteristics would closely reflect maturational differences.

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CHAPTER 1

INTRODUCTION

The factor of age presents unlimited problems in research involving anthropometric and performance comparisons between former and present Olympic Games and World Class competitors. The ages of the female gymnastic participants in these competitions appear to have decreased substantially with each successive Games. A wide age range of these competitors has made it difficult to draw any conclusive information from anthropometric comparisons of former and present elite, female gymnasts, other than the identification of obvious physical differences that normally exist between the adult female figure, and the younger pre-pubescent or adolescent female figure.

Many of today's elite female gymnasts are in the age range when normal pubertal developments are expected to take place. During the pubescent years, dramatic physical changes in size, shape, and body composition occur, along with differential changes in the reproductive and other organs. One such development is the onset of menarche, which marks a definite stage of physical maturity in the female progression through adolescence towards ultimate adult, physical status.

The recent trend of younger participants at elite gymnastic competitions seems to indicate that female gymnasts are reaching their prime or "peaking" at younger ages. This appears to be the case since, accompanying this decrease in age, is a progressive increase in skill complexity and the attainment of very high degrees of performance.

This age factor may play an important role in the evolution of gymnastic performance. A logical inquiry from these observations is, "whether or not certain physical advantages co-exist with the younger, female gymnast, rendering her a more appropriate candidate for gymnastic-type movement than the older, female gymnast". This inquiry may have some support in the fact that fame for female gymnasts is often short-lived, with female gymnasts tending to drop out of high caliber competition during, or soon after adolescence. This early retirement may be due to the stiff competition imposed by upcoming gymnasts, who "win" their way into the elite positions, or due to the adolescent development of other interests.

An overlooked, and possibly unconsidered, factor involved in this early retirement trend may lie in the fact that the body changes in size, shape, proportionality, and composition during puberty. Some of these obvious changes are; increases in height, weight, total body adiposity, and the development of secondary sex characteristics in general.

A declining age of participation, concurring with an increasing level of skill complexity, may reflect the changing nature and evolution of "women's" gymnastics. This trend suggests the possibility that important relationships exist between maturational status, anthropometric characteristics, and success in gymnastic performance.

STATEMENT OF THE PROBLEM

It is the purpose of this research to investigate the possibility that success in gymnastics is related to the concept of maturational age and anthropometric characteristics. More specifically, the questions to be investigated are as follows:

1. Are there maturational differences among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts?
2. Are there anthropometric differences among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts?

HYPOTHESES

It is hypothesized that:

1. The maturational status, as determined by skeletal age in reference to chronological age, is significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

2. The incidence of menarche is significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

3. The measures of height and length are significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

4. The measures of width, breadth, and depth are significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

5. The measures of girth are significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

6. The measures of skinfold thickness are significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

7. The measures of weight and proportional body mass are significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

DEFINITION OF TERMS

Anthropometry: as defined by Webster (1970: s.v.) is, "the study of human body measurements, especially on a comparative basis".

Anthropometric Characteristics: refers, in the present study, to the specific height, length, width, breadth, depth, girth, skinfold thickness, and weight measurements taken, as well as to the length and proportional mass measures derived.

Growth: refers to the physical act of enlargement of a structure, which may result in volume increases and shape changes.

Maturation: refers to the various stages of differentiation of cells, tissues, and organs, in preparation for functional and structural changes. It is also the occurrence of physical and physiological changes associated with progression towards ultimate and full adult development and function. The term "development" is used synonymously with "maturation".

Menarche: refers to, "the initiation of menstruation" (Webster, 1970: s.v.). It is an objective and easily identifiable stage in the maturation sequence of the female.

Morphology: is a collective term, referring to the shape, build, physique, structure, composition, and proportions of the body.

Proportional Body Masses: refers to, the derived fat, skeletal, muscle, and residual weights of the body, expressed in percentages of the total body weight, with total body weight for these derivations calculated as the sum of the four derived weights, and not the conventionally observed scale weight.

Pubertal or Adolescent Developments: refers, in the present study, to the initiation of the growth spurts in height and weight; to specific compositional, structural, and shape changes; as well as to physiological and functional developments, such as menarche, that accompany puberty.

Skeletal Age: is, "a measure of the developmental status of the skeleton as disclosed by an x-ray film" (Greulich & Pyle, 1970:2), usually of the hand and wrist area. The maturational status of the hand and wrist area "represents" the developmental status of the skeleton as a whole (Greulich & Pyle, 1970:11), and "reflects" the developmental and functional status of the reproductive system (Greulich & Pyle, 1970:15). The terms "bone age" and "physiological age" are used synonymously with the term "skeletal age".

DELIMITATIONS

1. The present study is delimited to maturational and anthropometric assessments of Canadian female gymnasts, between the ages of 11.5 and 18.0 years, with ability levels ranging from recreational, through provincial competitive levels A & B, to pre-national and national team caliber.

2. The concept of maturity is delimited to:
   a) skeletal age, as evaluated via the Tanner-Whitehouse II Method, twenty bone assessment, bone specific approach to assessing the skeletal maturity of the hand and wrist area (Tanner, Whitehouse, Marshall, Healy, & Goldstein, 1975); and
   b) the occurrence or absence of menarche.

3. The anthropometric assessment is delimited to the 39 measurements evaluated, and more specifically to the 11 height and length; 6 breadth, width, and depth; 11 girth; 6 skinfold thickness; 1 weight, and 4 proportional body mass measures.

LIMITATIONS

1. Skill level classification into Research Groups 1, 2, and 3, is limited to the Canadian Gymnastics Federation categorization of gymnasts into "National Elite, Pre-National Elite, and Provincial

Competitive Levels A and B", respectively. Categorization of gymnasts is based on their performance in a test of "gymnastic fitness" comprised of a battery of individual physical fitness and standard gymnastic moves tests (Bajin, 1977).

2. Since the training, competitive, and rest season may not coincide for gymnastic Groups 1, 2, and 3, it is recognized that the state of physical fitness "readiness" may not have been uniform among these groups. This situation may have influenced the difference values, among these groups, in those anthropometric variables readily influenced by activity level (weight, skinfold thickness, proportional fat mass, girth, proportional muscle mass measures).

3. The subjects' involvements in other sporting endeavours and physical pursuits were not controlled.

CHAPTER 2

REVIEW OF THE RELATED LITERATURE

Introduction

Research involving pre-adolescent and adolescent children involved in high levels of competition must be concerned with many variables in order to isolate those factors that may contribute significantly to the success of these young athletes. This thesis is directed toward isolating the contribution of "maturity" and "morphology", as these two domains relate to success in gymnastics.

The related literature for this study will be presented under the following headings:

I	MORPHOLOGICAL DESCRIPTORS:	conventional methods of describing the body morphologically.
II	MORPHOLOGY AND PERFORMANCE:	the importance of body "build" to performance outcomes.
III	PERFORMANCE AND MORPHOLOGY:	the role of exercise in developing and altering body "build".
IV	PERFORMANCE AND MATURITY:	physical exercise as it affects the maturing processes.
V	MORPHOLOGY AND MATURITY:	physical size and "build" as these affect the maturing processes.
VI	MATURITY AND MORPHOLOGY:	the time and rate of maturity as they affect the ultimate adult physique.

VII MATURITY AND PERFORMANCE: physical changes associated with maturity as they affect performance.

I MORPHOLOGICAL DESCRIPTORS

Three of the conventional methods of describing the body morphologically are; somatotypical analysis, anthropometric assessment, and body composition analysis.

Somatotypical Analysis

The concept of somatotyping, an evaluation of the total body's external shape, the degree of endomorphy, mesomorphy, and ectomorphy assessed through visual inspection of a series of photos, was introduced by Sheldon, Stevens, and Tucker in 1940. In order to increase the objectivity of the assessment, the Heath-Carter Method of Somatotyping, incorporating anthropometric elements into the photoscopic assessment, was later developed (Carter, 1975), based on earlier works of Cureton (1947, 1951), Parnell (1954, 1958), and Damon et al. (1962) (all cited in Carter, 1975:2-1).

Anthropometric Assessment

Anthropometric analysis involves taking surface measurements of lengths, girths, widths, breadths, depths, and skinfold thicknesses. These surface measurements offer a means of assessing the distribution of the body's composition; with girth measurements generally indicating muscular development; length, breadth, and width measurements reflecting skeletal development; depth, breadth, and width measurements generally encompassing the residual mass; and skinfold thickness measurements representing the subcutaneous fat distribution.

While the absolute values of anthropometric measurements are used for inter-individual and group comparisons (Alexander, 1976; De Garay, Levine, & Carter, 1974; Eiben, 1972; Hebbelinck & Ross, in Nelson & Morehouse, 1974:546; Lewis, 1969; Nelson, 1974; Novak, Woodward, Bestit, & Mellerowicz, 1977; Ross & Day, 1972; Smit, 1973), conversion into proportional values, the ratio of one measure to another or the adjustment of all measurements to a single measure, such as height, has also been employed. Proportional analysis has been used effectively in comparisons between individuals (Ross & Wilson, 1974), between groups (Eiben, Ross, Christensen, & Faulkner, 1976), in assessing biomechanical advantages of specific physiques (Hebbelinck & Ross, in Nelson & Morehouse, 1974:546; Le Veau, Ward, & Nelson, 1974; Tanner, 1964, and Tittel & Wutscherk, 1972, cited in Hebbelinck & Ross, in Nelson & Morehouse, 1974:546), and also in the monitoring of physical changes in shape and proportionality due to growth, maturity (Behnke, 1963; Behnke & Wilmore, 1974; Bielicki & Waliszko, 1975; Eiben, 1978; Huxley, 1932, cited in Behnke, 1961:953; Medawar, 1945; Ross & Wilson, 1974; Tanner & Whitehouse, 1976; Tosovsky, Prokopec, & Mejsharova, 1976), and altered levels of energy expenditure and nutritional status (Behnke & Wilmore, 1974).

Body Composition Analysis

A computer search program described by Deutch and Ross (1978, cited in Drinkwater & Ross, 1980:178) provides a basic bibliography of over 800 papers in the area of body composition. Comprehensive reviews of the various techniques developed to assess body composition are presented by Behnke and

Wilmore (1974), Brozek (1961), Friis-Hansen (1971), Ismail (1971), and Malina (1969b). Jackson and Pollock (1976) provide the computational framework for determining body composition from skinfold, girth, and diameter measurements, through the use of multivariate scaling. Kowalski (1972) examines the limitations and strengths of such models in anthropometric research.

Body composition analyses, especially of children and adolescence, are limited and fraught with problems of validity and reliability, with each technique and method having its own distinct and inherent errors.

Since direct compositional analysis involves the dissection of cadavers, the majority of the research to date has been conducted through indirect means. While chemical analysis of cadavers provides the framework for developing indirect methods for estimating in vivo body composition (Brozek, 1961; Damon & Goldman, 1964; Malina, 1969b), the majority of indirect methods developed are validated against more widely recognized indirect methods (Behnke & Wilmore, 1974), which themselves have not been validated against direct analysis. As a result, these indirect methods also involve major assumptions and errors, with regard to the amount and nature of the body components (Damon & Goldman, 1964).

<u>(i) Fat mass</u>. The body has conventionally been divided into a two component system comprised of a fat mass and a fat-free or lean body mass. The progenitor of most of the current procedures for fractionating the body weight into two compartments was Behnke (1942, cited in Drinkwater & Ross, 1980:178). Reviews of the techniques developed to assess body fat are presented by Keys and Brozek (1953), and Reynolds (1950).

The fat mass component has been identified through the use of anthropometric formulae (Behnke & Wilmore, 1974; Damon & Goldman, 1964;

Yuhasz, 1977), and equations involving skinfold measurements in the prediction of total body fat are essentially elaborations of the pioneer works of Matiegka (1921, cited in Drinkwater & Ross, 1980:178).

Skinfold thickness measurements have been shown to be useful predictors of body fatness in children and adolescents (Durnin & Rahaman, 1967; Hammond, 1955), in adolescents (Durnin & Womersley, 1974; Forbes et al., 1975, Michael & Katch, 1968, and Young et al., 1968, cited in Slaughter, Lohman, & Boileau, 1978:470), in men and women (Damon & Goldman, 1964; Hammond, 1955; Keys & Brozek, 1953; Matiegka, 1921, cited in Keys & Brozek, 1953:264); and of body density in children (Parizkova, 1961a; Shephard, Jones, Ishii, Kanek, & Albecht, 1969) and adolescents (Parizkova, 1961a). Tables to calculate body fat from skinfold measurements and body density have also been proposed (Durnin & Rahaman, 1967; Parizkova, 1961a).

Skinfold thickness and girth measurements were found to be useful predictors of body density in college women (Katch & Michael, 1968), and Best et al. (1953, cited in Brozek, 1961:923) found a close association between percent body fat and the ratio of height to abdominal girth in adult men.

Previous to Parizkova's investigations (1961a), there appears to have been no systematic investigation of the relationship of body fat to subcutaneous fat during childhood and adolescence, and in a later review of the literature (Durnin & Rahaman, 1967), no equations were available for use with children or adolescents to derive body fat from measurements of body density.

Although the site at which skinfold thickness had the highest correlation with body density varied with age and sex, the high correlations found suggested that the relationship between density and percent fat in children and adolescents, may be close to that found in adults (Parizkova, 1961a).

Ongoing cadaver analysis at the Vrije Universiteit Brussels, in conjunction with Simon Fraser University (Canada), has revealed some interesting observations concerning body compositional analysis:

> The basic assumptions that there are fixed relationships between external and internal adiposity, and between adiposity and lipid, are not supported by cadaver analysis.
> (Ross, 1980)

Previous accounts in the literature have also indicated the inadequacy of predicting total body fat from subcutaneous fat measurements. Allen, Peng, Chen, Huang, Chang, and Fang (1956) have demonstrated a curvilinear relationship between external and internal adiposity, with fat persons having approximately two-thirds of their excess adiposity subcutaneously located, and thin persons having most of it internally located. While Durnin and Womersley (1974) found males to have a higher proportion of body fat situated subcutaneously, than females, cadaver analysis (Alexander, 1964, cited in Durnin & Womersley, 1974:87) revealed that the "subcutaneous fat accounted for only 0.2 of the total fat in the men and 0.1 in the women" (referring to the ratio of subcutaneous fat to total body fat).

Young et al. (1964, cited in Shephard et al., 1969:1185) found that the triceps skinfold did not correlate well with obesity in females of a given age group. As well, this skinfold has been found to show little increase with age (Parizkova, 1963; Shephard et al., 1969), and its use in predicting body density and relative obesity is cautioned (Shephard et al., 1969). Wilmore, Royce, Girandola, Katch, and Katch (1970b); Wilmore, Girandola, and Moody (1970a); and Zwiren, Skinner, and Buskirk (1973) found individual skinfold thickness measurements basically unsound in assessing changes in body fat with exercise, as significant reductions in skinfold thicknesses were not reflected by changes in body density, body fat, or lean body weight.

While Damon and Goldman (1964) found the accuracy of predicting body fat from anthropometric equations to vary with the degree of endomorphy and mesomorphy, Young et al. (1963, cited in Malina, 1969b:20) and Skerlj, Brozek, and Hunt (1953) proposed that the relationship between subcutaneous skinfold thickness and total body fat may be a function of age and sex, as well as amount of fat. Both these studies indicated an increase in inner fat at the expense of outer fat during the later phase of maturity in females.

Skinfold thickness has been found to correlate negatively with body density (Malina, 1969b), and the relationship has been found to be non-linear in both sexes (Durnin & Womersley, 1974). However, a higher correlation found in boys than girls (Parizkova, 1961a) suggests the possibility of separate equations and site selections for the sexes.

From cadaver analyses, thickness of skin was found to vary with age, sex, and region of the body, with correlations between caliper and actual fat varying from .61 to .92 for females (Lee & Ng, 1965). For the same actual fat thickness, caliper readings were lower for females than males (Lee & Ng, 1965), with skinfold compressibility found to decrease with age (Brozek & Kinsey, 1960, cited in Durnin & Womersley, 1974:91). There is also some indication that the compressibility of thick skinfolds is greater than thin ones (Clegg & Kent, 1967). Himes, Roche, and Siervogel (1979) found significant differences among individuals in the compressibility of skinfolds, and reported that the difference between actual fat thickness and skinfold readings is systematic due to compression, with skinfold readings always underestimating actual fat thickness, but inconsistently so, depending on the site and perhaps sex. These studies serve to indicate that there is a degree of error introduced into results when constant pressure calipers are used in the estimation of total body fat, in assessments of the distribution of fat, and in the appraisal of variation in skinfold thickness and total body fat between individuals.

Until the exact relationships among subcutaneous, internal, total body fat, and adiposity are identified, the skinfold caliper technique will continue to be accepted as a valid and reliable method for estimating total body fatness, based on the firmly established observations that:

1. A considerable amount of body fat lies within the subcutaneous tissue (Malina, 1969b).
2. Results are highly reproducible and therefore reliable, although not necessarily valid. Inter-rater differences in caliper readings have led to reported maximum errors of 4% (Burkinshaw, Jones, & Krwpowicz, 1973) and 6% (Womersley & Durnin, 1973) in the estimation of total body fat, with no significant difference in variance, between observers, when the sites were marked (Burkinshaw et al., 1973).
3. Skinfold caliper measurements have a high correlation with measurements obtained through other indirect techniques, such as ultrasonic depth (Bullen, Quaade, Olesen, & Lund, 1965) and roentgenogrammetric measurements (Garn & Gorman, 1956).

(ii) Lean body mass. Because of its labile nature and its association with nutrition, exercise, disease, and mortality, the fat mass component of the body has received far more attention in the literature than the lean body mass component. The major obstacle in the current estimates of body composition is the lack of a verified in vivo method for quantifying skeletal weight and muscle mass (Baker, 1961, Garn, 1963, and Moore et al., 1963, cited in Malina, 1969b:21,25).

While the majority of the literature refers to a single definition of lean body mass for both sexes, Behnke and Wilmore (1974) term the anthropometrically calculated lean body weight in women "minimal weight". This measure is associated with the leanest individual for a given stature, and incorporates a certain amount of "essential fat" in mammary and other tissue. In the male, minimal weight is tantamount to lean body weight.

Malina (1969b) refers to lean body mass as an in vivo concept, and fat-free body mass as an in vitro concept, with the difference between the two masses being in the amount of essential lipids.

Moore et al. (1963, cited in Malina, 1969b:10) introduced the concept of body cell mass, "the working, energy metabolizing portion of the human body in relation to its supporting structure".

Morales, Rathbun, Smith, and Pace (1945) regard the mammalian body as consisting of five tissue components; fat, muscle, skin, visceral, and nervous tissue. From a biochemist's point of view, the body is reducible to fat, osseous and non-osseous protein, mineral, and intracellular and extra-cellular water (Malina, 1969b).

In many of the early studies, and in most studies where the lean body mass is considered subservient and secondary to the fat mass, the lean body mass is derived by subtraction of the fat weight from the total body weight (Behnke & Wilmore, 1974). Such a procedure leaves the prediction and estimation of this mass, subject to, affected by, and dependent on, the fat mass value and the accuracy with which this mass was obtained. Ideally the two mass components should be assessed independent of one another, although, changes in the composition of the non-fat component of the body have been reported to occur with changing fatness (Keys & Brozek, 1953).

Equations involving anthropometric surface measurements in the estimation of the lean body mass have been proposed and developed (Behnke, 1961; Behnke & Royce, 1966; Behnke, 1963, Hampton et al., 1966, and Roessler & Dunavant, 1967, cited in Forbes, 1972:336; Forsyth & Sinning, 1974, cited in Sinning, 1974:140; Matiegka, 1921, cited in Keys & Brozek, 1953:264; Wilmore & Behnke, 1970), and are often validated against more widely accepted, but not necessarily valid indirect methods. The most popular indirect method used in these validations, is the densitometric determinant of the lean body mass (Durnin & Rahaman, 1967; Cowgill, 1957, and Von Dobeln, 1959, cited in Bakker & Struikenkamp, 1977:194). However, the stability of the assumptions upon which densitometry is based; notably, that the lean body mass has a constant density and a constant proportion of water, bone is a constant proportion of the lean body mass, and cell water is a constant proportion of cell mass (Wilmore et al., 1970a) has been questioned (Bakker & Struikenkamp, 1977; Wedgewood, 1963, cited in Wilmore et al., 1970a:316). The density of the lean body mass in normal humans has been shown to be dependent on age, sex, race, intensity of muscular activity, and nutritional states (Bakker & Struikenkamp, 1977; Parizkova, 1961a).

Much of the change in the contribution of the skeleton to body weight during growth has been attributed to the maturation of the skeleton, the relative amount of bone to cartilage (Malina, 1969b), with a decrease in bone mineralization noted accompanying ageing (Behnke & Wilmore, 1974; Durnin & Womersley, 1974; Trotter, 1960, cited in Malina, 1969b:26).

The estimated muscular mass in females shows relative stability from 15 through 60 years, with a range of 23.0 to 24.3 kg (Malina, 1969b).

There is a lack of knowledge concerning body composition in children, particularly with respect to differences in the composition of the muscle and skeletal masses, and in their relationship to one another (Durnin & Rahaman, 1967).

Although the estimative and predictive equations for body composition have inherent weaknesses, the basic relationship that exists between body dimensions and weight allows for the description of the body's configuration in quantitative terms (Behnke & Wilmore, 1974). High correlations between selected body circumferences, stature, and body weight (Behnke, 1961); and between skeletal diameters, stature, and lean body weight (Behnke, 1961, cited in Behnke, 1963:191) have been demonstrated. Edwards (1950) noted a close relationship between subcutaneous tissue thickness and body weight however, Shephard et al. (1969) reported this relationship to be poor in adult women.

The lean body mass has been successfully predicted from skinfold thicknesses, muscular girths, and skeletal width measurements; in prepubescent children (Slaughter et al., 1978; Wilmore & Behnke, 1970); from wrist breadth and height in children and adolescents (Bugyi, 1972); from skinfold and diameter measurements in wrestlers (Sinning, 1974); and from body diameters in college men (Wilmore & Behnke, 1968). Parizkova (1963) has also noted a positive relationship in children and adolescents, between thorax width, pelvis width, and the proportion of lean body mass.

The Behnke and Wilmore (1974) estimates of lean body weight are based on the assumption that a certain amount of lean body mass, "muscle mass", is associated with a given skeletal size (Behnke, 1963, cited in Behnke & Royce, 1966:76). The studies of Maresh (1961) and Stuart et al. (1940) (Both cited in Malina, 1969b:32) indicated moderate correlations between bone and muscle during the early ages. The relationship between skeletal measures and true lean body mass has however, been found by other investigators to be poor (Bakker & Struikenkamp, 1977). Furthermore, the studies of Baker (1961) and Tanner (1965) (both cited in Bakker & Struikenkamp, 1977:198) have shown no important degree of relationship between muscle diameter and bone diameter. Hebbelinck and Ross (1972, cited in Ross, Marshall, Vajda, & Roth, 1978:4) found the bone widths of young girls to deviate in a positive direction and limb girths in a negative direction from relative height values, and Ross, McKim, and Wilson (in Taylor, 1976:257) speculated that this indicated that children may have a proportionally greater amount of skeletal tissue to muscle mass than adults, or less muscle mass per unit of size.

Drinkwater and Ross (1980) have developed the "phantom model", proposed by Ross and Wilson (1974), to include an anthropometric fractionation of the body mass into a four component system, comprised of fat, muscle, skeletal, and residual masses. The system is essentially based on a proposition of Matiegka's (1921, cited in Drinkwater & Ross, 1980:178), in which the body is divisible into an osseous, muscular, and skin plus fat component. Fractionation of the lean body components were "arbitrarily" derived from cadaver analysis cited by Behnke (1974, cited in Drinkwater & Ross, 1980:183).

The "Drinkwater Tactic" of fractionating the body mass into a four component system has a number of attractive features:

1. It accounts for total body mass with an absolute error tolerance of 5%, and has the theoretical advantage of permitting all four components to be derived independent of one another and of total body mass, with the total mass serving as a major validity criterion.
2. The fat mass value, when compared with those obtained through anthro-

pometric regression equations, is not a "maverick" estimate, and lies in the mid-range of these predictive values.

3. The approach is general, whereby, any measurement relating to a particular tissue mass, may be used as its predictor, by virtue of its departure from a specified, single, reference human, which can be regarded as a measuring device for comparative purposes.

(Drinkwater & Ross, 1980:186)

Summary: Morphological Descriptors

The accuracy and validity of anthropometric equations, to predict the composition of the body, are at this time suspect because of the absence of validation against direct means. Furthermore, the general applicability of these equations, to populations other than those from which they were originally derived, should not be assumed (Behnke & Wilmore, 1974; Cureton, Boileau, & Lohman, 1975; Damon & Goldman, 1964; Malina, 1969b; Parizkova, 1961a; Steinkamp et al., 1965, cited in Malina, 1969b:19).

Predictive formulae tend to be specific to technique, instrument, site, sex, age, and sample; and these factors most likely account for discrepancies observed in the literature.

In view of recent findings from direct compositional analyses, previously reported results and relationships should be accepted and considered with some reservations since, the biological constants underlying many indirect body composition estimates are questionable (Damon & Goldman, 1964).

It should also be recognized that most of the available data on body composition is derived from cross-sectional studies which inherently possess a wide range of sampling variability (Malina, 1969b).

II MORPHOLOGY AND PERFORMANCE

There is voluminous data to substantiate the claim that morphological characteristics have a very real and measurable effect on sport performance. It has also been established that the "nature" of the sport dictates, to a degree, those physical characteristics necessary for success and ultimate inclusion in elite competitions.

Gymnastics and Other Sport Disciplines

By collecting anthropometric data on National, World Class, and Olympic athletes, and comparing athletes with one another, or to a reference population, the morphological characteristics of specific athletic populations have been identified.

It is well documented and generally accepted that differences in size, shape, composition, and "physique" in general, exist between elite participants of various sports, and it is not unreasonable to postulate that these differences demonstrate the relationship between structure and function:

> The study of champion athletes, therefore may provide information on the structural requirements for success in the specific tasks as well as measures of the differences between tasks.
> (Carter, 1970:535)

In anthropometric comparisons of Olympic female athletes, gymnasts have consistently been described as the shortest and lightest participants, in comparison to swimmers, canoeists, springboard and high divers, fencers, equestrian, and track and field athletes of the 1964 Olympics (Hirata, 1966); sprinters, swimmers, divers, canoeists, and weight throwers of the 1968 Olympics (De Garay et al., 1974); runners and swimmers of the 1972 Olympics (Novak et al., 1977); and in comparison to rowers, swimmers, canoeists, fencers, and track sprinters, but not 1500 meter track athletes, who were the smallest and lightest of those female athletes sampled at the 1976 Olympic Games (Ross, 1980).

The 1968 Olympic gymnasts also had the smallest biacromial and biiliocristal breadths; the shortest arm, leg, and trunk lengths; the smallest skinfold values, and the lowest endomorphic rating, of the athletes sampled. They were more mesomorphic than the swimmers, divers, and sprinters, and more ectomorphic than the canoeists and weight throwers (De Garay et al., 1974).

The 1972 Olympic gymnasts also had a significantly smaller bicristal breadth than the runners and swimmers, and of the 33 anthropometric measurements taken they had the smallest values, except for lower leg length, forearm and upper arm girths, corrected upper arm diameter, and forearm and iliac crest skinfolds. In these latter measurements, the runners had the smallest values. In the triceps and biceps skinfolds, and percent lean body mass, the gymnasts had the largest values. The gymnasts differed significantly from the runners only in having more fat over the biceps. Compared with the swimmers, the gymnasts had significantly smaller forearm and upper arm girths; bi-epicondylar femur width; forearm, calf, iliac crest, and umbilicus skinfolds. As well, the gymnasts had significantly smaller absolute and percent fat masses, and a significantly larger percent lean body mass and biceps skinfold, than the swimmers (Novak et al., 1977).

The tendency towards shortness in stature and lightness in weight, noted for Olympic female gymnasts, has also been reported for lesser skilled gymnasts, in comparison to swimmers, divers, golfers, track and field, basketball, field hockey, softball, and tennis athletes (Morris, 1960, cited in Carter, 1970:559); middle distance swimmers and runners (Novak et al., 1973); swimmers (Sprynarova & Parizkova, 1969); figure skaters, rowers, swimmers, skiers, climbers, bowlers, handball, volleyball, basketball, table tennis, and track and field athletes (Medved, 1966); track and field athletes (Nelson, 1974), and in comparison to professional and amateur golfers, basketball, and track and field athletes (Carter, 1970).

Morris (1960, cited in Carter, 1970:560) also reported that of the athletes sampled, the divers, gymnasts, and track athletes were the highest in mesomorphy.

Novak et al. (1973) also reported their gymnasts to have significantly smaller thigh, hip, calf, and maximal chest circumferences; and bicristal, femural, corrected thigh, and calf diameters than the runners. As well, the gymnasts had a significantly smaller body weight and fat-free mass, and a significantly shorter stature than the runners. The triceps skinfold was significantly smaller in the gymnasts, compared with the runners and the swimmers. Of the 31 anthropometric measurements taken, the gymnasts had the smallest values, except for the forearm, thigh, and calf circumferences and diameters, where the swimmers had the smallest values, and except for the corrected upper arm diameter, where the gymnasts had a larger value than the runners.

The gymnasts of Sprynarova and Parizkova's study (1969) were also significantly shorter and lighter, possessed a smaller absolute lean body mass, percent fat mass, and absolute fat mass; and a higher percent lean body mass than the swimmers.

Nelson (1974) also found the gymnasts to have a similar chest circumference to the track and field athletes, with their leg circumference less than the track and field athletes.

Carter (1970) found that almost all groups of champion athletes are rated high on mesomorphy, and of the females, the track and field jumpers and runners have the lowest mesomorphic rating, and the gymnasts the highest.

Descriptive Studies of Gymnasts

While descriptive studies of female gymnasts from elite ability levels exist, documented studies of female gymnasts from varying ability levels are sparse. Most studies concerned with ability and morphology have involved elite level gymnasts, and have compared the winners of a competition with the lesser placing participants (Montpetit, in Salmela, 1976: 183; Pool, Binkhorst, & Vos, 1969; Youngren, 1969). While these studies are valuable, they do not provide a descriptive demonstration of morphological changes that may accompany progressive increases in ability from recreational through to elite levels.

Disparity in anthropometric descriptions of female gymnasts, that arise from inter-study comparisons, may be due to the fact that the ability level, age of the gymnasts, and the year that the study was conducted, varies from one study to another.

> In studies relating structure and function, a simple categorization such as "gymnasts", is misleading and inadequate for both descriptive and comparative purposes. ... Adequate structural description of samples is necessary for correct interpretation of findings related to function.
>
> (Carter, Sleet, & Martin, 1971:162)

Pool et al. (1969) studied the anthropometric measurements of the female competitors of the 1967 European Gymnastic Championship. Concerning anthropometric dimensions and performance, low correlations were found for height and weight, and performance. A positive correlation between thorax width and performance was found however, indicating that "possibly the best gymnasts have more muscle mass and are therefore more strongly built". As was expected, since "in gymnastics ... body weight is a handicap and body fat a superfluous load", a negative correlation between the skinfold measure and performance was reported (Pool et al., 1969:336). The Eastern gymnasts identified as the "better" performers in comparison to the Western gymnasts, were younger, shorter, lighter, and had a smaller mean skinfold value. However, none of these differences was statistically significant.

Pool et al. (1969) also compared the results of their study with those of six other studies of female gymnasts, from varying ability levels, in the same age range of 19 to 25 years. These gymnasts were; (a) from the 1964 Olympic Games, the mongolian and non-mongolian participants; (b) from the 1961 World Championships of Students; (c) from the Russian selection of top gymnasts, 1964; (d) from the Dutch selection of top gymnasts, 1966; (e) Dutch gymnasts of low capacity, 1966; and (f) Yugoslavian gymnasts of modern capacity, 1966. All top gymnasts from the various countries had similar mean heights and weights, ranging from 156.3 to 160.3 cm, and 51.0 to 55.3 kg, except the mongolian competitors who were shorter and lighter at 152.0 cm and 46.8 kg. Even though the Dutch mean performances were lower than the Europeans, they had similar mean heights and weights. However, the mean height and weight values of the Dutch top gymnasts were significantly shorter and lighter than lower caliber Dutch gymnasts, with a mean height of 167.7 cm and mean weight of 59.5 kg.

The U.S. National College Gymnastics Champions of 1970-71 were studied by Sinning and Lindberg (1972). With a mean age of 20 years, height of 158.5 cm, and weight of 51.1 kg, these female gymnasts were similar to the gymnasts of the European Championships described in Pool et al.'s study (1969).

The female gymnasts from Novak et al.'s study (1977) were all from one country that did not reach a significant place during the 1972 Olympic Games. These gymnasts, with a mean height of 163.5 cm, were substantially taller than the European and top ranking gymnasts from the various countries described in Pool et al.'s study (1969), and taller than the U.S. National College champions studied by Sinning and Lindberg (1972). With a mean weight of 52.5 kg, they were however, similar to the gymnasts from these studies.

Youngren (1969) studied the relationship of selected anthropometric measurements to gymnastic performance, in the 1968 U.S. National Women's Olympic Trials. These participants ranged in age from 15 to 30 years, with a mean age of 18.5 years, weight of 52.4 kg, and height of 159.7 cm. No significant differences were found between the selected anthropometric measurements and placement, although many anthropometric variations were found among the top performers, and in general:

> Those who were shorter and of thinner skinfolds had a tendency to rank higher. ... weight had little effect on how a top gymnast placed. ... Body type [described in terms of the ponderal index] was not significant to the performance of top women gymnasts ... However, body type was very similar in the women gymnasts.
> (Youngren, 1969:41-42)

Montpetit (in Salmela, 1976:183) noted the range in age, 18.5 to 19.9 years; in height, 158.9 to 162.3 cm; and weight, 46.8 to 52.5 kg, of the top five female gymnastic teams and the top six, all around winners, at the 1972 Olympics, and concluded that once international prominence is attained, size is no longer decisive in determining gymnastic success. The correlation coefficient between rank and height, calculated for the top 36 female gymnasts in these Games, resulted in a low "r" of 0.01.

Drazil (1971) has noted that the percentage of body fat in trained female gymnasts does not exceed 10 to 15%, and Grossfeld has observed that:

> with rare exceptions, the maximum height for a female gymnast is 5 feet 5 inches [165.1 cm]. The other end of the scale is about 4 feet 10 inches [147.3 cm].
> (Grossfeld, cited in Nichols, 1979:18)

Ross (1980) compiled anthropometric data on 15 of the female gymnastic competitors at the 1976 Olympic Games, and described them in terms of over 51 variables, including body compositional analysis.

In general, it has been noted that the higher the level of competition, the narrower the variability of physical characteristics. Carter et al.'s (1970) comprehensive investigations have led them to the general consensus that; athletes are somatotypically different from the general population; certain athletic groups are somatotypically different from one another; and performers at the same level of competition, in the same sport, tend to be of similar physique.

Biomechanical Advantages of Specific Physiques

While most descriptive and comparative studies have succeeded in identifying the physical characteristics common to participants of a particular sport (Alexander, 1976; Chovanova, 1972; Ross & Day, 1972), there is usually only general, if any, comment on how these characteristics aid or deter the athlete in performing specific elements of the sport.

