THE PREDICTION OF GYMNASTIC PERFORMANCE

The Prediction of Gymnastic Performance Through an Analysis of Selected Physical, Physiological and Anthropometric Variables

by

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ABSTRACT

The Prediction of Gymnastic Performance Through an Analysis of Selected Physical, Physiological and Anthropometric Variables

The purpose of this investigation was to determine the relative importance of selected physical, physiological and anthropometric variables in predicting all-around gymnastic ability and ability in each of the individual events. A total of 29 female, all-around gymnasts between the ages of 11 and 13 years, were evaluated on 13 variables: (1) height, (2) weight, (3) total skinfold, (4) anaerobic endurance, (5) flexibility, (6) power, (7) strength, (8) agility, (9) maximum aerobic capacity, (10) maximum lactate, (11) heart rate intensity during gymnastic routines, (12) post-exercise lactate and (13) experience. All-around and individual event gymnastic scores were used in the regression analysis as the dependent variables. All subjects were divided into two ability groups based on all-around scores (low ability $\leq$ 20 points, high ability $\geq$ 30 points). High ability gymnasts obtained significantly lower scores for agility and total skinfold and higher scores for flexibility, strength, average heart rate intensity and post-exercise lactate than the low ability gymnasts. Prediction equations for gymnastic ability were computed with (R^2=.878 to .940) and without (R^2= .815 to .888) the experience variable entered into the regression analysis. With experience excluded from the analysis, the flexibility variable was found to be the single best predictor of ability, however, when the experience variable was included in the analysis it was selected as the single best predictor in each equation.

RÉSUMÉ

Prédiction de la Performance en Gymnastique par L'analyse de Certaines Variables Physique, Physiologique et Anthropométrique

Le but de cette étude etait de déterminer l'importance relative des variàbles physique, physiologique et anthropométrique pour la prédiction de l'habileté en gymnastique, ainsi que l'habileté dans chaque épreuve. Un total de 29 jeunes filles gymnastes, âgées entre 11 et 13 ans, étaient évaluées selon 13 variables: (1) la grandeur, (2) le poids, (3) la quantité de graisse totale, (4) l'endurance anaérobique, (5) la flexibilité, (6) la force, (7) la puissance, (8) l'agilité, (9) la capacité aérobique maximale, (10) la quantité d'acide lactique maximale, (11) le rhythme cardiaque lors des exercices de gymnastique, (12) la quantité d'acide lactique après l'exercice et (13) l'expérience. Les résultats total ainsi qu'individuel utilisés pour l'analyse de régression représentaient les variables dépendantes. Tous les sujets étaient divisés en deux groupes d'habileté basés sur le résultat total (habileté basse $\leq$ 20 points, habileté haute $\geq$ 30 points). Les gymnastes de haute habileté ont significativement obtenu de bas résultats pour l'agilité, et pour la graisse totale et de hauts résultats pour la flexibilité, la force, la moyenne d'intensité du rhythme cardiaque et la quantité d'acide lactique après l'exercice comparativement aux gymnastes de basse habileté. Les équations prédites pour l'habileté en gymnastique étaient compilées avec la variable expérience (R^2=.878

à .940) et sans la variable expérience (R^2=.815 à .888) insérée dans l'analyse régressive. La variable expérience, étant exclue de l'analyse, la variable flexibilité était la meilleure pour la prédiction de l'habileté, ainsi donc, lorsque la variable expérience était incluse dans l'analyse, elle était le meilleur élément de prediction de résultats pour chaque équation.

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CHAPTER 1

INTRODUCTION

1.1 NATURE AND SCOPE OF THE PROBLEM

Successful participation in any sport requires specific training to develop the physical characteristics and physiological capacities essential to that sport. Specificity of training refers to the development of the energy system or systems predominately used during the performance of the sports activity (Mathews and Fox, 1976), as well as physical characteristics such as strength, flexibility and body composition which are essential for successful participation. Each sport is unique in that it requires the development of specific characteristics and qualities in its participants to enable them to achieve a high level of ability and success in that sport. Obtaining scientific information concerning the relative importance of specific physiological factors as they affect performance success is of prime concern when assessing the effectiveness of present training procedures or in improving existing training techniques.

There are basically three factors which influence physical performance: (1) neuromuscular function, (2) energy output, and (3) psychological factors (Saltin and Astrand, 1967). Gymnastics is primarily a skill activity that requires the development of neuromuscular coordination to a highly refined level (Drazil, 1971). Although skill development is vitally important in this sport, the criteria for evaluating performance success is based on the ability to combine these individual skills into a routine. Performing an entire routine, as opposed to a single gymnastic skill, requires a significantly greater amount of muscular endurance along with a concomitant increase in the metabolic level. Also there are psychological and emotional stresses placed on the gymnasts when the routines are performed before an audience.

Despite the relative importance that these factors have on performance, very little information is available, particularly concerning the physiological capacity of gymnasts and how this capacity affects performance. Many investigators have measured heart rate response and energy expenditure during the performance of gymnastic routines in men and women (Kozar, 1963; Sward, 1967; Sprynarova and Parizkova, 1969; Spitzer and Helliger, 1969; Cumming, 1970; Seliger et al., 1970; Faria and Phillips, 1970; and Montpetit, 1972). Few studies have measured aerobic capacity in gymnasts (Saltin and Astrand, 1967; Sprynarova and Parizkova, 1969; Cumming, 1970; Novak et al., 1970; and Montpetit, 1972). To this author's knowledge, the anaerobic responses of gymnasts has not been investigated.

Although there are similarities between the men's and women's events, the men's events are characterized by a more extensive involvement of arm work (i.e. on the rings, high bar, pommel horse, and parallel bars) and except for the floor exercise event the routines are shorter in duration than the longer women's events of balance beam and floor exercise. Thus, it would be incorrect to make assumptions concerning the physiological requirements of female gymnasts based on the data collected on subjects participating in men's events.

Previous studies have evaluated such variables as skinfold thickness (Gates, 1974; and Pool et al., 1969), anthropometric measurements (Pool et al., 1969; and Read, 1967), as well as individual test items measuring power (Boyd, 1971; and Pool et al., 1969) muscular strength and endurance (Read, 1967; and Wettstone, 1938), and agility (Wettstone, 1938) in an attempt to predict gymnastic potential. The prediction equations and multiple correlations eminating from these studies have been computed solely from physical and anthropometric variables. To this author's knowledge, no study has investigated the role of physiological variables as they relate to the gymnast's performance ability, or their relative significance as compared to physical and anthropometric factors. Also, since there is very little consistency or overlap in the specific variables that have been investigated, as well as the type of subject used (as far as experience and ability level), it is difficult to evaluate the significance of these variables on performance ability.

1.2 SIGNFICANCE OF THE STUDY

For training purposes and proper preparation of athletes for competition, it is important to know which physiological variables have the greatest effect on performance. The development of physical characteristics and physiological capacities is a very important and vital aspect of skill acquisition. To determine the variables which are important in each sport, it is necessary to obtain data on the physiological response of athletes to general work tasks as well as during the actual participation in their specific sport (Ferguson et al., 1969; and Montpetit, 1972). Information on physiological responses during actual participation in a sport will help isolate those variables which have the most significant effect on performance ability and determine where training emphasis should be placed.

Very little is known about the factors that affect gymnastic performance. A need for further information has been expressed. Broms et al., (1970) in their study of elite Belgan gymnasts, concluded that ...

> "...sports training for top class gymnasts is often very specific and that a profound examination must be continued in the field of local muscular endurance, flexibility and cardio-respiratory endurance."

Conclusive evidence pertaining to the importance of aerobic and anaerobic capacities to gymnastic performance is presently not available.

In the literature there is considerable disagreement about the relative importance of aerobic capacity in gymnastics. A few researchers have measured this capacity in gymnasts but none have related these values to ability level (Saltin and Astrand, 1967; Novak et al., 1968; Cumming, 1970; and Montpetit, 1972). Their general concensus is that gymnasts as a group have poor to average aerobic capacity and that this capacity is unimportant in the performance of gymnastic routines. On the other hand, many gymnastic authorities and coaches emphasize the importance of cardiovascular (aerobic) conditioning for gymnasts (Wolcott, 1964; Wolfe, 1967; Seliger et al., 1970; Spackman, 1970; Sokol, 1971; Kjeldsen, 1971; Black and Johnson, 1975; and Kudrnovsky, 1977). Seliger et al. (1970) stated that:

> "...gymnastics itself can't sufficiently develop the aerobic capacity of the organism to the needed level, until complementary exercises are added ... thus the optimum reaction to a given physical load cannot be attained."

The relative importance of anaerobic capacity is similarly unclear: After an investigation of four men's gymnastic events one researcher hypothesized that lactate production following the performance of gymnastic routines would be negligible, due to the brevity of the activity, but this has never been measured (Montpetit, 1972). This researcher further suggests that measuring blood lactate levels after gymnastic routines would "...provide a definite answer to the problem of the energy cost of gymnastics."

Few studies have measured and evaluated the physiological and anthropometric characteristics of female gymnasts. Still fewer have related these variables to performance success. In addition, there is no data available, to this author's knowledge, on the gymnasts' physiological response to the floor exercise event or the importance of specific variables to ability in this event. Characteristics dealing with agility, body composition, height, weight and experience have been evaluated in past investigations and in some cases were found to be significant factors in predicting performance ability. However, the importance of these variables in relation to physiological variables has not been investigated thus far, to this author's knowledge.

Therefore, the purpose of this investigation was to measure and evaluate physiological capacities as well as physical and anthropometric factors to determine their relative importance in gymnastic performance. Data on heart rate response and lactate accumulation were obtained on all four of the women's events. In addition, laboratory tests were used to measure strength, flexibility, agility, anaerobic muscular endurance, aerobic capacity, anaerobic capacity, power, body composition, height, weight, and experience. Evaluation of these selected variables have isolated those factors which are most important to predict all-around gymnastic ability and those factors which are most important in each of the women's individual events.

It is hoped that this study will provide important information to gymnastic coaches and trainers and will enable a more scientific application of training practices. Knowing the variables that are most important to predict performance, it will be possible to develop training techniques that will concentrate on the optimum development of these variables. In addition it will be helpful to coaches who are evaluating potential gymnasts for team selection. An awareness of important physiological characteristics that relate to high level gymnastic performance will assist the coach in the evaluation of potential gymnasts.