The biomechanical advantages afforded by certain physiques, in specific sporting endeavours, are very real (Hebbelinck & Ross, in Nelson & Morehouse, 1974:546; Lewis, 1969), and Khosla (1968) has gone as far as to suggest that certain events in the Olympic Games are unfair for specific competitors, because of their "build". In a later article, Khosla (1977) discusses the potential of nations to win medals at the Olympic Games, based on the distribution of height found in the populations.

Since gymnastic performance requires high relative, rather than absolute, strength, smallness is an advantage resulting in a high strength-to-mass ratio (Le Veau et al., 1974) since:

> Strength is proportional to the square of any length (height) ... we should expect strength to increase as the power 2 and mass as the power 3 of a chosen height value.
> (Ross & Marshall, 1979:13)

The smaller stature observed in gymnasts also allows them to perform free flight spins and rotations more easily than larger athletes since:

> The small stature results in a smaller moment of inertia about an axis in the transverse plane through the mass center. ... Further the moment of inertia of the total body about other axes such as the horizontal bar would also be less.
> (Le Veau et al., 1974:150)

and;

> When examining linear motion the inertia of the object is directly proportional to its weight. However, in angular (rotary) motion, not only is the weight important but also its distribution in relation to the axis of rotation .... A smaller person has a smaller moment of inertia when rotation occurs about his center of gravity in free flight or when he rotates about his hands.
> (Nelson, 1974:46)

The domination of men's gymnastics by the Japanese, in the 1972 Olympic Games, has led Le Veau et al. (1974) to speculations concerning advantages that they may have as a result of their physique. In comparison to the American male gymnasts, the Japanese gymnasts were shorter; smaller in hand, foot, shank, and arm lengths; greater in trunk and extremity circumferences; and greater in chest circumference and body weight relative to height. These differences appear to be conducive to movements in which the body is supported by the arms and moved about the hands, with the shorter shank and smaller feet making it easier to control the lower extremities (Le Veau et al., 1974). Furthermore, Nelson (1974) contends that a shorter arm would be an asset for swings performed on the horizontal bar; since:

> [with a shorter arm] the center of gravity of the body is nearer the axis of rotation in swings on the bars. ... [and this] tends to reduce the moment of inertia of the body when rotation occurs about the hands.
>
> (Nelson, 1974:46)

Similarly, Rozin (1974) noted that a gymnast with relatively long arms would need to expend more effort in order to maintain his body in the iron cross held position on the rings.

The biomechanical requirements of the long horse vault may have created a disadvantage for the Japanese, and thus contributed to their low placement in this event:

> Since the height of the horse is standard, it follows that a shorter person must raise his centre of gravity to a higher point before contacting the horse, which requires a greater vertical velocity at takeoff.
>
> (Le Veau et al., 1974:150)

Furthermore, Nelson (1974) claims that a shorter lower limb is less suited to running, and this may affect the running approach to the vault. The fact that this was the only event in which the Japanese men did not win at least two medals, and in which their highest finish was fourth, perhaps supports these contentions.

In addition to these factors, the takeoff in vaulting is not completely dependent on the ability of the gymnast, as a comparative study of five internationally approved gymnastic vaulting boards revealed:

> There would be an advantage for those gymnasts

> who use a beat board whose quality of elasticity was commensurate with their execution potential, that is their body mass, their speed and their force of takeoff.
> (George, in Salmela, 1976:96)

Furthermore, Valliere introduced the concept of "performance discrimination", notably that:

> The structure as well as the internal qualities of the apparatus do not provide equal advantages to all gymnasts during performance. Does not the diver adjust his diving board in relation to his execution potential, while the pole vaulter selects a pole that is compatible with his weight and speed? There still remains much to do to ensure the fact that the gymnast will become the only determining factor responsible for his performance.
> (Valliere, in Salmela, 1976:96-97)

It appears that the best body type for a gymnast, who competes in all events, is a compromise of the ideal morphological determinants best suited for a one-event specialist, such that "deficiencies in one component may be rectified by a surplus in another" (Salmela, Halle, Petiot, & Samson, 1976:169).

Youngren (1969) noted that those gymnasts that placed well on the floor exercise, also placed well on the beam, and those placing well on the uneven bars, also tended to place well on the vault. Rozin (1974) considers long arms a disadvantage on the rings, but an asset in performing on the side horse, where swinging movements predominate.

Hirata (1966) claims that, in the Olympic Games the method of training has little incidence on the results, because it has reached the top level in each country:

> Physique and constitution, which can by no means be reconstructed by training, seem to have an important effect. ... when training has reached the top level, the most adequate physique will win.
> (Hirata, 1966:222)

Tanner (1964) and Eiben (1972) support the credence that athletes are both "born" and "made", and that top athletes have already been selected according to their body build by the time they have arrived at the Olympics:

> Physique is a factor in the sort of success that may lead to inclusion in an Olympic Team; more negatively, that the lack of proper physique may make it impossible for an athlete to reach that degree of success. But we do not suppose that winning the Olympic event has much to do with physique, except perhaps in some rare cases where one single man is altogether outstanding. By the time the finals are reached even the physiques are becoming matched one with another.
> (Tanner, 1964:14)

<u>Summary: Morphology and Performance</u>

It has long been recognized that body "build" is an important prerequisite for successful participation in high level sporting endeavours.

In comparison to other athletic groups, the elite female gymnast has been identified as short in stature, light in weight, and possessing a high percent lean body weight accompanied by a low percent fat weight, as well as a high mesomorphic component. These characteristics have been associated with biomechanical advantages, such as a reduced moment of inertia, when rotation occurs about the transverse axis, around the center of gravity, or around the hands. As well, these characteristics result in a high strength-to-mass ratio, which is also conducive to gymnastic-type movements.

In comparison to lesser skilled gymnasts, the elite gymnast is shorter and lighter, and has smaller skinfold thicknesses.

Among elite female gymnasts a narrow variability in physique is observed. However, the more successful gymnasts tend to be shorter, lighter, and have smaller skinfold values. A large thorax width has also been identified with success at this level.

Relationships between body morphology and the properties of standard gymnastic equipment have revealed the occurrence of a "performance discrimination factor", in that, the equipment does not offer the same advantage or potential to all individuals.

The best morphological physique, for a gymnast competing in all events, has been identified as a compromise between the best build for each apparatus.

III PERFORMANCE AND MORPHOLOGY

While it is recognized that successful participation in a particular sporting endeavour entails specific "physique requirements", it is also realized that performance or training in that sport has the effect of modifying specific physical parameters.

It is well accepted that exercise has a potentially great influence on modifying the body, internally through compositional and physiological changes, which are reflected externally in altered contours and dimensions (Brozek, 1961; Malina, 1969a).

The potential or ability of an individual to respond to environmental pressures, such as exercise, with short term phenotypic modifications, such as biochemical, physiological, and morphological alterations, is referred to as the concept of plasticity (Malina, 1976).

> Individuals vary considerably in their plastic responses. Plasticity can be viewed in two ways, that operating during the period of growth and development (developmental plasticity) and that operating during adulthood. ... and modifications in the growth and development processes to environmental stress may become permanent and are

> thus irreversible when adulthood is attained. ... changes associated with regular physical activity reflect plastic responses and the limits of an individual's plasticity is set by his genotype.
>
> (Malina, 1976:157)

Fat Mass Content and Activity Levels

The consistently lower fat mass values of athletic females, in comparison to relatively sedentary female reference populations, illustrate the effect of exercise on the fat mass component of the body. Percent fat mass values of 20 to 30% have been noted for young adult women (Ljungren, 1965, cited in Novak et al., 1977:282; Malina, 1969b; Wilmore & Behnke, 1970); 14.8%, 19.2%, 23.4%, 24.9%, 21.7%, 24.0%, 22.2%, 23.2%, 23.6%, 28.1%, and 22.7%, for 8 to 18 year old females, inclusive; and 22.8 to 24.7% for 18.5 to 29.0 year olds (Forbes, 1972). In comparison to these values, the percent fat mass values of athletic females, have been reported as 13.0% for elite figure skaters (Faulkner, 1977); 11.1% (Ross, 1980), and 12.9% (Novak et al., 1977) for Olympic gymnasts, 14.6% for prominent gymnasts (Novak et al., 1973), 16.8% for low caliber gymnasts (Sprynarova & Parizkova, 1969); 13.3% for Olympic runners (Novak et al., 1977), 16.8% for prominent runners (Novak et al., 1973); 18.9% for Olympic swimmers (Novak et al., 1977), 17.0% for prominent swimmers (Novak et al., 1973), and 19.2% for high caliber swimmers (Sprynarova & Parizkova, 1969).

Since females are reported to possess more subcutaneous fat than males at almost all ages (Bonnet, Rocour-Brumioul, & Heuskin, 1979; Edwards, 1951; Parizkova, 1963; Reynolds, 1950), it is of interest to note how extreme activity may reduce this difference. Smit (1973) compared the skinfold thicknesses of adult male and female gymnasts, and noted remarkably small differences.

Significant reductions in the fat "content" of adolescent girls have been noted accompanying programs of regular physical activity (Wells et al., 1963), and Smit (1973) reported that skinfold values of gymnasts decreased as their number of activity hours per week increased. Johnson (1969) noted that children involved in daily physical education classes, in comparison to children participating 2 and 3 times a week, have smaller fat mass contents.

Parizkova (1959) studied a group of adolescent female gymnasts, and noted an increase in weight with no change in fat content, following a 6 week period of training. However, after a 10 week period of relative inactivity, a further increase in weight, accompanied by a substantial increase of 35.7% in subcutaneous fat (sum of the skinfolds), was noted. In comparison, a control group of females of the same age experienced a 6.9% increase in subcutaneous fat, during the same 10 week period.

Similarly, in a later study, Parizkova and Poupa (1963) studied a group of female gymnasts from the Czechoslovakian National Team, with a mean age of 23 years, and two groups of gymnastic sports students, with mean ages of 16 years. After periods of intense training, the weight remained unchanged in the groups, while a definite fall in fat content and increase in lean body mass was noted. After periods of relative rest, body weight rose significantly, along with increases in fat content. These changes were reported to have occurred in the younger gymnasts during considerably shorter periods.

These studies demonstrate the effect of exercise in "reducing" and "checking" or maintaining the fat "content" of the body.

> With weight reduction, as adipose tissue decreases in total size, the total number of cells remains constant. Hence weight reduction is achieved by a reduction in cell volume.
> (Hirsch, 1972:84)

Critical Periods for Fat Mass Deposition

Current evidence suggests that specific periods in the growth sequence of the human are associated with deposition of adipose tissue, hyperplasia, and with increases in adipocyte size, hypertrophy.

Hirsch (1972) claims that adipose cells are laid down late in gestation, in the first year of life, and in early adolescence.

Bonnet et al. (1979), in a cross-sectional study of normal weight infants, children, adolescents, and adults, noted that cell size significantly enlarged during the first six months of life, but beyond the first year there were no significant changes until puberty, when there was a substantial increase in adipocyte size. Concerning cell number, it was observed that no significant increase of mature adipocytes occurred in the first year of life. However, the number progressively rose during childhood, and there was a significant and very great increase during puberty, with the adult value being reached at the end of adolescence.

Behnke and Wilmore (1974) suggest that random development of new adipocytes probably occur when fat cells "normally present" attain maximal saturation (about 85%) with triglyceride.

There is some speculation that if the periods of adipocyte multiplication can be pinpointed, control over "fat potential" may be possible (Hirsch, 1972). Furthermore, according to Rarick (1947, cited in Barnes, 1979:117), percent body fat will be lower in young adults who exercised as children, and:

> exercise is more effective in influencing development if it takes place during the growth spurts of adolescence than it is during preadolescence.
> (Rarick, 1947, cited in Barnes, 1979:117)

Muscle Mass Content and Activity Levels

> Physical training results in muscular hypertrophy and an increase in contractile proteins, whereas physical inactivity results in atrophy and a reduction of contractile proteins.
> (Malina, 1969a:21)

The effects of exercise, on the muscle mass, can be observed directly in the increased muscular girths that result after prolonged periods of intense training.

Using a variety of weight training techniques, increased muscular girths have been reported in elementary children (Bready, 1961), in adolescent boys (Kusinitz et al., 1958), and in adults (Tanner, 1952, all cited in Malina, 1969a:24).

> Increased muscle mass can only result from muscle work, supported by an appropriate increase in dietary intake. Without muscle work, no food, vitamin, hormone or drug will increase muscle mass.
> (Smith, 1976:151)

Bulky, bulging muscles are almost impossible for females to attain through strenuous exercise, such as weight lifting, because they possess low testosterone levels. Testosterone is a "powerful hormone involved in the deposition of protein in the formation of muscle tissue" (Johnson, Updyke, Schaefer, & Stolberg, 1975:124).

As well, it should also be noted that deterioration in efficiency of gymnasts and basketball players, undergoing strenuous training, has been associated with breakdown of the lean body mass (Zhdanova & Parizkova, 1962, cited in Parizkova, 1968b:275).

In general, the type and intensity of the exercise, and hereditary influences, determine the appearance and shape of the muscles, as well as muscular development (Church, 1976).

Critical Periods for Muscle Mass Deposition

> During training there is an increase in muscle mass by an enlargement of the already existing fibers. Most investigators find no increase in the number of muscle cells with training, through a division of already existing cells. ... The total amount of protein in the muscle increases with training and decreases with inactivity. Disuse atrophy is associated with a decline in myofibrils, and the proportion of sarcoplasm proteins rises.
> (Astrand & Rodahl, 1970:399)

Whether or not the above is true during the active years of growth is not clear. Cheek (1968, cited in Ross, McKim, & Wilson, in Taylor, 1976: 257) presents longitudinal data which indicates an increase in skeletal muscle cell population for both boys and girls, with a markedly greater increase in boys after 10½ years. The superior strength performance of adult males over adolescent males, and the lack of a comparable difference in females (Jones, 1949, cited in Reynolds, 1950:107), suggests the occurrence of differential increases in the male and not the female (Ross, McKim, & Wilson, in Taylor, 1976:257).

It has been speculated that exercise may be a determinant in cell differentiation:

> If during the growth spurt exercise of the proper kind and amount is not forthcoming, stem cells may differentiate as fat cells rather than muscle cells. If large percentages of our population are unexercised at the critical period of muscle cell increase, we should expect the deleterious effect on strength and stamina would be greater in males than females.
> (Ross, McKim, & Wilson, in Taylor, 1976:257)

Furthermore, Bowden and Goyer (1960, cited in Malina, 1969a:19) suggest that the size differences, observed in the fibers of different muscles during normal growth, are directly related to functional activity.

Malina (1969a) has commented on the necessity of distinguishing the growth of skeletal muscle due to exercise, from the increase in muscle due to normal growth. Jokl et al. (1941, cited in Malina, 1969a:22) reported striking increases in body weight in 16 to 21-year old male recruits subjected to six months of systematic activity. They attributed this increase to muscle tissue gains and concluded that:

> Physical training may not be postponed until the age of developmental rigidity is reached. ... training, if applied to younger age groups, is capable of producing a much greater influence upon development. Had the training which our recruits received, been applied eight or ten years earlier, the effect would have been more marked; they would have developed a better physique.
> (Jokl et al., 1941, cited in Malina, 1969a:22)

Skeletal Mass Content and Activity Levels

The effect of exercise on the skeletal structure, mass, and composition, is difficult to assess. Morphological variables, that are genetically endowed, are probably more obviously expressed in the skeletal mass than in the fat and muscle masses, which appear to be more malleable to the influences of exercise. It is known however, that moderate exercise has a positive effect on bone growth by strengthening the organic matrix of the bone, through stimulating osteoblastic deposition:

> Bone is continually being deposited by osteoblasts, and it is continually being absorbed where osteoclasts are active. .... bone ordinarily adjusts its strength in proportion to the degree of bone stress. Consequently bone thickens when subjected to heavy loads. ... Even the shape of the bone can be

> rearranged for proper support of mechanical forces by deposition and absorption of bone in accord with stress patterns. .... the bones of children in whom the rate of deposition and absorption is rapid, show little brittleness compared with the bones of old age, at which time the rates of deposition and absorption are slow. .... Bone is deposited in proportion to the compressional load that the bone must carry. ... the bones of athletes become considerably heavier than those of nonathletes. .... Therefore continual physical stress stimulates osteoblastic deposition of bone.
> (Guyton, 1976:1058-1060)

Inactivity has been shown to have detrimental effects on the strength and composition of bones, and bones subjected to immobilizing casts become thin and decalcified through inactivity (Bullough, Goodfellow, & O'Connor, 1973; Guyton, 1976). Although resumption of physical activity corrects this disturbance, many years may be needed to restore the loss (Kotte, 1966, cited in Malina, 1969a:17).

While the mechanical stresses of normal weight-bearing, and the tension and compression of muscular forces, are generally recognized as essential for normal bone formation, development, and growth, the limits of tolerance, beyond which an increase in pressure or tension leads to destruction of bone, by resorption, remains undetermined (Malina, 1969a).

Critical Periods for Skeletal Mass Deposition

The potential size of the skeletal structure is predetermined by genetic factors (Church, 1976; Johnson et al., 1975), and the effect that stressors such as exercise have on this potential is not entirely understood. Since bone is continually undergoing change through osteoblastic deposition and osteoclastic absorption (Guyton, 1976), experiences periods of "stepped-up growth" (Tanner, 1962), and does not entirely stop growing until approximately the second decade of life (Greulich & Pyle, 1970; Tanner et al., 1975), it is probably more vulnerable to "stressors" during the developmental years, before full maturity is reached.

Arnold (1930) and Correnti (1941, both cited in Tanner, 1962: 134-135) claim that exercise increases the rate of growth, and Prives (1960, cited in Malina, 1969a:24) found physical exercise to favour growth of bone in length. On the other hand, Rarick (1960, cited in Johnson et al., 1975:123) claims that heavy pre-pubertal exercise may result in a somewhat heavier and shorter skeletal structure, and Goodings and Neuhauer (1965, cited in Malina, 1969a:18) noted increased vertical growth of the vertebral bodies, in the absence of normal weight-bearing function, during the growing years of humans.

Beyer (1896, cited in Malina, 1969a:22) studied a group of 16 to 20 year old male cadets subjected to six months of systematic "gymnastic" activity, and reported an average increase in stature for this group, of about one inch over controls. Since the greatest gain occurred between 16 and 17 years of age, Beyer inferred that factors capable of influencing growth would exert their effect at a time when the growth impulse was strong.

The specialized use of body parts, and lateral size differences, provide a possible means of assessing the effects of physical activity on bone growth and development. Van Dusen (1939, cited in Malina, 1969a:23) found that the right upper extremity measurements in children, one through eight years, were generally larger than the left. The measurements of the right tended to be larger more frequently with increasing age, suggesting development through specialized use. From radiographs, Vicinus (1962, cited in Malina, 1969a:23) noted a tendency for the right hand of adults to be larger than the left, in both length and width, with differences in breadths more marked. Buskirk et al. (1956, cited in Malina, 1969a:24) found nationally ranked tennis players to have greater musculature and osseous development, in both length and width of the radius and ulna, in the dominant hand and forearm than in the non-dominant members. Since the players had participated extensively during their teen years, this laterality difference was attributed to the effects of exercise on bone growth during adolescence.

While there is some speculation that participation in sports, during adolescence, may have an unfavourable effect on the adolescent female boney pelvis, Erdelyi (1962) did not confirm this hypothesis, and the data of Ivata and Kadsuo (cited in Erdelyi, 1962:177) also disputes this claim.

In a comparative study of female gymnasts, and a corresponding reference population, Smit (1973) found the intercristal width to be far smaller in gymnasts. The biacromial width, in comparison, was found to be nearer to the norms in spite of the relative shortness of the gymnasts. Buckler and Brodie (1977) reported similar results for 10 to 19 year old boys involved in gymnastics. Parizkova (1968a), in a study of active and inactive boys followed longitudinally from 11 to 15 years, found the active boys after a five year period, developed a larger biacromial breadth, and a significantly narrower pelvis in relation to their height, and to their biacromial breadth, than the less active boys. These results suggest that:

> Gymnastics, in addition to its obvious influence on the musculature has a favourable influence upon skeletal growth in the region of the shoulders.
>
> (Smit, 1973:484)

> The increased biacromial diameter is secondary to the prolonged physical activity, implying that muscular growth and use can influence the way in which bones develop.
>
> (Buckler & Brodie, 1977:462)

Adams (1938, cited in Malina, 1969a:22) found Negro women, ages 17 to 21 years, subjected to strenuous physical labor during their childhood years, to be taller, heavier, and larger in muscle girth, chest breadth and depth, and hip and knee width, than women of the same age not subjected to such stress. Similarly, Godin (1920, cited in Malina, 1969a:22) found "gymnasts" (active youths), ages 14½ to 18 years, to be taller, heavier, and larger in thoracic and forearm measurements than "non-gymnasts". The size differences in both these studies were attributed to the programs of heavy physical work.

Summary: Performance and Morphology

Exercise has been shown to dynamically affect the body for short terms, and possibly to the extent of resulting in some permanent tissue changes as critical periods have passed. The effects of exercise on the fat and muscular components of the body are easily observed and accepted. It is known that exercise has a positive effect on strengthening the organic matrix of the bone. However, whether or not exercise can substantially alter the development, structure, and size of the skeleton still remains an unanswered question.

Type of exercise, as well as genetic contributory factors, dictate to a degree, the extent of morphological changes possible. Genetic factors may well dictate the vulnerability of the body to specific exercise "stressors", and may affect the same individual in different ways at different times, depending on the stage of maturity reached.

While moderate exercise may favourably affect and stimulate growth, excessive, strenuous exercise may deter and negatively affect normal growth patterns and potentials. The maximum tolerance limits, beyond which the positive effects of exercise and training cease to exist, and the negative destructive forces come into operation, have not been determined.

IV PERFORMANCE AND MATURITY

As the number of pre-adolescent and adolescent children participating in strenuous training programs increases, concern over the effect of exercise on the growth and maturing processes has taken on a new emphasis:

> In 1966, 5 year olds weren't running marathons or training as Olympic gymnasts in the numbers they are today. Can cumulative microtrauma of some sort change the picture when preadolescents train long and hard?
>
> (Barnes, 1979:116)

Krustev (1977:25), in an Olympic Committee Bulletin, raised the question of setting age limits for participants in the Olympic Games, with concern for "the potential danger to health which such rigorous training at a very early age might entail". These concerns are well founded since:

> Puberty by itself is for the organism a stress which may cause troubles; if during this period, the individual undergoes training to its extreme limits, the stimulation which puberty exercises spontaneously on the endocrine glands is summed with that caused by motor activity; by consequence the functional load of a fast physical development is added to that of the training; it is a vicious circle with cumulative action, whose negative effects sometimes appear prematurely, but more often later on.
>
> (La Cava, 1974:163)

Maturity Indicators

While the term "growth" usually refers to the physical act of enlargement of a structure, such as a bone length, muscle girth, or volume increase; the term "maturity" is reserved for "qualitative" changes in the structure, and involves differentiation of the cells, leading to shape and/or functional changes:

> While growth and development proceed concomitantly in the normal child, they are to some degree potentially independent processes.
> (Greulich & Pyle, 1970:2)

There are a number of ways in which the level of maturity of the body, and the rate of maturity can be assessed and monitored. Among the techniques presently utilized for females are:

(a) morphological age: the changing shape and proportions of the body (Behnke & Wilmore, 1974; Bielicki & Waliszko, 1975; Eiben, 1978; Ross & Wilson, 1974; Tanner & Whitehouse, 1976; Tosovsky et al., 1976).

(b) secondary sex characteristics: the stages of development of the breasts, and pubic and axillary hair (Marshall, 1972; Tanner, 1962, 1978), as well as the number of maturity indicators or developmental milestones experienced, such as peak height spurt and menarche (Eveleth & Tanner, 1976; Tanner, 1962, 1978).

(c) dental age: the number of primary and secondary teeth erupted (Anderson, 1975; Demerjian et al., 1973, cited in Tanner, 1978: 82; Eveleth & Freitas, 1965; Eveleth & Tanner, 1976; Filippson & Hall, 1976; McGregor, Thomson, & Billewicz, 1968).

(d) endocrine secretion patterns: The presence and level of hormones circulating in the blood (Reiter & Kulinh, 1972; Tanner, 1978).

(e) skeletal age: assessing the stages of development of the bones from radiographs (Greulich & Pyle, 1970; Tanner et al., 1975).

<u>(i) Skeletal age as a maturity indicator</u>. Skeletal age as a maturity indicator has a number of attractive features:

1. It can be assessed with relatively objective criteria, and can be used throughout the entire lifespan until completion of skeletal development (Greulich & Pyle, 1970; Tanner et al., 1975).
2. The radiograph is easily attained without involving personal questioning or examination.
3. The data is portable, and can be re-evaluated.
4. As well as making the distinction between growth and maturity, the method is able to differentiate between "slow growers" and those who are inherently short; as well as between "fast growers" and those who are inherently tall (Johnston, 1962; Tanner et al., 1975).
5. The maturational changes in the skeleton are intimately related to those of the reproductive system (Tanner et al., 1975), and are associated with other growth and maturity indicators:

> Menstruation generally occurs between the skeletal ages of 13 and 14 years and it is said never to have been seen in a girl with a skeletal age of less than 12.5 years or more than 14.5 years.
> (Marshall, 1974:310)
>
> The ulnar sesamoid of the first metacarpophalangeal joint ... showed a very close relationship with the onset of secondary sex characteristics and with ages at initiation and peak of adolescent height velocity. Usually it became visible radiographically .5 years after the onset of pubic hair development, .75 years after the initiation of the height spurt and .7 years before peak height velocity. It indicates that puberty has already started and that height velocity is in the accelerating phase and that 88% of adult height is reached.
> (Onat & Numan-Cebeci, 1976:659)

6. The method is useful in the prediction of adult height from height during childhood or early adolescence (Acheson & Dupertuis, 1957; Tanner et al., 1975), and in the prediction of menarche. Menarche usually occurs between 10.0 and 16.5 years chronologically (Tanner, 1962), and between

12.5 and 14.5 years, skeletally (Marshall, 1974).

(ii) Skeletal age rating systems. The most commonly used methods of assessing skeletal maturity are those developed by Greulich and Pyle (1970) and Tanner et al. (1975), in which the left hand and wrist area is rated. Systematic differences between the two methods have been reported, with the Tanner-Whitehouse II method, bone specific approach, yielding a substantially higher value than the Greulich-Pyle method, atlas approach, for the same radiograph (Ross, McKim, & Wilson, in Taylor, 1976:257).

The relative stability of the rating systems is based on the stability of the maturing sequences of the skeleton:

> The bone stages and their individual sequences are the same in all populations.
> (Tanner et al., 1975:18)

and this,

> is evident both before and after birth.
> (Greulich & Pyle, 1970:24)

> Each bone passes through all stages, although stages last for varying times.
> (Tanner et al., 1975:4)

and,

> The bone stages and their individual sequences are unaffected by starvation.
> (Tanner et al., 1975:18)

(iii) Menarche as a maturity indicator. Menarche, as a maturity indicator, is commonly used to assess the rate of maturity of most female populations (Eveleth & Tanner, 1976). Menarcheal surveys are usually conducted using one of three methods: (a) prospective method - recording the onset of menarche in a longitudinal study; (2) retrospective method - recording recalled age of menarche; (3) status quo method - recording whether or not menarche has occurred at the time of investigation (De Wijn, 1966).

The strengths and weaknesses of each method are reviewed in Atwood and Taube (1976) and De Wijn (1966).

The time of menarche is also valuable as a maturity indicator because of its relationship to other developmental milestones, such as peak height velocity. "Menarche occurs almost invariably after the apex of the height spurt has passed" (Deming, 1957, cited in Tanner, 1962:39). Greulich and Pyle (1970) noted this invariable pattern in a study of eight menarcheal age groups, where the maximum annual increment in height occurred consistently during the year preceeding that in which the menarche took place.

Maturity and Population Studies

The most conventional method of assessing the rate of maturity of female populations is through the age at menarche (Eveleth & Tanner, 1976).

In every population there appears to be early, late, and average maturing females (Tanner, 1962), and differences in rate of maturation, as measured by age at menarche, exist between national or racial groups irrespective of environmental and geographical differences (Eveleth & Tanner, 1976). Ages of menarche of 12.3 years, for middle class European descendants living in Santiago; 12.8 years, for the United States population in general; 15.1 years, for Asiatics living in Maya; and a much later age of menarche of 18.4 years, for females of New Guinea; have been reported (Eveleth & Tanner, 1976). Mean ages at menarche, in six recent (1965-1973) non-athletic, American samples, ranged from 12.20 to 12.65 years (Malina, Harper, Avent, & Campbell, 1973:12). The standard deviation of most samples is about ± 2 years (Eveleth & Tanner, 1976).

Because there is a relatively high correlation between the onset of menarche in mothers and daughters (Damon, 1974; Damon, Damon, Reed, &

Valadian, 1969; Tanner, 1962), and between sisters (Damon et al., 1969; Tanner, 1962), and a very much higher one between identical twins (Damon et al., 1969; Petersen, 1979; Tanner, 1962), there is a genetic implication connected with age of menarche:

> Distribution of age of menarche in the population is Gaussian .:. the time of menarche is to a considerable extent under hereditary control and depends on the combined actions of genes at several different loci rather than on any single allele. ....this genetic control evidently operates throughout the whole process of growth and the conclusions regarding age at menarche apply equally to rate of development in general.
>
> (Tanner, 1962:114-115)

Genetic factors currently account for only 10 to 15% of variation in age at menarche, "a proportion that is increasing as growing uniformity of nutrition and health eliminates other variables" (Petersen, 1979:47).

Maturity and Athletic Populations

The ages of menarche of athletic populations have been studied with the purpose of evaluating whether or not elite performers, and those involved in physical training programs, differ with respect to the average rate of maturity, as defined by the normal population.

Erdelyi (1962) and Rarick (1973, cited in Ross, Brown, Faulkner, & Savage, 1976:191) found the age of menarche of young female athletes to be about the same as non-athletes. Furthermore, Erdelyi (1962) concluded that participation in active competitive sports does not disturb the onset of menarche.

Astrand, Engstrom, Eriksson, Karlberg, Nylander, Saltin, and

Thoren (1963) found Swedish swimmers to have an earlier menarche in relation to Swedish norms, and Bugyi and Kausz (1970) found eight of the best Hungarian swimmers to be advanced in skeletal age, in relation to their chronological age, by approximately 5.1 months.

Malina et al. (1973) found the mean age of menarche of college track and field athletes (13.58 years) to be significantly later than that found in a reference population of non-athletes (12.23 years). The ages of menarche of the athletic groups did not differ significantly among themselves. However, increasing lateness in menarche for these athletes was reported in the following order; shot putters (13.44 years), sprinters (13.54 years), distance runners (13.58 years), discus and javelin throwers (13.60 years), and jumpers and hurdlers (13.73 years).

In a later study, Malina, Spirduso, Tate, and Baylor (1978) found Olympic volleyball candidates to have a significantly later age of menarche (14.18 years) than high school (13.02 years), and college (13.05 years) athletes, with the high school and college athletes having a significantly later menarche than a non-athletic sample (12.29 years). In the college athletes, increasing lateness in menarche was reported in the following order: golfers (12.50 years), volleyball players (12.54 years), swimmers (12.84 years), basketball players (12.89 years), gymnastic and track athletes (13.21 years, n = 6, combined), and tennis players (13.73 years). The Olympic volleyball candidates attained menarche significantly later than all the sport specific groups, except the gymnastic and track, and tennis athletes.

Faulkner (1977) reported an age of menarche of 14.0 years for elite female figure skaters, and noted that none of the outstanding singles under 12 years had experienced menarche. Ross et al. (1976) reported ages of menarche of 14.0 years, for elite Canadian junior and senior figure skaters; and 12.9 years, for elite Canadian alpine racers. In comparison to this latter study, two high school reference samples had ages of menarche of 12.9 and 12.4 years, and a university sample had an age of menarche of 12.9 years.

External Stressors and Maturity

External "stressors", such as climate (Eveleth & Tanner, 1976), season (Bojlen & Bentzon, 1974; Burrell, Tanner, & Healy, 1961; Hillman, Slater, & Nelson). altitude (Frisch, 1973; Petersen, 1979), artificial lighting (Jafarey, Khan, & Jafarey; McClintock, 1971, cited in Johnston, 1974:167), parental age (Hillman et al., 1970; Newton & De Issekutz-Wolsky, 1969), and sleep (Goldfarb, 1977), to name but a few, have been shown to have an effect on the rate of maturity.

In comparison to these external stressors, it has been observed that nutrition has a very strong and significant influence on the rate of maturity, and especially in influencing the time of adolescence (Goldfarb, 1977; Tanner, 1962):

> Skeletal maturation is slower everywhere in the worse-off compared to the better-off socio-economic groups.
>
> (Tanner et al., 1975:19)

Tanner et al. (1962:121) have found that malnutrition in pre-adolescence delays the appearance of the adolescent growth spurt. Dreizen et al. (1967, cited in Johnston, 1974:165) and Frisch and Revelle (1969) have found that undernutrition delays menarche, while Charzewska, Ziemlanski, and Laseck (1975), Kralj-Cercek (1956), and Skerlj (1947, cited in Damon et al., 1969: 170) have reported lower ages of menarche in populations with high consumptions of animal proteinous foods.

There appear to be many factors influencing the age of menarche, and Kralj-Cercek (1956) presents age of menarche as a mathematical function incorporating environmental, nutritional, social, and physique factors.

Exercise as a Maturity Stressor

The impact of exercise on the body is very dramatic, and all of its effects may not have been identified. Continuous, strenuous exercise may act on the body and the maturing systems in much the same way as other external stressors, with its effect and influence subject to "critical growth periods" and genetic vulnerability.

During moderate to intense exercise, growth hormone circulates in the blood stream (1965, U.S. Department of Health Report, cited in Smit, 1973:484). Although this hormone is necessary for normal growth from birth to adulthood, its function in adult life is not entirely understood (Tanner, 1978), and furthermore:

> GH does not act directly on the bones to make them grow ... but on the liver to stimulate production of another hormone, called somatomedin ... a smaller molecule, that acts on the growing cartilage cells at the ends of bones, and probably on muscle cells, whose growth is also stimulated by GH.
>
> (Tanner, 1978:93)

Increased concentrations of growth hormone in the blood, as a result of exercise, does not necessarily indicate the potential for an increase in size. Differences, between normally large and normally small children and adults, are not caused by differences in GH secretion (Tanner,1978:93):

> Perhaps it is the receptors in the cartilage cells which control size ... normal children have plenty of GH and are not turned into normally big ones by being given GH in excess.
>
> (Tanner, 1978:93)

Two longitudinal studies on the effects of rigorous training on growth were located. Astrand et al. (1963) studied girl swimmers, who had commenced training before thirteen years of age. The growth curves from the 7th to 16th year were normal, and at 18 years a medical examination disclosed no harmful effects of the training. Motajova (1974) studied girl gymnasts involved in strenuous training, and a control group of females, from their 11th to 15th year. At the end of the 4th year no significant differences, between the groups, in bone age were found.

Since the mechanism that triggers menarche may not be the same as that which causes resumption of the menses after exercise, weight loss, or starvation induced amenorrhea (Billewicz, Fellowes, & Hytten, 1976), the contribution of exercise to the disruption of the menstrual cycle can not be considered as evidence that exercise disrupts the maturing processes.

Growth Rate Intervention and Catch-up Growth

The body is continually undergoing change due to the growth, maturing, and ageing processes, which are constantly being influenced by such factors as diet, exercise, and external stressors in general.

The existence of a "catch-up" growth phenomenon that occurs when adverse conditions are removed, strongly suggests the existence of a genetically established and predetermined plan or course of growth that is highly resistant to change (Tanner, 1963):

> When recovery takes place a "catch-up" period of growth ensues during which growth may proceed at as much as twice its normal rate for the age concerned.
>
> (Tanner,1962:133)

Furthermore, females show a greater resistance to growth changes caused by environmental stressors than males (Crimson & Turner, 1953, and Greulich, 1951, cited in Tanner, 1962:127).

Summary: Performance and Maturity

There is substantial evidence that factors, such as nutrition, affect the growth and maturing processes of the female, and interfere with normal development. Whether or not strenuous, prolonged exercise, stresses the body in much the same way, is not known. It has not been established whether the mechanism controlling the onset of the menses is the same as that controlling resumption of the menses following exercise and weight loss induced amenorrhea. The effect on growth and maturity, of growth hormone secretions in response to exercise, is not known.

Skeletal age and age of menarche are two useful maturity indicators often used in population surveys of rate of maturity. Although there is large variation, in the population, in the age of menarche, there is a high correlation between the ages of menarche of related females. This suggests that there is a genetic control over this variable. Furthermore, the existence of a "catch-up" growth phenomenon suggests the existence of a strong genetic control over the rate of growth, and possibly maturity, and suggests a control that is highly resistant to external stressors, that may include the stress of exercise.

Consistent trends concerning age of menarche and sport participation have been reported, with gymnasts and figure skaters tending to be late maturers, and swimmers tending to be early maturers.

The literature to date tends to indicate that exercise does not substantially affect the maturing processes. However, this relationship has not been investigated in light of the present trend toward younger participation in strenuous training programs.

V MORPHOLOGY AND MATURITY

While the maturing process per se involves changes in size, shape, composition, and proportionality, it has been speculated that these parameters are closely related to the initiation of the maturing processes.

Height, Weight, and Maturity

Women who mature early were reported to be less slender at maturity (McNeill & Livson, 1963), with a lower ponderal index (height-to-weight ratio) (Hillman et al., 1970) than late maturing women.

Children with an early puberty were found to be taller and heavier than late maturers, some time before puberty (McNeill & Livson, 1963). Richey (1937, cited in Tanner, 1962:87) found early maturers to be taller and heavier than late maturers, at ages 6, 7, and 8 years, and Dupertuis and Michael (1953, cited in Tanner, 1962:102) found that "as early as two years old those who at puberty will be late maturers weigh less for their height than do early maturers". Similarly, Shuttleworth (1939, cited in Tanner, 1962:102) reported this relationship as far back as six years.

Acheson and Hewett (1954, cited in Acheson and Dupertuis, 1957: 167) found children who reached a specific skeletal maturation stage "late", were taller at that stage than children who reached the same stage "early". Richey (1937, cited in Tanner, 1962:97) found no difference in height between early, late, and average maturing females, while Stone and Barker (1937, cited in Tanner, 1962:96) have shown late maturers to be slightly taller at maturity than early maturers. Frisch (1969) reported late maturers to be significantly taller than early maturers, at the initiation of the adolescent growth spurt, and at the maximum rate of growth peak.

Frisch and Revelle (1971) reported that the mean height at menarche increased significantly as the menarcheal age increased. Zacharias, Rand, and Wurtman (1976) found that a girl who experiences menarche at an early age, is likely to be shorter than a girl who is older when this event occurs.

For girls of the same height at menarche, the older ones tended to be lighter and thinner; and the younger ones tended to be heavier (Johnston, Malina, & Galbraith, 1971; Zacharias et al., 1976). At a constant menarcheal weight, the early maturers were found to be shorter than the late maturers (Johnston et al., 1971).

In general, a late menarche is associated with thinness, and a taller, lighter body; and an early menarche is associated with stoutness, and a shorter, heavier body (Johnston et al., 1971; Zacharias et al., 1976).

> Linear people, both men and women, develop late, ... [and it is] likely that linear individuals are less advanced in growth at all ages, and proceed in a more leisurely way along their track.
>
> (Tanner, 1962:102).

Secular Trends

An association between height, weight, and rate of maturity, appear to be evident in the secular trends that have been identified. Analysis of growth data has revealed that the whole process of growth and maturity has been progressively "stepped-up", with children getting progressively taller, and heavier, sooner; and with the growth spurt and time of menarche occurring earlier (Bakwin, 1964, Towns et al., 1966, Roberts & Dann, 1967, Harper & Collins, 1972, and Zacharias et al., 1970, cited in Johnston, 1974:168; Eveleth & Tanner, 1976; Tanner, 1962). Recognizing the existence of racial differences in rate of maturity, it has been noted that:

> In Norway the average girl begins to menstruate

> at just over 13 years of age, as opposed to 17 years in the 1840's. In the United States ... the average age at first menstruation has declined from 14.2 in 1900 to about 12.45 today. (Petersen, 1979:45)

On the other hand, the data of Damon et al., (1969) suggests that, in a general way, those factors affecting secular trends in adult height are not necessarily the same factors affecting secular trends to age at menarche. The secular trend of an earlier menarche has also been associated with a number of other variables, such as improved nutritional, environmental, and health care factors (Johnston, 1974; Petersen, 1979; Tanner, 1962), the breaking down of genetic isolates (Broman et al., 1942, cited in Tanner, 1962:150), and the occurrence of heterosis (Huise, 1957, and Lasker, 1960, cited in Tanner, 1962:151).

Recent investigations have suggested that, in some countries, the downward trend in age of menarche is coming to a halt (Brundtland & Walloe, 1973, and Zacharias et al., 1973, cited in Dann & Roberts, 1973:266; Dann & Roberts, 1973). Damon (1974) and Zacharias et al. (1976) have also reported secular trends of an earlier menarche to be no longer observable, and the data of Maresh (1972) indicates the possibility of a trend in the opposite direction.

Endomorphy, Mesomorphy, and Maturity

"Relative fatness in children has been associated with an early menarche" (Ross et al., 1976:191), and "at least in countries where nutrition may be more than adequate, fatness and maturity go together" (Tanner, 1962:102). Furthermore, early maturers have been found to be significantly more endomorphic than late and average maturers (Garn & Haskell, 1960; Frisch & Revelle, 1971; Reynolds, 1950; Rona & Pereira, 1974; Zuk, 1958).

Garn and Haskell (1960) found that the fatter the child, the taller he/she is, and the more advanced the skeletal age. Fat and developmental progress appear to be linearly related (Garn & Haskell, 1960; Reynolds, 1950; Rona & Pereira, 1974). However, an asymptotic point, beyond which increased fatness is no longer associated with accelerated development, is speculated (Garn & Haskell, 1960). Bruch (1941, cited in Johnston, 1974:161) found clinically obese children to be as much as 1½ years advanced in age of menarche, and Hammar et al. (1972, cited in Johnston, 1974:162) found obese girls to reach menarche at an average age of 11.3 years, and non-obese at 12.8 years.

Reynolds' comprehensive study (1946, cited in Reynolds, 1950:11) of fat patterning and maturity suggests the existence of developmental differences in subcutaneous fat in early, late, and average maturing females. Early maturing females were found to have relatively greater fat measurements in childhood, and prior to puberty, than late and average maturing females. Similarly, Garn and Haskell (1960) found girls who were relatively fat at 8.5 to 9.5 years, to be advanced in the age of menarche, and in the age of attainment of tibial union. Children between 1½ and 12½ years, who were one standard deviation above the mean in normalized fat scores, were advanced skeletally by approximately .4 years, and were taller than the average for their age, by about 6 months growth.

Barker and Stone (1936) and Wallau (1939, both cited in Tanner, 1962:101) have shown "pyknic" (endomorphic) women to experience menarche approximately eight months ahead of "leptosomic" (ectomorphic) women. Kralj-Cercek (1956) reported that girls of the "Baroque" type (pyknic, broad-built, feminine) reach menarche earlier than girls of the "renaissance" type (medium build), with the "gothic" type (linear or boyish build) having the latest menarche.

McNeill and Livson (1963) found that both endomorphy and ectomorphy were related to maturity, while mesomorphy was found to be essentially unrelated.

Johnston (1974) cautions against interpretting "cause-effect" relationships between body build and rate of maturity:

> Increased amounts of depot fat do not "cause" menarche to be early ... Rather these would seem to be the result of other determinants of growth variation, be they hormonal, nutritional, hereditary ... Thus, in all probability, a late maturing female will tend to have a more linear physique due to a longer period of pre-adolescent growth, characterized by relatively greater amounts of growth of the shafts of the long bones.
>
> (Johnston, 1974:162)

The Critical Mass Hypotheses

Frisch and Revelle (1970) proposed the hypothesis that critical body weights may trigger certain adolescent events in females. From their analyses of data from three longitudinal growth studies, they interpolated mean heights and weights, at three maturational events; at menarche, at the initiation of the weight spurt, and at the time of maximum rate of weight gain, and proposed that these events occurred at "invariant" mean weights of 48 kg, 31 kg, and 39 kg, respectively. They proposed that menarche occurs when:

> attainment of a body weight in the critical range causes a change in metabolic rate, which in turn, reduces the sensitivity of the hypothalamus to estrogen, thus altering the ovarian-hypothalamus feedback.
>
> (Frisch & Revelle, 1970:398)

Frisch, Revelle, and Cook (1973) expanded the hypothesis to include discussion of a critical "metabolic" mass component. From the height and weight values previously interpolated (Frisch & Revelle, 1970), they calculated total body water, lean body weight, and fat values, and noted the change in these components, between the maturational events. They proposed that:

> Total water and lean body weight are more closely correlated with metabolic rate than body weight ... as is expected since they represent the metabolic mass, as a first approximation.
> (Frisch et al., 1973:479)

In 1974, Frisch and McArthur revised the critical mass hypothesis to include critical fat mass values, calculated from total body water, necessary for the onset of the menses, and for the maintenance of menstruation. They proposed that:

> the minimal weight for body height for the onset of menstrual cycles ... is equivalent to about 17% fat of body weight. ... about 22% fat of body weight, indicates a minimal weight for height necessary for the restoration and maintenance of menstrual cycles for women of age 16 years and over.
> (Frisch & McArthur, 1974:949)

In 1976, Frisch presented a nomogram for estimating total body water as a percentage of body weight (an index of fatness) from height and weight values of females.

The concept of "critical masses" is not a new one. In 1923, Moulton (cited in Friss-Hansen, 1971:272; and Parizkova, 1961a:805-806) introduced the concept of "chemical maturity", indicating that at a certain age a constant composition of water, protein, and ash content would be achieved.

The Frisch-Revelle (1970), Frisch-Revelle-Cook (1973), and the Frisch-McArthur (1974) hypotheses have been tested against other longitudinal growth data, and have found little support and much skeptical criticism (Billewicz et al., 1976; Cameron, 1976; Crawford & Osler, 1975; Johnston et al., 1971; Johnston, Roche, Schell, & Wettenhall, 1975).

One of the major shortcomings of the hypotheses is that they are based on interpolated and not directly observed data. The new data are then treated as if they are observed values. Furthermore, the process of allotting all girls of a given height and weight the same body water value, and thus the same "fatness" value, is questioned (Billewicz et al., 1976), as this implies that there is no compositional variation between individuals of similar size. As well, the invariant mean values specified in the original hypothesis appear to be representative of central tendencies, and applicable to group means, and not to individuals, who demonstrate their own unique patterns of growth (Billewicz et al., 1976; Crawford & Osler, 1975; Johnston et al., 1975).

Summary: Morphology and Maturity

It appears that females who are above average for their age, in height, weight, and fat "content", are also advanced in maturity, and reach menarche at an earlier age than their peers.

In general, an early menarche is associated with stoutness, shortness, and a heavy body; while a late menarche is associated with thinness, and a taller, lighter body.

The secular trend of an earlier menarche has been associated with the secular trend of children getting progressively taller and heavier sooner.

The concept of "critical metabolic masses" triggering certain adolescent events, has not received much support.

Although exercise has the effect of modifying the "physique" and composition of the body, it is not known at this time, whether a modification of the body's physical morphology can, in turn, substantially affect the rate of maturity, which appears to be a predetermined genetic trait.

VI MATURITY AND MORPHOLOGY

While it has been demonstrated that early and late maturers possess distinctly different physiques, at the initiation of specific adolescent events, there is some speculation that the time and rate of maturity may also affect the ultimate, adult physique, with early maturers possessing different physical characteristics, as adults, than late maturers.

Practically all of our knowledge on morphological changes accompanying growth and maturity is substantiated from longitudinal studies. Since most of these studies are concerned primarily with the dramatics surrounding adolescence, they usually delve descriptively into these events, and comment briefly, if at all, on the persistence of certain growth trends into adulthood. The effect of specific growth characteristics and phenomena, upon ultimate, adult physique, has not received much attention in the literature.

Although early, average, and late maturers pass through the same maturational and growth events, and in relatively the same order, the characteristics of the adolescent events appear to differ depending on the time of maturity:

> The earlier the spurt occurs, the more intense it appears to be ... the earlier the menarche, the greater the peak velocity; and the earlier the menarche, the less time elapses between it and peak velocity. ... as a result of the greater peak the total contribution of the spurt to adult height is also greater in early maturing children.
>
> (Tanner, 1962:94)

Height, Weight, and Maturity

Richey (1937, cited in Tanner, 1962:96-97) found late maturers to be lighter in weight than early maturers, both at menarche and at 18 years, with no difference in adult height reported. Stone and Barker (1973) and Shuttleworth (1939, both cited in Tanner, 1962:97) found late maturing females to be slightly taller as adults. Frisch and Revelle (1969) reported that the adult height, at age 18 years, of four maturity groups, with ages of menarche of 11.4, 12.5, 13.5, and 14.4 years, was approximately the same, except for the latest maturing group which was shorter by 8 centimeters. This group showed a mean peak height increase that was lower than the others, and was also found to be lighter in weight at age 18 years than the others.

Tanner (1962:102) reported no significant relationship between age at menarche and adult height, weight, or triceps skinfold thickness. However, Hillman et al. (1970) and Tanner (unpublished data, as cited in Tanner, 1962:102) reported a strong association between menarcheal age and adult body form, and women with a high ponderal index as adults, had a significantly later onset of the menses. Zuk (1958) also found early maturers to be less ectomorphic at age 17 years than late and average maturers.

Proportionality, Shape, and Maturity

While some differences in physique are the result of variations in the magnitude of the growth spurt and its time of initiation, others, such as the wider shoulders of the male and the wider hips of the female, result at adolescence through differential growth rates, which account for differences in shape and tissue structure. Still other differences, such as the relatively longer male forearm, develop continuously throughout the whole period of growth (Tanner, 1962:40).

Bayley (1943b, cited in Tanner, 1962:102) noted that late maturing girls have wider shoulders, as adults, than early maturing girls.

Malina (1978, cited in Malina et al., 1978:221) found the late maturing girl to be characteristically longer-legged and narrower hipped, with a more linear physique and less weight for height, with less relative fatness, than the early maturing female. Tanner (unpublished, cited in Tanner, 1962:102) similarly confirmed a linearity relationship between height and bi-iliac diameter for late maturers. Shuttleworth (1939, cited in Tanner, 1962:97) attributed the greater adult height observed in late maturing females to a greater leg length.

These results may indicate that late maturing girls have an adolescent spurt appoximating the boys' spurt, in composition, as well as in time (Tanner, 1962). The difference in height, and the relatively longer legs of the male, in comparison to the female, is due to a later age of maturity, and more specifically, to a longer growing period prior to the adolescent spurt (Tanner, 1962):

> In girls the spurt begins about 2 years earlier than in boys ... and is somewhat smaller in magnitude. ... the peak height velocity averaging about 8 cm. per year [in females] .... In the immediate preadolescent years, it is the legs which are growing relatively fastest of all skeletal dimensions ... and so if allowed to grow for an extra 2 years before the spurt, the legs become relatively longer.
> (Tanner, 1962:1,46)

Smit (1973:484) attributed the longer lower limbs in proportion to total height, observed in gymnasts, to their "reaching a pubertal growth spurt sooner than those from the population". However, it is apparent from the above quotation, that this is due, in fact, to a delayed spurt.

The degree of androgyny; "the masculinity of form in the female, or femininity in the male" (Tanner, 1962:102), has been studied in an attempt to associate it with certain developmental events, such as the time of initiation of the growth spurt, and menarche. Deming (1957, cited in Tanner, 1962:104) did not find girls with growth spurts resembling that of boys, to have a more masculine physique, as adults, than the average. Malina and Zavaleta (1976) investigated the relationship between androgyny scores and age of menarche in female track and field athletes, and found low and non-significant results. Olympic female swimmers and divers, in a study by Hebbelinck et al. (1975, cited in Malina & Zavaleta, 1976:444), were found to have androgyny scores in the masculine range. The androgyny scores however, are said to confuse mesomorphy with masculinity, and endomorphy with femininity (Tanner, 1962:104).

Endomorphy, Mesomorphy, and Maturity

Zuk (1958) studied the changes in physique with maturity, in an attempt to determine the degree of stability of the somatotypes. Mesomorphy and endomorphy in females, were found to increase consistently from 12 to 17 years, and from 17 to 33 years, while ectomorphy declined consistently. In general, the somatotype tended to be fairly stable and consistent from early adolescence through adulthood. The endomorphic component fluctuated randomly from late adolescence to adulthood, but tended to be stable within the adolescent years, and females, as they grew older, tended to take on endomorphy.

Boothby et al. (1952, cited in Tanner, 1962:102) found a clear tendency for those with an early menarche to have more subcutaneous fat at age 18 years than those with a late menarche. However, Zuk (1958) found late maturers to have a higher degree of endomorphy at age 33 years, than early and average maturers. This difference however, was reported as not statistically significant.

Little research effort has been directed towards monitoring shape changes from childhood, through adolescence, and into adulthood. The general impression however, is that; "shape changes far less than size at least from 2 years onwards" (Tanner, 1962:91).

Summary: Maturity and Morphology

The time of maturity has been shown to affect the physical characteristics of the adolescent events. Although the literature is non-conclusive, the rate of maturity appears to have some effect on the ultimate adult morphology, with late maturers tending, as adults, to have a more linear physique, a higher ponderal index, narrower hips, and longer legs, but not necessarily a taller stature.

Differences in adult physique, and especially the longer lower limbs found in late maturers, may result both from differences in the rate of growth, and the time of initiation of the growth spurt.

Somatotype components appear to be fairly stable from early adolescence throughout adulthood. However, the endomorphic component fluctuates randomly and tends to increase with age.

In view of these findings:

> It would certainly be wrong to leave any impression that the adolescent spurt, whether late or early, causes any radical changes in body build; it certainly does not. It adds only the finishing touches to a physique which is recognized years before.
>
> (Tanner, 1962:104)

VII MATURITY AND PERFORMANCE

The process of physical growth and maturity involves dramatic changes in size, shape, composition, and proportionality (Edwards, 1950, 1951; Friis-Hansen, 1971; Garn & Haskell, 1960; Malina, 1974; Parizkova, 1961a; Reynolds, 1950; Skerlj et al., 1953; Tanner, 1962). These changes are especially marked at adolescence:

> Every muscular and skeletal dimension of the body seems to take part in the adolescent growth spurt. Even the head diameters, practically dormant since a few years after birth, accelerate somewhat in most individuals. The cartilages of the wrist grow and ossify more rapidly. The heart grows faster; so also do the abdominal viscera. The reproductive organs in particular enlarge.
> (Tanner, 1962:10)

Since each stage of maturity presents a different and changed physique, there may also exist, concurrent with these physical alterations, changes in physical potential and performance. In view of the significant contribution of physical morphology to performance outcomes, it is not unreasonable to expect performance potential to vary in relation to the stage of maturity reached.

Maturity and Muscular Development

In males, puberty is accompanied by an increase in muscular development (Tanner, 1965, as cited in Malina, 1969b:22) and strength, and these are attributable to an increase in hormonal secretions (Clarke, 1968, 1973; Jones, 1949, cited in Reynolds, 1950:107). In females, little, if any, strength increase is detected accompanying pubertal development, and although there is an increase in hormone production, it is not as great as that experienced in males (Church, 1976).

Espenchade (1940, 1960, cited in Malina, 1974:127) found that performance in a variety of motor tasks requiring power, speed, agility, co-ordination, and balance, reached a plateau in females at approximately 14 years of age, with little improvement thereafter. Johnson and Buskirk (1974) have observed similar results, with performance in some tasks showing slight declines after the age of 14 years. Whether or not these declines are functions of biological ageing is questionable however, since Kriesel (1977) noted an obvious unwillingness in girls to perform strength related tasks to the best of their ability. Furthermore, the cross-sectional studies of Fleishman (1964) and Hunsicker and Reiff (1966, both cited in Malina, 1974:128) indicate a slight but continued improvement in running and jumping performance of girls, through to 17 years.

Hebbelinck and Ross (1972, cited in Ross, McKim, & Wilson, in Taylor, 1976:257) found that in female children, bone widths deviate in a positive direction, and comparable girths in a negative direction, from relative height values, suggesting that children have greater skeletal tissue relative to muscle mass than adults. They proposed that this "reduced" proportion of muscle mass was a physiological reason why children are at a disadvantage in relative strength and stamina.

The theoretical expectancy of weakness with increasing size has recently been shown to be non-applicable to growing children, as the basic assumption of geometrical similarity is not tenable, since children change in shape and composition as they gain in height (Ross & Marshall, 1979:15):

> The muscular girths increase with age. Thus we have a relative increase in muscle mass with growth which must be taken into account when appraising strength and relative strength performances in growing children.
> (Ross & Marshall, 1979:15)

Early Maturity and Performance

Although there appears to be no strength "advantage" in pubertal development, for the female, an earlier maturation has been associated with improved performance of 12 year old female swimmers (Kanitz & Bar-Or, 1973, cited in Bar-Or, Zwiren, & Ruskin, 1974:214). Asmussen (1966) discusses changes in anthropometric dimensions accompanying puberty, in relation to aerobic capacity and strength, and presents a credible case for attributing some of the improvements in performance, especially of female swimmers, to an earlier maturity.

During the adolescent growth spurt there is a fairly regular order in which the various dimensions accelerate:

> hands and feet reach adult size first, followed by calf and forearm, then hips and chest width, then by shoulders, and lastly by trunk length and chest depth.
> (Hebbelinck & Ross, 1974:546)

Hebbelinck and Ross (in Nelson & Morehouse, 1974:546) have commented on the "tempting" speculation that the sequence of events of maturity, especially with the hands and feet being relatively large with respect to the body and to the shoulders, may provide a biomechanical advantage for young swimmers, with respect to propulsion and resistance in the water.

Late Maturity and Performance

While certain advantages have been associated with an early or advanced maturity, there are also advantages associated with a delayed or late maturity:

> In swimming and perhaps other sports where body weight is supported or gives a biomechanical advantage, earlier maturation with a concomitant increase in size may be an advantage. However,

> a post-adolescent increase in body mass due to an increased percentage of fat may be a deterrent to sports requiring force to support or move the whole body mass. Thus in some track events and possibly in gymnastics and figure skating, delayed maturation may be somewhat of an advantage.
> (Ross et al., 1976:191)

In a longitudinal study of female non-athletes, Espenchade (1940, cited in Malina et al., 1973:12) found the better performers, on a test battery of track and field related items, to be late maturers, both menarcheally and skeletally.

Faulkner (1977) studied the physique characteristics of nationally ranked senior figure skaters and outstanding skaters under the age of 12 years, and concluded that the growth characteristics of the younger skaters, including their low fat content, small general size, light weight, and their proportional length and width measurements, provided biomechanical advantages in the performance of acrobatic moves:

> The proportionally wider knee widths and longer feet may benefit stability. ... The relatively narrow bitrochanteric and mesosternal widths ... may be advantageous in performing some motor skills.
> (Faulkner, 1977:92-93)

All of the outstanding skaters under 12 years of age were pre-menarcheal, and the differences in proportional measures between these skaters and the senior skaters were attributed to differences in maturity.

Concerning shock absorption and joint structure, it appears that children are well equipped to absorb forces caused by physical activity:

> For their size, children have proportionately larger knees, ankles and feet. Thus they have proportionately greater area for weight-bearing stress than adults. In addition, from early infancy to the adolescent growth spurt children tend to grow taller more quickly than they add weight: this linearity is an advantage in meeting the stress of running. On the other hand

> young tissue may be more vulnerable to stress-induced injury.
> (Ross, cited in Taunton, 1979:20)

Johnston et al. (1975) reported that a structural factor affecting running performance is the width of the pelvis, with a wider pelvis providing a less efficient angle for weight bearing and for attachment of the tendons of the quadraceps muscle group. Since there are structural and shape changes occurring in the hip joint with growth and development (Bullough et al., 1973; Ralis & McKibbin, 1973); and at puberty, "Girls have a particularly large spurt in hip width" (Tanner, 1962:45), it is possible that these changes also affect the efficiency of the running stride.

Maturity and Critical Learning Periods

Ross and Marshall (1979:15) have noted that skating professionals seem resigned to the dictum that, "if a girl does not double jump by the time she is twelve, she never will", and have suggested that there may exist a "critical pre-pubertal learning period", where skating skills can be mastered easier than after puberty, when there may be structural disadvantages. Faulkner (1977) has also commented that although the elite, adult female figure skater possesses physical factors that can be regarded as "deterrents" to performance, these disadvantages are offset by her acquisition of required skills before these factors came into play.

The importance of the pre-pubertal growth period to future potential and athletic success has been studied by Bannister (1968) and Ekblom (1970, both cited in Bailey, 1973:5). These studies emphasize the importance of pre-pubertal training in the setting of upper limits of the functional aerobic capacity. The necessity of building world class athletes by beginning training before the ages of 10, 11, and 12 years is emphasized by Councilman (cited in Bailey, 1973:5).

Age and Olympic Participation

From observing the ages of the female Olympic participants, it appears that they are younger in comparison to the male participants. Hirata noted that the ages of the female participants of the 1964 Olympic Games ranged from 13 to 35 years, with a mean of 22.8 years, and concluded that:

> The best period of man's physical function is in his age of 20 to 30 years in males and 17 to 25 years in females. And it may be concluded that the male's development is completed later than the females and maintained longer.
> (Hirata, 1966:208)

In comparison to other Olympic sports, it appears that the female gymnasts are among the youngest participants. De Garay et al. (1974) found the female gymnasts of the 1968 Olympic Games, with ages ranging from 13 to 26 years, and a mean age of 17.8 years, to be among the youngest participants of these Games. Novak et al. (1977) has observed that:

> While track and field events are dominated by adult women, figure skating, gymnastics and particularly swimming seems to have more record holders in the teenage group.
> (Novak et al., 1977:275)

Krustev (1977) reported a lowering in the average age of both the participants and the medalists of women's gymnastics, in the Olympic Games. The average age of the participants dropped from 23 years 10 months (range 18 to 38 years), in the 1896 to 1956 Games; to 18 years 2 months (range 14 to 31 years), in the 1976 Olympic Games. The average age of the medalists dropped from 25 years 6 months (range 19 to 31 years), to 19 years 2 months (range 15 to 24 years). An association between age and performance appears to be apparent since, comcomitant with these decreases in age, there is also observed an increase in the display and mastery of complex skills.

Summary: Maturity and Performance

The physical changes and developments accompanying puberty may affect performance and performance potential. While improvements in strength related skills are observed accompanying puberty in males, no such improvements are seen in the female, with performance tending to plateau at this time.

A late maturity in the female may provide an advantage in sports, such as gymnastics and figure skating, where smallness in general is required to perform complex skills, and where relative, rather than absolute, strength is displayed. In these sports, the longer pre-pubertal period accompanying delayed maturity is associated with an "extended critical learning period", a period when specific complex skills can be mastered with ease, and after which mastery may not be possible.

In comparison to the males, the female Olympic participants appear to be younger, and in comparison to the other female athletes, the gymnasts are among the youngest participants.

There appears to be an association in female gymnasts between age and performance since, concomitant with increasing displays of complex skills, there is also observed a decrease in the ages of the participating gymnasts and the medalists of the Olympic Games.

CHAPTER 3

METHODS AND PROCEDURES

SUBJECTS

Sixty-nine Canadian female gymnasts between the ages of 11.5 and 18.0 years participated in the study. Descriptions of the test groups, and subject selection for these groups, are as follows:

Group 1

Fifteen of the seventeen designated Canadian National Gymnastics Team Members (1977) were available for testing during an official Canadian Gymnastics Federation Training Camp. These gymnasts, termed "National Elite", are classified by the Canadian Gymnastics Federation as Level III or Level IV gymnasts, based on their performance results from a battery of physical fitness and standard gymnastic moves tests.

These are Canada's best gymnasts and comprise the Canadian National Gymnastics Team competing internationally in World and Olympic Games competitions.

Group 2

Thirteen of approximately thirty-five eligible gymnasts were available for testing. These gymnasts, termed "Pre-National Elite", are classified by the Canadian Gymnastics Federation as Level I or Level II gymnasts, based on their performance results from a battery of physical fitness and standard gymnastic moves tests.

These gymnasts have a very real potential of becoming national team members, and are eligible for selection for some international tournaments (Bajin, 1978:1).

Group 3

Twenty gymnasts between the ages of 11.5 and 18.0 years were randomly selected from the Vancouver and Thunder Bay areas to represent this test group. These gymnasts, termed "Competitive", are classified by the Canadian Gymnastics Federation as Competitive Level A or Level B gymnasts, and are active participants of certified Regional and Provincial Competitions. Some of these gymnasts have attempted the Canadian Gymnastics Federation elite tests, but none have met the requirements for the lowest level, Level I.

Group 4

Twenty-one gymnasts between the ages of 11.5 and 18.0 years were randomly selected from the Vancouver and Thunder Bay areas to represent this test group. These gymnasts, termed "Recreational", have never trained for, or competed in, certified Provincial or Regional Level A or Level B competitions.

These gymnasts have attended gymnastic classes for at least one year, and for at least one hour per week.

PROCEDURES

Participants selected for the study were sent an introductory letter explaining the nature of the project, its testing concerns, and the subject's expected involvement. The parent or guardian of each subject was then contacted by phone, at which time any concerns were discussed, and an appointment for having the radiographic photo taken was arranged.

Prior to the actual test session the project was again explained to the participating gymnasts.

All radiographic photos were taken by one of two qualified technicians at one of two medical institutions, U.B.C. Medical Institution and Health Centre in Vancouver, or St. Joseph's General Hospital in Thunder Bay. The procedures for hand positioning specified in the Tanner-Whitehouse II Radiographic Atlas (Tanner et al., 1975:41) were followed. All radiographs were taken in random order.

Menarcheal data were collected at the time when the radiograph was taken, by one of two females, the author, or a previously instructed assistant.

All anthropometric measurements were taken by the same Internationally Certified Criterion Anthropometrist, aided by a recorder previously instructed in recording procedures. The same measurement tape, calipers, and anthropometers were used for all subjects. One of two beam scales validated for precision was used in the attainment of body weight. Group 1 subjects had their anthropometric measurements taken as a group, while all other subjects were randomly measured. For this phase of the testing, all subjects were attired in two piece bathing suits or undergarments.

In order to accommodate the gymnasts, the anthropometric measurements were taken at a variety of gymnastic training centres, and over several days. The complete series of anthropometric measurements for each individual subject was taken at a single test session.

The anthropometric measurements and the radiograph were not taken on the same day, for all subjects. However, complete anthropometric and maturational data for a single subject were collected within seven days.

Complete data collection for the study took place from December 28th, 1977 to January 30th, 1978.

MEASUREMENTS

The present study consisted of maturational and anthropometric measurements.

Maturational Measurements

I Skeletal age. One radiographic photo of the left hand and wrist was taken for each subject to provide a measure of the overall maturation of the skeleton, as expressed in terms of a skeletal age.

II Menarche. The status quo method of data collection was used, in that it was determined whether menarche had, or had not occurred.

Anthropometric Measurements

A total of 35 anthropometric variables were directly measured, and 8 anthropometric variables were further derived from these directly observed measurements. A list of these anthropometric variables is provided on the following pages, after which a detailed explaination of the variables is presented.

A detailed description of the anthropometric measurements, and the procedures, techniques, and landmarks employed in taking them, is provided in this text because there is at this time, no internationally recognized single manual or source referencing these specifics, which often vary from one study to another (Ross, 1980).

The following series of anthropometric measurements were taken.

Heights and Lengths

vertex standing height
sitting height
acromial height *
radial height *
stylion height *
dactylion height *
iliospinale height
trochanterion height
symphysion height *
tibial height
foot length

Girths

relaxed arm girth
flexed arm girth
forearm girth
wrist girth
chest girth
waist girth
thigh girth
calf girth
ankle girth
head girth
neck girth

Note: * measurements not used in statistical analysis

Breadths, Widths and Depths

biacromial breadth
biiliocristal breadth
transverse chest width
anterior-posterior chest depth
bi-epicondylar humerus width
bi-epicondylar femur width

Skinfolds

triceps skinfold
subscapular skinfold
suprailiac skinfold
abdominal skinfold
front thigh skinfold
medial calf skinfold

Weight

body weight

The following measurements were derived from the directly observed measurements previously listed.

Lengths: upper arm, forearm, hand, trunk, thigh.

Proportional Masses: fat, skeletal, muscle, residual.

The landmarks and terminology referred to were those established by, Brown, Carter, Hebbelinck, Ross, Behnke, Jr., and Savage, in a Leon and Thea Koerner Foundation Study Group (Ross, Brown, Hebbelinck & Faulkner, in Shephard & Lavallee, 1978:44-49).

The landmarks were identified by palpation of the skeleton and were marked with a dermatographic pencil. Care was taken to ensure that movement of the underlying skin did not misplace the actual marking. Prior to taking the actual measurement, the anthropometrist again identified the point, ensuring that the landmark was identified accurately.

I Height and Length Measurements

Unless otherwise indicated, the following conditions applied to the height and length measurements:

Instruments

All height and length measurements, except foot length, were made with an adaptable Martin design anthropometer, comprised of four, 50 centimeter long segments, and a horizontal pointed crossbar. (Manufactured by G P M and distributed by Siber-Hegner).

Accuracy

Measurements were read to the nearest 0.1 centimeter.

Body Position

The subject stood erect, feet together, with toes directed forward, and with the weight equally distributed on both feet. The head and eyes were fixed in the Frankfort plane, and the arms were extended loosely down the sides of the body with the fingers extended, but not held along the thighs.

Technique

The anthropometer base was stabilized on the standing surface by the anthropometrist and was located in front, and to the right side, of the subject. The anthropometer spine was held vertical and stable by the supporting base and the anthropometrist.

The anthropometer crossbar was lowered down the vertical spine until the point of the arm was on the designated landmark. "The anthropometer arm indicated the height from the floor of each designated landmark" (Whittingham, 1978:72).

All measurements were taken from the right side of the body.

I (i) Vertex Standing Height

Definition of measurement: "Maximum height from the soles of the feet to the vertex when the head is in the Frankfort Plane" (Whittingham, 1978:61).

Landmark: "Vertex - the most superior point on the skull, in the mid-sagittal plane when the head is held in the Frankfort Plane" (Ross et al., in Shephard & Lavallee, 1978:46).