1.3 STATEMENT OF THE PROBLEM

The primary concern of this investigation was the measurement of selected physical, physiological and anthropometric variables in female gymnasts, representing a wide range of ability, and the evaluation of their relative importance to predict success in all-around performance, as well as in each event. Judges' scores awarded for optional routines in each of the four women's events (vaulting, uneven parallel bars, balance beam, and floor exercise) were used to determine ability level. The specific hypothesis tested were as follows:

1. There are no significant difference between the two gymnastic ability groups in the thirteen selected variables.

2. The thirteen variables are nonsignificant in predicting gymnastic performance as determined by judges' score.
3. The four women's events have similar physiological responses in heart rate intensity and post exercise blood lactate concentration.

1.4 DELIMITATIONS OF THE STUDY

Because of the small sample size used in this study, all conclusions and inferences are confined to the population under investigation. Other delimitations of the study were as follows:

1. The number of subjects in the study was limited to 30 females between the ages of 11 and 13 years.
2. All subjects were all-around gymnasts with at least one year of experience.
3. A bicycle ergometer was used to determine maximum aerobic capacity.
4. Heart rate intensity for each event was monitored only once during a practice situation.
5. Performance scores from qualified gymnastic judges (with adjustments made for differences in difficulty level), were accepted as valid measures of each subject's ability.

1.5 OPERATIONAL DEFINITIONS

Agility - The time, to the nearest tenth of a second, required to complete the A.A.H.P.E.R. 30 foot shuttle run.

Flexibility - The total degrees of range of motion measured by a Leighton Flexometer, for the movements of hip flexion, hip abduction, shoulder hyperflexion and hyperextension, trunk flexion and trunk extension.

Heart rate intensity - The working heart rate corrected for resting heart rate and expressed as a percent of the potential heart rate (maximum heart rate minus resting heart rate).

Maximum aerobic capacity - The highest level of oxygen consumption attained during a discontinuous graded bicycle ergometer test performed to the point of volitional exhaustion with an R.Q. greater than 1.0.

Maximum alactic power (muscular power) - The highest score recorded (out of six attempts) on the Margaria-Kalmen stair power test.

Muscular endurance (anaerobic) - The total duration in seconds at which the gymnast can pedal a bicycle ergometer between 60 and 70 rpm at a resistence corresponding to six percent of her body weight.

Maximum heart rate - The highest six second heart rate average recorded either during the maximum aerobic test by a single channel ECG recorder, or during gymnastic routines via radio telemetry.

Muscular strength - The total strength score recorded in kg/kg body weight as determined by the cable tensiometer strength battery for Junior High girls (ages 11 1/2 to 14 1/2 years) developed by Clarke and Munroe (1970).

Peak heart rate - The highest six second heart rate average recorded during each of the routines or in the first few seconds during the recovery portion following the performance of the routines.

CHAPTER II

REVIEW OF RELATED LITERATURE

2.1 THE PHYSIOLOGICAL NATURE OF GYMNASTICS

Gymnastics, as well as any other physical activity, can be classified and described in terms of energy requirement and utilization. Muscular contraction or work requires the production and splitting of high energy phosphate bonds in the ATP and CP molecules. The production of ATP from glycogen can be accomplished in the presence (aerobically) or absence (anaerobically) of oxygen. Due to physiological adjustments and adaptations to the intensity of muscular work the amount of oxygen that is available to the tissues varies. As a result both processes of energy production are required and the extent to which each process contributes to the total energy production depends on the intensity and duration of the activity (Astrand and Rodahl, 1977).

During vigorous activity of short duration (less than one minute) there is little time for respiratory and circulatory adjustment and the work is carried out under oxygen debt. As a result the majority of the energy production is provided anaerobically. When the activity requires about two and one half minutes for completion, the energy supply is nearly 50% aerobic, while for an activity of 30 minutes in duration, the aerobic contribution increases to 90% (Astrand and Rodahl, 1977).

Gymnastic routines are vigorous in nature but are very short in duration. In women's gymnastics the longest event is the balance beam which has a required performance time between one minute and 20 seconds and one minute 45 seconds. Floor exercise has a time requirement of one minute to one minute 30 seconds (F.I.G. Code of Points, 1978). Routines on the uneven parallel bars and side horse vaulting have no time restrictions. The average duration of a bar routine is 30 to 45 seconds while a vault requires only four to six seconds for completion. Because of the brevity of the routines, gymnastics is classified as highly anaerobic in nature.

Montpetit (1972), studied the physiological responses of eight male gymnasts performing routines in four events; side horse, horizontal bar, parallel bars and rings. The average duration of the exercises was between 20 to 30 seconds. Through indirect calorimetry he determined that the contribution of anaerobic processes during the performance of gymnastic routines can be as high as 80 percent. It was also calculated that male gymnasts utilize about 30 percent of their maximal aerobic power during the performance of their routines. According to Andersen's relative load index classification (1970), the oxygen requirement expressed as a percent of the $\dot{V}O_2$max., gymnastics is classified as "moderately heavy work." Therefore, gymnastics is highly anaerobic in nature, and is an activity that is associated with a substantial increase in the metabolic rate.

Andersen's Relative Load Index

Grading	Percent of $\dot{V}O_2$ max.
Light Work	$<$ 25%
Moderate Heavy Work	25-49%
Heavy Work	50-75%
Extremely Heavy Work	$>$ 75%

In addition to being short in duration and explosive in nature, gymnastics is also characterized by an extensive amount of arm work and frequent changes in body position. Asmussen and Hemmingsen (1958) observed differences in physiological response to arm work and leg work on a bicycle ergometer. For a given workload, pulse rate, oxygen consumption and ventilation were always higher for arm work than for leg work. Astrand et al., (1968) reported similar results after studying the circulatory responses to arm exercise. It was determined that at the same absolute workload, measurements of heart rate, blood pressure, ventilation and lactate concentration were all higher with arm exercise as opposed to leg exercise. In addition, Astrand and Saltin (1961) calculated that maximum work with the arms produces an oxygen uptake that was 30% lower than that attained by leg cycling work. Maximum aerobic capacity is also reduced with a change in body position (Astrand and Saltin 1961). Cycling in a supine position resulted in a maximum oxygen consumption that was 15% lower than cycling in a sitting position.

Also in reference to a change in body position, Shvartz (1968) studied the physiological responses while performing a handstand. He found a substantial increase in energy cost from an oxygen consumption of .365 l/min. in the sitting position to 2.01 l/min. in the handstand. Rapid changes in body position also have a profound effect on the venous return which in turn affects blood pressure, heart rate and stroke volume (Astrand, 1956). As a result, training in gymnastics has been observed to improve the vestibular system (Drazil, 1971) and orthostatic efficiency (Shvartz, 1968), or circulatory adjustment to gravity.

Gymnastic activity is characterized by low ventilation, tidal volume and respiratory rate, with a high rate of oxygen extraction (Montpetit, 1972). Low ventilation and tidal volume are due to an increase in the intrathoracic pressure caused by the nature of the activity which demands fixation and control of the thorax in order to perform specific skills. Respiratory rate is reduced because of the degree of breath holding that takes place, up to 40-50% of the time in the inexperienced gymnasts but no more than 10-15% of the time in the advanced gymnasts (Montpetit, 1972). With lower ventilation there is an increase in oxygen extraction to compensate for the insufficient supply to the working tissues.

Summary

1. Because of the brevity and intensity of the routines, gymnastics is classified as a highly anaerobic activity - as high as 80% (Montpetit, 1972).

2. There is a substantial increase in the metabolic rate when gymnastic routines are performed (Kozar, 1963; Sward, 1967; Faria and Phillips, 1970; Seliger et al., 1970; and Drazil, 1971). Gymnasts utilize about 30% of their maximal aerobic power during the performance of gymnastic routines (Montpetit, 1972).

3. Gymnastics is characterized by an extensive amount of arm work and frequent changes in body position. When compared to leg work, arm work is associated with a higher heart rate, blood pressure, ventilation, oxygen consumption and blood lactate concentration (Astrand, 1956; Asmussen and Hemmingsen, 1958; Astrand and Saltin, 1961; and Astrand et al., 1968).

4. Gymnastic activity is characterized by low ventilation, tidal volume and respiratory rate (Montpetit, 1972).

2.2 CHARACTERISTICS OF GYMNASTS

2.2.1 Physique and Body Composition

In an attempt to determine the factors that affect gymnastic performance many researchers have felt it significant to investigate the characteristics which are common to successful participants (Carter et al., 1971; Cumming, 1970; Novak et al., 1968; Pool et al., 1969; Sinning and Lindberg, 1972; Sprynarova and Parizkova, 1969). In support of this premise, Espenschade (1964) in essence states that top athletes are naturally endowed with a body type, body structure and capacity which is largely responsible for their superior ability. Others believe that it may be participation in the activity itself which causes modification and adaptation in body composition and capacity (Novak et al., 1968).

Carter et al (1971) found a significant relationship between physical performance and somatotype. In this study they concluded that: (1) athletes are somatotypically different from the general population, (2) certain athletic groups are different from each other, and (3) performers at the same level of competition tend to be similar. Gymnasts are classified as being highly mesomorphic with the highly successful gymnast having a somatotype evaluation of 2.1-6.0-2.2. This classification is based on a seven point scale developed by Sheldon (Mathews and Fox, 1976). The number one indicates a lack of a certain characteristic and seven indicates a great amount of the characteristic. The first number describes endomorphy (fatness), the second mesomorphy (musculature) and the third ectomorphy (thinness), (Mathews and Fox, 1976). In specific reference to gymnasts it was concluded that (1) outstanding gymnasts are similar in somatotype and proportion, but may differ considerably in terms of gross body size, and (2) within the same competition. The highly successful competitors are more mesomorphic than the less successful competitors.

College age female gymnasts are reported to have a significantly higher body density than non-athletic women of the same age due to their superior muscular development (Sinning and Lindberg, 1972). In addition, other studies have shown that gymnasts are typically characterized by small skinfolds (Pool et al., 1969) and low percent body fat measurements (Bosco, 1964; Drazil, 1971; Novak et al., 1968; Sinning and Lindberg, 1972). Top female gymnasts usually do not exceed 10-15 percent body fat but women at lower levels of ability have body fat percentages as high as 21.9 percent. Compared to other athletes, distance runners, low weight wrestlers and gymnasts have been found to be the leanest (Montpetit, 1972). Novak et al. (1968) reported that male gymnasts had 95 percent fat-free mass and the top gymnast tested had a total body fat amounting to only 2.7 percent.