Technique: The anthropometer base was stabilized on the standing surface by the anthropometrist and was located posterior to the subject. The anthropometer spine was held vertical and stable by the supporting base and the anthropometrist.

The horizontal crossbar of the anthropometer was brought down in the mid-sagittal plane to sit firmly on the subject's vertex.

I (ii) Sitting Height

Definition of measurement: "The maximum height of the vertex while seated with the head in the Frankfort Plane" (Whittingham, 1978:64). This measurement is also referred to as stem height.

Landmark: The vertex (see Vertex Standing Height)

Body Position: The subject sat on a table with her knees bent over the edge at approximately 90 degrees, and with her legs suspended. The subject's hands rested on her thighs. With the weight equally distributed on the buttocks, and with the sacral and thoracic spine resting against the anthropometer, the subject was instructed to "sit tall" and was manually assisted to do so. The head was positioned in the Frankfort plane.

Technique: The technique was the same as that used in taking the Vertex Standing Height measurement, only with the anthropometer base stabilized on the sitting surface.

I (iii) Acromial Height

Definition of measurement: The height from the soles of the feet to the acromial point with the arms relaxed and hanging loosely at the sides.

Landmark: "Acromiale - Acromial point - the point at the superior and external border of the acromial process when the subject is standing erect with relaxed arms" (Ross et al., in Shephard & Lavalle, 1978:47).

This point was located by palpating along the length of the spine of the scapula, or by having the subject bend the trunk laterally to relax the deltoid muscles (Whittingham, 1978:74).

I (iv) Radial Height

Definition of measurement: The height from the soles of the feet to the radial point, with the arms relaxed and hanging loosely at the sides.

Landmark: "The point at the upper and lateral border of the head of the radius" (Ross et al., in Shephard & Lavallee, 1978:47).

> This point was located by palpating downward in the lateral dimple at the elbow where the rotating head of the radius could be felt under the stationary condyle of the humerus, especially when the subject slightly pronated and supinated the forearm.
>
> (Whittingham, 1978:75)

I (v) Stylion Height

Definition of measurement: The height from the soles of the feet to the stylion point with the arms relaxed and hanging loosely at the sides.

Landmark: "The most distal point of the styloid process of the radius" (Ross et al., in Shephard & Lavallee, 1978:47).

By approaching the area from the distal aspect of the wrist joint, this point was located in the "anatomical snuff box" or that triangular area formed when the thumb was extended laterally. The area was defined by the raised tendons of the muscles of the abductor pollicus longus and extensor pollicus brevis with the extensor pollicus longus. Palpation of the point during passive abduction and adduction of the hand and wrist also aided in identifying the landmark (Ross et al., in Shephard & Lavallee, 1978:47).

I (vi) Dactylion Height

Definition of measurement: The height from the soles of the feet to the most distal point of the third digit (middle finger), with the arms hanging at the sides of the body and the fingers outstretched downwards (Ross et al., in Shephard & Lavallee, 1978:47).

Landmark: "Tip of the middle finger", also termed Dactylion III (Ross et al., in Shephard & Lavallee, 1978:47).

I (vii) Iliospinale Height

Definition of measurement: The height from the soles of the feet to the iliospinale point.

Landmark: Iliospinale - the anterior superior iliac spine. The most pronounced tip, and not the most frontally curved site of the crista iliaca, is the designated landmark (Ross et al., in Shephard & Lavallee, 1978:48).

The anthropometrist palpated anteriorly along the crest of the ilium following the curve downwards until the landmark, a prominent posteriorly directed curve, was detected (Whittingham, 1978:76).

I (viii) Trochanterion Height

Definition of measurement: The height from the soles of the feet to the trochanterion point.

Landmark: "Trochanterion - the most superior point on the greater trochanter of the femur" (Ross et al., in Shephard & Lavallee, 1978:48).

This point was located by having the subject slightly abduct his leg and move it forward and backward, while the anthropometrist palpated the femur progressively upwards to determine the landmark, on the uppermost point of the greater trochanter (Ross et al., in Shephard & Lavallee, 1978:48).

I (ix) Symphysion Height

Definition of measurement: The height from the soles of the feet to the symphysion point.

Landmark: "The superior border of the symphysis pubis at the midsagittal plane" (Ross et al., in Shephard & Lavallee, 1978:47).

The landmark is generally at the upper level of the pubic hair zone and is located by proceeding downward from the navel, palpating the abdominal wall with the left thumb until the boney surface of the pubis is located. The foreside of the subject's symphysis and genitalia are inferior to the landmark (Ross et al., in Shephard & Lavallee, 1978:46).

I (x) Tibial Height

Definition of measurement: The height from the soles of the feet to the tibial externum point.

Landmark: Tibiale externum point above the capitulum fibulare on the lateral border of the head of the tibia (Ross et al., in Shephard & Lavallee, 1978:48).

The point is located at the centre of the triad formed by the epicondylar femur, the epicondylar tibia, and the head of the fibula, and is in practically the same transverse plane as the tibiale internum point on the medial border of the head of the tibia (Ross et al., in Shephard & Lavallee, 1978:48).

The upper border of the tibia was located by palpating the tendon of the quadraceps muscle at the distal end of the patella, and location of the landmark was facilitated by having the subject flex her knee, while palpation continued at the frontal border of the ligamentum collaterale (Whittingham, 1978:77).

I (xi) Foot Length

Definition of measurement: "The distance from the pternion to the akropodion" (Whittingham, 1978:90).

Landmarks: "Pternion - the most posterior point on the heel of the foot when the subject is standing" (Ross et al., in Shephard & Lavalle, 1978:49).

"Akropodion - the most anterior point on the toe of the foot when the subject is standing. This may be the first or second phalange" (Ross et al., in Shephard & Lavallee, 1978:49).

Instrument: The upper section of the Martin anthropometer, which is comprised of a double scale of measurements in cm. and mm., was used as a large sliding caliper with the addition of two straight and pointed crossbars.

Accuracy: Measurement was read to the nearest .01 centimeters.

Technique: "The caliper was fixed at the pternion and adjusted to the akropodion" (Whittingham, 1978:91). The crossbars were applied to the points at approximately halfway along their length.

Derived Lengths

The following lengths were derived from the directly observed height measurements, described previously.

I (xii) Upper Arm Length

Definition and Derivation: The distance from the acromial point to the radial point. Upper Arm Length = Acromial Height - Radial Height.

I (xiii) Forearm Length

Definition and Derivation: The distance from the radial point to the stylion point. Forearm Length = Radial Height - Stylion Height.

I (xiv) Hand Length

Definition and Derivation: The distance from the stylion point to the dactylion point. Hand Length = Stylion Height - Dactylion Height.

I (xv) Trunk Length

Definition and Derivation: The distance from the acromial point to the symphysion point "projected" horizontally.
Trunk Length = Acromial Height - Symphysion Height.

I (xvi) Thigh Length

Definition and Derivation: The distance from the symphysion point to the tibial externum point "projected" horizontally.
Thigh Length = Symphysion Height - Tibial Height.

II Breadth, Width, and Depth Measurements

Unless otherwise indicated, the following conditions applied to the breadth, width, and depth measurements:

Instruments

The biacromial and biiliocristal breadth, and the transverse chest measurements were made with a large, sliding anthropometer, an adaptation of the Martin anthropometer. The upper section of the Martin anthropometer, which is divided into a double scale of centimeters and millimeters, was used with the addition of two pointed crossbars. (Manufactured by G P M and distributed by Siber-Hegner).

Anterior-posterior chest depth was measured using the wide spreading calipers, an adaptation of the Martin caliper, consisting of a crossbar and two curved olive tipped branches. (Manufactured by G P M and distributed by Siber-Hegner).

The bi-epicondylar humerus and the bi-epicondylar femur width measurements were made with the Mitutoyo vernier calipers, as adapted by Carter in 1975 (Whittingham, 1978:57). The caliper consisted of a crossbar fitted with two branches, each having a 15 millimeter disc at their end to serve as the contact points.

Accuracy

All measurements were read to the nearest 0.1 centimeter, except the bi-epicondylar humerus and femur widths which were read to the nearest 0.01 centimeter.

Body Position

As stated in Height and Length Measurements.

Technique

Since the purpose of these measurements was to measure "skeletal" dimensions, the instrument was held firm against the subject during readings in order to reduce the influence of the subcutaneous fat.

All measurements involving the extremities were taken with the right appendages of the body.

II (i) Biacromial Breadth

Definition of measurement: "The maximum distance between the most lateral aspect of the acromion processes" (Whittingham, 1978:89).

Landmarks: The most lateral aspects of the right and left acromion processes. These aspects were slightly inferior to the most superior lateral margin defined as the acromiale (Whittingham, 1978:89).

Body Position: As stated, and with the shoulder girdle in a relaxed standing position and not abducted or adducted.

Technique: As stated, and with the pointed crossbars of the anthropometer directed upwards from the rear as the horizontal bar was held parallel to the floor and supported on the anthropometrist's forearms (Whittingham, 1978:89). The crossbars were applied to the body at approximately halfway along their length.

II (ii) Biiliocristal Breadth

Definition of measurement: "The maximum distance between the two iliac crests or the iliocristal diameter" (Whittingham, 1978:89).

Landmarks: "Iliocristale - the outermost lateral point of the crista iliaca". These landmarks are usually encompassed when obtaining biiliocristal breadth (Ross et al., in Shephard & Lavallee, 1978:48).

Technique: As stated, and the pointed crossbars were directed upwards, posteriorly from the front, at an angle of approximately 30 degrees (Whittingham, 1978:90). The horizontal bar was held parallel to the floor and supported on the anthropometrist's forearms. The crossbars were applied to the body at approximately halfway along their length.

II (iii) Transverse Chest Width

Definition of measurement: "The transverse distance from the most lateral points of the chest at the level of the fourth rib" (Whittingham, 1978:90), taken during the pause between normal expiration and inspiration. This width is also referred to as the "transverse breadth of the thorax" (Carter 1976:3).

Landmarks: The most lateral points of the ribs at the level of the fourth costosternal articulation (Carter,1976:3).

Technique: The subject's arms were raised while the caliper was positioned and then lowered for the reading.

The pointed crossbars were directed downwards at about 30 degrees, and the measurement was taken during the pause between normal expiration and inspiration. The crossbars were applied to the body at approximately halfway along their length.

Because distortion of the rib cage by applied pressure is likely to occur when measuring young children, special attention was given to applying the correct pressure and care was taken to ensure that the cross-bar arms did not slip into an intercostal space (Whittingham, 1978:90).

II (iv) Anterior-Posterior Chest Depth

Definition of measurement: "The depth of the chest at the level of the fourth intercostal articulation at end tidal expiration " (Whittingham, 1978:92).

Landmark: "Mesosternale - point located on the corpus sterni at the intersect of the midsagittal plane and the horizontal plane at the midlevel of the fourth chondrosternal articulation" (Ross et al., in Shephard & Lavallee, 1978:46).

Recognizing that the first articulation was under the clavicle, counting was started at the manubriosternal joint, which corresponds to the level of the second costal cartilage (Ross et al., in Shephard & Lavallee, 1978).

Body Position: As stated for Sitting Height.

Technique: One of the tips of the curved branches was placed on the landmark, and the other on a spinous process judged to be at the same level as the first point. The measurement was taken during the pause between normal expiration and inspiration.

As the force generated in this caliper is magnified, light pressure was applied to the instrument (Whittingham, 1978:93).

II (v) Bi-epicondylar Humerus Width

Definition of measurement: "The width between the medial and lateral epicondyles of the humerus, with the arm horizontal and forming a right angle with the forearm" (Carter, 1976:3).

Landmark: "The point on either epicondyle of the distal extremity of the humerus most lateral to the medial plane of the bone" (Carter, 1975:A-2).

Body Position: The right arm was raised forward to approximately the level of the shoulders, and the forearm flexed at the elbow forming a right angle with the upper arm (Carter, 1975:A-3).

Technique: Starting several centimeters proximal to the elbow joint the condyles were palpated (Whittingham, 1978:91).

"The discs on the branches of the calipers were applied against the epicondyles in such a manner as to bisect the angle of the joint and to lie in the same plane as the limb" (Carter, 1975:A-2).

II (vi) Bi-epicondylar Femur Width

Definition of measurement: The width between the medial and lateral epicondyles of the femur, with the thigh horizontal and forming a right angle with the lower leg.

Landmark: "The point on either epicondyle of the distal extremity of the femur most lateral to the medial plane of the bone" (Carter, 1975:A-2).

Body Position: The right foot was raised and placed flat on a bench so that the tibia was vertical to the floor, and at right angles to the femur.

Technique: Starting several centimeters proximal to the knee joint the condyles were palpated (Whittingham, 1978:92).

Also as stated for Bi-epicondylar Humerus Width.

III Girth Measurements

Unless otherwise indicated, the following conditions applied to the girth measurements:

Insruments

As cloth fiber tape tends to stretch with use, all girth measurements were taken with a narrow and flexible steel tape. The tape used was a Wyteface Tiptop, two meter long tape, #860358, manufactured by Keuffel & Esser.

Accuracy

All measurements were read to the nearest 0.1 centimeter.

Body Position

As stated for Height and Length Measurements.

Technique

> A crossed tape technique was used such that the zero line of the tape was in line with the measuring aspect of the tape. The tape was always in the horizontal plane of the body part being measured.
> (Whittingham, 1978:79)

Light pressure sufficient to maintain the tape's position, but so as not to produce indentation of the skin, was applied.

All measurements involving the extremities were taken with the right appendages of the body.

III (i) Relaxed Arm Girth

Definition of measurement: The circumference of the relaxed upper arm, taken at mid-distance between the acromion and the olecranon processes.

Landmark: Halfway between the acromion and the olecranon processes of the right arm.

With the elbow slightly flexed, a tape was placed posteriorly on the acromiale, and extended to the point of the elbow. The mid-distance was marked by a horizontal line. A vertical line joining the acromiale and the point of the elbow was projected, and a vertical mark along this projection was drawn to intersect with the horizontal line.

III (ii) Flexed Arm Girth

Definition of measurement: "The maximum girth of the flexed (and tense) arm when measured at right angles to the long axis of the humerus" (Whittingham, 1978:81).

Landmark: On the flexed bicep muscle.

Body Position: With the upper arm horizontal, the forearm was supinated and fully flexed at the elbow. The subject clenched her fist and contracted the biceps as strongly as possible (Carter, 1975:A-3).

Technique: The tape was passed around the muscle and the region of the muscle explored, with the tape always at right angles to its long axis (Carter, 1975:A-3).

III (iii) Forearm Girth

Definition of measurement: Maximum girth of the forearm when measured at right angles to the long axis of the radius, with the forearm extended at the elbow and held in the anatomical position (open palm to the front) (Whittingham, 1978:81).

Landmark: In the region of the most muscular part of the forearm.

Technique: The tape was passed around the forearm one to two centimeters distal to the elbow, and manipulated to obtain the maximum girth at right angles to the long axis of the radius (Whittingham, 1978:82).

III (iv) Wrist Girth

Definition of measurement: "Minimal girth of the wrist when measured at right angles to the long axis of the radius at a point proximal to the styloid processes of the radius and ulna." (Whittingham, 1978:82).

Landmark: Proximal to the styloid processes of the radius and ulna.

Body Position: The arm and hand were held in line and horizontal.

Technique: The tape was passed around the wrist, proximal to the styloid processes of the radius and ulna, and manipulated to obtain the minimal girth measured at right angles to the long axis of the radius (Whittingham, 1978:82).

III (v) Chest Girth

Definition of measurement: "Girth at the level of the fourth costosternal articulation obtained when the subject was in the end-tidal phase of expiration" (Whittingham, 1978:82).

Landmark: Mesosternale - see Anterior-Posterior Chest Depth.

Technique: The measurement was made facing the subject. With the subject's arms raised to the horizontal, the tape was placed around the chest at the level of the landmark. The arms were lowered to hang freely at the sides, and after checking to ensure that the tape was in a horizontal position, the measurement was taken (Whittingham, 1978:83).

The measurement was taken during the pause between normal expiration and inspiration.

III (vi) Waist Girth

Definition of measurement: "Girth at the level of the noticeable waist narrowing located approximately halfway between the costal border and the iliac crest" (Whittingham, 1978:83).

Landmark: At the narrowest point of the waist.

Technique: Light pressure was applied to the tape as it was manipulated to find the smallest girth measurement in this area.

III (vii) Thigh Girth

Definition of measurement: The girth, "one centimeter distal to the horizontal gluteal fold at the lower border of the gluteus maximus" (Whittingham, 1978:84).

Landmark: At the upper thigh, just below the gluteus maximus muscle.

Body Position: The subject stood with legs slightly parted to permit passage of the tape around the limb (Whittingham, 1978:84). Weight was equally distributed on both limbs.

Technique: The tape was placed perpendicular to the axis of the thigh, with its upper border about one centimeter distal to the gluteal fold (Carter, 1976:4).

III (viii) Calf Girth

Definition of measurement: "Maximum calf girth when measured at right angles to the long axis of the tibia" (Whittingham, 1978:84).

Landmark: On the gastrocnemius muscle.

Body Position: The subject stood with her feet approximately 10 centimeters apart, and with weight equally distributed on both limbs.

Technique: The tape was passed around the leg, near the top of the calf muscle, then lowered and manipulated to obtain the greatest girth measured at right angles to the long axis of the tibia (Carter, 1975:A-3).

III (ix) Ankle Girth

Definition of measurement: "Minimal girth of the ankle located proximally to the malleoli" (Whittingham, 1978:85).

Landmark: Proximal to the malleoli.

Body Position: As stated for Calf Girth.

Technique: "The tape was passed around the ankle proximal to the malleoli and manipulated to obtain minimal girth at right angles to the long axis of the tibia" (Whittingham, 1978:85).

Due to the elliptical shape of the ankle, visual judgement of "minimal girth" was inaccurate, and manipulation of the tape was manditory (Whittingham, 1978:85).

III (x) Head Girth

Definition of measurement: "The maximum girth of the head, immediately superior to the glabellar point" (Whittingham, 1978:85).

Landmark: Glabellar point (brow ridge).

Body Position: As stated for Sitting Height.

Technique: "The tape was pulled tight to minimize the contribution of soft tissue and hair to the true boney measurements" (Whittingham, 1978:85).

III (xi) Neck Girth

Definition of measurement: "The circumference of the neck taken at a level immediately superior to the larynx" (Whittingham, 1978:86).

Landmark: Immediately superior to the larynx.

Body Position: As stated for Sitting Height.

Technique: "The tape was kept horizontal to the longitudinal axis of the neck with little tension applied to the tape" (Whittingham, 1978:86).

IV Skinfold Thickness Measurements

Unless otherwise indicated, the following conditions applied to the skinfold measurements:

Instruments

All skinfold measurements were taken with the Harpenden skinfold caliper (Manufactured by Holtain and distributed by Quinton Instruments).

> This caliper has a spring which exerts a practically constant tension of 10 gm/mm^2 jaw surface over the measuring range 2 to 40 mm.
>
> (Tanner, 1962:241)

Accuracy

Measurements were read to the nearest 0.1 millimeter.

Body Position

As stated in Height and Length Measurements.

Technique

"The objective is to measure the thickness of a complete double layer of skin and subcutaneous tissue without including any underlying muscle tissue " (Carter, 1975:A-1).

> In all instances the skinfold was picked up at the landmark. A fold of skin plus underlying fat was grasped between the thumb and three fingers, with the back of the hand facing the measurer. Keeping the jaws of the calipers at right angles to the body surface, the contact faces of the caliper were placed one centimeter below the lowest finger, and at the depth of the mid-finger tip. The trigger of the caliper was released and while the pressure on the fingers was maintained the measurement was taken. The measurement was taken two seconds after the caliper jaws were applied. The arms of the caliper were always at right angles to the skinfold.

(Whittingham, 1978:67)

The measurement was repeated if the calipers began to slip during the measurement.

All measurements were made on the right side of the body, except for the umbilicus measurement (abdominal), which was taken on the left side.

IV (i) Triceps Skinfold

Definition of measurement: A measurement of a double layer of skin and subcutaneous tissue taken on the triceps muscle, mid-distance between the acromiale and the point of the elbow.

Landmark: As stated for Relaxed Arm Girth.

Technique: As stated, and the skinfold ran parallel to the long axis of the arm.

IV (ii) Subscapular Skinfold

Definition of measurement: A measurement of a double layer of skin and subcutaneous tissue taken below the scapula.

Landmark: "Just beneath the inferior angle of the scapula in a direction which was obliquely downwards and outwards" (Carter, 1976:5).

Technique: As stated, and "The forefinger was placed on the landmark and the thumb picked up the natural fold such that the line of the fold ran at approximately 40 degrees to the horizontal" (Whittingham, 1978:69).

IV (iii) Suprailiac Skinfold

Definition of measurement: A measurement of a double layer of skin and subcutaneous tissue taken just above the iliospinale.

Landmark: The skinfold was picked up five to seven centimeters superior to the iliospinale, and on an imaginary line joining the acromiale and iliospinale (Whittingham, 1978:70).

iliospinale -- see Iliospinale Height

acromiale -- see Acromial Height

Technique: As stated, and "the line of the fold sloped downward towards the midline at an angle of approximately 45 degrees" (Whittingham, 1978:70).

IV (iv) Abdominal Skinfold

Definition of measurement: A measurement of a double layer of skin and subcutaneous tissue taken to the left of the umbilicus.

Landmark: "The skinfold was selected five to seven centimeters to the left of and level with the umbilicus" (Whittingham, 1978:70).

Technique: As stated, and "the line of the fold was vertical" (Whittingham, 1978:70).

IV (v) Front Thigh Skinfold

Definition of measurement: A measurement of a double layer of skin and subcutaneous tissue taken on the anterior of the thigh, mid-distance between the iliac fold and the patella (Whittingham, 1978:71).

Body Position: As stated for Bi-epicondylar Femur Width, and with the thigh muscle relaxed.

Technique: As stated, and "the line of the skinfold was parallel to the long axis of the thigh" (Whittingham, 1978:71).

With some subjects, the skinfold was particularly difficult to grasp and the procedure was painful. In these cases, the subject was instructed to support the underside of the thigh with the hands. When the weight of the underthigh was heavy, it was necessary for the anthropometrist to further support the knees, with her knee under the thigh (Whittingham, 1978:71).

IV (vi) Medial Calf Skinfold

Definition of measurement: A measurement of a double layer of skin and subcutaneous tissue taken on the medial aspect of the calf.

Landmark: The measurement was made on the most medial aspect of the calf, at the level where the girth was seen to be maximal (Whittingham, 1978:71).

Body Position: As stated for Bi-epicondylar Femur Width, and with the calf muscle relaxed.

Technique: "The line of the skinfold was vertical" (Whittingham, 1978:72).

V Weight and Proportional Mass Measurements

V (i) Weight

Definition of measurement: The weight of the body taken in minimal clothing.

Instruments: Body weight was determined for all subjects with either a Detecto-Medic beam scale, or a Homs full-capacity beam scale (Both distributed by Industrial Scales Ltd.).

Accuracy: Body weight was recorded to the nearest 0.1 kilogram. Both scales were calibrated for accuracy, and where applicable, corrections were made to the recorded weight. Corrected weight values were used in all statistical tests.

Body Position: The subject, wearing minimal clothing stood in the center of the scale's platform.

Technique: The locking device was turned to the free position. With the subject standing on the platform, the weight indicators were adjusted until a balance was reached. The weight of each subject was then recorded.

V (ii) Proportional Fat Mass

Definition of measurement: The percent of estimated total body weight, that is fat weight (estimated total body weight is calculated as the sum of the anthropometrically derived fat, skeletal, muscle, and residual masses).

Derivation of measurement: The following directly observed variables were used in calculating the proportional fat mass: triceps, subscapular, suprailiac, abdominal, front thigh, and medial calf skinfolds, and vertex standing height.

V (iii) Proportional Skeletal Mass

Definition of measurement: The percent of estimated total body weight that is skeletal weight (see Proportional Fat Mass).

Derivation of measurement: The following directly observed variables were used in calculating the proportional skeletal mass: bi-epicondylar humerus and femur widths, wrist and ankle girths, and vertex standing height.

V (iv) Proportional Muscle Mass

Definition of measurement: The percent of total body weight that is muscle weight (see Proportional Fat Mass).

Derivation of measurement: The following directly observed variables were used in calculating the proportional muscle mass: relaxed arm, chest, thigh, calf, and forearm girths; triceps, subscapular, front thigh, and medial calf skinfolds; and vertex standing height.

V (v) Proportional Residual Mass

Definition of measurement: The percent of total body weight that is residual weight (see Proportional Fat Mass).

Derivation of measurement: The following directly observed variables were used in calculating the proportional residual mass: biacromial and biiliocristal breadths, transverse chest width, anterior-posterior chest depth, and vertex standing height.

Derived Proportional Masses

The fat, skeletal, muscle, and residual masses were derived from the directly observed anthropometric variables, previously described.

The Drinkwater Tactic (Drinkwater & Ross, 1979), which provides an anthropometric fractionation of the body mass into fat, skeletal, muscle, and residual mass components, was used to determine these masses, and their subsequent proportional mass contribution to total body weight.

Total body weight in these equations is the sum of the derived component weights; the skeletal, residual, muscle, and fat weights, and is referred to as the "predicted body weight". This predicted body weight may vary from the observed and directly measured "true body weight", with the difference between the two weights, indicating the ability of the anthropometric components to estimate "true" or observed body weight (SEE APPENDIX A).

The proportional mass contribution of each mass component was calculated as:

$$\frac{\text{the mass in kg.} \times 100}{\text{predicted mass (which is the sum of the 4 mass components)}}.$$

Masses were calculated for each subject, in each group, using the formulae[1]:

$$M = \frac{\bar{z} \times S + P}{\left(\frac{170.18}{h}\right)^{d}}$$

where: M = the estimated mass (Fat, Skeletal, Muscle, Residual).

h = the subject's height.

d = 3 for all masses.

P = a specific Phantom value which changes for each mass.

S = a specific Phantom standard deviation value for the mass being estimated

Mass	P	S
fat	12.13	3.25
skeletal	10.49	1.57
muscle	25.55	2.99
residual	16.41	1.90

[1] D. T. Drinkwater and W. D. Ross, "Anthropometric fractionation of body mass", in Kinanthropometry II, ed. M. Ostyn, G. Beunen and J. Simons, (Baltimore: University Park Press, 1980), p. 183.

$\bar{z}$ = the mean phantom z value, calculated for each subject, from the selected subset of variables.

The subset of variables used in calculating the specific masses, and the Phantom specification values used in calculating the z score values, for each individual subject, are:

	Phantom Specification Values[2]	
Fat Mass Variables	p	s
triceps skinfold	15.4	4.47
subscapular skinfold	17.2	5.07
suprailiac skinfold	15.4	4.47
abdominal skinfold	25.4	7.78
front thigh skinfold	27.0	8.33
medial calf skinfold	16.0	4.67
Skeletal Mass Variables		
bi-epicondylar humerus width	6.48	.35
bi-epicondylar femur width	9.52	.48
wrist girth	16.35	.72
ankle girth	21.71	1.33
Residual Mass Variables		
biacromial breadth	38.04	1.92
transverse chest width	27.92	1.74
biiliocristal breadth	28.84	1.75
anterior-posterior chest depth	17.50	1.38

[2] Ibid., p. 181.

Muscle Mass Variables	Phantom Specification Values p	s
relaxed arm girth - (π X triceps skinfold*)	22.05	1.91
chest girth - (π X subscapular skinfold*)	82.36	4.86
thigh girth - (π X front thigh skinfold*)	47.33	3.59
calf girth - (π X medial calf skinfold*)	30.22	1.97
forearm girth	25.13	1.41

Note: *skinfolds expressed in centimeters

The Phantom z values for these variables were calculated from the formula[3]:

$$z = \frac{1}{s}\left[v\left(\frac{170.18}{h}\right)^{d} - p\right]$$

where:

z = the Phantom z value (for the subject) for the variable sought

h = the subject's height

d = 1 for all of these calculations

p = the Phantom specification value for the variable

s = the Phantom standard deviation value for the variable

v = the subject's value for the variable being converted to a z score

EVALUATION OF MEASUREMENTS

Chronological Age

Chronological age, for each subject, was calculated in decimal years, from the birthdate and the date when the radiograph was taken.

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[3]Ibid., p. 183.

Maturational Evaluation

All skeletal radiographs were assessed by the criterion anthropometrist. Each radiograph was identified by a randomly assigned number, permanently embedded in the film at the time of exposure. The identities of the radiographs, and the chronological ages of the subjects remained anonymous to the rater. The rater was given all radiographs at one time, and the radiographs were assessed in no specific order.

The Tanner-Whitehouse II Method, the 20 bone specific approach for the assessment of the skeletal bones of the wrist and hand, was used exclusively in assigning skeletal ages to the radiographs. The rater was trained and practised in this method.

A difference value for Chronological Age minus Skeletal Age was computed for each subject. A positive value indicated a younger skeletal than chronological age, or a "delayed skeletal age" in reference to the chronological age. A negative value indicated an older skeletal than chronological age, or an "advanced skeletal age" in reference to the chronological age. The absolute difference value indicated the amount of this deviation in decimal years. A difference value of zero indicated that the chronological and skeletal ages were identical.

The statistics on menarche were compiled by the author.

Anthropometric Evaluation

All anthropometric derivations were calculated by the author.

Proportional mass measurements were calculated in a computer program developed by T. Wood (1980).

Mean and standard deviation values: for the maturational and anthropometric variables, for each test group, were obtained using the computer program SIMPLE DATA DESCRIPTION (Halm, 1974).

STATISTICAL ANALYSIS

Test Groupings

The research groups, designated as Group 1, Group 2, Group 3, and Group 4, were combined into the following preplanned orthogonal contrasts, for all statistical analyses:

Group 1 + Group 2 + Group 3	vs	Group 4
Group 1 + Group 2	vs	Group 3
Group 1	vs	Group 2

Statistical Analysis of Maturational Data

I Skeletal age data. A difference value for Chronological Age minus Skeletal Age was calculated for each subject. Since the skeletal age analysis of the Tanner-Whitehouse II system (Tanner et al., 1975) considers a skeletal age of 16 years as a fully mature skeleton, subjects assessed at full maturity (that is a skeletal age rating of 16 years), and over the chronological age of 16 years, were given a skeletal age rating equal to their chronological age. This adjustment was necessary in order to eliminate the introduction of artifactual Chronological Age minus Skeletal Age differences, caused exclusively by the rating system's definition of "full" maturity. It is recognized however, that this adjustment is a conservative procedure since, hypothetically, a chronologically aged 18 year old, with a full maturity rating of 16 years, and an adjusted skeletal age rating of 18 years, may have "just" attained full maturity, and thus also "just" attained the skeletal rating of 16 years.

Chronological Age minus Skeletal Age values were subjected to an analysis of variance test with application of the preplanned comparisons previously stated, using the computer program MULTIVAR (Finn, 1978).

II Menarcheal data. The incidence of menarche values were subjected to a chi-square analysis test with application of the preplanned comparisons previously stated.

Statistical Analysis of Anthropometric Data

The 39 anthropometric variables analyzed statistically, for group differences, were assembled into appropriate subset classifications as follows:

Heights and Lengths (11 variables)

Breadths, Widths, and Depths (6 variables)

Girths (11 variables)

Skinfolds (6 variables)

Weight (1 variable) and Proportional Masses (4 variables).

Each classification group of variables was subjected to a multivariate and univariate analysis of covariance test, with application of the preplanned comparisons stated previously, using the computer program MULTIVAR (Finn, 1978). The mean chronological ages for the various ability groups were not similar, and since it has been shown that the absolute values for specific anthropometric variables are functions of age (Burgess, 1937, cited in Greenberg & Bryan, 1951:163), chronological age was used as a covariate.

CHAPTER 4

RESULTS AND DISCUSSION

Sixty-nine gymnasts of varying ability levels were studied to determine if significant differences existed among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts, with respect to maturational and anthropometric characteristics.

Fifteen of the designated National Team Members formed testing Group 1, termed "National Elite". Complete anthropometric, radiographic, and menarcheal data were obtained on all fifteen subjects.

Thirteen elite gymnasts represented the "Pre-National Elite" ability group and formed testing Group 2. Complete anthropometric and menarcheal data were obtained on all thirteen subjects. Radiographic data were obtained on eight of the subjects.

Forty-one non-elite gymnasts of varying gymnastic ability were randomly selected to represent the lesser skilled, "Competitive", Group 3; and the "Recreational", Group 4, ability groups. Complete anthropometric, radiographic, and menarcheal data were obtained on all subjects in these two groups, with the exception of one radiograph for one subject in Group 4.

In this chapter the results and discussions are presented in the following manner:

Under the heading RESULTS, reference is made only to those results significant at a level of $p < .01$. Based on these results, reference to all hypotheses takes place.

Reference to the significant maturational differences, that emerge from the orthogonal contrasts, takes place under the sub-classifications of Skeletal Age, and Menarche.

Reference to the significant anthropometric differences, that emerge from the orthogonal contrasts, takes place under the collective categorial term to which that variable belongs. Discussion of a univariate is dependent on a significant multivariate.

The results are presented under the following headings:

MATURATIONAL ASSESSMENT

I Skeletal Age, II Menarche,

Summary of Results: Maturational Assessment

ANTHROPOMETRIC ASSESSMENT

I Height and Length Measures, II Breadth, Width, and Depth Measures,

III Girth Measures, IV Skinfold Thickness Measures,

V Weight and Proportional Mass Measures,

Summary of Results: Anthropometric Assessment

Under the heading DISCUSSION, reference is made to both significant and non-significant results.

The discussion proceeds under the following headings:

MATURATIONAL ASSESSMENT

ANTHROPOMETRIC ASSESSMENT

I Height and Length Measures, II Breadth, Width, and Depth Measures,

III Girth Measures, IV Skinfold Thickness Measures,

V Weight and Proportional Mass Measures

MATURITY-ANTHROPOMETRIC RELATIONSHIP

RESULTS

MATURATIONAL ASSESSMENT

I Skeletal Age

Hypothesis 1

> The maturational status, as determined by skeletal age in reference to chronological age, is significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

Table 1 presents the observed cell means and standard deviations for the chronological age, skeletal age, and the chronological age minus skeletal age difference.

Table 2 presents the univariate analysis of variance results for the chronological age minus skeletal age difference, for each preplanned orthogonal contrast.

Differences, in the mean chronological age minus skeletal age difference, in the following comparisons were found to be significant at $p < .001$ and $p < .0003$ respectively:

Group 1 + 2 + 3 vs Group 4

Group 1 + 2 vs Group 3

The difference in the mean chronological age minus skeletal age difference between Group 1 and Group 2 was not significant ($p < .03$).