In reference to other body measurements, gymnasts are characterized by small height and weight, above normal upper arm girth and shoulder width and below normal leg length, hip width and arm span (Bosco, 1964; Pool et al., 1969; Read, 1967; Sinning and Lindberg, 1972).

2.2.2 Flexibility

Throughout the literature investigated, coaches and authorities were consistent in stating the necessity of a high degree of flexibility in achieving success in gymnastic performance (Bates, 1976; Kjeldsen, 1971; Leighton, 1955; Mathews, 1968; Takei, 1977). Flexibility, defined as the range of possible movement about a joint or a sequence of joints (Clarke, 1975), is a highly specific characteristic in two ways (Mathews and Fox, 1976).

First of all, vastly differing and specific patterns of flexibility have been observed in the participants of various sporting events. For example, male swimmers had a high degree of flexibility in the shoulders, wrists and hips in comparison to other athletic groups, while weight lifters demonstrated the greatest amount of trunk flexibility (Leighton, 1955). In a study by Matz (1954) it was shown that participating in gymnastics resulted in an increase in shoulder flexibility in 71 percent of the male subjects tested. However, this improvement in flexibility is highly specific because it occurs in some joints and not in others (Clarke, 1975). Gardner (1972), comparing flexibility in male divers, swimmers and gymnasts reported that there were significant differences between the groups in shoulder and hip measurements.

While gymnasts would be expected to score high on a flexibility battery, as reported by one investigator (Bosco, 1964), it was demonstrated by Leighton (1955) that in male athletes, swimmers and baseball players demonstrated the highest overall flexibility. Gymnasts scored high on 15 measurements especially in the hip area but low on six measures involving the shoulders, wrists, ankles and trunk. This brings us to the second point of specificity, which is that flexibility is joint-specific, i.e. a high degree of flexibility in one joint does not establish the existence of high flexibility in other joints (Mathews and Fox, 1976).

Both the number of years of participation and the ability level of an athlete seem to have a significant effect on flexibility (Clarke, 1975). Olympic swimmers scored higher on ankle and trunk flexibility tests than did varsity college swimmers while gymnasts who had participated competitively for the greatest number of years scored higher than their less experienced counterparts.

Female gymnasts also possess a high degree of hip flexibility but unlike men they are characterized by a significant amount of shoulder and upper back flexibility (Kjeldsen, 1971). Flexibility in this area is due to the difference in the nature of the women's events, specifically the balance beam and floor exercise. Twelve women gymnasts were shown to improve significantly in shoulder and upper back flexibility as a result of a season of gymnastic participation (Clare, 1975).

In addition, there is a tendency for girls to be more flexible than boys (deVries, 1966). The average girl generally reaches her peak flexibility at the age of 12 and thereafter shows a gradual decline (Hupprich and Sigerseth, 1950). There have been no studies investigating the development and or possible decline of flexibility in female gymnasts during the same age period.

2.2.3 Strength

Because an individual's motor fitness and athletic ability are closely paralleled by his/her muscular strength, a great deal of concern and resultant research has occured in this area (Clarke, 1973; Clarke, 1974). Strength training is employed by coaches of all sport activities in an attempt to improve speed, power, endurance and specific sport skills.

In gymnastics, strength is a necessity for learning many gymnastic movements and a very important part of a skilled performance. As early as 1938, Wettstone demonstrated the importance of strength in gymnastics and determined that it was one of the most significant factors in predicting potential gymnastic ability. Sale (1976) suggests that the improvement of strength at specific joint angular velocities may be of greater benefit to the performance of gymnastic skills than the improvement of static or low velocity dynamic strength. From preliminary investigations he has concluded that the poor tumbler is stronger at low velocity but weaker at high velocity than the good tumbler.

Chu and Krepton (1977) in a recent article stress the importance of weight training for female gymnasts. This type of program would assist the beginner in acquiring the basic gymnastic skills, which are highly strength dependent and improve the performance and efficiency of the more advanced gymnast. In addition, female gymnasts, at all levels of competition are at a distinct disadvantage if they have low strength-weight ratios (Espenschade, 1964).

Muscular strength, endurance and power are reported to be outstanding characteristics of highly trained gymnasts (Borms, 1970; Bosco, 1973; Cumming, 1970; Jackson, 1971; Pool et al., 1969; Sale, 1976). As would be expected, trained gymnasts are considerably stronger than untrained individuals but they also achieve significantly higher strength scores than other athletic groups (Cumming, 1970). After testing athletes representing Canada at the 1967 Pan American Games, Cumming (1970) concluded that for males, the volleyball and gymnastic teams were by far the strongest with a total strength score of 4.18 kg/kg body weight and that the female gymnasts had the highest overall strength for the women tested with a score of 3.43 kg/kg body weight.

Explosive strength or power is very important in gymnastic events such as vaulting and floor exercise and as a result of participation in such activities, gymnasts have shown improvement in power at the completion of a training season (Bosco, 1973). Also DiGiovanna (1943) reported that gymnasts were more powerful than members of other varsity teams, while Jackson (1971) demonstrated that gymnasts have significantly greater vertical jump ability than football and baseball players as well as golfers.

2.2.4 Aerobic Capacity

Maximum aerobic capacity is an accurate and reliable measure of a person's capacity and tolerence for prolonged work. Due to the brief nature of a gymnastic performance it has been reported that participation in gymnastic training has no significant influence on the development or improvement of the cardiovascular system (Bosco, 1973; Roskamm, 1967; Seliger et al., 1970). To support this belief, two researchers report little or no increase in the heart volume of gymnasts. After comparing untrained normal persons of the same age to athletes representing German national teams, Roskamm (1967) found that both well-trained weight lifters and gymnasts had no increase in heart volume. Reporting on the results of another study, Drazil (1971) states that the heart of the gymnast is small in comparison to other trained athletes because only 5 percent of the subjects x-rayed showed an enlarged heart.

Despite these findings there is considerable concensus in the literature among coaches and authorities that aerobic training is important and necessary in gymnastics (Biesterfeldt, 1972; Black, 1975; Kjeldsen, 1971; Saltin, 1967; Spackman, 1970; Wolfe, 1967), and that without it the full potential of one's ability cannot be attained. On the other hand, Astrand (1956) states that the more complicated an exercise is (like gymnastics), the greater the inter-individual variation in mechanical efficiency. Efficiency can be increased by technique training, which in turn can compensate for a low aerobic capacity.

Wolfe (1967) claims that improving the aerobic capacity will result in a concomitant improvement in performing gymnastic routines due to an increased ability to sustain a given work load. Spackman (1970) emphasizes the importance of cardiovascular fitness in floor exercise because of the length and intensity of the exercise. Black (1975) stresses the importance of both muscular and cardiovascular endurance as necessities for successful performance of difficult routines and for minimizing the effect of the static muscular contractions involved. In all cases, however, these statements appear to be based solely on personal opinion and conjecture since they present no research data to substantiate their views. Although there is no specific evidence in reference to gymnastics, Astrand states that when large muscle groups are very active for a minute or longer, the individual's aerobic work capacity greatly affects his ability to perform (Astrand, 1967).

Along with the insufficient evidence as to the importance of aerobic fitness in gymnastics, there have been relatively few studies that have measured this capacity. The available $\dot{V}O_2max$ data as reported by various researchers is summarized in Table 1.

In the study conducted by Novak et al.(1968) it was noted that the top gymnast also possessed the highest aerobic capacity of 60 ml/kg. min. Montpetit (1972) obtained similarly high $\dot{V}O_2max$ values but concluded that gymnasts were characterized by a low maximal aerobic power. However, according to Astrand's norms for maximum aerobic capacity (1960), male gymnasts were rated in the "Good" to "High" categories. Both studies of female gymnasts indicate that they have $\dot{V}O_2max$ ratings from "Average" to "Good".

Table 1. Maximum oxygen consumption in gymnasts.

SUBJECTS	V̇O2max (ml/kg.min.)
Males	
Swedish National Team (n=6) (Saltin and Astrand, 1967)	60.0
College (n=7) (Novak et al., 1968)	55.5
Canadian National Team (n=15) (Cumming, 1970)	42.1
College (n=8) (Montpetit, 1972)	51.6
Females	
Canadian National Team (n=4) (Cumming, 1970)	43.1
High School (n=10) (Sprynarova and Parizkova, 1969)	42.5

Summary

1. Gymnasts are classified as being highly mesomorphic with the highly successful gymnast having a somatotype evaluation of 2.1-6.0-2.2 (Carter, 1971; Wolcott, 1964).

2. Gymnasts are typically characterized by small skinfolds, and low percent body fat measurements. In addition, they are small in height and weight, above normal upper arm girth and shoulder width, and below normal leg length, hip width and arm span (Bosco, 1964; Pool et al. 1969; Read, 1967; Sinning and Lindberg, 1972).

3. Male gymnasts score high on flexibility measurements especially in the hip area but low on measures involving the shoulder, wrists, ankles and trunk (Leighton, 1955).

4. Female gymnasts are characterized as having better than average shoulder and upper back flexibility as well as extremely good hip flexibility (Kjeldsen, 1971).

5. Strength is a necessity for learning many gymnastic movements and a very important part of a skilled performance (Chu and Krepton, 1977; Espenschade, 1964; Sale, 1976; Wettstone, 1938).

6. Compared to other female athletes female gymnasts obtain the highest overall strength scores (Cumming, 1970).

7. Gymnasts score high on power tests like the vertical jump, and on muscular endurance tests involving the arms (Borms et al., 1970; Bosco, 1973; Cumming, 1970; Jackson, 1971; Pool et al., 1969; Sale, 1976).

8. Female gymnasts have "average to good" maximum aerobic capacities while some male gymnasts attain a "high" rating (Åstrand, 1960; Astrand, 1967; Cumming, 1970; Sprynarova and Parizkova, 1969).