The results of this study partially support the above hypothesis that there are significant differences in maturational status among the four groups. Group 1, 2, and 3, taken together, in comparison to Group 4, was found to be significantly younger in mean skeletal age in reference to

TABLE 1

OBSERVED CELL MEANS AND STANDARD DEVIATIONS FOR CHRONOLOGICAL AGE, SKELETAL AGE, AND THE CHRONOLOGICAL AGE MINUS SKELETAL AGE DIFFERENCE

		Group 1	2	3	4	1+2	1+2+3
Chronological Age (decimal years)		(n=15)	(n=13)	(n=20)	(n=21)	(n=28)	(n=48)
	$\overline{X}$	15.1	14.3	15.0	15.3	14.7	14.8
	s.d.	1.4	1.3	1.4	1.4	1.4	1.4
Chronological Age For Those Subjects With Skeletal Assessments (decimal years)		(n=15)	(n=8)	(n=20)	(n=20)	(n=23)	(n=43)
	$\overline{X}$	15.1	14.1	15.0	15.2	14.7	14.8
	s.d.	1.4	1.1	1.4	1.4	1.4	1.4
Skeletal Age (decimal years)	$\overline{X}$	12.9	13.0	14.4	14.8	12.9	13.6
	s.d.	.8	.9	1.5	1.6	.8	1.4
Chronological Age Minus Skeletal Age (decimal years)	$\overline{X}$	2.2	1.2	.6	.3	1.8	1.3
	s.d.	1.0	.6	1.2	1.1	1.0	1.2

TABLE 2

UNIVARIATE ANALYSIS OF VARIANCE RESULTS
FOR THE CHRONOLOGICAL AGE MINUS SKELETAL AGE DIFFERENCE
FOR EACH PREPLANNED ORTHOGONAL CONTRAST

	Orthogonal Contrasts		
	1+2+3 vs 4	1+2 vs 3	1 vs 2
Chronological Age Minus Skeletal Age Difference			
	(n=63)	(n=43)	(n=23)
F	11.48	15.20	5.07
p <	.001	.0003	.03

chronological age (1.0 decimal years). Similarly Group 1 and 2, taken together, in comparison to Group 3, was found to be significantly younger in mean skeletal age in reference to chronological age (1.2 decimal years).

Group 1 was found to be younger than Group 2 in mean skeletal age in reference to chronological age (1.0 decimal years). However, due possibly to the small sample size, this difference was not significant and thus does not support the stated hypothesis.

Thus, the national elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, have a significantly younger mean skeletal age in reference to chronological age than do recreational gymnasts. Similarly, national elite and pre-national elite gymnasts, taken together, have a significantly younger mean skeletal age in reference to chronological age, than do lesser skilled competitive gymnasts. However, national elite gymnasts do not differ significantly in mean skeletal age in reference to chronological age from pre-national elite gymnasts.

II Menarche

Hypothesis 2

> The incidence of menarche is significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

Table 3 presents the observed cell frequencies for the incidence of menarche.

Table 4 presents the chi-square analysis results for the incidence of menarche for each preplanned orthogonal contrast.

Differences in the mean incidence of menarche in the following comparisons were found to be significant at $p < .01$:

TABLE 3

OBSERVED CELL FREQUENCIES FOR THE INCIDENCE OF MENARCHE

	Group					
	1 (n=15)	2 (n=13)	3 (n=20)	4 (n=21)	1+2 (n=28)	1+2+3 (n=48)
Frequency of Menarche	2	6	13	19	8	21
Percent of Subjects to Have Experienced Menarche	13.3	46.2	65.0	90.5	28.6	43.8

TABLE 4

CHI-SQUARE ANALYSIS RESULTS FOR THE INCIDENCE OF MENARCHE FOR EACH PREPLANNED ORTHOGONAL CONTRAST

	Orthogonal Contrasts		
	1+2+3 vs 4	1+2 vs 3	1 vs 2
Incidence of Menarche			
X^2	21.65	7.45	3.8
$p <$	.01	.01	$p > .05$

Group 1 + 2 + 3 vs Group 4

Group 1 + 2 vs Group 3

The difference in the mean incidence of menarche between Group 1 and Group 2 was not significant ($p > .05$).

The results of this study partially support the above hypothesis that the incidence of menarche is significantly different among the four groups. Group 1, 2, and 3, taken together, was found to have a significantly smaller mean incidence of menarche than Group 4 (46.7%). Similarly Group 1 and 2, taken together, was found to have a significantly smaller mean incidence of menarche than Group 3 (36.4%).

Group 1 was found to have a smaller mean incidence of menarche than Group 2 (32.9%). However, due possibly to the small sample size, this difference was not significant and thus does not support the stated hypothesis.

Thus, the national elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, have a significantly smaller mean incidence of menarche than do recreational gymnasts. Similarly, national elite and pre-national elite gymnasts, taken together, have a significantly smaller mean incidence of menarche than do lesser skilled competitive gymnasts. However, national elite gymnasts do not have a significantly different mean incidence of menarche than do pre-national elite gymnasts.

Summary of Results: Maturational Assessment

Statistical analysis of the two maturity indicators, skeletal age and menarche, disclosed that Hypotheses 1 and 2 were partially supported. More specifically, the statistical analysis indicated that at a level of significance of $p < .01$:

1. National elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, in comparison to recreational gymnasts, are maturationally delayed, both skeletally and menarcheally.

2. National elite and pre-national elite gymnasts, taken together, in comparison to lesser skilled competitive gymnasts, are maturationally delayed, both skeletally and menarcheally.

3. National elite gymnasts, in comparison to pre-national elite gymnasts, are not maturationally different, skeletally or menarcheally.

ANTHROPOMETRIC ASSESSMENT

I Height and Length Measures

Hypothesis 3

> The measures of height and length are significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

Table 5 presents the observed cell means and standard deviations for the eleven height and length measures.

Table 6 presents the multivariate and univariate analysis of covariance results for the height and length measures for each preplanned orthogonal contrast, using chronological age as the covariate.

Group 1 + 2 + 3 vs Group 4. In the orthogonal contrast Group 1 + 2 + 3 vs Group 4, the highly significant multivariate F ($p < .001$) was due primarily to the trunk length difference (univariate $p < .0001$) with some contribution from the sitting height difference (univariate

TABLE 5

OBSERVED CELL MEANS AND STANDARD DEVIATIONS FOR HEIGHT AND LENGTH MEASURES

Variables (cm.)		Group 1 (n=15)	Group 2 (n=13)	Group 3 (n=20)	Group 4 (n=21)	Group 1+2 (n=28)	Group 1+2+3 (n=48)
Vertex Standing Height	$\bar{X}$	154.0	152.6	156.4	157.0	153.4	154.6
	s.d.	6.8	8.7	4.5	6.2	7.6	6.6
Tibial Height	$\bar{X}$	40.4	40.1	40.6	40.4	40.3	40.4
	s.d.	2.7	2.4	1.5	2.1	2.5	2.2
Iliospinale Height	$\bar{X}$	86.3	84.9	86.6	86.4	85.6	86.0
	s.d.	4.9	5.3	3.2	4.4	5.0	4.3
Trochanterion Height	$\bar{X}$	79.0	78.5	79.8	79.5	78.7	79.2
	s.d.	4.5	4.4	2.7	3.9	4.4	3.8
Foot Length	$\bar{X}$	23.1	22.8	22.9	23.2	22.9	22.9
	s.d.	1.1	1.2	.9	.9	1.2	1.1
Sitting Height	$\bar{X}$	80.2	79.5	82.5	83.3	79.9	81.0
	s.d.	3.3	4.3	3.0	3.3	3.8	3.7

TABLE 5 CONTINUED

Variables (cm.)		Group 1 (n=15)	Group 2 (n=13)	Group 3 (n=20)	Group 4 (n=21)	Group 1+2 (n=28)	Group 1+2+3 (n=48)
Upper Arm Length	$\bar{X}$	30.0	29.1	29.9	29.6	29.6	29.7
	s.d.	1.7	1.8	1.2	1.9	1.8	1.6
Forearm Length	$\bar{X}$	21.6	21.2	21.8	21.5	21.4	21.6
	s.d.	1.0	1.5	1.2	1.2	1.2	1.2
Hand Length	$\bar{X}$	17.8	18.0	17.7	18.3	17.9	17.8
	s.d.	1.3	1.0	.9	1.1	1.1	1.1
Trunk Length	$\bar{X}$	44.9	47.0	49.2	50.4	45.8	47.3
	s.d.	1.9	3.5	2.3	2.7	2.9	3.1
Thigh Length	$\bar{X}$	38.9	35.6	37.1	36.8	37.4	37.2
	s.d.	2.6	2.6	2.3	2.2	3.1	2.7

TABLE 6

MULTIVARIATE AND UNIVARIATE ANALYSIS OF COVARIANCE RESULTS FOR HEIGHT AND LENGTH MEASURES FOR EACH PREPLANNED ORTHOGONAL CONTRAST

		Orthogonal Contrasts		
		1+2+3 vs 4	1+2 vs 3	1 vs 2
Multivariate	$p <$	.001	.006	.0003
Univariates				
Vertex Standing Height	$p <$	.38	.14	.91
Tibial Height	$p <$	.75	.77	.98
Iliospinale Height	$p <$	.89	.57	.75
Trochanterion Height	$p <$	.87	.44	.84
Foot Length	$p <$	.47	.91	.72
Sitting Height	$p <$	.02	.01	.82
Upper Arm Length	$p <$	.37	.57	.34
Forearm Length	$p <$	.60	.31	.75
Hand Length	$p <$	.19	.37	.34
Trunk Length	$p <$	.0001	.0001	.001
Thigh Length	$p <$	.28	.57	.002

$p < .02$). All other height and length differences for this contrast were not significant (p's $> .19$).

Group 1 + 2 vs Group 3. In the orthogonal contrast Group 1 + 2 vs Group 3, the highly significant multivariate F ($p < .006$) was due to the trunk length difference (univariate $p < .0001$) and the sitting height difference (univariate $p < .01$). All other height and length differences for this contrast were not significant (p's $> .14$).

Group 1 vs Group 2. In the orthogonal contrast Group 1 vs Group 2, the highly significant multivariate F ($p < .0003$) was due to the trunk length difference (univariate $p < .001$) and the thigh length difference (univariate $p < .002$). All other height and length differences for this contrast were not significant (p's $> .34$).

The results of this study partially support the above hypothesis that measures of height and length are significantly different among the four groups, with primary support due to differences noted in the trunk length measure, and secondary support due to differences noted in the sitting height and the thigh length measures.

National elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, in comparison to recreational gymnasts, are significantly shorter in mean trunk length (3.1 cm).

National elite and pre-national elite gymnasts, taken together, in comparison to lesser skilled competitive gymnasts, are significantly shorter in mean trunk length (3.4 cm) and sitting height (2.6 cm).

National elite gymnasts in comparison to pre-national elite gymnasts, are significantly shorter in mean trunk length (2.1 cm) and significantly longer in mean thigh length (3.3 cm).

II Breadth, Width, and Depth Measures

Hypothesis 4

> The measures of breadth, width, and depth are significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

Table 7 presents the observed cell means and standard deviations for the six breadth, width, and depth measures.

Table 8 presents the multivariate and univariate analysis of covariance results for the breadth, width, and depth measures for each pre-planned orthogonal contrast, using chronological age as the covariate.

Group 1 + 2 + 3 vs Group 4. In the orthogonal contrast Group 1 + 2 + 3 vs Group 4, the significant multivariate F ($p < .01$) was due to the bi-epicondylar femur width difference (univariate $p < .002$). All other breadth, width, and depth differences for this contrast were not significant (p's > .09).

Group 1 + 2 vs Group 3. In the orthogonal contrast Group 1 + 2 vs Group 3, the multivariate F was not significant ($p < .14$), indicating that differences in the breadth, width, and depth measures, for this contrast, were not significant. It is of interest to note however, that irrespective of the multivariate analysis, univariate analysis (univariate $p < .007$) shows the biiliocristal breadth difference to be significant for this contrast.

Group 1 vs Group 2. In the orthogonal contrast Group 1 vs Group 2, the highly significant multivariate F ($p < .005$) was due to the anterior-posterior chest depth difference (univariate $p < .0008$). All

TABLE 7

OBSERVED CELL MEANS AND STANDARD DEVIATIONS
FOR BREADTH, WIDTH, AND DEPTH MEASURES

Variables (cm.)		Group 1 (n=15)	2 (n=13)	3 (n=20)	4 (n=21)	1+2 (n=28)	1+2+3 (n=48)
Biacromial Breadth	$\bar{X}$	34.1	33.4	34.8	34.6	33.8	34.2
	s.d.	1.6	2.1	1.5	1.8	1.9	1.8
Biiliocristal Breadth	$\bar{X}$	24.0	23.5	25.2	25.3	23.8	24.4
	s.d.	1.3	2.1	1.4	1.9	1.7	1.7
Transverse Chest Width	$\bar{X}$	23.0	22.6	23.7	23.4	22.8	23.2
	s.d.	1.2	1.5	1.3	1.4	1.4	1.4
Bi-epicondylar Humerus Width	$\bar{X}$	6.1	5.9	6.1	6.1	6.0	6.1
	s.d.	.4	.4	.3	.3	.4	.4
Bi-epicondylar Femur Width	$\bar{X}$	8.4	8.3	8.4	8.7	8.3	8.4
	s.d.	.3	.5	.3	.4	.4	.4
Anterior-Posterior Chest Depth	$\bar{X}$	14.2	15.7	15.5	15.4	14.9	15.2
	s.d.	1.0	1.5	1.4	1.2	1.4	1.4

TABLE 8

MULTIVARIATE AND UNIVARIATE ANALYSIS OF COVARIANCE RESULTS FOR BREADTH, WIDTH, AND DEPTH MEASURES FOR EACH PREPLANNED ORTHOGONAL CONTRAST

		Orthogonal Contrasts		
		1+2+3 vs 4	1+2 vs 3	1 vs 2
Multivariate	$p <$	.01	.14	.005
Univariates				
Biacromial Breadth	$p <$	.80	.07	.66
Biiliocristal Breadth	$p <$	.09	.007	.98
Transverse Chest Width	$p <$	.92	.02	.85
Bi-epicondylar Humerus Width	$p <$	.90	.39	.27
Bi-epicondylar Femur Width	$p <$	.002	.64	.66
Anterior-Posterior Chest Depth	$p <$	.71	.16	.0008

other breadth, width, and depth differences for this contrast were not significant (p's > .27).

The results of this study partially support the above hypothesis that measures of breadth, width, and depth are significantly different among the four groups, with primary support due to differences noted in the bi-epicondylar femur width and the anterior-posterior chest depth measures.

National elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, in comparison to recreational gymnasts, are significantly smaller in mean bi-epicondylar femur width (.3 cm).

National elite gymnasts in comparison to pre-national elite gymnasts, are significantly smaller in mean anterior-posterior chest depth (1.5 cm).

Although a number of differences, with respect to the breadth, width, and depth measures, were noted between the national elite and pre-national elite gymnasts, taken together, and the lesser skilled competitive gymnasts, none of these differences was significant and thus the results of this contrast do not support the stated hypothesis.

III Girth Measures

Hypothesis 5

> The measures of girth are significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

Table 9 presents the observed cell means and standard deviations for the eleven girth measures.

Table 10 presents the multivariate and univariate analysis of covariance results for the girth measures for each preplanned orthogonal contrast, using chronological age as the covariate.

TABLE 9

OBSERVED CELL MEANS AND STANDARD DEVIATIONS FOR GIRTH MEASURES

Variables (cm.)		Group 1 (n=15)	Group 2 (n=13)	Group 3 (n=20)	Group 4 (n=21)	Group 1+2 (n=28)	Group 1+2+3 (n=48)
Relaxed Arm Girth	$\overline{X}$	23.4	23.0	24.6	24.5	23.2	23.8
	s.d.	1.5	2.3	2.3	2.3	1.9	2.2
Flexed Arm Girth	$\overline{X}$	25.0	24.7	26.0	25.6	24.8	25.3
	s.d.	1.4	2.4	2.1	2.1	1.9	2.1
Forearm Girth	$\overline{X}$	22.1	21.5	22.7	22.3	21.8	22.2
	s.d.	1.1	1.7	1.4	1.2	1.4	1.5
Wrist Girth	$\overline{X}$	14.5	14.2	14.5	14.4	14.3	14.4
	s.d.	.6	.9	.6	.6	.8	.7
Chest Girth	$\overline{X}$	78.3	78.3	81.5	80.5	78.3	79.7
	s.d.	4.7	6.1	5.6	6.0	5.3	5.6
Waist Girth	$\overline{X}$	61.1	62.6	63.9	64.9	61.8	62.7
	s.d.	3.2	6.5	4.2	5.4	4.9	4.7

TABLE 9 CONTINUED

Variables (cm.)		Group 1 (n=15)	Group 2 (n=13)	Group 3 (n=20)	Group 4 (n=21)	Group 1+2 (n=28)	Group 1+2+3 (n=48)
Thigh Girth	$\overline{X}$	47.1	47.1	50.8	51.9	47.1	48.7
	s.d.	3.0	4.3	5.1	4.4	3.6	4.6
Calf Girth	$\overline{X}$	30.2	31.3	31.7	32.6	30.7	31.1
	s.d.	2.9	3.1	2.0	1.8	3.0	2.7
Ankle Girth	$\overline{X}$	19.2	19.4	19.7	20.0	19.3	19.5
	s.d.	1.1	1.5	1.1	.9	1.3	1.2
Head Girth	$\overline{X}$	53.5	52.7	53.2	53.9	53.1	53.1
	s.d.	.8	1.4	1.3	1.4	1.2	1.2
Neck Girth	$\overline{X}$	29.8	29.6	30.6	30.3	29.7	30.1
	s.d.	1.0	2.2	1.6	1.6	1.6	1.7

TABLE 10

MULTIVARIATE AND UNIVARIATE ANALYSIS OF COVARIANCE RESULTS
FOR GIRTH MEASURES
FOR EACH PREPLANNED ORTHOGONAL CONTRAST

		Orthogonal Contrasts		
		1+2+3 vs 4	1+2 vs 3	1 vs 2
Multivariate	p <	.0004	.29	.04
Univariates				
Relaxed Arm Girth	p <	.42	.04	.92
Flexed Arm Girth	p <	.99	.06	.77
Forearm Girth	p <	.95	.04	.44
Wrist Girth	p <	.64	.52	.51
Chest Girth	p <	.87	.05	.34
Waist Girth	p <	.18	.18	.16
Thigh Girth	p <	.01	.004	.43
Calf Girth	p <	.05	.20	.07
Ankle Girth	p <	.10	.28	.49
Head Girth	p <	.03	.93	.13
Neck Girth	p <	.91	.08	.94

Group 1 + 2 + 3 vs Group 4. In the orthogonal contrast Group 1 + 2 + 3 vs Group 4, the highly significant multivariate F ($p < .0004$) was due primarily to the thigh girth difference (univariate $p < .01$) with some contribution from the head girth difference (univariate $p < .03$). All other girth differences for this contrast were not significant (p's > .05).

Group 1 + 2 vs Group 3. In the orthogonal contrast Group 1 + 2 vs Group 3, the multivariate F was not significant ($p < .29$), indicating that differences in the girth measures, for this contrast, were not significant. It is of interest to note however, that irrespective of the multivariate analysis, univariate analysis (univariate $p < .004$) shows the thigh girth difference to be significant for this contrast.

Group 1 vs Group 2. In the orthogonal contrast Group 1 vs Group 2, the multivariate F was not significant ($p < .04$), indicating that differences in the girth measures, for this contrast, were not significant.

The results of this study partially support the above hypothesis that measures of girth are significantly different among the four groups, with primary support due to the difference noted in the thigh girth measure.

National elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, in comparison to recreational gymnasts, are significantly smaller in thigh girth (3.2 cm).

Although a number of differences, with respect to the girth measures, were noted between national elite and pre-national elite gymnasts, taken together, and lesser skilled competitive gymnasts; and between national elite and pre-national elite gymnasts, none of these differences was significant and thus the results of these contrasts do not support the stated hypothesis.

IV Skinfold Thickness Measures

Hypothesis 6

> The measures of skinfold thickness are significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

Table 11 presents the observed cell means and standard deviations for the six skinfold thickness measures.

Table 12 presents the multivariate and univariate analysis of covariance results for the skinfold thickness measures for each preplanned orthogonal contrast, using chronological age as the covariate.

Group 1 + 2 + 3 vs Group 4. In the orthogonal contrast Group 1 + 2 + 3 vs Group 4, the highly significant multivariate F ($p < .0001$) was due to all of the skinfold thickness differences; the triceps (univariate $p < .0001$), subscapular (univariate $p < .001$), suprailiac (univariate $p < .009$), abdominal (univariate $p < .0002$), front thigh (univariate $p < .0001$), and medial calf (univariate $p < .0001$).

Group 1 + 2 vs Group 3. In the orthogonal contrast Group 1 + 2 vs Group 3, the significant multivariate F ($p < .01$) was due primarily to the triceps (univariate $p < .001$), suprailiac (univariate $p < .009$), abdominal (univariate $p < .003$), front thigh (univariate $p < .004$), and medial calf (univariate $p < .002$) skinfold thickness differences, with some contribution from the subscapular skinfold thickness difference (univariate $p < .02$).

Group 1 vs Group 2. In the orthogonal contrast Group 1 vs Group 2, the multivariate F was not significant ($p < .98$), indicating that differences in the skinfold measures, for this contrast, were not significant.

TABLE 11

OBSERVED CELL MEANS AND STANDARD DEVIATIONS
FOR SKINFOLD THICKNESS MEASURES

Variables (mm.)		Group 1 (n=15)	2 (n=13)	3 (n=20)	4 (n=21)	1+2 (n=28)	1+2+3 (n=48)
Triceps Skinfold	$\overline{X}$	7.0	6.7	9.3	11.5	6.9	7.9
	s.d.	1.5	1.1	1.9	3.5	1.4	2.0
Subscapular Skinfold	$\overline{X}$	5.5	5.8	8.0	9.9	5.6	6.6
	s.d.	1.1	1.2	2.4	5.5	1.1	2.1
Suprailiac Skinfold	$\overline{X}$	4.0	4.0	6.6	7.5	4.0	5.1
	s.d.	1.2	1.0	3.9	4.2	1.1	2.9
Abdominal Skinfold	$\overline{X}$	5.0	4.9	9.0	11.7	5.0	6.7
	s.d.	1.3	1.2	4.9	6.1	1.2	3.9
Front Thigh Skinfold	$\overline{X}$	11.2	11.4	15.5	19.3	11.3	13.1
	s.d.	3.2	3.3	4.6	6.0	3.2	4.3
Medial Calf Skinfold	$\overline{X}$	6.4	6.2	8.9	10.9	6.3	7.4
	s.d.	1.9	1.6	1.9	4.2	1.7	2.2

TABLE 12

MULTIVARIATE AND UNIVARIATE ANALYSIS OF COVARIANCE RESULTS FOR SKINFOLD THICKNESS MEASURES FOR EACH PREPLANNED ORTHOGONAL CONTRAST

		Orthogonal Contrasts		
		1+2+3 vs 4	1+2 vs 3	1 vs 2
Multivariate	$p <$	.0001	.01	.98
Univariates				
Triceps Skinfold	$p <$	.0001	.001	.94
Subscapular Skinfold	$p <$	.001	.02	.65
Suprailiac Skinfold	$p <$	.009	.009	.71
Abdominal Skinfold	$p <$	.0002	.003	.76
Front Thigh Skinfold	$p <$	.0001	.004	.65
Medial Calf Skinfold	$p <$	.0001	.002	.89

The results of this study partially support the above hypothesis that measures of skinfold thickness are significantly different among the four groups, with primary support due to differences noted in the triceps, suprailiac, abdominal, front thigh, and medial calf skinfold thickness measures, and secondary support due to differences noted in the subscapular skinfold thickness measure.

National elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, in comparison to recreational gymnasts, are significantly smaller in mean triceps (3.6 cm), subscapular (3.3 cm), suprailiac (2.4 cm), abdominal (5.0 cm), front thigh (6.2 cm), and medial calf (3.5 cm) skinfold thickness measures.

National elite and pre-national elite gymnasts, taken together, in comparison to lesser skilled competitive gymnasts, are significantly smaller in mean triceps (2.4 cm), suprailiac (2.6 cm), abdominal (4.0 cm), front thigh (4.2 cm), and medial calf (2.6 cm) skinfold thickness measures.

Although a number of differences, with respect to the skinfold thickness measures, were noted between national elite and pre-national elite gymnasts, none of these differences was significant and thus the results of this contrast do not support the stated hypothesis.

V Weight and Proportional Mass Measures

Hypothesis 7

> The measures of weight and proportional mass are significantly different among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

Table 13 presents the observed cell means and standard deviations for the single weight and the four proportional mass measures.

TABLE 13

OBSERVED CELL MEANS AND STANDARD DEVIATIONS FOR WEIGHT AND PROPORTIONAL MASS MEASURES

Variables		Group 1 (n=15)	Group 2 (n=13)	Group 3 (n=20)	Group 4 (n=21)	Group 1+2 (n=28)	Group 1+2+3 (n=48)
Body Weight (kg.)	$\overline{X}$	43.7	44.1	48.7	50.0	43.9	45.9
	s.d.	5.3	8.0	6.7	7.8	6.6	7.0
Proportional Fat Mass *	$\overline{X}$	9.5	9.4	11.8	13.9	9.4	10.4
	s.d.	1.1	.9	1.6	3.2	1.0	1.8
Proportional Skeletal Mass *	$\overline{X}$	18.3	17.7	17.0	17.0	18.0	17.6
	s.d.	1.5	1.2	1.5	1.5	1.4	1.5
Proportional Muscle Mass *	$\overline{X}$	46.9	46.9	45.7	44.2	46.9	46.4
	s.d.	1.6	1.5	1.6	1.8	1.5	1.6
Proportional Residual Mass *	$\overline{X}$	25.6	26.1	25.6	25.0	25.8	25.7
	s.d.	1.2	1.4	1.3	1.3	1.3	1.3

* Note: Masses expressed in percent

TABLE 14

MULTIVARIATE AND UNIVARIATE ANALYSIS OF COVARIANCE RESULTS
FOR WEIGHT AND PROPORTIONAL MASS MEASURES
FOR EACH PREPLANNED ORTHOGONAL CONTRAST

		Orthogonal Contrasts		
		1+2+3 vs 4	1+2 vs 3	1 vs 2
Multivariate	$p <$	.0001	.006	.37
Univariates				
Body Weight	$p <$	.07	.02	.32
Proportional Fat Mass	$p <$	.0001	.0003	.87
Proportional Skeletal Mass	$p <$	.35	.01	.04
Proportional Muscle Mass	$p <$	.0001	.009	.82
Proportional Residual Mass	$p <$	.04	.48	.35

Table 14 presents the multivariate and univariate analysis of covariance results for the weight and proportional mass measures for each preplanned orthogonal contrast, using chronological age as the covariate.

Group 1 + 2 + 3 vs Group 4. In the orthogonal contrast Group 1 + 2 + 3 vs Group 4, the highly significant multivariate F ($p < .0001$) was due primarily to the proportional fat (univariate $p < .0001$) and muscle mass (univariate $p < .0001$) differences, with some contribution from the proportional residual mass difference (univariate $p < .04$). Body weight and proportional skeletal mass differences for this contrast were not significant (p's > .07).

Group 1 + 2 vs Group 3. In the orthogonal contrast Group 1 + 2 vs Group 3, the highly significant multivariate F ($p < .006$) was due primarily to the proportional fat (univariate $p < .0003$), skeletal (univariate $p < .01$), and muscle (univariate $p < .009$) mass differences, with some contribution from the body weight difference (univariate $p < .02$). The proportional residual mass difference for this contrast was not significant (univariate $p < .48$).

Group 1 vs Group 2. In the orthogonal contrast Group 1 vs Group 2, the multivariate F was not significant ($p < .37$) indicating that differences in the body weight and the proportional mass measures, for this contrast, were not significant.

The results of this study partially support the above hypothesis that measures of weight and proportional mass are significantly different among the four groups, with primary support due to differences noted in the proportional skeletal mass measure.

National elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, in comparison to recreational gymnasts, are significantly smaller in mean proportional fat mass (3.5%) and significantly larger in mean proportional muscle mass (2.2%).

National elite and pre-national elite gymnasts, taken together, in comparison to lesser skilled competitive gymnasts, are significantly larger in mean proportional muscle (1.2%) and skeletal (1.0%) masses; and significantly smaller in mean proportional fat mass (2.4%).

Although a number of differences, with respect to the weight and proportional mass measures, were noted between national elite and pre-national elite gymnasts, none of these differences was significant and thus the results of this contrast do not support the stated hypothesis.

Summary of Results: Anthropometric Assessment

Statistical analysis of the anthropometric measures of height and length; breadth, width, and depth; girth; skinfold; and weight and proportional mass disclosed that Hypotheses 3, 4, 5, 6, and 7 were partially supported. More specifically, the statistical analysis indicated that at a level of significance of $p < .01$:

1. National elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, in comparison to recreational gymnasts, are shorter in mean trunk length, smaller in mean bi-epicondylar femur width, thigh girth, and triceps, subscapular, suprailiac, abdominal, front thigh, and medial calf skinfolds. They also have a smaller mean proportional fat mass and a larger mean proportional muscle mass than the recreational gymnasts.

2. National elite and pre-national elite gymnasts, taken together, in comparison to lesser skilled competitive gymnasts, are shorter in mean sitting height and trunk length, and smaller in mean triceps, suprailiac, abdominal, front thigh, and medial calf skinfolds. They also have a smaller mean proportional fat mass, and larger mean proportional muscle and skeletal masses, than the lesser skilled competitive gymnasts.

3. National elite gymnasts, in comparison to pre-national elite gymnasts, are shorter in mean trunk length, longer in mean thigh length, and smaller in anterior-posterior chest depth.

DISCUSSION

MATURATIONAL ASSESSMENT

Maturational differences among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts were expected. Those females involved in gymnastics and gymnastic-related sports, such as figure skating, in comparison to normal reference (Faulkner, 1977; Ross et al., in Taylor, 1976:257) and athletic samples (Malina et al., 1973), have consistently been assessed as late maturers based on their ages of menarche.

Significant maturational differences among female gymnasts of varying ability levels were found in the present study. These differences indicated that there may be a relationship between gymnastic ability and maturity, with highly skilled gymnasts being developmentally less mature than lesser skilled gymnasts. The fact that significant maturational differences were not found between national elite and pre-national elite gymnasts, possibly serves to further support a maturity-ability relationship since these two groups are considered to be relatively close in ability.

> Some of the gymnasts who passed Level II and all the gymnasts of Level III, [Level III gymnasts referred to are categorized as pre-national elite gymnasts] if they also show very good results at selection meets, could be eligible for selection for some international tournaments and dual meets' for junior and senior levels [junior and senior levels referred to, are categorized as national elite gymnasts].
>
> (Bajin, 1978:1)

However, it should also be noted that the Chronological Age minus Skeletal Age difference, when compared between Group 1 and Group 2 was approaching significance, with the former group being developmentally less mature than the latter group.

Furthermore, the maturity indicators suggest a consistent trend concerning maturational status and success in gymnastics, such that accompanying progressive increases in gymnastic ability are progressive decreases in maturational status (Chronological Age minus Skeletal Age differences increase such that; Group 4 < Group 3 < Group 2 < Group 1; and also Group 1 + 2 + 3 < Group 1 + 2. The frequency (%) of the incidence of menarche decreases such that; Group 4 > Group 3 > Group 2 > Group 1; and also Group 1 + 2 + 3 > Group 1 + 2).

From these observations, it can be hypothesized that; "those female gymnasts who are late maturers, are more apt, than average or early maturing female gymnasts, to progress to higher performance levels".

It is not unreasonable to expect that maturity is related both directly and indirectly to success in gymnastics since:

1. Some of the major physique characteristics of female gymnasts that have reached a high degree of success, a relatively short stature and light weight; small skinfold thickness, girth, bicristal breadth, and trunk length measurements; relatively long legs, and low percent body fat

(De Garay et al., 1974; Drazil, 1971; Grossfeld, in Nichols, 1979:18; Hirata, 1966; Nelson, 1974; Novak et al., 1973, 1977; Pool et al., 1969; Sinning & Lindberg, 1972; Smit, 1973; Sprynarova & Parizkova, 1979; Youngren, 1969) are also present in the young pre-pubescent and late maturing female (Tanner, 1962).

> The late maturing girl is characteristically longer-legged and narrower hipped, has a more linear physique, has less weight for height, and has less relative fatness than her early maturing peers.
>
> (Malina et al., 1978:221)

2. The ultimate adult physique of the late maturing female appears also to resemble that physique associated with success at elite gymnastic levels. Although the literature is non-conclusive, "late" maturing females, as adults, are reported to be shorter than average (Frisch & Revelle, 1969) or of average height (Tanner, 1962:96), to possess a higher ponderal index (Hillman et al., 1970), to be more ectomorphic (Zuk, 1958), have wider shoulders (Bayley, 1943b, cited in Tanner, 1962:102), and a smaller bi-iliac diameter in relation to height (Tanner, unpublished, cited in Tanner, 1962:102) than average and late maturing females.

3. A delayed maturity with its concomitantly longer pre-pubescent period has been associated with an extended critical learning period in female figure skaters (Faulkner, 1977; Ross & Marshall, 1979). Whether or not critical learning periods per se, do exist in gymnastics and other gymnastic-related sports, such as figure skating, is not known. It appears reasonable however, to suggest that a physique free of pubertal characteristics, such as increased weight, fat, and overall dimensions, (Tanner, 1962:10) would be an advantage in learning and mastering specific skills.

4. The literature tends to indicate that puberty in females offers no "strength advantage", as it does in males (Church, 1976) and furthermore, is associated with a plateau or decrease in performance (Espenchade, 1940, 1960, cited in Malina, 1974:127; Johnson & Buskirk, 1974). This occurrence however, may well be a social or life-style related phenomenon rather than a result of biological maturity and ageing, since an obvious unwillingness in females to "perform" has been noted (Kriesel, 1977), and the cross-sectional studies of Fleishman (1964) and Hunsicker and Reiff (1966, both cited in Malina, 1974:128) indicate a slight but continued improvement in performance through to 17 years.

   Furthermore, Pool et al. (1969:336) reported that strength did not correlate with performance in female gymnasts, and concluded that; "this measure has likely no meaning for selection or training of top gymnasts". This result is not surprizing in view of the fact that gymnastic-activity for females involves "high relative, rather than absolute strength" (Ross & Marshall, 1979:13). Thus, any strength increase that puberty may bring, without an associated increase in relative strength, would probably affect gymnastic performance very little.

5. Regular, strenuous exercise has a potentially great influence on modifying the body, compositionally, physiologically, and dimensionally (Astrand & Rodahl, 1970; Behnke & Wilmore, 1974; Brozek, 1961; Malina, 1969a), and it has been proposed that exercise carried to excess during or previous to the pubertal years, may affect the maturing processes by "loading" an organism already "stressed" by pubertal changes (La Cava, 1974). Such a proposal is well founded since other external variables,

such as sleep (Goldfarb, 1977) and nutrition (Charzewska et al., 1975; Kralj-Cercek, 1956; Tanner et al., 1975:19), are known to "stress" and affect specific adolescent events. As well, "critical metabolic fat masses" have been associated with triggering the onset of menarche (Frisch & McArthur, 1974). In the event that such "critical masses" do exist, and at the present time there is a lack of evidence to suggest that they do (Billewicz et al., 1976; Crawford & Osler, 1975; Johnston et al., 1971, 1975), it can be conjectured that exercise can directly affect the maturing processes by altering the composition of the body.

Gymnasts at elite and competitive ability levels, involved in regular strenuous training regimes, display the effects of exercise in modifying the body (a low percent fat mass in the presence of a high percent lean body mass), to a greater degree than gymnasts with less involvement. Furthermore, without disregarding genetical associations with the rate of maturity, it can be expected that those gymnasts involved in more frequent and strenuous training programs, would reflect maturational changes associated with exercise to a greater extent, than gymnasts with less strenuous and regular involvement. If regular, strenuous exercise has the effect of altering the "normal" rate of maturity, of an individual, then dramatic changes in growth and/or maturity should be "expected" upon cessation of activity, in accordance with the "catch-up" phenomenon proposed by Tanner (1963). While there is no supportive documentation, a number of gymnasts have reported experiencing menarche following an extended period of rest, following cessation of strenuous training, and accompanying increases in weight.

The advantage of a delayed maturity and an extended pre-pubescent period may be a very real and important factor in success for female gymnasts, since there is some speculation that female gymnasts from the Soviet Union and Eastern Europe may be using a "brake" drug to remain petite and lithe, by delaying puberty (Quinn, 1979:50). Dr. Klein, the chief medical examiner at the 1978 World Gymnastic Championships, has reported seeing photos of a leading Soviet gymnast, showing a steady regression of breast development during a four year period. It is suspected that the drug acts on the pituitary gland, and gives the smaller, lighter females, a higher strength-to-weight ratio allowing them to outperform their competitors (Quinn, 1979: 50).

The lowering in age of both the participants and the medalists of women's gymnastics in the Olympics, from the 1956 to the 1976 Games (Krustev, 1977), the domination of Olympic gymnastics by females in the teenage group (Novak et al., 1977), and the increasing complexity of skill performance, has led to the speculation that the "younger" gymnast may possess distinct "advantages" over the "older" performer, by virtue of her unique build.

Since a "performance discriminating factor", in that the equipment does not offer equal advantages to all gymnasts, is recognized as operating in gymnastics (Valliere, in Salmela, 1976:96), it follows that those gymnasts possessing physical attributes that "co-operate" with the equipment's properties and potentials, are more successful in performing specific movements than those gymnasts with physical attributes that do not conform with the equipment's capacities. These attributes may well be uncontrollable and unalterable physical expressions as skeletal proportions, size, or "build" in general. There is the possibility then, that as yet unidentified variables are present in the young female gymnastic competitor, rendering her more "biomechanically" equipped to perform gymnastic-type movements than the "older" performer, and biasing performance in her favour.

Whether or not the pre-pubescent female is better equipped "biomechanically" and functionally, to perform complex gymnastic skills, and whether or not puberty is the "despoiler of athletic maids" as Cranston (cited in Clark, 1980:6) contends, is at this time only speculative since there is an absence of direct evidence.

ANTHROPOMETRIC ASSESSMENT

Anthropometric differences among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts were expected since:

1. Disparity and inconsistencies in anthropometric descriptions of gymnasts have been attributed, in part, to ability differences (Carter et al., 1971).

2. Specific anthropometric characteristics have been shown to present biomechanical advantages (Hebbelinck & Ross, in Nelson & Morehouse, 1974:546; Khosla, 1968, 1977; Lewis, 1969), and to affect performance outcomes of gymnastic skills (George, in Salmela, 1976:96; Le Veau et al., 1974; Nelson, 1974; Ross & Marshall, 1979; Rozin, 1974; Salmela, 1976; Valliere, in Salmela, 1976:96). These "advantageous" characteristics were expected to be present more consistently in the higher skilled than in the lesser skilled gymnasts. However, it was also considered that while specific physical characteristics would be an advantage to performance in one event, they may serve as deterrents

to success in another (Le Veau et al., 1974; Rozin, 1974; Youngren, 1969). Therefore, it was recognized that the best body-type for gymnasts competing in all events, would be a compromise of the ideal morphological determinants best suited for a one-event specialist, as suggested by Salmela et al. (1976:169). In this respect, it was expected that "dramatic differences" among the ability groups would not be displayed, since the better gymnasts, competing in all events, would have physique characteristics of a compromising nature.

3. Exercise has the effect of modifying specific physical parameters, such as skinfold thickness values, and muscle girth dimensions (Brozek, 1961; Malina, 1969a), and it was expected that highly skilled gymnasts involved in frequent, vigorous training would display exercise induced changes to a greater extent than lesser skilled gymnasts.

4. Maturational differences were expected among the ability groups, and it was expected that these differences would be represented anthropometrically, in those physical parameters, such as biiliocristal breadth, height, weight, and percent body fat, undergoing changes associated with maturity (Parizkova, 1959, 1961b; Reynolds, 1950; Tanner, 1962:45).

Because of the relative closeness in ability of the national elite and the pre-national elite gymnasts (Bajin, 1978), and because it has repeatedly been shown that the higher the ability level the narrower the variability of physique (Carter, 1970; Montpetit, in Salmela, 1976:183), few significant differences between these groups, in those anthropometric variables related to success, were expected. Differences between these groups were expected however, since anthropometric differences between higher and lesser placing gymnasts at elite competitions have been reported (Montpetit, in Salmela, 1976:183; Pool et al., 1969; Youngren, 1969). It was also considered that significant differences would possibly indicate those anthropometric variables distinguishing the consistently "better" gymnasts, the national elites, from the "very good" gymnasts, the pre-national elites.

Trends concerning anthropometric parameters and gymnastic ability were not clearly identifiable in the literature, due primarily to an absence of studies concerned directly with varying ability levels and anthropometric parameters. Of the three studies located, involving these two variables (Montpetit, in Salmela, 1976:183; Pool et al., 1969; Youngren, 1969), all were comparisons between the "winners" of a competition and the lesser placing participants. Montpetit (in Salmela, 1976:183) compared the top five placing women's gymnastic teams at the 1972 Olympic Games. Although there were no consistent trends among the five teams, in age, height, or weight, the first and second placing teams were shorter in height and lighter in weight than the third placing team. Similarly, Pool et al. (1969) compared the higher and lower placing gymnasts of the 1967 European Gymnastic Championships, and found the better performers to be younger, shorter, lighter, and smaller in the skinfold thickness meaurement taken. Youngren (1969) compared the placing and non-placing gymnasts at the 1968 U.S. Olympic Gymnastic Trials, and also noted that those gymnasts who were younger, shorter, and thinner in skinfold thickness measures, tended to rank higher.

In the absence of studies concerned directly with varying levels of gymnastic ability and anthropometric parameters, trends concerning these two variables were investigated and interpolated through inter-study comparisons of Olympic (De Garay et al., 1974; Hirata, 1966; Montpetit, in Salmela, 1976:187; Novak et al., 1977; Pool et al., 1969; Ross, 1980), "highly skilled" (Carter, 1970; Nelson, 1974; Novak et al., 1973; Pool et al., 1969; Sinning & Lindberg, 1972; Smit, 1973; Sprynarova & Parizkova, 1969; Youngren, 1969), and recreational female gymnasts (Medved, 1966; Pool et al., 1969). This procedure was followed with some reservation however, since measurement techniques, and the criterion for defining ability levels, were not consistent from one study to the next. These inconsistencies may well account for anothropometric differences noted among the ability groups, as well as for the concealment of any "true" and existing differences. Even within the seemingly well defined ability group, "Olympic gymnasts", there exists varying ability levels. The "Olympic participants" of one country may well be, merely, of equal ability to the "highly skilled" gymnasts of another. The Olympic gymnasts studies by Novak et al. (1977:276) were all from one country that "did not reach a significant place during the competition". The Olympic gymnasts studied by Montpetit (in Salmela, 1976:183), comprised the "top five teams" of the 1972 Olympic Games. Furthermore, the ability classifications "highly skilled" and "recreational" contain much variability in terms of gymnastic skill level and ability.

Age is another factor that may account for anthropometric differences noted among varying ability levels, and among gymnasts of the same ability. Large age differences among the various studies compared may also mask "true" anthropometric differences and similarities. There is much variability in mean ages among the gymnastic groups referred to in the inter-study comparisons. The "Olympic gymnasts" vary in mean ages from 17.0 to 23.1 years (De Garay et al., 17.8 yrs; Hirata, 22.7 yrs; Montpetit, 20.2 yrs; Novak et al., 19.0 yrs; Pool et al., 23.1 and 19.2 yrs; Ross, 17.0 yrs), the "highly skilled gymnasts" from 15.0 to 20.5 years (Carter, age not given; Nelson, 20.5 yrs; Novak et al., 14.3 yrs; Pool et al., 20.5 yrs; Sinning & Lindberg, 20.0 yrs; Smit, 15.0 yrs; Sprynarova & Parizkova, 17.2 yrs; Youngren, 18.5 yrs), and the "recreational gymnasts" from 20.1 to 22.7 years (Medved, 20.1 yrs; Pool et al., 22.7 yrs).

The gymnasts in the varying ability groups from the present study range in mean ages from 14.3 to 15.3 decimal years.

I Height and Length Measures

Vertex standing height. The literature did not indicate a trend towards shortness in stature with increasing gymnastic ability, contrary to what was expected. Olympic gymnasts (De Garay et al., 1974; Hirata, 1966; Montpetit, in Salmela, 1976:187; Novak et al., 1977; Pool et al., 1969; Ross, 1980) did not differ notably in mean height from highly skilled gymnasts (Carter, 1970; Nelson, 1974; Novak et al., 1973; Pool et al., 1969; Sinning & Lindberg, 1972; Smit, 1973; Sprynarova & Parizkova, 1969; Youngren, 1969), or from recreational gymnasts (Medved, 1966; Pool et al., 1966). However, in comparison to appropriate female reference populations, the gymnasts described by Carter (1970), Medved (1966), Nelson (1974), Sinning and Lindberg (1972), and Smit (1973) were reported to be shorter in stature, with the Sinning and Lindberg gymnasts significantly shorter. On the other hand, the highly skilled gymnasts of Nelson's study (1974) were reported to be of similar height to an appropriate reference population of females.

Significant differences in height between national elite and pre-national elite gymnasts, taken together, and lesser skilled competitive gymnasts; and between national elite and pre-national elite gymnasts, were not expected based on the observation that elite and highly skilled gymnasts in general are short, and it appears that a relatively short stature is a prerequisite for successful participation at these levels.

A significant difference between national elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, and recreational gymnasts were expected since, a relatively short stature does not appear to be a prerequisite for participation at recreational levels, where skill level is relatively low and emphasis is generally placed on participation, rather than on performance.

Although Group 1 + 2 + 3 has a shorter mean height than Group 4 (2.6 cm), Group 1 + 2 a shorter mean height than Group 3 (3.0 cm), and Group 1 a taller mean height than Group 2 (1.4 cm), these differences were not significant. However, they do indicate a trend towards shortness in stature for higher skilled in comparison to lesser skilled gymnasts.

The non-significant difference in height noted between Group 1 and Group 2 was expected due to the relative closeness in ability of these two groups (Bajin, 1978). This result is similar to results noted in the studies of Pool et al. (1969) and Youngren (1969), in which higher placing gymnasts were not significantly different in height from lower placing gymnasts of similar ability. However, the tendency for higher placing gymnasts to be shorter than lower placing gymnasts noted in these studies, was not evident in the present comparison of national and pre-national elite gymnasts.

The non-significant difference noted between Group 1 + 2 + 3 and Group 4 is not in agreement with the expected result, and with the comparison of gymnasts in Pool et al.'s study (1969), in which high caliber Dutch gymnasts were found to be significantly shorter in stature than lower caliber, non-competing Dutch gymnasts. The non-significant difference in the present study may have occurred as a result of club "attitudes". In clubs where the recreational level is viewed as a "base" for the competitive programs, participants are often pre-selected on shortness in stature, among other variables, for inclusion in the recreational program. Perhaps too, those girls who are relatively tall pursue activities other than gymnastics, while relatively short girls are attracted to recreational gymnastic classes.

Because significant height differences among the ability groups were not found, this does not simultaneously indicate that height is not an important variable for participation and success in gymnastics. A relatively small stature, coupled with a light weight, has been shown to present a biomechanical advantage in performing gymnastic-type movements (Le Veau et al., 1974; Nelson, 1974; Ross & Marshall, 1979).

In comparison to Olympic gymnasts described by De Garay et al. (1974), Hirata (1966), Montpetit (in Salmela, 1976:187), Novak et al. (1977), and Ross (1980), both the national elite and the pre-national elite gymnasts in the present study have a smaller mean height. The non-mongolian Olympic competitors described by Pool et al. (1969) are also taller in mean height than both the national elite and the pre-national elite gymnasts, while the mongolian competitors are the only Olympic gymnasts described in the literature to be similar in height to both the national elite and the pre-national elite gymnasts.

In comparison to highly skilled gymnasts described by Carter (1970), Nelson (1974), Sinning and Lindberg (1972), Smit (1973), Sprynarova and Parizkova (1969), and Youngren (1969), the competitive gymnasts in the present study have a shorter mean height. However, in comparison to the highly skilled gymnasts described by Novak et al. (1973), the competitive gymnasts have a similar mean height.

In comparison to the recreational gymnasts described by Medved (1966) and Pool et al. (1969), the recreational gymnasts in the present study have a shorter mean height.

Trunk length. This measurement appears to have been neglected in the literature, with only a single study (De Garay et al., 1974) including this measure in an anthropometric series of measurements. Speculations concerning trunk length and ability were not made although it was noted in the literature that; "A very long torso ... will get in your way on the uneven bars" (Grossfeld, cited in Nichols, 1979:18).

The trunk length measure was significantly smaller in Group 1 + 2 +3 in comparison to Group 4, in Group 1 + 2 in comparison to Group 3, and in Group 1 in comparison to Group 2. This consistency indicates a trend towards shortness in trunk length for higher skilled gymnasts in comparison to lesser skilled gymnasts, and a possible relationship between ability and trunk length, with a shorter trunk length presenting an advantage in gymnastics. Perhaps a short trunk length in relation to height may result in a reduced moment of inertia about the trunk and head in twisting movements. Furthermore, proportional analysis of the trunk length measure, in relation to leg length or height would have maturational implications:

> About a year separates the peaks of total leg length and trunk length ... The spurt in height is due more to an increase in length of trunk than length of leg, however, and the ratio of trunk length/leg length always increases during adolescence.
>
> (Tanner, 1962:12-13)

These results indicate that the trunk length measure is worthy of further analysis, especially with respect to proportional assessments.

In comparison to Olympic gymnasts described by De Garay et al. (1974), both the national elite and the pre-national elite gymnasts in the present study have a shorter mean trunk length. It should be noted however, that the suprasternal point, used in obtaining this measure, was not the same landmark point as that used in the present study.

Sitting height. This measure appears to have been neglected in the literature with only two studies (Nelson, 1974; Ross, 1980) including this measure in an anthropometric series of measurements. The Olympic gymnasts described by Ross (1980), in comparison to the highly skilled gymnasts described by Nelson (1974), have a smaller mean sitting height. Based on this comparison it was speculated that in the present study higher skilled gymnasts would possess a smaller mean sitting height than lesser skilled gymnasts.

The sitting height measure was significantly smaller in Group 1 + 2 in comparison to Group 3, and the sitting height difference between Group 1 + 2 + 3 and Group 4 was approaching significance, with this former group having a smaller mean than the latter. These results, in conjunction with those obtained for trunk length and vertex height, strongly suggest a trend towards shortness in the torso for higher skilled in comparison to lesser skilled gymnasts. These results also suggest that a short torso in relation to height may be associated with gymnastic ability, either directly by providing some biomechanical advantage, or indirectly, possibly by presenting less weight in the upper body; assuming that a long torso would weight more than a short. Such a weight distribution may have some implications for angular (rotary) motion where "not only is the weight important but also its distribution in relation to the axis of rotation" (Nelson, 1974:46). Further analysis is necessary however, before such relationships can be established.

In comparison to Olympic gymnasts described by Ross (1980), both the national elite and the pre-national elite gymnasts in the present study have a shorter mean sitting height.

In comparison to highly skilled gymnasts described by Nelson (1974), the competitive gymnasts in the present study have a shorter mean sitting height.

Thigh length. A trend concerning thigh length and gymnastic ability was not evident in an inter-study comparison of Olympic (Novak et al., 1977; Ross, 1980) and highly skilled gymnasts (Nelson, 1974). The gymnasts described by Ross (1980) were given two values for thigh length, each derived using different equations, with a difference of 13.6 cm in thigh length between the two measurements. This difference serves to illustrate that caution should be used in inter-study comparisons of anthropometric measurements, especially with respect to those measurements likely to have varying landmark points, or derivations.

The thigh length measure was significantly longer in Group 1 in comparison to Group 2. Since this was the only significant difference to emerge among the contrasts, it is possible that this is a spurious result. However, since Group 1 + 2 and Group 1 + 2 + 3, both have "slightly" longer mean thigh lengths than Group 3 and Group 4 respectively, there appears to be a "suggestion" that highly skilled gymnasts, in comparison to lesser skilled gymnasts tend to have longer thigh lengths.

Considering the thigh length results, those of the trunk length, and the tendency for higher skilled gymnasts to be shorter in vertex standing height than lesser skilled gymnasts, it appears that there may be proportional length differences among the ability groups, especially with respect to the segmental lengths contributing to stature height.

Furthermore, a thigh length, proportionately long in relation to total leg length or height, may indicate a developmental stage in the adolescent growth spurt since:

> Within the leg there is a definite gradient of timing. The foot has its rather small acceleration about 6 months before the calf and thigh. .... The calf length accelerates a little before the thigh.
>
> (Tanner, 1962:12)

Proportional analysis is necessary however, before these proportionality hypotheses can be tested among the present ability groups.

These results may indicate that there is a relationship between gymnastic ability and thigh length, with a longer thigh length providing a biomechanical advantage to performance. Possibly this variable is one of the few differentiating variables in which "better" gymnasts, the national elites, can be distinguished from "very good" gymnasts, the pre-national elites.

In comparison to Olympic gymnasts described by Ross (1980), both the national elite and the pre-national elite gymnasts in the present study have a longer mean thigh length. However, it should be noted that the thigh length measure in the present study was derived from an equation different from that used by Ross. In comparison to Olympic gymnasts described by Novak et al. (1977), both the national elite and the pre-national elite gymnasts have a shorter mean thigh length. However, the derivation of the thigh length measure in this study was not specified.

In comparison to the highly skilled gymnasts described by Nelson (1974), the competitive gymnasts in the present study have a smaller mean thigh length. However, the derivation of thigh length in this study was not specified.

<u>Other height and length measures (tibial, iliospinale, and trochanterion height; foot, upper arm, forearm, and hand length)</u>.

Trends concerning tibial height (Nelson, 1974; Novak et al., 1977; Ross, 1980), forearm length (Nelson, 1974; Novak et al., 1977; Ross, 1980), and foot length (Nelson, 1974; Ross, 1980), and gymnastic ability, were not evident in an inter-study comparison of Olympic and highly skilled gymnasts.

The upper arm length was longer in Olympic gymnasts (Novak et al., 1977; Ross, 1980) than in highly skilled gymnasts (Nelson, 1974). The iliospinale height was shorter in Olympic gymnasts (Ross, 1980) than in highly skilled gymnasts (Smit, 1973). These comparisons suggest a tendency for higher skilled gymnasts to have a longer upper arm length and a shorter iliospinale height than lesser skilled gymnasts.

The hand length and trochanterion height measurements appear to have been neglected in the literature, with only a single study including a hand length measure (Ross, 1980), and only a single study including a trochanterion height measurement (Nelson, 1974). There were also a few studies referring to a "total leg length" measurement (De Garay et al., 1974; Pool et al., 1969; Ross, 1980). In two of these studies, in which the leg length measure was derived using the same equation, Olympic gymnasts (Ross, 1980), in comparison to highly skilled gymnasts (Pool et al., 1969), were found to have a longer mean total leg length. This comparison suggests a tendency for higher skilled gymnasts to have a longer leg length than lesser skilled gymnasts.

Speculations concerning the tibial, iliospinale, and trochanterion height, the foot, forearm, and hand length measurements, and gymnastic ability in the present study were not made. However, it was noted in the literature that highly skilled gymnasts, in comparison to an appropriate reference population of females, had "longer lower limbs proportionate to their total height" (Smit, 1973:484).

Significant differences among the national elite, pre-national elite, lesser skilled competitive and recreational gymnasts were not found for any of these height and length variables. Furthermore, differences in these variables, among the various groups do not suggest any trends or tendencies.

While statistical analysis indicated non-significant differences in these variables for the various contrasts, further analysis is necessary in order to determine whether or not proportional differences exist. Such differences may indicate developmental stages in the adolescent growth spurt. A long tibial length, in relation to thigh or total leg length; or a long forearm length, in relation to upper arm or total arm length, may indicate specific stages in the growth sequences of these extremities, since during the adolescent growth spurt:

> The calf length accelerates a little before the thigh.
>
> (Tanner, 1962:12)

and;

> The forearm has its peak velocity about 6 months ahead of the upper arm. It seems that the peripheral parts of the limbs are throughout growth more advanced than the proximal.
>
> (Maresh, 1955, cited in Tanner, 1962:12)

Relatively long legs (as measured by trochanterion or iliospinale height) may indicate a delayed maturity in which a longer pre-adolescent period would provide "extra" growing time before the growth spurt:

> In the immediate preadolescent years, it is the legs which are growing relatively fastest of all skeletal dimensions ... and so if allowed to grow for an extra 2 years before the spurt, the legs become relatively long.
>
> (Tanner, 1962:46)

Proportionately longer feet and hands would also have maturational implications (Hebbelinck & Ross, in Nelson & Morehouse, 1974:546):

> Foot length is probably the first of all skeletal dimensions below the head to cease growing.
>
> (Tanner, 1962:12)

as well as biomechanical implications (Faulkner, 1977), such that longer feet and hands would benefit balance, and aid in movements where the body is propelled from them.

In comparison to Olympic gymnasts described by Novak et al. (1977), both the national elite and the pre-national elite gymnasts in the present study have a shorter mean upper arm and forearm length, and a similar mean tibial height. However, the landmarks used in deriving these measurements were not specified. In comparison to Olympic gymnasts described by Ross (1980), both the national elite and the pre-national elite gymnasts have a shorter mean tibial and iliospinale height, foot, upper arm, and forearm length, and a similar mean hand length. The same landmarks were used in obtaining these measurements for this latter study as were used in the present study.

In comparison to highly skilled gymnasts described by Nelson (1974), the competitive gymnasts in the present study have a shorter mean tibial and trochanterion height, a shorter mean forearm and foot length, and a similar mean upper arm length. However, the landmarks used in obtaining these measurements were not specified.

II Breadth, Width, and Depth Measures

Biacromial breadth. A trend concerning biacromial breadth and gymnastic ability was not evident in an inter-study comparison of Olympic (De Garay et al., 1974; Novak et al., 1977; Ross, 1980) and highly skilled gymnasts (Nelson, 1974; Novak et al., 1973; Sinning & Lindberg, 1972; Smit, 1973). However, in comparison to an appropriate female reference population, the highly skilled gymnasts of Sinning and Lindberg's study (1972) were reported to have a significantly smaller biacromial diameter.

A significant difference in biacromial breadth was expected between national elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, and recreational gymnasts, based on the observation that elite and highly skilled gymnasts appear to have relatively wider biacromial breadths than recreational gymnasts. It was also expected that exercise would show a positive effect upon skeletal growth in the region of the shoulders, as was suspected to have occurred in previous studies of gymnasts (Buckler & Brodie, 1977; Parizkova, 1968a; Smit, 1973). Furthermore, late maturing females, as adults, have been reported to have wider shoulders than early maturing females (Bayley, 1943b, cited in Tanner, 1962: 102). Since it was speculated that higher skilled gymnasts would be developmentally less mature than lesser skilled gymnasts, it was expected that this difference would be displayed in the biacromial breadth measure.

Although the biacromial breadth was smaller in Group 1 + 2 in comparison to Group 3, "slightly" smaller in Group 1 + 2 + 3 in comparison to Group 4, and larger in Group 1 in comparison to Group 2, these differences were not significant and in contradiction to the expected result. These differences however, "suggest" a tendency for higher skilled gymnasts to have a smaller biacromial breadth than lesser skilled gymnasts.

It is suspected that the "observed" wide biacromial breadth measure "appears" this way in relation to height, or to a "seemingly" narrow biiliocristal breadth, and is not necessarily "wide" when considered alone, in absolute terms. Furthermore, Smit (1973) noted that highly skilled gymnasts, in comparison to an appropriate reference sample, had a smaller biacromial breadth in absolute terms however, in relation to their height, they had a relatively large breadth. Proportional analysis is necessary however, before such a relationship, among the present ability groups, can be investigated.

In comparison to gymnasts of similar ability (Olympic gymnasts) described in the literature (De Garay et al., 1974; Novak et al., 1977; Ross, 1980), both the national elite and the pre-national elite gymnasts in the present study have smaller mean biacromial breadths.

In comparison to gymnasts of similar ability (highly skilled gymnasts) described in the literature, the competitive gymnasts in the present study have a similar mean biacromial breadth to the gymnasts described by Novak et al. (1973) and Sinning and Lindberg (1972); a smaller mean breadth than the gymnasts of Nelson's study (1974); and a larger mean breadth than the gymnasts of Smit's study (1973).

<u>Biiliocristal breadth</u>. A trend concerning biiliocristal breadth and gymnastic ability was not evident in an inter-study comparison of Olympic (De Garay et al., 1974; Novak et al., 1977; Ross, 1980) and highly skilled gymnasts (Nelson, 1974; Novak et al., 1973; Sinning & Lindberg, 1972; Smit, 1973). However, in comparison to an appropriate female reference population, the highly skilled gymnasts of Sinning and Lindberg's study (1972) were reported to have a significantly smaller biiliac diameter.

A significant difference in biiliocristal breadth was expected between national elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, and recreational gymnasts, based on the observation that elite and highly skilled gymnasts appear to have a relatively smaller biiliocristal breadth than recreational gymnasts. Since it was also speculated that higher skilled gymnasts would be developmentally less mature than lesser skilled gymnasts, it was expected that this difference would be displayed in the biiliocristal breadth measure. Late maturing females, as adults, have been reported to have smaller biiliac diameters in relation to their height, than early maturing females (Tanner, unpublished, cited in Tanner, 1962:102). Furthermore, at maturity there are changes in the pelvic bones, with "a particularly large spurt in hip width" (Tanner, 1962:45).

Although the biiliocristal breadth was smaller in Group 1 + 2 + 3 in comparison to Group 4, in Group 1 + 2 in comparison to Group 3, and larger in Group 1 in comparison to Group 2, these differences were not significant and thus not in agreement with the the expected result. These differences however, indicate a tendency for higher skilled gymnasts to have a smaller biiliocristal breadth than lesser skilled gymnasts. Furthermore, it should be noted that irrespective of the non-significant multivariate analysis, univariate analysis shows the biiliocristal breadth difference to be significant for Group 1 + 2 in comparison to Group 3.

It is suspected that the "observed" narrow biiliocristal breadth measure "appears" this way in relation to height or to a "seemingly" wide biacromial breadth, and is not necessarily "narrow" when considered alone, in absolute terms. Furthermore, Smit (1973) noted that highly skilled gymnasts, in comparison to an appropriate reference sample, had a smaller intercristal width in absolute terms, and also in relation to their height.

Proportional analysis is necessary however, before such a relationship among the present ability groups can be investigated. Such an analysis would also have developmental implications, as a broadening of the hips relative to the shoulders and waist is characteristic of female adolescence (Malina, 1974:119).

In comparison to gymnasts of similar ability (Olympic gymnasts) described in the literature (De Garay et al., 1974; Novak et al., 1977; Ross, 1980), both the national elite and the pre-national elite gymnasts in the present study have smaller mean biiliocristal breadths.

In comparison to gymnasts of similar ability (highly skilled gymnasts) described in the literature, the competitive gymnasts in the present study have a similar mean biiliocristal breadth to the gymnasts described by Novak et al. (1973) and Sinning and Lindberg (1972); a smaller mean breadth than the gymnasts of Nelson's study (1974); and a larger mean breadth than the gymnasts of Smit's study (1973).

Bi-epicondylar femur width. A trend concerning bi-epicondylar femur width and gymnastic ability was not evident in an inter-study comparison of Olympic (Novak et al., 1977; Ross, 1980) and highly skilled gymnasts (Nelson, 1974; Novak et al., 1973; Pool et al., 1969; Sinning & Lindberg, 1972). Speculations concerning bi-epicondylar femur width and gymnastic ability in the present study were not made. However, the observation of Adam's (1938, cited in Malina, 1969b:22), that women subjected to strenuous physical labor during childhood had larger knee widths than women not subjected to such stress, was noted.

The bi-epicondylar femur width was significantly smaller in Group 1 + 2 + 3 in comparison to Group 4. Since this was the only significant difference to emerge among the contrasts, it is possible that this is a spurious result. However, observing the similar mean values for Group 1, Group 2, Group 3, and Group 1 + 2, it can be conjectured that this measure is related to performance, such that highly skilled gymnasts, in general, have a similar bi-epicondylar femur width, and in comparison to recreational gymnasts have a significantly smaller width. This difference may be a reflection of the generally small skeletal structure associated with highly skilled gymnasts, and known to present distinct advantages in performing gymnastic-type movements.

This result may also have implications with respect to total body weight, with a small bi-epicondylar femur width indicating a small skeletal structure and thus a small skeletal weight.

This measure should also be viewed in proportion to height or total leg length, since these comparisons have developmental implications:

> for their size, children have proportionately larger knees, ankles and feet.
> (Ross, cited in Taunton, 1979:20)

as well as biomechanical implications:

> The proportionally wider knee widths ... may benefit stability [and provide] a proportionately greater area for weight-bearing stress.
> (Faulkner, 1977:22)

In comparison to gymnasts of similar ability (Olympic gymnasts) described in the literature (Novak et al., 1977; Ross, 1980), both the national elite and the pre-national elite gymnasts in the present study have similar mean bi-epicondylar femur widths.

In comparison to gymnasts of similar ability (highly skilled gymnasts) described in the literature (Nelson, 1974; Novak et al., 1973; Pool et al., 1969; Sinning & Lindberg, 1972), the competitive gymnasts in the present study have a similar mean bi-epicondylar femur width.

Anterior-posterior chest depth. A tendency for Olympic gymnasts (Ross, 1980) to have a smaller anterior-posterior chest depth than highly skilled gymnasts (Nelson, 1974; Novak et al., 1973; Sinning & Lindberg, 1972) was evident in an inter-study comparison of these two ability levels. This comparison was made with some reservation however, since the value obtained for this measurement is subject to the landmark points used, as well as to the technique followed. With a difference of 8.3 cm in anterior-posterior chest depth between two of the studies describing highly skilled gymnasts, it is speculated that one of these measurements may have been taken at full expiration, while the other at full inspiration. Speculations concerning anterior-posterior chest depth and gymnastic ability in the present study were not made.

Anterior-posterior chest depth was significantly smaller in Group 1 in comparison to Group 2. Since this was the only significant difference to emerge among the contrasts, it is possible that this is a spurious result. Conceivably however, this may well be one of the few differentiating variables distinguishing the "better" gymnasts, the national elites, from the "very good" gymnasts, the pre-national elites. Furthermore, since Group 1 + 2 has a smaller mean anterior-posterior chest depth than Group 3, and Group 1 + 2 + 3 has a "slightly" smaller mean than Group 4, there appears to be a tendency for higher skilled gymnasts to have a smaller mean chest depth than lesser skilled gymnasts. This difference may be a reflection of the generally small skeletal structure associated with highly skilled gymnasts, and known to present distinct advantages in performing gymnastic-type movements.

This result may also have implications with respect to the body mass components, with a small anterior-posterior chest depth indicating a relatively small skeletal structure and thus, a small skeletal mass. Since the anterior posterior chest depth measure encompasses the organs of the chest, a small measure may also indicate a small residual mass.

Although none of the individual subject's values for this variable are in discord with those of the other subjects, it should not be overlooked that this significant difference may be the result of measurement error. Since this measurement is taken at that "instance" before normal inspiration, it is possible that this "point" may have been misjudged for some individuals.

In comparison to Olympic gymnasts described by Ross (1980), both the national elite and the pre-national elite gymnasts in the present study have a smaller mean anterior-posterior chest depth.

In comparison to gymnasts of similar ability (highly skilled gymnasts) described in the literature (Nelson, 1974; Novak et al., 1973; Sinning & Lindberg, 1972), the competitive gymnasts in the present study have a smaller mean anterior-posterior chest depth.

Other breadth, width, and depth measures (transverse chest and bi-epicondylar humerus widths).

A trend concerning transverse chest width and gymnastic ability was not evident in an inter-study comparison of Olympic (Ross, 1980) and highly skilled gymnasts (Nelson, 1974; Novak et al., 1973; Pool et al., 1969; Sinning & Lindberg, 1972).

A tendency for Olympic gymnasts (Novak et al., 1977; Ross, 1980) to have a larger bi-epicondylar humerus width than highly skilled gymnasts (Nelson, 1974; Novak et al., 1973; Sinning & Lindberg, 1972), was evident in an inter-study comparison of these two ability levels.

Speculations concerning the transverse chest and bi-epicondylar humerus widths, and gymnastic ability, in the present study, were not made. However, the observation of Adam's (1938, cited in Malina, 1969b:22), that women subjected to strenuous physical labor during childhood had larger chest breadths than women not subjected to such stress, was noted.

Significant differences among the national elite, pre-national elite, lesser skilled competitive and recreational gymnasts were not found for the transverse chest or the bi-epicondylar humerus widths. Furthermore, differences in these variables, among the various groups, do not suggest any trends. The non-significant transverse chest width differences found among the ability groups are in discord with the findings of Pool et al. (1969), in that thorax width was found to correlate significantly with gymnastic performance.

While statistical analyses indicated non-significant differences in the bi-epicondylar humerus width for the various contrasts, further analysis is necessary in order to determine whether or not proportional differences, especially with respect to height or total arm length, are in existence among the ability groups. Furthermore, proportional assessments of this variable may have developmental as well as biomechanical implications. A proportionally wide bi-epicondylar humerus width while indicating a developmentally immature physique (Ross, 1980) would also benefit stability of balances performed on the hands by presenting a larger surface area for weight-bearing stress. A proportionally wide bi-epicondylar humerus width, especially in a post-pubescent gymnast, may also indicate the positive effect of exercise upon skeletal growth in this region since:

> bone thickens when subjected to heavy loads ... [and] is deposited in proportion to the compressional load that the bone must carry.
> (Guyton, 1976:1058)

A proportionally wide transverse chest width may also indicate the effects of exercise in developing this area.

In comparison to gymnasts of similar ability (Olympic gymnasts) described in the literature, both the national elite and the pre-national elite gymnasts in the present study have similar mean bi-epicondylar humerus widths (Novak et al., 1977; Ross, 1980), and smaller mean transverse chest widths (Ross, 1980).

In comparison to gymnasts of similar ability (highly skilled gymnasts) described in the literature (Nelson, 1974; Novak et al., 1973; Sinning & Lindberg, 1972), the competitive gymnasts in the present study have a similar mean bi-epicondylar humerus width. The competitive gymnasts also have a similar mean transverse chest width to the gymnasts from Pool et al.'s study (1969); a smaller mean width than the gymnasts described by Nelson (1974) and Novak et al. (1973); and a larger mean width than the gymnasts of Sinning and Lindberg's study (1972).