2.3 HEART RATE RESPONSE AND ENERGY EXPENDITURE DURING THE PERFORMANCE OF GYMNASTIC ROUTINES.

Since the mid 1960's telemetry has been used by many researchers on athletes in an effort to determine the heart rate response to specific sports activities. This information then becomes an important contribution to the general body of physiological data that is vital in determining the necessity for a change in training methods and techniques. Also, through the use of telemetry it has become possible to classify many sports in terms of energy expenditure and intensity. Following the telemetry monitoring of many sports, Skubic and Hodgkins (1965, 1967) have compiled a sports intensity classification based on the heart rate classification by Andersen (1970).

Sports Intensity Classification

Sport	Classification
Tennis	Moderate
Badminton	Moderate
Golf	Light
Archery	Light
Bowling	Light
Basketball	Heavy
Hockey	Heavy
Softball	Moderate
Volleyball	Moderate

Other sports that have been investigated with the use of telemetry equipment are: track (Skubic and Hilgendorf, 1964; McArdle et al., 1967), little league baseball (Hanson, 1967), water-polo (Goodwin and Cumming, 1966), figure skating (Gordon et al., 1969), ski jumping (Imhof et al., 1969), women's basetball (McArdle et al., 1971), squash (Blanksby et al., 1973; Beaudin et al., 1978), tennis, swimming fencing and boxing (Keul, 1973), gymnastics (Kozar, 1963; Seliger et al., 1970; Montpetit, 1972), speedskating (Cumming, 1975), weight lifting (Stone and Smith, 1977) and ice hockey (Wilson and Hedberg, 1976; Seliger et al., 1972).

Several investigators have monitored the heart rate response of gymnasts while actually performing their routines. Kozar (1963) monitored the heart rate response of one male gymnast on four different events; parallel bars, high bar, side horse and still rings. The parallel bars and still rings routines were identical in duration at 30 seconds and the intensity was similar at 169 and 164 beats/min., respectively. High bar and side horse routines were slightly less intense at 162 and 158 beats/min. respectively, but the duration of the activity was only 14 seconds.

Faria and Phillips (1970) reported that heart rate response of 30 boys and girls ages 7 to 13 years during gymnastic participation in five activities; warm-up, vaulting, tumbling, floor exercise and trampoline. Similar responses were observed for both boys and girls. Activity on the trampoline elicited the highest heart rate with a mean of 175±12.7 beats/min., followed by floor exercise (158±16.7 beats/min.), vaulting (153±19.8 beats/min.) and tumbling (153±15.2 beats/min.). Drazil (1971) reported that the pulse rate of adults during individual routines can attain values of 150 to 180 beats/min.

Montpetit (1972) monitored eight male gymnasts performing routines on four events at three levels of difficulty; novice and junior compulsory routines and senior optional routines. The mean terminal heart rates for the three levels were 136, 158 and 180 beats/min. for novice, junior and senior routines, respectively. The greater the difficulty (i.e. the greater the number of medium and advanced stunts in the routine) the higher was the cardiac response. The senior routines were found to elicit the highest heart rates with a maximal rate of 182±4.6 beats/min., followed closely by the still rings (181±3.9 beats/min.), parallel bars (180±5.7 beats/min.) and side horse (180±4.3 beats/min.)

Seliger et al., (1970) in an earlier study reported similar results for 10 male gymnasts performing novice routines in four events; parallel bar, side horse and still rings. The heart rates ranged from 129±8.0 to 136±9.0 beats/min. Reporting on female gymnasts, Seliger et al., (1970) monitored heart rate responses that were of similar intensity to that reported for male gymnasts. Floor exercise routines were not studied, but they did record mean values of 134±10.4 beats/min. for uneven bar routines, 133±13.7 beats/min. for vaulting and 130±12.6 beats/min. for the balance beam.

Montpetit (1972) observed an elevation in heart rate prior to the performance of routines. This anticipatory reaction was similar in intensity regardless of the difficulty of the routine about to be performed. A similar anticipatory response has been noted in telemetry studies evaluating male and female track athletes (McArdle et al., 1967; and Skubic and Hilgendorf, 1964) and ski jumpers (Imhof et al., 1969). Unlike gymnasts, track athletes showed a significant difference in the anticipatory heart rate depending on the duration of the event to be run. In preparation for a 60 yard run the anticipatory heart rate represented 74 percent of the heart rate adjustment recorded for the activity while for the two mile run the anticipatory heart rate represented only 33 percent of the total heart rate adjustment.

In two male gymnastic events, side horse and still rings, the highest heart rates were observed after the completion of the routine (Montpetit, 1972). This could be due to the fact that sustained muscular contractions predominate in performing these routines. With sustained exercise there is mechanical compression of the blood vessels which impedes blood flow. At the end of exercise both blood flow and heart rate increase to a peak and then fall to resting levels (Lind and McNicol, 1967).

In another study, Imhof et al., (1969) attributed an increase in heart rate in ski jumpers after the landing to the release of catecholamines during the jump, which was brought about by emotional stress. After administering 40mg of oxprenolol, a beta-receptor blocking agent, the emotional tachycardia was reduced by 34.2 percent and the increase in heart rate after landing was negligible.

Evaluating the intensity of gymnastic routines on the bases of heart rate response is possible using the classification established by Andersen (1970). The heart rate responses reported by Montpetit (1972) for senior routines are classified as "very heavy" in intensity while the heart rate responses observed by Seliger et al. (1970) for both male and female gymnasts have an intensity rating of "heavy".

Andersen's Heart Rate Intensity

Grading	Heart Rate (beats/min.)
Very Low	< 75
Low	75-100
Moderate	100-125
Heavy	125-150
Very Heavy	> 150

Alternatively, heart rate intensity can be evaluated using the Karvonen method. Karvonen (1957) formulated a method which uses potential heart rate (i.e. maximal heart rate minus the resting heart rate) for the estimation of work intensity. Methods which use a percent of the maximal heart rate for the prediction of intensity are at a disadvantage because of the inequality that exists between the percent of heart rate max. and the percent of $\dot{V}O_2max$. For example, a 70 percent heart rate max. response corresponds to a 55-60 percent $\dot{V}O_2max$. (Fox et al., 1971). However, when the percent heart rate is corrected for resting heart rate a much more accurate prediction can be made. After testing nine subjects on a treadmill at four 5-minute workloads representing 25,45,65 and 85 percent of their $\dot{V}O_2$max, Davis and Convertino (1975) showed that the Karvonen method of predicting exercise intensity was not significantly different (p 0.05) from the exercise intensity actually measured during the test. In this same study they determined that the standing resting heart rate (as opposed to resting heart rates obtained while sleeping, upon awaking in the morning, or during supine rest) was the best measure to utilize in determining potential heart rate.

Karvonen Formula

$$\text{Exercise Intensity} = \frac{\text{Working HR} - \text{Resting HR}}{\text{Maximum HR} - \text{Resting HR}} \times 100$$

Using a Kofranyi-Michaelis respirometer to collect expired air, Sward (1967), Seliger et al., (1970) and Montpetit (1972), were able to calculate the energy requirement of gymnastic routines in terms of metabolic cost in kilocalories and oxygen consumption. Montpetit (1972) found an energy expenditure from 12.4$\pm$2.5 kcal/min. on the parallel bars to 18.6$\pm$3.1 kcal/min. on the side horse while Seliger et al., (1970) found slightly lower values ranging from 13.1$\pm$3.1 kcal/min. on the parallel bars to 17.5$\pm$4.5 kcal/min. on the high bar. Sward (1967) reported values ranging from 7.2 kcal/min. on the still rings to 11.4 kcal/min. on the side horse. Sward also reported an energy expenditure of 10.6 kcal/min. for both men's floor exercise and long horse vaulting, two events which were not measured by either Montpetit of Seliger. In Seliger's article, the investigators reported on the results of still another researcher (Blochin, 1965) who found values of 6.1 to 24.4 kcal/min. for tumbling and floor exercise and values for 12.7 to 39.9 kcal/min. for apparatus exercise. The wide range in values could possibly be due to different laboratory procedures, age and size of the subjects, and the ability levels of the gymnasts and/or the difficulty level of the routines used by the investigator.

For female gymnasts, Seliger et al., (1970) reported consistently lower energy expenditure for routines on the parallel bars (10.5± 2.2 kcal/min.), balance beam (10.3±2.4 kcal/min.) and vaulting (9.2±2.5 kcal/min.). The only other report available on female gymnasts was that by Spitzer and Helliger (1969) who reported even lower values of 9.2, 8.6 and 6.9 kcal/min. for vaulting, uneven parallel bars and balance beam respectively. The lower values would be expected because of the smaller body size of the female gymnasts as compared to the male gymnasts.

In terms of oxygen consumption, Montpetit (1972) and Seliger et al., (1970) by means of indirect calorimetry, reported similar findings for male gymnasts with values ranging from 16.4±2.5 to 20.5±6.3 ml/kg.·min., while Sward (using the same method) reported higher values of up to 34.7 ml/kg. min. for side horse routines. Again, discrepancies in oxygen consumption measurements are most likely due to differences in the length and difficulty of the routines used in each study as well as differences in the age and size of the subjects. For female gymnasts, Seliger et al., (1970) found an average oxygen consumption of 15.0±4.9 ml/kg.·min. for the balance beam, 16.5±3.6 ml/kg.·min. for uneven parallel bars and 16.9±3.5 ml/kg.·min. in vaulting.

Summary

1. Heart rate responses to performing gymnastic routines are classified as "heavy" (125-150 beats/min.) to "very heavy" (greater than 150 beats/min.) (Andersen, 1970).

2. Telemetry monitoring of gymnasts while performing routines has revealed that there is an elevation in heart rate prior to performance (Montpetit, 1972).

3. In two male events, side horse and still rings, the highest heart rates occur after the completion of the routines (Montpetit, 1972) due to the effect of sustained muscular contractions (Lind and McNicol, 1967) and the release of catecholamines (Imhof et al., 1969).

2.4 BLOOD LACTATE CONCENTRATION FOLLOWING PHYSICAL EXERCISE

Glycolysis and oxidative phosphorylation are two processes which are responsible for the production of ATP, the major energy source for muscle contraction (Astrand anf Rodhal, 1977). The mechanism of anaerobic glycolysis is necessary for the regeneration of ATP under hypoxic conditions (Gollnick and Hermansen, 1973). During exercise there are two situations during which there will be an insufficient oxygen supply in the muscles: (1) at the onset of exercise when the cardio-respiratory adjustments lag behind the increased metabolic demand and (2) during very heavy work when the oxygen requirement for ATP production exceeds the oxygen consumption (Karlsson, 1971; Nagle et al., 1970; and Saiki et al., 1967). With a limited availability of oxygen, the chemical reaction of ATP resynthesis is altered and pyruvate is converted to lactic acid by lactic dehydrogenase (LDH), which diffuses from the muscles into the blood (Astrand and Rodahl, 1977).

The blood lactate concentration following exercise is determined by the intensity and duration of the exercise, the type of exercise being performed, and the fitness level of the individual. At intensities below 50% $\dot{V}O_2$max there is no accumulation of lactic acid in the average individual because at this work rate there is sufficient oxygen to synthesize ATP aerobically (Karlsson, 1971). However, after extensive training, which improves the cardio-respiratory system, intensities as high as 85% $\dot{V}O_2$max can be maintained without significant increases in blood lactate concentration (Costill, 1970; and Costill and Fox, 1969). Training also results in lower lactate levels at submaximal workloads and higher concentrations at the end of exhaustive work (Cunningham and Faulkner, 1969; Hermansen and Andersen, 1965; Karlsson, 1971; Karlsson et al., 1972; Kilbom, 1971; and Penny and Wells, 1975). The untrained person is more dependent on glycolytic energy production and in addition possesses higher concentrations of ADP in the skeletal muscles, which causes stimulation of glycolytic activity (Nagle, 1973).

In reference to the type and duration of exercise it has been observed that work with small muscle groups will produce greater levels of blood lactate than work with larger muscle groups. Also, work at high intensity and short duration produces the highest lactate levels measured thus far (Astrand and Saltin, 1961; Cumming and Faulkner, 1969; and Karlsson, 1971).

As stated previously, arm exercise, as compared to leg exercise, causes a higher rise in heart rate, blood pressure, pulmonary ventilation and blood lactate concentration (Astrand, 1968). Because the feeling of exertion depends greatly on the rate of lactate production, work with small muscle groups will elicit this feeling despite the relatively small amount of energy utilized. Although higher levels of blood lactate are obtained with arm exercise after submaximal loads, Hägerman et al., (1974) have observed maximum lactate levels comparable to those obtained with leg work. They reported a mean lactate maximum of 131mg% with a range from 115 to 153mg% for women after exhaustive ergometric rowing.

Hermansen et al., (1965), Saifi et al., (1967) and Penny and Wells (1975) provided evidence that lactic acid accumulation is greatest during the first few minutes of exercise due to the oxygen debt caused by the inefficient cardio-respiratory adjustment to the higher metabolic requirement. Maximal lactate concentrations are obtained after brief exhaustive work between one to 10 minutes in length with the highest values recorded with a seven minute test (Karlsson, 1971). Astrand and Saltin (1961) reported maximal blood lactates between 160 to 175mg% for male subjects and about 135mg% for female subjects using exhaustive intensities that terminated the test between two to eight minutes. As a result of these observations it has been concluded that sporting events which are short in duration and high in intensity rely heavily on the lactic acid system for ATP production (Mathews and Fox, 1976). By measuring blood lactate levels after exercise of short duration (less than 10 minutes) the intensity of the activity can be evaluated with greater accuracy provided the work engages large muscle groups (Astrand, 1956; Gollnick and Hermansen, 1973; and Karlsson, 1971).

Cranford (1972), in a recent investigation of blood lactate concentrations as related to various intensities in women has devised the following classification:

Cranford's Blood Lactate Intensity Classification

Classification	Lactate (X resting value)	Heart Rate(bpm)
mild	within normal limits	120
moderate	2X	140
heavy	3X	160
strenuous	6X	180
maximal	greater than 6X	greater than 180

When the duration of an activity exceeds 10 minutes there is a decline in the blood lactate levels as the lactaid O_2 debt, caused by the onset of activity, is repaid when a "steady state" between oxygen requirement and oxygen consumption is attained (Costill and Fox, ;969; and Saiki et al., 1967). This reduction in lactate level is apparent even at high intensities. Nagle et al., (1970) reported that at intensities between 74-79% $\dot{V}O_2$max, lactate levels plateaued at 45mg% by the 20th minute of a 40-minute exercise, while at intensities of 67 - 74% $\dot{V}O_2$max, lactate levels ranged from 18 to 29mg% and were sustained over a 60minute exercise period.

Low lactate levels have also been reported in cross country skiers by Astrand et al., (1963) and marathon runners by Costill and Fox (1969) and Costill (1970). In marathon runners utilizing 75% of their aerobic capacity, post race lactate values average 19mg%. From his observations Costill concluded that in long duration events there is an "inverse curvilinear relationship between the length of the competitive race and the blood lactate concentration." Astrand et al., (1963) came to a similar conclusion about cross country skiing, reporting a decrease in lactate accumulation with an increase in the distance of the race despite similar intensities of work.

A compilation of lactate levels in sports activities and exercises of various intensities and durations are presented in Table 2. It can clearly be seen that the shorter,more intensive activities produce the highest levels of lactate at 216mg% and marathon running the lowest at 19mg%.

Table 2. Blood lactate concentrations following various types of physical exercise.

Reference	Type of exercise	Blood lactate (mg%)
Males		
Astrand and Saltin(1961)	bicycle test (2-8 min.)	160-175
Astrand et al.(1963)	cross country skiing	
	10km race	139
	30km race	68
	50km race	39
Faulkner & Cunningham (1969)	short exhaustive run	96-156
Costill and Fox(1969)	running events	
	10km race	131
	marathon	19
Astrand and Rodahl(1977)	skiing events	
	downhill skiing	113
	special slolam	135
	giant slolam	144
	cross country motorcycling	71
	maximum bicycle test	180
	maximum run*	180
	maximum dash**	216
Females		
Astrand(1960)	maximum bicycle test	121
Cranford(1972)	exhaustive run (5 min.)	105
Hagerman et al.(1974)	ergometric rowing	130

*3 X 1,000m at maximum speed with a few minutes rest between
**3 X 50 second sprint

Few studies have been conducted on the anaerobic capacity of women. At submaximal workloads women have higher heart rate, more rapid increase in heart rate, higher diastolic blood pressure and higher lactate concentrations (Cranford, 1972; and Drinkwater, 1973). At maximal work, Mathews and Fox (1976) and Astrand and Saltin (1961) reported that females tend to have lower levels of lactate than males due mainly to their smaller muscle mass.

Summary

1. When the muscles exercise under hypoxic conditions, lactic acid is produced by the tissues and diffuses into the blood (Astrand and Rodahl, 1977).

2. Blood lactate concentration following exercise is determined by: (1) the intensity and duration of the exercise (Astrand and Saltin, 1961; Cunningham and Faulkner, 1969; Karlsson, 1971; and Karlsson et al., 1972), the type of exercise being performed (Astrand et al., 1968; and Hagerman et al., 1974), and the fitness level of the individual (Costill, 1970; and Costill and Fox, 1969).

3. Maximal lactate concentrations are obtained after brief exhaustive work between 1-10 minutes in length with the highest values recorded with a seven minute test (Karlsson, 1971).

4. Work with small muscle groups will produce greater levels of blood lactate than work with larger muscle groups (Astrand et al., 1968; and Hagerman et al., 1974).

5. The more highly fit individual will attain lower lactate levels at submaximal workloads and higher maximum concentrations at the

end of exhaustive work (Costill, 1970; and Costill and Fox, 1969).

6. Blood lactate levels will begin to decline if the duration of the activity exceeds 10 minutes. Low lactate levels have been observed for both cross country skiers and marathon runners (Åstrand et al., 1963; Costill and Fox, 1969; and Costill, 1970).

7. Women have higher lactate levels at absolute submaximal workloads than men, but tend to have lower levels after a maximal test (Cranford, 1972; Drinkwater, 1973; and Mathews and Fox, 1976).

2.5 PHYSICAL AND ANTHROPOMETRIC VARIABLES AS THEY RELATE TO GYMNASTIC ABILITY

To date, most of the research in this area has concentrated on evaluating various physical characteristics and capacities which may be relevant in predicting gymnastic ability. Wettstone (1938) formulated a regression equation to predict potential ability. This equation had a multiple correlation of .79 and consisted of two anthropometric measurements (thigh circumference and height), a strength score based on a three item test (chinning, dipping and thigh flexion), and an agility score acquired from the administration of the Burpee test.

Read (1967) after evaluating anthropometric and strength characteristics in high school gymnasts, concluded that the good gymnasts averaged significantly less than poor gymnasts in measures of standing height, sitting height, arm span, leg length and upper arm length. He also stated that the good gymnasts were more ponderous than the poor gymnasts and had proportionally greater chest breadth than chest depth.

The first study to evaluate factors to predict performance ability using female gymnasts was carried out at California State College (Youngren, 1969). The variables evaluated were height, weight, a ponderal index and three skinfold measurements of the triceps, abdomen and thigh. The only high correlations were observed with triceps and total skinfold sites to uneven bar scores. A moderate correlation existed between the same skinfold measurements and vaulting scores.

Another investigation using top female gymnasts was reported by Pool et al. (1969). Subjects for this research consisted of 38 female gymnasts from the 1967 European Championship in Amsterdam. Again a variety of anthropometric and physical measurements were obtained and the important results were as follows:

1. The scapula skinfold was negatively correlated while thorax width was positively correlated with all-around score.
2. The running distance used as an approach to the vault and the time taken to cover that distance was significantly correlated with the vaulting score.
3. Jumping height was significantly correlated with the vaulting score.
4. The running time for the approach to the vault correlated significantly with the mark for floor exercise.
5. Body height and weight as well as handgrip strength did not correlate significantly with performance scores.

Korando (1970) and Boyd (1971) attempted to determine predictor variables for single events. Korando, investigating balance beam performance of beginners found that the most valid measure contained the modified Scott sideward leap test and the experience variable. Evaluating predictors of success on the uneven parallel bars, Boyd concluded that the most effective single predictors were vertical jump, flexed arm hang, weight and bent leg sit-ups. The most significant combination of tests was vertical jump and flexed arm hang with an R=.38.