III Girth Measures

Since it is well established that exercise has the effect of increasing muscular girths (Bready, 1961, Kusinitz et al., 1958, Tanner, 1952, cited in Malina, 1969a:24), it was expected that highly skilled gymnasts involved in frequent and strenuous training, would display larger exercise induced muscle girths than lesser skilled gymnasts involved in relatively fewer hours of concentrated activity. Thus, significant differences among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts were expected.

Thigh girth. A trend concerning thigh girth and gymnastic ability was not evident in an inter-study comparison of Olympic (Novak et al., 1977; Ross, 1980) and highly skilled gymnasts (Nelson, 1974; Novak et al., 1973; Sinning & Lindberg, 1972).

The thigh girth measure was significantly smaller in Group 1 + 2 + 3 in comparison to Group 4. In a multivariate sense, the thigh girth measure was not significantly smaller in Group 1 + 2 in comparison to Group 3. However, irrespective of the insignificant multivariate analysis, univariate analysis shows the thigh girth difference to be significant for this contrast. These results indicate a trend towards smallness in thigh girth for higher skilled gymnasts in comparison to lesser skilled gymnasts.

Although these results are in the opposite direction to the expected results, they do not indicate that the effects of exercise are displayed to a greater degree in the lesser skilled compared to the higher skilled gymnasts, or that this former group has a larger "muscle" girth than the latter group. Lesser skilled gymnasts consistently have a larger mean thigh skinfold than higher skilled gymnasts, and since girth measures were not "corrected" for skinfold thickness, it is suspected that this former group has a larger "absolute" thigh girth comprised of a smaller "muscle" girth, relative to a larger layer of subcutaneous fat plus skin, than the latter group. These results do however, reflect the general smallness in physique associated with highly skilled gymnast, in comparison to lesser skilled gymnasts. Furthermore, this "smallness" has been known to present distinct advantages in performing gymnastic-type movements.

Proportional assessments of the thigh girth, especially with respect to height or total leg length, would more graphically identify shape differences among the ability groups. Such an assessment would also have developmental implications, since major changes in the thigh girth are evident with growth:

> The principle changes in shape ... from 2.5 years to 12 years, are relative decrease in size of the waist, and enlargement of hips and thighs. Thus development to maturity can be followed progressively as the deviations of the converted dimensions migrate to the midline [which represents the fully mature figure of a 20 - 24 year old female].
> (Behnke & Wilmore, 1974:88-89)

In comparison to gymnasts of similar ability (Olympic gymnasts) described in the literature (Novak et al., 1977; Ross, 1980), both the national elite and the pre-national elite gymnasts in the present study have smaller mean thigh girths.

In comparison to gymnasts of similar ability (highly skilled gymnasts) described in the literature, the competitive gymnasts in the present study have a similar mean thigh girth to the gymnasts described by Nelson (1974); a smaller mean girth than the gymnasts of Sinning and Lindberg's study (1972); and a larger mean girth than the gymnasts of Novak et al.'s study (1973).

<u>Other girth measures (relaxed arm, flexed arm, forearm, wrist, chest, waist, calf, ankle, head, and neck girths)</u>.

Trends concerning the relaxed arm, calf (Nelson, 1974; Novak et al., 1973, 1977; Pool et al., 1969; Ross, 1980; Sinning & Lindberg, 1972), flexed arm (Novak et al., 1973, 1977; Ross, 1980; Sinning & Lindberg, 1972), forearm (Nelson, 1974; Novak et al., 1973, 1977; Ross, 1980; Sinning & Lindberg, 1972), and waist girths (Nelson, 1974; Ross, 1980; Sinning & Lindberg, 1972), and gymnastic ability were not evident in an inter-study comparison of Olympic and highly skilled gymnasts.

A tendency for Olympic gymnasts (Ross, 1980) to have a larger wrist girth than highly skilled gymnasts (Nelson, 1974; Sinning & Lindberg, 1972) was evident in an inter-study comparison of these two ability levels.

Nelson (1974) noted a tendency for highly skilled gymnasts to have larger chest circumferences than females from an appropriate reference population. However, there appears to be no trend concerning chest girth and gymnastic ability in an inter-study comparison of Olympic (Ross, 1980) and highly skilled gymnasts (Nelson, 1974; Novak et al., 1973; Sinning & Lindberg, 1972). This latter comparison was made with some reservation, since the value obtained for this measurement is subject to the height of the tape, as well as to the technique followed. Ross (1980) took the chest girth measurement at the height of the fourth costosternal articulation. Sinning and Lindberg (1972) recorded two values, one taken from a measurement made at the level of the axilla, and the other from a measurement made at a level just below the breasts, while Novak et al. (1973) recorded a maximum and a minimum chest girth measurement. Specifics on the chest girth measurement taken in Nelson's study (1974) were not given. Furthermore, only the study by Ross (1980) indicated the breathing phase in which the chest girth measurement was taken.

The ankle, head, and neck girth measurements appear to have been neglected in the literature with only a single study including a head girth measurement (Nelson, 1974), and only a single study including a neck girth measurement (Sinning & Lindberg, 1972). Two studies describing highly skilled gymnasts included an ankle girth measurement (Nelson, 1974; Sinning & Lindberg, 1972).

Significant differences among the national elite, pre-national elite, lesser skilled competitive and recreational gymnasts were expected, particularly in the relaxed arm, flexed arm, forearm, and calf girths. Since these are relatively muscular sites, it was expected that the effects of exercise would be displayed at these sites, to a greater extent in those highly skilled gymnasts involved in frequent and strenuous training. Significant differences in wrist, chest, waist, ankle, head, and neck girths, among the ability groups, were expected to a lesser degree.

Significant differences among the national elite, pre-national elite, lesser skilled competitive and recreational gymnasts were not found for the relaxed arm, flexed arm, forearm, wrist, waist, calf, ankle, chest, head, and neck girths. Differences among the ability groups, in the flexed arm, forearm, wrist, ankle, head, and neck girths do not suggest any consistent trends. However, the relaxed arm, calf, chest, and waist girths are smaller in Group 1 + 2 + 3 in comparison to Group 4, and in Group 1 + 2 in comparison to Group 3, suggesting a tendency for higher skilled gymnasts to have smaller girth measurements, in these variables, than lesser skilled gymnasts.

These results, especially those noted for the relaxed arm and calf girths, are in the opposite direction to the expected trend, and no tendencies concerning the flexed arm and forearm girths, and gymnastic ability were found, in contradiction to what was expected. It is possible that, similar to the thigh girth result, the "muscular" girth differences of the relaxed arm, flexed arm, forearm, and calf girths were obscured by the subcutaneous fat plus skin layer. Furthermore, lesser skilled gymnasts in comparison to higher skilled gymnasts consistently have larger mean triceps, subscapular, suprailiac, abdominal, and medial calf skinfolds. Since girth measurements were not "corrected" for skinfold thickness, it is suspected that this former group has larger "absolute" girths, comprised of smaller "muscle" girths relative to larger subcutaneous fat layers, than the latter group.

Proportional assessments of the girth measurements, especially with respect to height, would more graphically identify shape differences among the ability groups. Such an assessment would also have developmental implications, since during growth and maturity the head, waist, and calf girths become progressively smaller in proportion to height (Behnke & Wilmore, 1974:84-85).

It should be noted that the head girth difference between Group 1 + 2 + 3 and Group 4, with the former group having a smaller mean than the latter, was approaching significance. This difference may be attributable to the thickness of the hair, since this measure encompasses the hair as well as the skull. This difference may also indicate a developmental difference between the two groups since during the adolescent growth spurt:

> the head diameters, practically dormant since a few years after birth, accelerate somewhat in most individuals.
>
> (Tanner, 1962:10)

Furthermore, in general, the circumference of the head in relation to height becomes progressively smaller with growth and maturity (Medawar, 1945; Ross, 1980).

Proportionally large wrist, ankle, and chest girths, in addition to having developmental implications, may also reflect the effects of exercise in developing these areas.

In comparison to gymnasts of similar ability (Olympic gymnasts) described in the literature, both the national elite and the pre-national elite gymnasts in the present study have smaller mean relaxed arm (Novak et al., 1977; Ross, 1980), flexed arm (Novak et al., 1977; Ross, 1980), forearm (Novak et al., 1977; Ross, 1980), wrist (Ross, 1980), chest (Ross, 1980), waist (Ross, 1980), and calf girths (Novak et al., 1977; Ross, 1980).

In comparison to highly skilled gymnasts described by Nelson (1974), the competitive gymnasts in the present study have a smaller mean relaxed arm, forearm, chest, calf, and ankle girth; a similar mean wrist and head girth; and a larger mean waist girth. In comparison to the gymnasts described by Novak et al. (1973), the competitive gymnasts have a smaller mean relaxed arm girth; a larger mean flexed arm, forearm, and chest girth; and a similar mean calf girth. In comparison to Sinning and Lindberg's gymnasts (1972), the competitive gymnasts have a larger mean relaxed arm and waist girth; a similar mean flexed arm, forearm, wrist, neck, and ankle girth; and a smaller mean calf girth. In comparison to the highly skilled gymnasts of Pool et al.'s study (1969), the competitive gymnasts have a smaller mean relaxed arm and calf girth.

IV Skinfold Thickness Measures

It is well established that exercise has the effect of reducing the thickness of the subcutaneous fat layer (Johnson, 1969; Parizkova & Poupa, 1963; Smit, 1973; Well, Jokl, & Bohranen, 1963); and Smit (1973: 480) noted that; "the skinfolds of gymnasts decreased as their hours of activity per week increased". Furthermore, exercise has also been noted to "check" or maintain the level of fat in growing adolescence, so that as growth proceeds, the skinfold thickness measures remain relatively constant (Parizkova, 1959). For these reasons, it was expected that highly skilled gymnasts, involved in frequent and rigorous training, would display smaller skinfold thickness measures than lesser skilled gymnasts, involved in comparatively fewer hours of concentrated activity.

Triceps, subscapular, suprailiac, abdominal, front thigh, and medial calf skinfold thickness measures.

A tendency for Olympic gymnasts to have smaller suprailiac (Novak et al., 1973, 1977; Ross, 1980) and abdominal skinfolds (Novak et al., 1973, 1977; Ross, 1980; Smit, 1973; Youngren, 1969) than highly skilled gymnasts was evident in an inter-study comparison of these two ability levels.

A tendency for Olympic gymnasts (Novak et al., 1977; Ross, 1980) to have a larger triceps skinfold than highly skilled gymnasts (Novak et al., 1973; Pool et al., 1969; Smit, 1973; Youngren, 1969) was evident in an inter-study comparison of these two ability levels.

Trends concerning the subscapular (Novak et al., 1973, 1977; Pool et al., 1969; Ross, 1980; Smit, 1973), front thigh (Novak et al., 1973, 1977; Ross, 1980; Youngren, 1969), and medial calf skinfolds (Novak et al., 1973, 1977; Ross, 1980), and gymnastic ability were not evident in an inter-study comparison of Olympic and highly skilled gymnasts. Although it was expected that the Olympic gymnasts would consistently have smaller skinfold thicknesses than highly skilled gymnasts, these results are not surprising in view of the findings of Wilmore et al. (1970a, 1970b) and Zwiren et al. (1973), in that skinfold measurements were found to be basically unsound in assessing changes in body fat with exercise. Furthermore, Young et al. (1964, cited in Shephard et al., 1969:1185) noted that the triceps skinfold did not correlate well with obesity. It should also be noted that trends concerning skinfold thickness and ability, in the inter-study comparisons, may have been masked by variations in the landmark site at which the measurement was taken. Ross (1980) takes the suprailiac skinfold measurement approximately five to seven centimeters superior to the iliospinale, while

Novak et al. (1973, 1977) takes this measurement at the iliac crest. Techniques and landmark points for the skinfold measurements were not specified in the majority of the studies reviewed.

All of the skinfold thickness measures, the triceps, subscapular, suprailiac, abdominal, front thigh, and medial calf, were found to be significantly smaller in Group 1 + 2 + 3 in comparison to Group 4, as was expected. Similarly all of the skinfold thickness measures, with the exception of the subscapular skinfold, were significantly smaller in Group 1 + 2 in comparison to Group 3. However, even the subscapular skinfold was smaller in Group 1 + 2 in comparison to Group 3, with the skinfold difference for this contrast approaching significance. These differences indicate a definite trend towards smaller skinfold thickness measurements for highly skilled in comparison to lesser skilled gymnasts.

None of the skinfold thickness measures, the triceps, subscapular, suprailiac, abdominal, front thigh, or medial calf, was significantly different in Group 1 in comparison to Group 2. This result is not surprising in view of the fact that these groups are very close in ability, and are assumed to have training programs of similar intensity and frequency. Furthermore, this result is in agreement with those results reported by Pool et al. (1969) and Youngren (1969), in which higher placing gymnasts did not have significantly different skinfolds than lower placing gymnasts. However, the "tendency" for higher placing gymnasts to have smaller skinfold thickness measures than lower placing gymnasts, noted in these two studies, was not evident in the present comparison of national elite and pre-national elite gymnasts.

In comparison to the Olympic gymnasts described by Novak et al. (1977) and Ross (1980) both the national elite and the pre-national elite gymnasts in the present study have a smaller mean triceps, subscapular, suprailiac, abdominal, front thigh, and medial calf skinfold.

In comparison to the highly skilled gymnasts described by Novak et al. (1973), the competitive gymnasts in the present study have a larger mean triceps, subscapular, medial calf, and front thigh skinfold; a similar mean abdominal skinfold; and a smaller mean suprailiac skinfold. In comparison to the gymnasts of Smit's study (1973), the competitive gymnasts have a similar mean triceps skinfold, and a smaller mean subscapular and abdominal skinfold. In comparison to the gymnasts described by Youngren (1969), the competitive gymnasts have a similar mean triceps and front thigh skinfold, and a smaller mean abdominal skinfold. In comparison to the gymnasts measured by Pool et al. (1969), the competitive gymnasts have a larger mean triceps and subscapular skinfold.

V Weight and Proportional Mass Measures

Practical and workable anthropometric equations for fractionating the body mass into muscular, skeletal, residual, and fat components have just recently been presented (Behnke & Wilmore, 1974; Drinkwater & Ross, in Ostyn et al., 1980:177). As a result, there were few studies located referring to "muscular, skeletal, and residual masses" distinguishable from a lean body mass.

Since exercise tends to reduce the fat "content" of the body as it encourages the "deposition" of muscle tissue (Parizkova, 1959; Parizkova & Poupa, 1963), higher skilled gymnasts were expected to possess a smaller "proportional" fat mass, in relation to a larger "proportional" muscle mass, than lesser skilled gymnasts.

It was expected that higher skilled gymnasts would be shorter in stature, and have generally smaller skeletal and girth dimensions, as well as smaller skinfold thicknesses than lesser skilled gymnasts. Therefore, it was speculated that these differences would be reflected in smaller "absolute" fat, skeletal, muscular, and residual masses for higher skilled in comparison to lesser skilled gymnasts. However, in proportional terms, due to the expected smaller "proportional" (percent) fat mass of the higher skilled, in comparison to the lesser skilled gymnast, there would thus be a larger proportion of the body mass due to the other three mass components. Therefore, differences in the "proportional" skeletal, muscle, and residual masses among the ability groups were expected to emerge, with higher skilled gymnasts having larger "proportional" muscle, skeletal, and residual masses than lesser skilled gymnasts. Furthermore, these differences were expected to be the direct result of a smaller proportional fat mass in the higher skilled, in comparison to the lesser skilled gymnasts. It should also be emphasized that the "proportional masses" incorporated a "calculated" mass, which is the sum of the four fractional masses, in their derivation, and not the directly measured scale weight.

<u>Weight</u>. A trend concerning weight and gymnastic ability was not evident in an inter-study comparison of Olympic (De Garay et al., 1974; Hirata, 1966; Montpetit, in Salmela, 1976:187; Novak et al., 1977; Pool et al., 1969; Ross, 1980), highly skilled (Carter, 1970; Nelson, 1974; Novak et al., 1973; Pool et al., 1969; Sinning & Lindberg, 1972; Smit, 1973; Sprynarova & Parizkova, 1969; Youngren, 1969), and recreational gymnasts (Pool et al., 1969). However, in comparison to appropriate reference populations, the gymnasts described by Carter (1970), Sinning and Lindberg (1972), and Smit (1973) were reported to be lighter in weight, and the

Sinning and Lindberg gymnasts were significantly lighter. On the other hand, the highly skilled gymnasts of Nelson's study (1974) were found to be similar in weight to an appropriate reference population of females, to whom they were compared.

Significant differences in weight among national elite, pre-national elite, and lesser skilled competitive gymnasts were not expected, based on the observation that elite and highly skilled gymnasts, in general, "appear" light in weight. It also appears that a relatively light weight is a prerequisite for successful participation at these levels. Highly skilled gymnasts were expected to possess a low "proportional" fat mass in relation to a high "proportional" lean body mass (muscle, skeletal, and residual masses), while lesser skilled gymnasts were expected to possess a higher "proportional" fat mass in relation to their proportional lean body mass. These differences were expected as a product of the varying degrees of exercise involvement of the groups. However, since adipose tissue is less dense than muscle tissue (Behnke & Wilmore, 1974), and since "the bones of athletes become considerably heavier than those of non-athletes" (Guyton, 1976:1060), it was conjectured that the compositional differences among the ability groups would cancel weight differences, and "absolute" weight would thus show no difference.

It was expected that national elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, would have a significantly lighter mean body weight than recreational gymnasts. This speculation was based on the assumption that the higher skilled gymnasts would be smaller in height and overall skeletal dimensions (indicating less absolute skeletal weight), and possess smaller skinfold thickness values (indicating less absolute fat weight) and smaller girth measures (indicating less absolute muscle weight), than the recreational gymnasts. Furthermore, it was speculated that the "absolute" muscle mass (but not the proportional muscle mass) would be less in the higher ability group, due to their general overall smallness in skeletal dimensions, which according to Behnke (1963, cited in Behnke & Royce, 1966:76) would indicate a smaller muscle mass since, a specific amount of lean body mass is associated with a given skeletal size.

Although Group 1 + 2 + 3 has a smaller mean weight than Group 4 (4.1 kg), Group 1 + 2 a smaller mean weight than Group 3 (4.8 kg), and Group 1 a smaller mean weight than Group 2 (0.4 kg), these differences were not significant. It should be noted however, that the difference in weight between Group 1 + 2 and Group 3 was approaching significance. These differences indicate a trend towards lightness in weight for higher skilled in comparison to lesser skilled gymnasts. These results, and especially the non-significant weight difference noted between Group 1 and Group 2, are in agreement with the results of Pool et al.'s study (1969), in that higher placing gymnasts tended to weigh less than lower placing gymnasts, but not significantly so.

Although these results are not as expected, they are not surprising in view of the fact that the anthropometric indicants of weight differences, height, and most of the other skeletal dimensions, as well as all of the girth measures, with the exception of the thigh girth, were not significantly different among the ability groups. Differences in these variables, among the ability groups, were not of sufficient magnitude to affect the weight measures. However, since there was a tendency for higher skilled gymnasts to be both shorter and lighter than lesser skilled gymnasts, perhaps a ponderal index (height-to-weight) comparison, among the ability groups, would be a more meaningful comparison.

The non-significant weight difference between Group 1 + 2 + 3, and Group 4, may be a reflection of club "attitudes". In clubs where the recreational level is viewed as a "base" for the competitive program, participants are often pre-selected on lightness in weight, among other variables, for inclusion in the recreational program.

In comparison to gymnasts of similar ability (Olympic gymnasts) described in the literature (De Garay et al., 1974; Hirata, 1966; Montpetit, in Salmela, 1976:187; Novak et al., 1977; Pool et al., 1969; Ross, 1980), both the national elite and the pre-national elite gymnasts in the present study have smaller mean weights.

In comparison to gymnasts of similar ability (highly skilled gymnasts) described by Carter (1970), Nelson (1974), Pool et al. (1969), Sinning and Lindberg (1972), Smit (1973), Sprynarova and Parizkova (1969), and Youngren (1969), the competitive gymnasts in the present study have a smaller mean weight. However, in comparison to the highly skilled gymnasts described by Novak et al. (1973), the competitive gymnasts have a larger mean weight.

In comparison to the recreational gymnasts referred to in Pool et al.'s study (1969), the recreational gymnasts in the present study have a smaller mean weight.

Proportional fat mass. A tendency for Olympic gymnasts to have a smaller percent fat mass (Novak et al., 1977; Ross, 1980) than highly skilled gymnasts (Novak et al., 1973; Sinning & Lindberg, 1972; Sprynarova & Parizkova, 1969), was evident in an inter-study comparison of these two ability levels.

The proportional fat mass was significantly smaller in Group 1 + 2 + 3 in comparison to Group 4, and in Group 1 + 2 in comparison to Group 3, as expected. The non-significant proportional fat mass difference between Group 1 and Group 2 was also expected, due to the relative closeness of the two groups, in training intensity and regime in general. These results suggest a trend towards smallness in proportional fat mass in higher skilled gymnasts in comparison to lesser skilled gymnasts.

While these results may reflect the effects of exercise in reducing the fat "content" of the body, they may also have developmental implications, especially since significant differences in maturity were also reported for these contrasts. Around the time of puberty there are marked changes in the composition of the female body, with a noted increase in the fat "content" (Edwards, 1951; Parizkova, 1959; Reynolds, 1950). Those gymnasts that are further advanced in maturity, would likely exhibit this increase to a greater extent than those gymnasts who are less mature. Furthermore, in the present study, lesser skilled gymnasts in comparison to higher skilled gymnasts were significantly more mature, and also had significantly larger proportional fat masses.

Since the proportional fat mass value (also referred to as the percent fat mass value) varies considerably with the derivative equation used (Damon & Goldman, 1964; Malina, 1969b; Steinkamp et al., 1965, as cited in Malina, 1969b:19), it is with much reservation that the percent fat mass values in the present study are compared with those reported in the literature. Keeping this point in view, it is noted that in comparison to the Olympic gymnasts described by Novak et al. (1977) and Ross (1980), both the national elite and the pre-national elite gymnasts in the present study have a smaller mean proportional fat mass. This latter study employed the same equations as the present study, in the calculation of proportional fat mass.

In comparison to the highly skilled gymnasts described by Novak et al. (1973), Sinning and Lindberg (1972), and Sprynarova and Parizkova (1969), the competitive gymnasts in the present study have a smaller proportional fat mass.

Proportional muscle mass. The proportional muscle mass was significantly larger in Group 1 + 2 + 3 in comparison to Group 4, and in Group 1 + 2 in comparison to Group 3, as expected. The non-significant proportional muscle mass difference between Group 1 and Group 2 was also expected, due to the relative closeness of the two groups in ability and in training regime. These results suggest a trend towards larger proportional muscle masses in higher skilled in comparison to lesser skilled gymnasts, and generally reflect the effect of exercise in developing the muscular component of the body.

The proportional muscle mass value was derived from height, "calculated" body weight, skinfold thickness, and girth measures. Of these measures, only the skinfold thicknesses and the thigh girth were found to be significantly smaller in higher skilled in comparison to recreational gymnasts. However, calculation of the proportional muscle mass measure incorporated muscle girths "corrected" for the subcutaneous fat layer. Furthermore, while larger girths indicated larger "absolute" muscle masses for lesser skilled in comparison to higher skilled gymnasts, "corrected" girths, led to smaller "proportional" muscle masses for the lesser skilled in comparison to the higher skilled gymnasts.

In comparison to the Olympic gymnasts described by Ross (1980), both the national elite and the pre-national elite gymnasts in the present study have similar mean proportional muscle masses. This study employed the same equation as the present study, in the calculation of proportional muscle mass.

<u>Proportional skeletal mass</u>. The proportional skeletal mass was significantly larger in Group 1 + 2 in comparison to Group 3. Although Group 1 + 2 + 3 has a larger mean proportional skeletal mass than Group 4, and Group 1 a larger mean mass than Group 2, these differences were not significant. However, these results do indicate a tendency for higher skilled gymnasts to have larger proportional skeletal masses than lesser skilled gymnasts.

The proportional skeletal mass value was derived from height, "calculated" body weight, wrist and ankle girths, and bi-epicondylar humerus and femur widths. Of these measures, only the bi-epicondylar femur width was significantly smaller in higher skilled in comparison to recreational gymnasts. While these results may indicate a smaller "absolute" skeletal mass, they do not simultaneously indicate a smaller "proportional" skeletal mass. The fact that there was a significantly smaller proportional fat mass in higher skilled in comparison to lesser skilled gymnasts, indicates that "automatically" the other mass components would have larger proportional weightings, with respect to the "calculated" weight. Thus, the proportional skeletal mass measure has emerged as having a significantly larger contribution to the "calculated" weight in higher skilled in comparison to lesser skilled gymnasts.

In comparison to the Olympic gymnasts described by Ross (1980), both the national elite and the pre-national elite gymnasts in the present study have larger mean proportional skeletal masses. This study employed the same equations as the present study, in the calculation of proportional skeletal mass.

Proportional residual mass. Although Group 1 + 2 + 3 has a larger mean proportional residual mass than Group 4, Group 1 + 2 a larger mean mass than Group 3, and Group 1 a smaller mean than Group 2, these differences were not significant. However, the residual mass difference between Group 1 + 2 + 3 and Group 4 was approaching significance. Furthermore, these results suggest a tendency for higher skilled gymnasts to have larger proportional residual masses than lesser skilled gymnasts.

The proportional residual mass was derived from height, the biacromial and biiliocristal breadths, the transverse chest width, and the anterior-posterior chest depth. Of these measures, only the anterior-posterior chest depth was significantly smaller in Group 1 in comparison to Group 2. Considering these results, it is not surprising that the proportional residual mass measures did not differ significantly for any of the contrasts.

In comparison to the Olympic gymnasts described by Ross (1980), the national elite gymnasts have a similar mean proportional residual mass, and the pre-national elite gymnasts have a larger mean proportional residual mass. This study employed the same equations as the present study, in the calculation of proportional residual mass.

MATURITY-ANTHROPOMETRIC RELATIONSHIP

Because significant differences in maturity were found among the ability groups, it was expected that these maturational differences would also be reflected in the anthropometric characteristics, since maturity and morphology are so closely related (Frisch & McArthur, 1974; Frisch & Revelle, 1970, 1971; Garn & Haskell, 1960; Johnston et al., 1971; Maresh, 1972; McNeill & Livson, 1963; Reynolds, 1950).

While absolute values of the anthropometric variables indicate quantitative growth, proportional values more graphically reflect developmental growth. In the present study, all anthropometric variables, with the exception of the proportional mass measures, were assessed in terms of their absolute values only. While anthropometric differences among the gymnastic ability groups were found, it was not possible to infer maturational developments from these differences. It is possible however, to implicate maturational developments from proportional differences. Furthermore, proportional assessments are concerned with shape and not amount, and therefore quantity is not confused with representing a mature physique, as may easily occur when maturity is implied from absolute values alone.

The maturity-anthropometric relationship is illustrated by Ross and Wilson (1974) in a shape comparison between a pre-pubescent and a post-pubescent female. Using anthropometric variables proportionally adjusted to a standard height, the pre-pubescent female in contrast to the post-pubescent female, has a shorter trunk length and a longer total leg length, comprised of a longer lower leg and thigh length. These results are interesting in view of the findings noted in the present study. Highly skilled gymnasts in comparison to lesser skilled gymnasts were found to be significantly delayed in maturity (Group 1 + 2 + 3 vs Group 4, Group 1 + 2 vs Group 3), and anthropometrically, were significantly shorter in trunk length (Group 1 + 2 + 3 vs Group 4, Group 1 + 2 vs Group 3, Group 1 vs Group 2), and thigh length (Group 1 vs Group 2), while significant differences in height were not found.

From the discussion of the anthropometric variables, it is evident that further analysis with respect to proportional assessments, is necessary to explicitly illustrate shape differences among gymnasts from varying ability levels. Furthermore, such analysis is necessary before anthropometric variables can be closely associated with maturational status.

CHAPTER 5

SUMMARY AND CONCLUSIONS

SUMMARY

Fame for female gymnasts is often short-lived, with many highly skilled gymnasts dropping out of elite caliber competitions during, or soon after adolescence. Many of today's elite female gymnasts are in the age range when normal pubertal developments, such as increases in weight, height, adiposity, and dimensions in general, are expected to occur.

The recent trend towards younger participation at elite gymnastic competitions, coupled with an increasing display of movement perfection and task complexity, seems to indicate that female gymnasts are reaching their prime, or "peaking" at younger ages. This trend also suggests the possibility that important relationships exist among maturational status, anthropometric characteristics, and success in gymnastic performance.

It was the purpose of this study to investigate the possibility that success in gymnastics is related to the concept of maturity and anthropometric characteristics. Furthermore, it was hypothesized that there would be significant maturational (skeletal age in reference to chronological age; incidence of menarche) and anthropometric differences (height and length measures; width, breadth, and depth measures; girth measures; skinfold thickness measures; weight and proportional mass measures) among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts.

Sixty-nine Canadian female gymnasts, ages 11.5 to 18.0 years, with ability levels ranging from recreational through to national elite, were participants in the study. Performance levels and research groups were identified as; Group 1, National Elite Gymnasts; Group 2, Pre-National Elite Gymnasts; Group 3, Competitive Gymnasts; and Group 4, Recreational Gymnasts. All available subjects were participants in Groups 1 and 2, while subjects were randomly selected to represent Groups 3 and 4.

Maturational assessment for each subject consisted of a skeletal age rating, based on a radiographic photo of the left hand and wrist, and an indication that menarche had, or had not occurred.

Anthropometric assessment consisted of 39 selected variables. Specifically, 11 height and length; 6 breadth, width, and depth; 11 girth; 6 skinfold thickness; 1 weight and 4 proportional mass measures were evaluated.

In all statistical analyses the following preplanned orthogonal contrasts were used; Group 1 + 2 + 3 vs Group 4, Group 1 + 2 vs Group 3, and Group 1 vs Group 2. The chronological age minus skeletal age difference, when compared between groups, was assessed using analysis of variance. The incidence of menarche difference between groups was assessed using chi-square analysis. The anthropometric differences were assessed using multivariate and univariate analysis of covariance, using chronological age as the covariate. The level of significance for all statistical tests was set at $p < .01$.

The results of the statistical tests indicated that the two maturational hypotheses, and the five anthropometric hypotheses were partially supported. More specifically, at a level of significance of $p < .01$, the following results were noted.

Highly skilled gymnasts in comparison to lesser skilled gymnasts (Group 1 + 2 + 3 vs Group 4, Group 1 + 2 vs Group 3) were maturationally delayed both skeletally and menarcheally. Anthropometrically, they were shorter in trunk length; smaller in triceps, suprailiac, abdominal, front thigh, and medial calf skinfolds; smaller in proportional fat mass and larger in proportional muscle mass. In addition, highly skilled gymnasts (Group 1 + 2 + 3), in comparison to recreational gymnasts (Group 4), were smaller in bi-epicondylar femur width, thigh girth, and subscapular skinfold. As well, elite gymnasts (Group 1 + 2), in comparison to lesser skilled competitive gymnasts (Group 3), were smaller in sitting height and larger in proportional skeletal mass.

National elite gymnasts (Group 1), in comparison to pre-national elite gymnasts (Group 2), were not maturationally different, skeletally or menarcheally. Anthropometrically, they were shorter in trunk length, longer in thigh length, and smaller in anterior-posterior chest depth.

The results of the maturational assessment indicated that there may be a relationship between gymnastic ability and maturity, with highly skilled gymnasts being developmentally less mature than lesser skilled gymnasts.

The results of the anthropometric assessment indicated that there may be a relationship between gymnastic ability and anthropometric parameters. It was suggested that the shorter sitting height, trunk and thigh lengths, observed in higher skilled in comparison to lesser skilled gymnasts, provided specific biomechanical advantages in performing gymnastic-type movements. The smaller anterior-posterior chest depth, thigh girth, and bi-epicondylar femur width, observed in higher skilled in comparison to lesser skilled gymnasts, were considered to be reflections of the generally small physique associated with biomechanical advantages for gymnastic-type movements. As well it was considered that, due to the nature of the measurement, the anterior-posterior chest depth difference may have been a product of measurement error.

The skinfold thickness, proportional fat and muscle mass differences, among the ability groups, were presumed related to differences in training regime, with higher skilled gymnasts involved in considerably more hours of intense training displaying smaller skinfold thickness values, a lower proportional fat mass, and a higher proportional muscle mass, than lesser skilled gymnasts. The larger proportional skeletal mass, observed in higher skilled in comparison to lesser skilled gymnasts, was attributed to the low fat mass value of this former group, which consequently led to a higher weighting of the skeletal mass, as well as of the other lean body mass components, when assessed in proportional terms of "calculated" total body weight.

It was conjectured that the differences noted, among the ability groups, in thigh and trunk length, sitting height, bi-epicondylar femur width, thigh girth, and proportional fat mass, were reflections of maturational differences. However, it was postulated that proportional analysis of these variables, in relation to height, would more closely indicate developmental differences. Furthermore, the significant thigh and trunk length, and sitting height differences, and the non-significant vertex standing height differences, suggested proportional differences among the ability groups, in those segmental lengths comprising the vertex standing height measure.

Since height and weight were not significantly different among the ability groups, and since there was a tendency for higher skilled gymnasts to be shorter and lighter than lesser skilled gymnasts, it was speculated that a ponderal index comparison would be a meaningful variable to investigate.

It was suggested that girth measurements "corrected" for the subcutaneous layer of fat plus skin, would be more appropriate in assessing muscular development at specific sites.

Finally, it was proposed that further analysis of the anthropometric variables, with respect to proportional assessments, would be meaningful in identifying shape differences among the ability groups, and would more graphically illustrate maturity-anthropometric relationships.

CONCLUSIONS

The two maturational and the five anthropometric hypotheses were partially supported at a level of significance of $p < .01$. Thus, there are maturational and anthropometric differences among national elite, pre-national elite, lesser skilled competitive and recreational gymnasts. More specifically, at $p < .01$, the following results were noted:

1. National elite, pre-national elite, and lesser skilled competitive gymnasts, taken together, in comparison to recreational gymnasts, are maturationally delayed, both skeletally and menarcheally. Anthropometrically, they are shorter in trunk length, smaller in bi-epicondylar femur width, thigh girth, triceps, subscapular, suprailiac, abdominal, front thigh, and medial calf skinfolds; have a smaller proportional fat mass, and a larger proportional muscle mass.
2. National elite and pre-national elite gymnasts, taken together, in comparison to lesser skilled competitive gymnasts, are maturationally delayed, both skeletally and menarcheally. Anthropometrically, they are shorter in sitting height and trunk length; smaller in triceps,

suprailiac, abdominal, front thigh, and medial calf skinfolds; have a smaller proportional fat mass; and larger proportional muscle and skeletal masses.

3. National elite gymnasts, in comparison to pre-national elite gymnasts, are not maturationally different, skeletally or menarcheally. Anthropometrically, they are shorter in trunk length, longer in thigh length, and smaller in anterior-posterior chest depth.

It is both necessary and vital to the advancement of the sport of gymnastics that coaches understand the relationships among anthropometric characteristics, maturity, and performance, since the best performers may not necessarily possess the potential for future promise, and to select teams on the grounds of present performance and physique alone is misleading, and may deter those with true potential from participating:

> We wonder how much Canadian competitive talent is lost by failure to recognize that youngsters with ideal physique characteristics for these sports have a tendency to be late maturers.
> (Ross et al., in Taylor, 1976:277)

SUGGESTIONS FOR FURTHER RESEARCH

There are many ways in which anthropometric and maturational data can be observed and compared. The present study focused on comparing gymnasts from varying ability levels, on maturational and anthropometric parameters.