Data collected on 15 variables for 216 female gymnasts participating in the 1974 Ontario Provincial Championships are still at this time under evaluation but tentative findings have been published (Wilson, 1976). It was reported that six of the 15 variables showed significant relationships for the uneven bars, balance beam and floor exercise, while eight variables were significantly correlated to the vaulting score. High correlations were found between attractiveness and the vaulting and uneven parallel bars events, and the number of years of competition with the balance beam and floor exercise events. The highest correlation of .90 was observed between the preflight jump on the horse and the ability level.

Gates (1974) examined 12 structural and functional measures to compute predictive equations for two men's events (rings and parallel bars) plus tumbling and trampoline. The highest multiple correlation (R=.75) was obtained for ring skills. The variables that were most frequently selected to predict ability were dips, sustained hand grip, weight and pull-ups.

Summary

1. Size, strength and agility were important variables for predicting potential ability in gymnastics (Read, 1967; and Wettstone, 1938).

2. Triceps and total skinfold sites were highly and moderately correlated to uneven bar and vaulting scores (Youngren, 1969).

3. Scapula skinfold, thorax width, jumping height and the running distance and time to the vault were significantly correlated to gymnastic scores (Pool et al., 1969).

4. Beginning balance beam performance was best predicted by the modified Scott sideward leap test and experience (Korando, 1970).

5. An R=.38 was found between uneven parallel bar scores and a combination of vertical jump and flexed arm hang (Boyd, 1971).

6. High correlations were found between attractiveness and the vaulting and uneven bar scores (Wilson, 1976).

7. High correlations were found between experience and the balance beam and floor exercise events (Wilson, 1976).

8. Strength and weight variables were the best predictors of ability on the rings, parallel bars, tumbling and trampoline for men (Gates, 1974).

2.6 THE VALIDITY OF GYMNASTIC JUDGING

In gymnastic competition, and any other sport in which artistic qualities must be evaluated, the ability and relative success or failure of each participant is determined by judges. Whenever this type of evaluation is necessary there are always doubts about the accuracy, reliability and objectivity of the judges. In an attempt to evaluate gymnastic judges, researchers have applied various approaches to examine this problem (Calkin, 1969; Huges, 1959; Hunsiker and Loken, 1951;

Landers, 1970; and Wilson, 1976).

For most competitions there are four judges evaluating each event. To determine the gymnasts score, the high and low scores are thrown out and the middle two scores are averaged. One approach used to study judging is to evaluate the range of scores given to each participant and then calculate the average difference between the high and low scores for the whole meet (Hughes, 1959; and Landers, 1970). It has not yet been determined what the average difference should be for a well judged meet but it is assumed that the lower the range of scores for a particular performer the better or more objective is the quality of the judging (Landers, 1970).

Another approach is to investigate the correlations between the judges scores or between the sets of ranks established by each judge (Landers, 1970). Hunsicker and Loken (1951) calculated the intercorrelations of five judges on six events in the men's National Collegiate Athletic Association Gymnastic Meet. There was good agreement between judges as 50 relationships attained an r=.85 or higher. They also concluded that scores for the horizontal bar were the most objective (i.e. showed the greatest amount of agreement) while floor exercise scores were the least consistant. In another study, Landers (1970) reported that there was poor agreement in events having a small range of ability and in scoring routines in which there was a fall from the apparatus (i.e. incomplete performances).

During the 1972 Canadian Women's European Trials Competition the routines on the uneven parallel bars and the vaulting were videotaped from four different viewpoints, and rejudged at a later date by the same judges that scored the meet (Wilson, 1976). Correlations were calculated between the competition scores and the videotape replay scores to evaluate judging validity. The average correlation for uneven parallel bar scores showed a high concensus reliability at .95 but very low for vaulting with an average of .09. To evaluate retest reliability, correlations were calculated from judges viewing each performer from each camera position twice. Again the uneven parallel bar routines had a high average correlation of .96 and the vault a low average correlation of -.03. From the results of this study it can be concluded that judges' scores for uneven parallel bar routines can be considered highly valid and reliable estimations of performance while vaulting scores are not as valid or as reliable.

In 1969, Calkin developed a computer program to evaluate gymnastic judging. The information he obtained enabled him to determine if a judge's score differed significantly from the other judges or if the entire judging panel differed significantly from judges that had evaluated the individual or team in the past. He did however contend that there may be very valid reasons for a difference in score from one meet to the next as gymnasts would be expected to improve with time or have a bad day just like any other athlete.

CHAPTER III

METHODS AND PROCEDURES

3.1 SUBJECTS

Thirty girls from gymnastic clubs and high schools in the Montreal area, between the ages of 11 and 13 years, volunteered to be subjects in this study. One subject was dropped, however, due to incomplete data. Informed consent was obtained from all participants. The girls were all-around gymnasts and had been training in gymnastics for at least one season. For the purpose of statistical analysis, all-around scores were used to divide the subjects into two ability levels. The low ability gymnasts (n=17) had all-around scores below 20 points while the high ability gymnasts (n=12) had total scores of 30 points or greater.

3.2 LABORATORY TESTS

3.2.1 MAXIMUM HEART RATE AND MAXIMUM AEROBIC CAPACITY

A graded, discontinuous bicycle ergometer test was utilized to determine each subjects maximum heart rate and aerobic capacity. The initial workload was set at 180 kpm/min. with a pedaling frequency of 60 rpm set by a metronome. Thereafter, the workload was incremented by 180 kpm every three minutes with a one minute rest period, (pedaling at zero resistance), permitted between each workload. With the subject breathing into a low resistance Modified Otis McKerow valve, expired air was collected in a Douglas bag during the last minute of each workload and analyzed for percentages of oxygen and carbon dioxide by Beckman OM-11 and LB-2 analyzers. The analyzers were calibrated against a known reference gas prior to each testing session. The volume of inspired air was measured with a Parkinson Cowans gasometer. Heart rate was recorded at rest, during the last 15 seconds of each workload, and during the first, third and fifth minute of recovery with a single channel ECG recorder. Electrodes were placed for a bipolar lead recording at the manubrium and the V_5 position. After an R.Q. of 1.0 had been obtained, the test was terminated at the point of volitional exhaustion.

3.2.2 ANAEROBIC ALACTIC POWER

Maximal anaerobic power can be measured by evaluating the energy release during the first four to five seconds of maximum exercise. The power that can be generated in a very short exercise is directly related to the splitting rate of the high energy phosphate compounds (ATP and CP) (Astrand and Rodhal, 1977). The Margaria-Kalmen power test (Mathews and Fox, 1976) was utilized to measure alactic power in all subjects. This test involves measuring the subjects speed for a specific vertical component during a maximum run up a flight of stairs. It has been determined that an individual can reach peak velocity within two seconds when running up a set of stairs and can maintain that speed for only three seconds (Margaria, 1966).

A Dekan performance analyzer, with two contact pads that control the timer, was used to measure the subjects speed to the nearest hundreth of a second. The first mat, which starts the timer, was placed on the fourth stair and the second mat, which stops the timer, was placed on the tenth stair. A starting line was located six meters from the first stair. The height of each stair was 17.5 centimeters.

Each subject was instructed to ascend the stairs as quickly as possible, by contacting the first stair and thereafter three steps at a time. Six trials of the test were taken with a one to two minute rest between trials. The best (fastest) time was recorded for the calculation of anaerobic alactic power, which will hence forth be known simply as "power" in this study. Knowing the individuals weight, the vertical component (1.05 meters), and the time, power was determined in kilogram meters per second using the following formula:

$$P = \frac{W \times D}{t}$$

P= power (kg -m./min.)
W= weight in kg.
D= vertical height between the first and last test stair in meters.
t= time recorded from the first to last test stair to the nearest hundreth of a second

3.2.3 ANAEROBIC LACTATE CAPACITY AND MUSCULAR ANAEROBIC ENDURANCE

Maximum blood lactate is an indication of an individuals anaerobic lactate capacity (Cumming, 1970). The highest concentrations of blood lactate have been recorded after brief exhaustive work between one to ten minutes in length (Astrand and Saltin, 1961; Karlsson, 1971; Mathews and Fox, 1976), with the highest values recorded after a seven minute test.

To obtain maximum blood lactate levels, each subject exercised on the bicycle ergometer at a pedaling frequency between 60 and 70 rpm and at a resistance corresponding to six percent of her body weight in kilograms. When the subject dropped below a speed of 60 rpm or when she became maximally fatigued, the test was terminated. This work rate was sufficiently intense to tax the anaerobic energy system maximally and cause termination of the test between two and eight minutes. Blood samples were taken from a pre-warmed and dry finger tip, prior to the test and five minutes post exercise. Analysis for lactate concentration was performed on each sample using the enzymatic technique developed by Calbiochem (**Calbiochem rapid lactate reagents, 1975**).

The total duration of the test in seconds was determined for each subject. The measure of anaerobic muscular endurance used in this study was the length of time in seconds that the subject could pedal a submaximal load (six percent of body weight) at a rate between 60 to 70 revolution per minute.

3.2.4 STRENGTH BATTERY

A cable-tension strength test battery for girls ages 11 1/2 to 14 1/2 years, developed by Clarke and Munroe (1970) was used to evaluate total body strength. This test battery has been found to produce a high multiple correlation (R=.941) with total body strength scores and therefore is a good predictor of overall strength for this age group. This battery measures strength values for shoulder extension, hip extension, and trunk extension. In each instance a strength composite was calculated by adding the gross score in pounds from the three cable-tension strength tests. This score was then converted into kilograms and divided by the subjects body weight in kg. to give a relative strength score for each subject. Maximum isometric contractions were performed twice for each test. A rest period of at least one minute was provided between each attempt. In all cases, strength was measured on the subjects dominant side. The best socre from each test was used to calculate the strength score.

3.2.5 FLEXIBILITY BATTERY

A flexibility test battery measuring the movement range of four body parts was administered to each subject. The movements and measurement procedures utilized were modifications of those developed by Leighton (1955). The test items were specifically selected because of their importance in gymnastic performance. The movements measured were as follows: (1) active hip abduction (both legs), (2) active hip flexion (both legs), (3) shoulder hyperflexion and hyperextension, and (4) trunk flexion and extension.

Each range of movement was measured in terms of degrees of rotation with a Leighton Flexometer. The instrument was strapped to the body segment to be tested. The dial was locked into position on zero degrees when the subject assumed the starting position. The subject then moved the body segment through the greatest possible range of movement and the pointer was locked. Degrees of rotation for the movement were read directly from the instrument. Each of the eight measurements were repeated twice and the mean score for each test was added together to determine the total flexibility score (i.e. Flexibility= hip abduction - left leg + hip abduction - right leg + hip flexion - left leg + hip flexion - right leg + shoulder hyperflexion + shoulder hyperextension + trunk flexion + trunk extension). A third measurement was taken if the scores were not within five degrees.

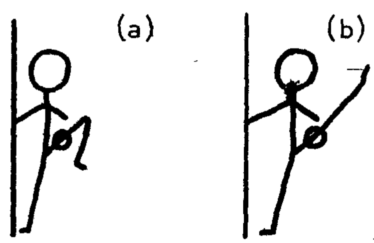
Test Descriptions: To prevent injury, subjects were allowed a sufficient warm-up period before extreme positions were attempted. The testing prosedures for each of the individual tests were as follows:

(1) Active Hip Abduction - both legs:

Starting position:

- standing position, feet in first position, heels together, knees outwardly rotated, side to the wall, one hand on the wall for balance. The dial was locked in the starting position.

Movement:



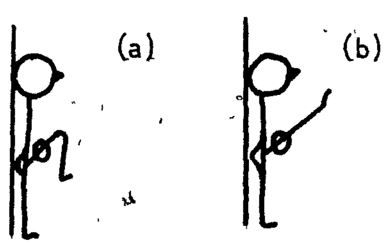
- The subject then elevated the knee on the leg being tested, as high as possible (a) and straightened the leg maintaining as much abduction as possible (b). The pointer was locked in this position and degrees of abduction recorded.

(2) Active hip flexion - both legs:

Starting position:

- standing position, feet together, heels against wall, arms at the sides. The dial was locked in the starting position.

Movement:



- The subject then elevated the knee on the leg being tested, as high as possible (a) and straightened the leg maintaining as much flexion as possible(b). The pointer was locked in this position and degrees of flexion recorded.

(3) Shoulder Hyperflexion and Hyperextension;

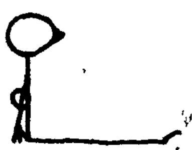
Hyperflexion starting position:

- standing position, legs together, back pressed against a door jam, arms above head, palms facing inwards and towards each other. The dial was locked in the starting position.

Movement:

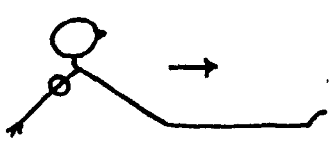
- To keep the subjects back against the wall jam to prevent lower back hyperextension, pressure was applied at the sternum and abdomen. The subject then hyperflexed the shoulders as far as possible. The pointer was locked in this position and degrees of hyperflexion recorded.

Hyperextension starting position:



- sitting position, legs extended, knees straight, arms at side, fists clenched and positioned at the hip. The dial was locked in the starting position.

Movement:



- Keeping the fists at the starting position and the arms straight, the subject slid forward extending the shoulders as far as possible. The pointer was locked in this position and the degrees of hyperextension recorded.

(4) Trunk Flexion and Extension:

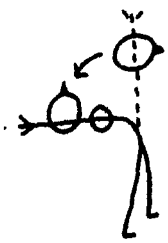
Starting position - flexion and extension

- standing position, feet shoulder width apart, legs straight, arms extended above head. The dial was locked in the starting position.

Flexion movement:

- Keeping the knees extended at all times, the subject flexed forward and downward as far as possible, using her arms to help pull her further into flexion at the extreme position. The pointer was locked in this position and the degrees of flexion recorded.

Extension movement:



- Keeping the knees extended at all times, the subject extended backwards as far as possible. Assistance was given to help maintain balance by supporting the subject at the hips. The pointer was locked in this position and the degrees of extension recorded.

3.2.6 AGILITY

To evaluate agility the AAHPER 30 foot shuttle run was performed by each subject. The test design consisted of two parallel lines, 30 feet apart, and two small blocks of wood placed on the 30 foot line (Figure 1). Two subjects were tested at the same time. The procedure was repeated three times with a rest period of at least three minutes between each trial. The subjects started in the standing position behind one of the lines, with the blocks of wood located on the opposite line. On the commands "ready", "GO" the subjects were instructed to run to the opposite line, pick up one block, run to the original line and place the block on the line, return to the opposite line again, pick up the second block and sprint back over the starting line as quickly as possible. Each trial was timed with two stop watches that recorded the time to the nearest tenth of a second. The fastest time was recorded as the agility score.

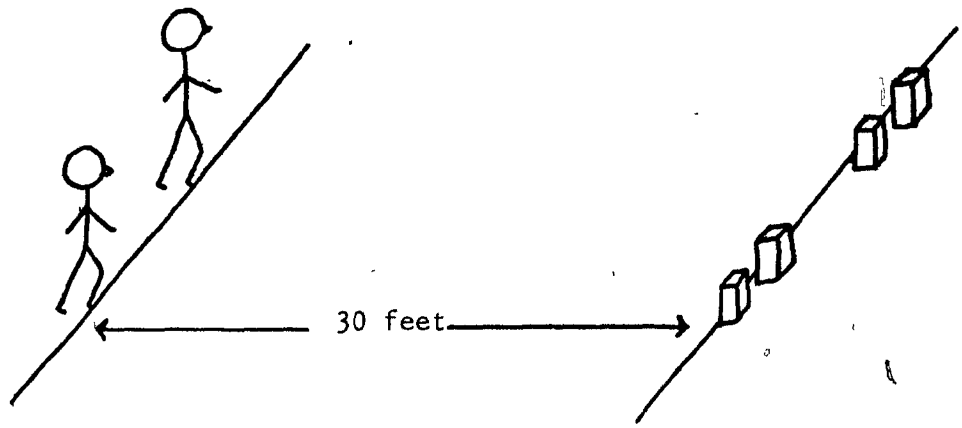


Figure 1. AAHPER 30 foot shuttle run.

3.2.7 BODY COMPOSITION

Body composition was evaluated by a composite score of four skinfold sites that had been found to be highly reliable in evaluating body composition (Montoye, 1970). A Harperden skinfold caliper was used to measure the four sites: (1) triceps, (2) subscapular, (3) abdominal, and (4) supra-iliac crest. The triceps skinfold was taken on the right arm, parallel to the long axis of the arm about half way between the tip of the acromial process and the tip of the elbow. The subscapular skinfold site was measured at the tip of the right scapula on a diagonal plane about 45 degrees from the horizontal, laterally downward. The abdominal skinfold was measured by a vertical fold about one centimeter to the right of the navel. The suprailiac crest skinfold site was measured on the right mid-axillary line at the crest of the illium on a diagonal line, dorsally upward (Montoye, 1970).

Two measurements were taken at each site and when the difference between these two measurements exceeded five percent, a third measurement was taken. When two measurements were taken the mean value was used as the score for that site. When a third measurement was necessary, the mean of the two closest values was accepted as the representative score.

3.3 FIELD TESTS

3.3.1 HEART RATE INTENSITY DURING GYMNASTIC ROUTINES

To determine the intensity required for gymnasts to perform on each of the four events, the heart rate response was monitored via radiotelemetry during the performance of optional routines. Prior to elctrode placement the skin was prepared by first swabing the areas with alcohol, then removing the horny epidermal layer of skin with an abrasive. The skin was then wiped with alcohol again and dried with tissues. Disposable (ConMed Medical Electrodes) or reuseable silver-silver chloride electrodes were placed on the manubrium and V_5 positions for a bipolar lead recording. The transmitter (Narco Bio Systems FM 1100 E2), worn around the waist in a small padded belt, conveyed information on heart rate response to the reciever (Narco Bio Systems Biotelemetry Reciever FM-1100-7) and bio-tachometer (BT-1200) which in turn produced a visual representation on a calibrated recorder (Hewlett Packard 400 BM Strip Chart Recorder). Transmission of cardiac frequency data via a single channel telemetry link is shown in Figure 2. This short range telemetry system uses frequency modulation (FM) techniques and operates in the FM broadcast band between 88 and 108 MHz. The transmitter used during the experiment was small

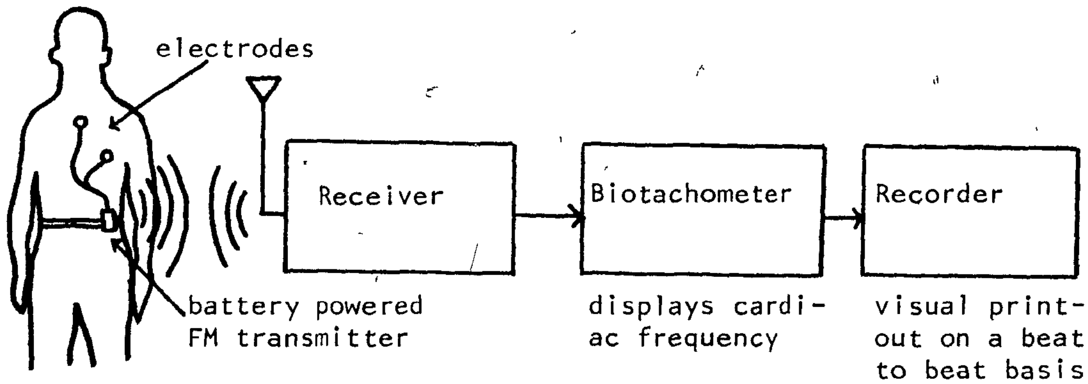


Figure 2. Heart frequency telemetry link.

(3 cm X 2.5 cm X 1.5 cm) and did not hinder the movements of the subject during the performance of her routines.

Optional routines for balance beam, uneven parallel bars, floor exercise and two identical vaults were monitored once during a practice situation. Whenever possible, all routines were monitored on the same day and sufficient rest time was allowed between the performance of each routine and between the two vaults to allow for heart rate recovery. A heart rate below 100 beats/min. was used as the criterion for sufficient recovery. The routines were performed in a random order, which in many cases was dependent on the practice schedule set up by the coaches.

After a sufficient warm-up period, the gymnasts rested to stabilize and recover the heart rate below 100 beats/min. before performing the routine. The subject was notified that she could begin the performance and was allowed to make final gymnastic equipment adjustments. Heart rate was monitored approximately 30 seconds prior to the performance, during the entire routine and one to three minutes into recovery.