It is proposed that conversion of the absolute anthropometric values into proportional values, would result in the nascency of new information, that would be interpretable in maturational and possibly biomechanical terms. Furthermore, such assessments may aid in the identification of optimum body proportions for success in gymnastics.

It would also be of interest to compare the values of the anthropometric variables from each ability group, with the statistics from normative data, in order to identify the degree of deviation of the gymnastic populations from the norm. Such comparisons would also offer further insights into the "uniqueness" of the female gymnast's physique. For example, recognizing that the present sample of gymnasts is comprised of females 11.5 to 18.0 years, with a mean age of 14.9 years, the anthropometric statistics of this population are compared with those of 14 year olds from a reference population described by Ross, Drinkwater, Whittingham, and Faulkner (in Berg & Erikson, 1980:3). Compared with these 14 year olds, highly skilled gymnasts (Group 1 + 2 + 3) are at the 10th percentile for height and the 20th percentile for weight; while recreational gymnasts (Group 4) are at the 20th percentile for height and the 45th percentile for weight. These results indicate that while the gymnasts are comparatively shorter in stature than the average 14 year old, they are heavier for their height in comparison to those 14 year olds of the same height. However, the higher skilled gymnasts (Group 1 + 2 + 3) are less heavy for their height than the recreational gymnasts (Group 4). Furthermore, this "heaviness" is probably due to muscular development and not excess adiposity since, muscular tissue is more dense than adipose tissue (Behnke & Wilmore, 1974), and exercise tends to encourage the "deposition" of muscle tissue (Smit, 1976) while it discourages the "accumulation" of adipose tissue (Parizkova & Poupa, 1963). The skinfold thickness values for these Groups further support this contention.

Most anthropometric and maturational studies describing the female gymnastic population have included only college aged gymnasts, and have been concerned with gymnasts from only one ability level. As the number of young female gymnasts undergoing serious gymnastic training, and participating and succeeding in elite competitions increases, the need for maturational and anthropometric descriptions of this "new" gymnastic population becomes evident.

REFERENCES

Acheson, R. M., & Dupertuis, C. W. The relationship between physique and rate of skeletal maturation in boys. Human Biology, 1957, 29, 167-193.

Alexander, M. J. The relationship of somatotype and selected anthropometric measures to basketball performance in highly skilled females. Research Quarterly, 1976, 47(4), 575-585.

Allen, T. H., Peng, M. T., Chen, K. P., Huang, T. F., Chang, C., & Fang, H. S. Prediction of total adiposity from skinfolds and the curvilinear relationship between external and internal adiposity. Metabolism, 1956, 5, 346-352.

American Psychological Association: Publication Manual (2nd ed.). Baltimore: Pridemark Press Inc., 1979.

Anderson, D. L. Interrelationships of dental maturity, skeletal maturity, height, and weight from age 4 to 14 years. Growth, 1975, 39(4), 453-462.

Asmussen, E. Growth and athletic performance. In K. Kato (Ed.), Post-War trends of growth and development of males and females in each country. Proceedings of the International Congress of Sport Sciences, Denmark, 1966, pp. 103-110.

Astrand, P. O., Engstrom, L., Eriksson, B. O., Karlberg, P., Nylander, I., Saltin, B., & Thoren, C. Girl Swimmers: With special reference to respiratory and circulatory adaptation and gynaecological and psychiatric aspects. ACTA Paediatrics Supplementum, 1963, 147, 1-75

Astrand, P. O., & Rodahl, K. Textbook of work physiology. New York: McGraw Hill, 1970.

Atwood, C. L., & Taube, A. Estimating mean time to reach a milestone, using retrospective data. Biometrics, 1976, 32, 159-172.

Bailey, D. A. Exercise, fitness and physical education for the growing child: A concern. Paper presented at the meeting of the National Conference on the Child in Sport and Physical Activity, Kingston, May 1973, pp. 1-23.

Bajin, B. Physical ability and standard moves manual. Unpublished bulletin, Canadian Gymnastics Federation, Special bulletin for coaches, No. 3, September 1977. (Available from Women's Technical Committee [333 River Rd., Vanier, Ottawa, K1L 8B9]).

Bajin, B. Elite program IV. Unpublished bulletin, Canadian Gymnastics Federation, 1978. (Available from Women's Technical Committee [333 River Rd., Vanier, Ottawa, K1L 8B9]).

Baker, I. A., Hughes, J., & Jones, M. Temporal variation in the height of children during the day. The Lancet, June 17, 1978, p. 1320.

Bakker, H. K., & Struikenkamp, R. S. Biological variability and lean body mass estimates. Human Biology, 1977, 49(2), 187-203.

Barnes, L. Preadolescent training: How young is too young? The Physician and Sportsmedicine, 1979, 7(10), 114-119

Bar-Or, O., Zwiren, L. D., & Ruskin, H. Anthropometric and developmental measurements of 11 and 12 year old boys as predictors of performance 2 years later. ACTA Paediatrica Belgica Supplement, 1974, 28, 214-220

Behnke, A. R. Anthropometric fractionation of body weight. Journal of Applied Physiology, 1961, 16(6), 949-954.

Behnke, A. R. Anthropometric estimate of body size, shape, and fat content. Postgraduate Medicine, 1963, 34, 190-198.

Behnke, A. R., & Royce, J. Body size, shape and composition of several types of athletes: Original papers. Journal of Sports Medicine and Physical Fitness - Quarterly Review, 1966, 6(2), 75-88.

Behnke, A. R., & Wilmore, J. H. Evaluation and regulation of body build and composition, Eaglewood Cliffs: Prentice Hall, 1974.

Bielicki, T., & Waliszko, A. Wroclaw growth study: Part 1, females. Studies in Physical Anthropology, 1975, 2, 53-83.

Billewicz, W. Z., Fellowes, H. M. & Hytten, C. A. Comments on the critical metabolic mass and the age of menarche. Annals of Human Biology, 1976, 3(1), 51-59.

Bojlen, K., & Bentzon, M. W. Seasonal variation in the occurrence of menarche. Danish Medical Bulletin, 1974, 21(5), pp. 161-168.

Bonnet, F. P., Rocour-Brumioul, D., & Heuskin, A. Regional variations of adipose cell size and local cellularity in human subcutaneous fat during normal growth. ACTA Paediatrica Belgica, 1979, 32, 17-27.

Brozek, J. Body composition: The relative amounts of fat, tissue, and water vary with age, sex, exercise, and nutritional state. Science, 1961, 134, 920-930

Buckler, J. M. H., & Brodie, D. A. Growth and maturity characteristics of schoolboy gymnasts. Annals of Human Biology, 1977, 4(5), 455-463

Bugyi, B. Lean body weight estimation in 6 to 16 year old children, based on wrist breadth and body weight. Journal of Sports Medicine and Physical Fitness, 1972, 12(1), 171-173.

Bugyi, B., & Kausz, I. Radiographic determination of the skeletal age of young swimmers. Journal of Sports Medicine and Physical Fitness, 1970, 10, 269-270.

Bullen, B. A., Quaade, F., Olesen, E., & Lund, S. A. Ultrasonic reflections used for measuring subcutaneous fat in humans. Human Biology, 1965, 37, 375-384.

Bullough, P., Goodfellow, J., & O'Connor, J. The relationship between degenerative changes and load-bearing in the human hip. Journal of Bone and Joint Surgery, 1973, 55(B), 746-758.

Burkinshaw, L., Jones, P. R. M., & Krupowicz, D. W. Observer error in skinfold thickness measurements. Human Biology, 1973, 45(2), 273-279.

Burrell, R. J. W., Tanner, J. M., & Healy, M. J. R. Age at menarche in South African Bantu girls living in the Transkei reserve. Human Biology, 1961, 33, 250-261.

Cameron, N. Weight and skinfold variation at menarche and the critical body weight hypothesis. Annals of Human Biology, 1976, 3(3), 279-282.

Carter, J. E. L. The somatotypes of athletes: A review. Human Biology, 1970, 42(4), 535-569.

Carter, J. E. L. The Heath-Carter somatotype method: Manual. San Diego: San Diego State University, 1975.

Carter, J. E. L. Montreal Olympic Games anthropological project: Anthropometric instruments and measurements. Unpublished manuscript, San Diego State University, May 12, 1976 (revised November 1976). (Available from Kinesiology Department, [Simon Fraser University, Burnaby, B. C., Canada, V5A 1S6]).

Carter, J. E. L., Sleet, D. A., & Martin, G. N. Somatotypes of male gymnasts. Journal of Sport Medicine and Physical Fitness, 1971, 11(3), 162-171.

Charzewska, J., Ziemlanski, S., & Lasecka, E. Menarcheal age, nutrition, and socio-economic environment. Studies in Physical Anthropology, 1975, 2, 47-51.

Chovanova, E. Anthropometric characterization of the best Czechoslovak Ice-Hockey Players. ACTA Facultatis Rerum Naturalium Universitatis Comenianae Anthropologia, 1972, 20, 87-100.

Church, K. R. Children's exercise: Facts and fiction. Elementary School Journal, 1976, 77(2), 110-115.

Clark, S. "Tracey": Diamond on ice. Canadian Weekend Magazine, March 8, 1980, pp. 2-4;6.

Clarke, H. H. Characteristics of the young athlete: A longitudinal look. In Council of Kinesiology, Kinesiology Review. Washington: American Association of Health, Physical Education and Recreation, 1968, pp. 33-42.

Clarke, H. H. Characteristics of athletes. Physical Fitness Research Digest, 1973, 3(2), 1-20.

Clegg, E. J., & Kent, C. Skinfold compressibility in young adults. Human Biology, 1967, 39, 418-429.

Crawford, J. D., & Osler, D. C. Body composition at menarche: The Frisch-Revelle hypothesis revisited. Pediatrics, 1975, 56(3), 449-458.

Cureton, K. J., Boileau, R. A., & Lohman, T. G. A comparison of densitometric, potassium-40, and skinfold estimates of body composition in prepubescent boys. Human Biology, 1975, 47(3), 321-336.

Damon, A. Larger body size and earlier menarche: The end may be in sight. Social Biology, 1974, 21(1), 8-11.

Damon, A., Damon, R., Reed, R., & Valadian, I. Age at menarche of mothers and daughters with a note on accuracy of recall. Human Biology, 1969, 41, 160-175.

Damon, A., & Goldman, R. F. Predicting fat from body measurements: Densitometric validation of ten anthropometric equations. Human Biology, 1964, 36, 32-44.

Dann, T. C., & Roberts, D. F. End of the trend? A 12 year study of age at menarche. British Medical Journal, 1973, 3, 265-267.

De Garay, A. L., Levine, L., & Carter, J. E. L. Genetic and anthropological studies of Olympic athletes. New York: Academic Press, 1974.

De Wijn, J. F. Estimation of age at menarche in a population. In H. E. Stenfert, & N. V. Kroese, Somatic growth of the child. Proceedings of a Boerhaave Course for postgraduate medical teaching, Leiden, Holland, 1966, pp. 16-24.

Drazil, V. Gymnastics: Physical activity, sports, games, and exercises. In L. Larson, & D. Herrmann (Eds.), Encyclopedia of sports sciences and medicine. New York: MacMillan, 1971, pp. 353-354.

Drinkwater, D. T., & Ross, W. D. Anthropometric fractionation of body mass. In M. Ostyn, G. Beunen, & J. Simons (Ed.), Kinanthropometry 2. Baltimore: University Park Press, 1980, pp. 177-188.

Durnin, J. V. G., & Rahaman, M. M. The assessment of the amount of fat in the human body from measurements of skinfold thickness. British Journal of Nutrition, 1967, 21, 681-689.

Durnin, J. V. G., & Womersley, J. Body fat assessed from total body density and its estimation from skinfold thickness measurements on 481 men and women aged from 16 to 72 years. British Journal of Nutrition, 1974, 32, 77-97.

Edwards, D. A. W. Observations on the distribution of subcutaneous fat. Clinical Science, 1950, 9, 259.

Edwards, D. A. W. Differences in the distribution of subcutaneous fat with sex and maturity. Clinical Science, 1951, 10, 305-315.

Eiben, O. G. The physique of woman athletes. Budapest: Hungarian Scientific Council for Physical Education, 1972.

Eiben, O. G. Changes in body measurements and proportion of children: Based on Kormend growth study. In L. Gedda, & P. Parisi (Ed.), Auxology: Human growth in health and disorder. Proceedings of the Serno Symposia, London: Academic Press, 1978, 13, pp. 187-198.

Eiben, O. G., Ross, W. D., Christensen, W., & Faulkner, R. A. Proportionality characteristics of female athletes. Anthropologiai Kozlenenyek, 1976, 20, 55-67.

Erdelyi, G. J. Problems and inquiries: Gynecological survey of female athletes. Journal of Sports Medicine and Physical Fitness, 1962, 2, 174-179.

Eveleth, P. B., & De Souza Freitas, J. A. Tooth eruption and menarche of Brazilian born children of Japanese ancestry. Human Biology, 1965, 37, 176-184.

Eveleth, P. B., & Tanner, J. M. Worldwide variation in human growth. Cambridge: Cambridge University Press, 1976.

Faulkner, R. Physique characteristics of Canadian figure skaters. Unpublished master's thesis, Simon Fraser University, 1977.

Filipsson, R., & Hall, K. Correlation between dental maturity, height development and sexual maturation in normal girls. Annals of Human Biology, 1976, 3(3), 205-210.

Finn, J. D. Multivariance (Code: GENL-02). Faculty of Education, Research Service Centre, University of British Columbia, November 1978.

Forbes, G. B. Growth of the lean body mass in man. Growth, 1972, 36, 325-338.

Friis-Hansen, B. Body composition during growth. Pediatrics, 1971, 47(1), 264-274.

Frisch, R. Influences on age of menarche. The Lancet, May 5, 1973, p. 1007.

Frisch, R. E. Fatness of girls from menarche to age 18 years with a nomogram. Human Biology, 1976, 48(2), 353-359.

Frisch, R. E., & McArthur, J. W. Menstrual cycles: Fatness as a determinant of minimum weight for height necessary for their maintenance or onset. Science, 1974, 185(4155), 949-951.

Frisch, R. E., & Revelle, R. The height and weight of adolescent boys and girls at the time of peak velocity of growth in height and weight: Longitudinal data. Human Biology, 1969, 41, 536-559.

Frisch, R. E., & Revelle, R. Height and weight at menarche and a hypothesis of critical body weights and adolescent events. Science, 1970, 169, 397-399.

Frisch, R. E., & Revelle, R. Height and weight at menarche and a hypothesis of menarche. Archives of Disease in Childhood, 1971, 46, 695-701.

Frisch, R. E., Revelle, R., & Cook, S. Components of weight at menarche and the initiation of the adolescent growth spurt in girls: Estimated total water, lean body weight, and fat. Human Biology, 1973, 45(3), 469-483.

Garn, S. M., & Gorman, E. L. Comparison of pinch-caliper and teleroentgenogrammetric measurements of subcutaneous fat. Human Biology, 1965, 28, 407-413.

Garn, S. M., & Haskell, J. A. Fat thickness and developmental status in childhood and adolescence. Journal of Diseases of Children, 1960, 99, 746-751.

George, G. S. Selected execution techniques common to aerial gymnastic skills. In J. Salmela, The advanced study of gymnastics. Springfield: Charles, C. Thomas, 1976, pp. 138-147.

Goldfarb, A. F. Puberty and menarche. Clinical Obstetrics and Gynecology, 1977. 20(3), 625-631.

Greenberg, B. G., & Bryan, A. H. Methodology in the study of physical measurements of school children. Human Biology, 1951, 23(1), 160-179.

Greulich, W. W., & Pyle, S. I. Radiographic atlas of skeletal development of the hand and wrist (2nd ed.). Stanford: Stanford University Press, 1970.

Guyton, A. C. Textbook of medical physiology (5th ed.). Philadelphia: W. B. Saunders, 1976.

Halm, J. Simple data description (adapted from UCLA BMD documentation). University of British Columbia Computing Center, (September 1971), revised April 1974.

Hammond, W. H. Measurement and interpretation of subcutaneous fat with norms for children and young adult males. British Journal of Preventive Social Medicine, 1955, 9, 201-211.

Hebbelinck, M., & Ross, W. D. Kinanthropometry and biomechanics. In R. C. Nelson, & C. A. Morehouse (Eds.), Biomechanics 4, Baltimore: University Park Press, 1974, pp. 537-552.

Hillman, R. W., Slater, P., & Nelson, M. J. Season of birth, parental age, menarcheal age and body form: Some inter-relationships in young women. Human Biology, 1970, 42, 570-580.

Himes, J. H., Roche, A. F., & Siervogel, R. M. Compressibility of skinfolds and the measurement of subcutaneous fatness. American Journal of Clinical Nutrition, 1979, 32, 1734-1740.

Hirata, K. Physique and age of Tokyo champions. Journal of Sports Medicine and Physical Fitness, Quarterly Review, 1966, 6, 207-222.

Hirsch, J. Can we modify the number of adipose cells? Postgraduate Medicine, 1972, 51, 83-86.

Ismail, A. H. Body composition, In L. Larson, & D. Herrmann (Eds.), Encyclopedia of sports sciences and medicine. New York: MacMillan, 1971, pp. 1209-1211.

Jackson, A. S., & Pollock, M. L. Factor analysis and multivariate scaling of anthropometric variables for the assessment of body composition. Medicine and Science in Sports, 1976, 8(3), 196-203.

Jafarey, N. A., Khan, M. Y., & Jafarey, S. N. Role of artificial lighting in decreasing the age of menarche. The Lancet, August 29, 1970, p. 471.

Johnson, L. V. Effects of 5-day a week, vs 2, and 3-day a week physical education class on fitness, skill, adipose tissue, and growth. Research Quarterly, 1969, 40(1), 93-98.

Johnson, W. R., & Buskirk, E. R. Developmental aspects: Maturing and aging in relation to exercise and sport. In W. R. Johnson (Ed.), Science and medicine of exercise and sport (2nd ed.). New York: Harper and Row, 1974, pp. 330-333.

Johnson, P. B., Updyke, W. F., Schaefer, M., & Stolberg, D. C. Sport, exercise and you. New York: Holt Rhinehart, and Winston, 1975.

Johnston, F. E. The concept of skeletal age. Clinical Pediatrics, 1962, 1(3), 133-144.

Johnston, F. E. Control of age at menarche. Human Biology, 1974, 46(1), 159-171.

Johnston, F. E., Malina, R. M., & Galbraith, M. A. Height, weight, and age of menarche and the critical weight hypothesis. Science, 1971, 174, 1148-1149.

Johnston, F. E., Roche, A. F., Schell, L. M., & Wettenhall, H. N. Critical weight at menarche: Original articles. American Journal of Diseases of Children, 1975, 129, 19-23.

Katch, F. I., & Michael, E. D., Jr. Prediction of body density from skinfold and girth measurements of college females. Journal of Applied Physiology, 1968, 25, 92-94.

Keys, A., & Brozek, J. Body fat in adult man. Physiological Reviews, 1953, 33(3), 245-325.

Khosla, T. Unfairness of certain events in the Olympic Games. British Medical Journal, 1968, 4, 111-113.

Khosla, T. Will the Olympics survive? British Journal of Sports Medicine 1977, 11(1), 20-25.

Kowalski, C. J. A commentary on the use of multivariate statistical methods in anthropological research. American Journal of Physical Anthropology, 1972, 36, 119-132.

Kralj-Cercek, L. The influence of food, body build, and social origin on the age at menarche. Human Biology, 1956, 28(4), 393-406.

Kriesel, G. Interrelationships between some somatic characteristics and hand strength of 14 to 18 year old boys and girls. Symposia Biologica Hungarica (Budapest), 1977, 20, 291-298.

Krustev, K. Age limits for the Olympics. Comite Olympique Bulgare, Bulletin D'Information, July 1977, 25, pp. 25-29.

La Cava, G. Sport and puberty. The Journal of Sports Medicine and Physical Fitness, Quarterly Review, 1974, 14(3), 163-164.

Lee, M. M. C., & Ng, C. K. Postmortem studies of skinfold caliper measurements and actual thickness of skin and subcutaneous tissue. Human Biology, 1965, 37, 91-103.

Le Veau, B., Ward, T., & Nelson, R. C. Body dimensions of Japanese and American gymnasts. Medicine and Science in Sport, 1974, 6(2), 146-150.

Lewis, A. S. Physique as a determinant of success in sport with particular reference to Olympic oarsmen. New Zealand Journal of Health, Physical Education and Recreation, 1969, 2(3), 5-21.

Malina, R. M. Exercise as an influence upon growth: Review and critique of current concepts. Clinical Pediatrics, 1969a, 8, 16-26.

Malina, R. M. Quantification of fat, muscle, and bone in man. Clinical Orthopedics and Related Research, 1969b, 65, 9-38.

Malina, R. M. Adolescent changes in size, build, composition, and performance. Human Biology, 1974, 46(1), 117-131.

Malina, R. M. Physical anthropology, physical activity, and sport. Canadian Journal of Applied Sport Sciences, 1976, 1, 155-161.

Malina, R. M., Harper, A. B., Avent, H. H., & Campbell, D. E. Age at menarche in athletes and non-athletes. Medicine and Science in Sports, 1973, 5(1), 11-13.

Malina, R. M., Spirduso, W. W., Tate, C., & Baylor, A. M. Age at menarche and selected menstrual characteristics in athletes at different competitive levels and in different sports. Medicine and Science in Sports, 1978, 10(3), 218-222.

Malina, R. M., & Zavaleta, A. N. Androgyny of physique in female track and field athletes. Annals of Human Biology, 1976, 3(5), 441-446

Maresh, M. M. A forty-five year investigation for secular changes in physical maturation. American Journal of Physical Anthropology, 1972, 36, 103-110.

Marshall, W. A. Growth in children: Puberty in normal girls. Update, 1972, 4, 1345-1352.

Marshall, W. A. Late onset of puberty. British Medical Journal, 1974, 4, 310.

McGregor, I. A., Thomson, A. M., & Billewicz, W. Z. The development of primary teeth in children from a group of Gambian villages and critical examination of its use for estimating age. British Journal of Nutrition, 1968, 22, 307-314.

McNeill, D., & Livson, N. Maturation rate and body build in women. Child Development, 1963, 34, 25-32.

Medawar, P. B. The shape of the human being as a function of time. Proceedings of the Royal Society of London, 1945, 132, pp. 133-141.

Medved, R. Body weight and predisposition for certain sports. Journal of Sports Medicine and Physical Fitness, 1966, 6(2), 89-91.

Montpetit, R. R. Physiology of gymnastics. In J. Salmela, The advanced study of gymnastics. Springfield: Charles, C. Thomas, 1976. pp. 183-217.

Morales, M. F., Rathbun, E. N., Smit, R. E., & Pace, N. Studies on body composition: Theoretical considerations regarding the major body tissue components with suggestions for application to man. Journal of Biological Chemistry, 1945, 158, 677-691.

Motajova, J. Effect of special stress over a four-year period on certain morphological parameters and bone age in growing children. Folia Morphologica Praha, 1974, 22(4), 358-361.

Nelson, R. C. Comparison of the body dimensions of Japanese, Hungarian, and American gymnasts. Gymnast Magazine, October 1974, 16(10), pp. 44-46.

Newton, M. B., & De Issekutz-Wolsky, M. The effect of parental age on the rate of female maturation. Gerontologia, 1969, 15(16), 328-331.

Nichols, H. Petite, elite: Good gymnasts come in small packages. Women's Sports, March 1979, pp. 17-19.

Novak, L. P., Bierbaum, M., & Mellerowicz, H. Maximal oxygen consumption, pulmonary function, body composition, and anthropometry of adolescent female athletes. Internationale Zeitschrift fur Anglewandte Physiologie (einschlieBlich Arbeitsphysiologie), 1973, 31, 103-119.

Novak, L. P., Woodward, W. A., Bestit, C., & Mellerowicz, H. Working capacity, body composition, and anthropometry of Olympic female athletes. Journal of Sports Medicine and Physical Fitness, 1977, 17, 275-283.

Onat, T., & Numan-Cebeci, E. Sesamoid bones of the hand: Relationships to growth, skeletal, and sexual development in girls. Human Biology, 1976, 48(4), 659-676.

Parizkova, J. The development of subcutaneous fat in adolescents and the effect of physical training and sport. Physiologia Bohemoslovenica, 1959, 8, 112-119.

Parizkova, J. Total body fat and skinfold thickness in children. Metabolism, 1961a, 10, 794-807.

Parizkova, J. Age trends in fat; in normal and obese children. Journal of Applied Physiology, 1961b, 16, 173-174

Parizkova, J. Impact of age, diet, and exercise on man's body composition. Annals of the New York Academy of Sciences, 1963, 110, 671-673.

Parizkova, J. Longitudinal study of the development of body composition and body build in boys of various physical activity. Human Biology, 1968a, 40, 212-225.

Parizkova, J. Body composition and physical fitness. Current Anthropology, 1968b, 9(4), 273-287.

Parizkova, J., & Poupa, O. Some metabolic consequences of adaptation to muscular work. British Journal of Nutrition, 1963, 17, 341-345.

Petersen, A. C. Can puberty come any earlier? Psychology Today Magazine, 1979, 12(9), pp. 45-47.

Pool, J., Binkhorst, R. A., & Vos, J. A. Some anthropometric and physiological data in relation to performance of top female gymnasts. Internationale Zeitschrift fuer angewandte Physiologie Einschliesslich Arbeitsphysiologie, 1969, 27(4), 329-338.

Popham, W. J., & Sirotnik, K. A. Educational statistics: Use and Interpretations (2nd ed.). New York: Harper and Row, 1973.

Quinn, H. With a little help from their friends! MacLean's Magazine, January 8, 1979, p. 50.

Ralis, Z., & McKibbin, B. Changes in shape of the human hip joint during its development and their relation to its stability. Journal of Bone and Joint Surgery, 1973, 55(B), 780-785.

Reiter, E. O., & Kulinh, E. Sexual maturation in the female. Pediatric Clinics of North America, 1972, 19(3), 581-587.

Reynolds, E: L. The distribution of subcutaneous fat in childhood and adolescence. Monographs of the Society for Research in Child Development, 1950, 15(2, Serial No.52), pp. 1-189.

Rona, R., & Pereira, G. Factors that influence age of menarche in girls in Santiago, Chile. Human Biology, 1974, 46(1), 33-42.

Ross, W. D. Personal communication, unpublished data, 1980.

Ross, W. D., Brown, S. R., Hebbelinck, M., & Faulkner, R. A. Kinanthropometric terminology and landmarks: A report based on agreements reached by a Leon and Thea Koerner Foundation study group held at the University of British Columbia, July 1973: Presented to the International Committee for the Standardization of Physical Fitness Tests (Trois Rivieres, July 1976). In R. J. Shephard, & H. Lavallee, Physical fitness assessment. Springfield: Charles, C. Thomas, 1978, pp. 44-49.

Ross, W. D., Brown, S. R., Faulkner, R. A., & Savage, M. V. Age of menarche of elite Canadian skaters and skiers. Canadian Journal of Applied Sport Sciences, 1976, 1(3), 191-193.

Ross, W. D., & Day, J. A. P. Physique and performance of young skiers. Journal of Sports Medicine and Physical Fitness, 1972, 12, 30-37.

Ross, W. D., Drinkwater, D. T., Whittingham, N., & Faulkner, R. A. Anthropometric prototypes: Ages 6 to 18 years. In K. Berg, & B. O. Erikson (Ed.), Pediatric Work Physiology 9. Baltimore: University Park Press, 1980, pp. 3-12.

Ross, W. D. & Marshall, G. R. Physique characteristics and the child athlete. Recreational Research Review, February 1979, pp. 13-17.

Ross, W. D., Marshall, G. R., Vajda, A., & Roth, K. D. Some comments on kinänthropometry and theoretical dimensional relationships. Dimensionalitat Und Proportionalitat Von Kraftleistungen: Leiftungsstort, 1978, 8, 1-8.

Ross, W. D., McKim, D. R., & Wilson, B. D. Kinanthropometry and young skiers. In A. Taylor (Ed.), Application of science and medicine in sport. Springfield: Charles, C. Thomas, 1976, pp. 257-277.

Ross, W. D., & Wilson, N. C. Growth and development: A stratagem for proportional growth assessment. ACTA Paediatrica Belgica Supplement, 1974, 28, 169-182.

Rozin, E. U. The influence of anthropometric parameters on successful learning in gymnastics. Yessis Review, 1974, 9(1), 16-21.

Salmela, J. H. The advanced study of gymnastics. Springfield: Charles, C. Thomas, 1976.

Salmela, J., Halle, M., Petiot, B., & Samson, R. Determinants of Olympic gymnastic performance. Proceedings of the International Congress of Physical Activity Sciences, Quebec, July 1976, 7, pp. 169-177.

Shephard, R. J., Jones, J., Ishii, K., Kanek, M., & Albecht, A. J. Factors affecting body density and thickness of subcutaneous fat. American Journal of Clinical Nutrition, 1969, 22, 1175-1189.

Sinning, W. E. Body composition assessment of college wrestlers. Medicine and Science in Sports, 1974, 6(2), 139-145.

Sinning, W. E., & Lindberg, G. D. Physical characteristics of college age women gymnasts. Research Quarterly, 1972, 43(2), 226-234.

Skerlj, B., Brozek, J., & Hunt, E., Jr. Subcutaneous fat and age changes in body build and body form in women. American Journal of Physical Anthropology, 1953, 11, 577-600.

Slaughter, M. H., Lohman, T. G., & Boileau, R. A. Relationship of anthropometric dimensions to lean body mass in children. Annals of Human Biology, 1978, 5(5), 469-482.

Smit, P. J. Anthropometric observations on South African gymnasts. South Africa Medical Journal, 1973, 47, 480-485.

Smith, N. J. Gaining and losing weight in athletics. Journal of the American Medical Association, 1976, 236(2), 149-151.

Sprynarova, S., & Parizkova, J. Comparison of the functional circulatory and respiratory capacity in girl gymnasts and swimmers. Journal of Sports Medicine, 1969, 9, 165-172.

Tanner, J. M. Growth at adolescence (2nd ed.), Oxford: Blackwell Scientific Publications, 1962.

Tanner, J. M. The regulation of human growth. Child Development, 1963, 34, 817-847.

Tanner, J. M. The physique of the Olympic athlete. London: George Allen, and Unwin Ltd., 1964.

Tanner, J. M. Foetus into man: Physical growth from conception to maturity. Cambridge: Harvard University Press, 1978.

Tanner, J. M, & Whitehouse, R. H. Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. Archives of Disease in Childhood, 1976, 51(3), 170-179.

Tanner, J. M., Whitehouse, R. H., Marshall, W. A., Healy, M. J. R., & Goldstein, H. Assessment of skeletal maturity and prediction of adult height (TW2 Method). London: Academic Press, 1975.

Taunton, C. Children and running: The experts speak. B. C. Runner Magazine, Winter 1979/80, 5, pp. 15-23.

Tosovsky, J., Prokopec, M., & Mejsnarova, B. Growth curves and their application to the growth of anthropometric characteristics of an individual during ontogenesis. ACTA Facultatis Medicae Universitatis Brunensis, 1976, 57, 243-252.

Valliere, A. Biomechanical misconception in artistic gymnastics. In J. Salmela, The advanced study of gymnastics. Springfield: Charles, C. Thomas, 1976, pp. 93-107.

Webster's seventh new collegiate dictionary: Based on Webster's third new international dictionary. Springfield: G. & C. Merriam Co., 1970.

Well, J. B., Jokl, E., & Bohranen, J. The effect of intensive physical training upon body composition of adolescent girls. American Corrective Therapy Journal, 1963, 17(3), 68-72.

Whittingham, N. Anthropometric prototypes for boys and girls aged 6 to 18, exemplified by structure analysis of sub-12 year old figure skaters. Unpublished master's thesis, Simon Fraser University, 1978.

Wilmore, J. H,, & Behnke, A. R. Predictability of lean body weight through anthropometric assessment in college men. Journal of Applied Physiology, 1968, 25(4), 349-355.

Wilmore, J. H., & Behnke, A. R. An anthropometric estimation of body density and lean body weight in young women. American Journal of Clinical Nutrition, 1970, 23, 267-274.

Wilmore, J. H., Girandola, R. N., & Moody, D. L. Validity of skinfold and girth assessment for predicting alterations in body composition. Journal of Applied Physiology. 1970a, 29(3), 313-317.

Wilmore, J. H., Royce, J., Girandola, R. N., Katch, F. I., & Katch, V. L. Body composition changes with a 10 week program of jogging. Medicine and Science in Sports, 1970b, 2(3), 113-117.

Womersley, J., & Durnin, J. V. G. An experimental study on variability of measurements of skinfold thickness on young adults. Human Biology, 1973, 45(2), 281-292.

Wood, T. Computer program: Calculation of proportional mass values, January 1980.

Youngren, D. H. A relationship of selected anthropometric measurements to performance of the U. S. women gymnastic athletes in the 1968 Olympic trials. Unpublished master's thesis, California State College at Long Beach, 1969.

Yuhasz, M. S. Fat measurements and classification, and a method for the individual prediction of optimal body weight. In M. S. Yuhasz, Physical fitness laboratory manual. London: University of Western Ontario, 1977, p. 158.

Zacharias, L., Rand, W. M., & Wurtman, R. J. A prospective study of sexual development and growth in American girls: The statistics of menarche. Obstetrical and Gynecological Survey, 1976, 31(4), 325-337.

Zuk, G. H. The plasticity of the physique from early adolescence through adulthood. Journal of Genetic Psychology, 1958, 92, 205-214.

Zwiren, L., Skinner, J. S., & Buskirk, E. R. Use of body density and various skinfold equations for estimating small reductions in body fatness: Original papers. Journal of Sports Medicine and Physical Fitness, 1973, 13(1), 213-218.

APPENDIX A

APPENDIX A

THE ABILITY OF THE DRINKWATER TACTIC* (ANTHROPOMETRIC FRACTIONATION OF BODY MASS) TO ESTIMATE OBSERVED BODY MASS IN THE PRESENT SAMPLE OF GYMNASTS

OBM = Obtained Body Mass ≑ Scale Weight

PBM = Predicted Body Mass = FAT MASS + MUSCLE MASS + SKELETAL MASS + RESIDUAL MASS

DIFF = (PBM - OBM) = Difference

% ERR = $\frac{\text{DIFF}}{\text{OBM}} \times 100$ = % Error

		Group					
		1	2	3	4	1+2	1+2+3
OBM	$\bar{X}$	43.7	44.1	48.7	50.0	43.9	45.9
PBM	$\bar{X}$	41.9	41.5	46.1	47.1	41.7	43.5
DIFF	$\bar{X}$	-1.8	-2.6	-2.6	-2.9	-2.2	-2.4
% ERR	$\bar{X}$	4.3	6.3	5.6	6.2	5.3	5.5

* Drinkwater & Ross, 1980

APPENDIX A CONTINUED

The Drinkwater Tactic systematically underestimated obtained body mass (scale weight) in the present sample of female gymnasts. The original formulae (applied to the present sample) were based on deviations from a unisex adult model, and it is hypothesized that the specific anthropometric variables, selected to represent the individual masses, do not reflect these masses in children as closely as they do in adults.