Average percent intensity, peak heart rate and duration were calculated for all events from the printed recording. Average percent intensity was determined by first calculating a mean heart rate for each six second period of the balance beam and floor exercise routines and for each four second and two second periods of the uneven parallel bar routine and vaulting respectively. The mean heart rates were totaled for a given routine and divided by the number of periods observed to give an overall average heart rate for the routine. Knowing each subjects maximum and resting heart rate, percent intensity was calculated using the Karvonen method. Peak heart rate was the highest six second average attained during (or in the time period immediately following) the performance of the routine. Duration of the routine was calculated from the paper speed. The recorder paper speed was set at 30 cm/min. for vaulting and uneven parallel bar routines and at 15 cm/min. for balance beam and floor exercise routines.

3.3.2 BLOOD LACTATE CONCENTRATION FOLLOWING GYMNASTIC ROUTINES

Finger tip blood samples were drawn five minutes after the performance of each routine for blood lactate analysis. Blood samples were not taken following vaulting because the activity is too brief (four to six seconds) for the activation of the anaerobic lactate energy system. The finger was hydrolysed in hot water for the five minute period, then wiped dry and sterilized with alcohol. A puncture was made with a sterilized blood lancet. After the first drop of blood had been wiped away, one hundred microliters of blood were drawn, immediately added to 0.2 ml of ice cold perchloric acid and spun in a centrifuge within 15 minutes of collection. The deproteinized sample was stored at refrigerator temperature (2 to 8 degrees centigrade) until analysis could be performed at a later time. It has been shown that samples prepared in the preceeding manner can be kept for 24 hours without significant changes in the analysis results (Marguire and Copeland, 1972). Lactate analysis was performed on each blood sample using the Calbiochem technique.

The enzymatic technique for lactate determination depends on the oxidation of lactate (CH_3CHOH COOH) to pyruvate (CH_3CHO COOH) and NADH. This reaction requires the presence of NAD (Nicotinamide-adenine dinucleotide) and the enzyme LDH (lactate dehydrogenase), Both of which are present in the reconstituted reagents prepared by Calbiochem. Pyruvate is removed from the reaction when its' carbonyl group combines with the glutamate and GPT (glutamate pyruvate transaminase), also present in the reagent. Removal of pyruvate brings the reaction to an end when all the lactate has been converted into pyruvate. The result is an accumulation of NADH, which is the indicator of the reaction. Since it is known that NADH has maximal absorbance at 340nm, the amount of lactate converted to pyruvate is proportional to the change in absorbance at 340nm.

The major modification in the assay procedure used in this study was that 20 microliters (instead of 100 microliters) of supernatant were used along with a dilution factor of 4.87 for the determination of blood lactate concentrations. The assay procedure was as follows:

1. 2.9 ml of prepared reagent were dispensed into a clean dry cuvet with a 1 cm light path.

2. The cuvet was placed in a constant tenperature water bath (30 degrees centigrade) for about three minutes or as long as needed to bring the reagent to the established temperature. The deproteinized blood sample was preincubated for the same amount of time in the water bath.
3. The cuvet was wiped dry and placed into the spectrophotometer to read the initial absorbance of the reagent.
4. Twenty microliters of supernatant were added to the reagent. The cuvet was covered with a square of parafilm, gently inverted and replaced into the water bath for 15 minutes of additional incubation.
5. After 15 minutes the final absorbance was read.
6. All measurements were made at 340 nm. The spectrophotometer was calibrated for 100 percent transmittance with a cuvet of distilled water before each measurement.
7. Calcution: blood lactate in mg% = change in absorbance X 131 X 4.87

The number 131 represents the factor for converting the change in absorbance to lactate in miligrams percent. The dilution factor 4.87 was used for all calculations because 20 microliters of supernatant were used during the assay procedure instead of the 100 microliters suggested by Calbiochem.

3.4 EXPERIENCE

A criterion score representing each subjects' experience as a gymnast was determined from four factors. The information was obtained from a questionnaire completed by each girl with assistance from her coach. The factors used to evaluate experience were: (1) years of formal gymnastic training, (2) number of meets in which the subject has competed, (3) average number of hours of practice per week and (4) number of months per year devoted to gymnastic training. Points were awarded for each factor and the sum of all points was the criterion score used to represent the experience variable. The points were awarded in the following manner: (1) one point for each year of formal gymnastic training, (2) one point for each meet that the subject had competed in, (3) one point for each average hour of practice per week (i.e. if the subject practiced on the average 10 hour per week she was awarded 10 points) and (4) one point for the number of months of training per year (i.e. if the subject trained three months out of the year then she was awarded three points).

EXAMPLE:

Gymnastic Questionnaire

Subject: C.H.

Age: 12 years

1. How many years have you been training in gymnastics?

   Ans. 2 years

2. How many gymnastic meets have you competed in to date?

   Ans. 23 meets

3. On the average, how many hours per week do you practice?

   Ans. 21 hours

4. How many months out of the year are you involved with gymnastic training?

Ans. 12 months

EXPERIENCE = 2 years + 23 meets + 21 hours/week + 12 months/yr.

= 58

3.5 DEPENDENT VARIABLE - GYMNASTIC SCORES

Average gymnastic scores for all events were obtained from the most recent competitive season. In order to standardize the scores each routine was given a difficulty rating as determined by the International Gymnastic Federation Code of Points (1978). The scores were then multiplied by this difficulty rating and divided by 10 (the highest possible score). Routines that contained all the necessary difficulty movements (three superior and four medium difficulty stunts) were given a difficulty rating of 10.

EXAMPLES:

#1. Subject: M.H.

event: vault - handspring with 1/2 twist on and 1/2 twist off

difficulty rating: 10 points

score: 8.30

CALCULATION $8.30 \times \frac{10}{10} = 8.30$

#2 Subject: B.A.

event: vault - layout squat

difficulty rating: 8 points

score: 6.10

CALCULATION $6.10 \times \frac{8}{10} = 4.90$

#3 Subject: M.H.

event: Floor exercise

difficulty rating: 10

score: 8.70

CALCULATION $8.70 \times \frac{10}{10} = 8.70$

#4 Subject : C.G.

event: floor exercise

difficulty rating: 5.9 points (3 medium stunts)

score: 6.0

CALCULATION $6.0 \times \frac{5.9}{10} = 3.50$

3.6 STATISTICAL ANALYSIS:

For purposes of statistical analysis, all subjects were divided into two levels of ability, based on the all-around scores obtained from the most recent competitive season. Descriptive statistics of all variables, consisting of the range, mean, standard error and variance were computed for the total group (n=29) and each ability level (high ability n=12, low ability n=17). Analysis of variance and t-tests were performed to evaluate significant differences between the ability levels for each of the variables measured. Post hoc analysis was performed for all significant F values.

Multiple stepwise regression was computed using all variables; (1) to determine the best linear prediction equation for all-around gymnastic ability and for each individual event, and (2) to evaluate the relative contribution of specific variables or sets of variables to gymnastic ability. The all-around gymnastic score was used as the dependent or criterion variable when determining the prediction equation for all-around gymnastic ability, and the scores obtained for individual events were the dependent variables when prediction equations for each event were being computed. Two of the independent variables (1) heart rate percent intensity for each event, and (2) blood lactate concentration for each event, were converted into mean values for the four events when used as a variable in the regression analysis for all-around gymnastic ability. Raw score values obtained on each event were used when formulating the prediction equation for each event.

CHAPTER IV

RESULTS

4.1 INTRODUCTION

The purpose of this investigation was to obtain physical, physiological, and anthropometric measurements on female gymnasts, representing a wide range of ability, and to determine which variables or groups of variables were the best indicators of gymnastic ability. Statistical procedures, which included analysis of variance and t-tests were performed to determine significant differences between high and low ability gymnasts on the measured variables. Hence, it was possible to determine which variables most clearly distinguish the high ability gymnasts from the low ability gymnasts. In addition, correlation coefficients were computed to determine the relationships between the measured variables and gymnastic ability. Finally, multiple stepwise regression analysis was utilized to select the best linear prediction equation for all-around and individual event gymnastic ability. The most significant predictors of gymnastic ability were computed, and within the regression equation, the relative importance of each variable as a predictor was determined.

4.2 PHYSICAL, PHYSIOLOGICAL AND ANTHROPOMETRIC CHARACTERISTICS

Means, standard errors and ranges for physical and anthropometric variables are presented in Table 3, while the values obtained for physiological measurements are presented in Table 4.

Table 3. Physical and anthropometric characteristics of female gymnasts.

Variable	Total Group (n=29) ($\bar{X}$ ±SE)	Range
Height (cm)	146 ± 1.5	131 - 166
Weight (kg)	37 ± 1.1	26 - 49
Total Skinfold (mm)	32 ± 2.7	18 - 84
Anaerobic Endurance (sec.)	218 ±14.4	120 - 380
Total Flexibility (degrees)	742 ±19.2	535 - 967
Power (kg-m./sec.)	62 ± 2.1	50 - 89
Agility (sec.)	10.0 ± 0.1	9.3 - 11.9
Strength (kg/kg body wt.)	1.2 ± 0.1	0.6 - 2.1

To further evaluate heart rate response during the performance of gymnastic routines, a mean heart rate was calculated for each six second period for the total duration of both balance beam and floor exercise routines, for all subjects. In order to obtain a significant number of data points, the routines for the uneven parallel bars were divided into four second periods because of the brevity of the routines. The average heart rate for each period was expressed as a percent of the maximum potential heart rate (percent intensity) and plotted against time (Figure 3). As would be expected, the balance beam and floor exercise routines were longer in duration than the uneven parallel bar routine. A gradual

Table 4. Physiological characteristics of female gymnasts.

Variables	Total Group (n = 29) ($\bar{x}$ ± SE)	
Resting HR (bpm)	81 ± 1.6	60 - 98
Maximum HR (bpm)	197 ± 1.5	182 - 213
Resting lactate (mg%)	14 ± 1.0	3 - 27
Ave. post exercise lactate (mg%)	25 ± 2.3	10 - 60
Maximum lactate (mg%)	77 ± 2.7	52 - 118
$\dot{V}O_2$ max (l/min.)	1.8 ± 0.1	1.2 - 2.4
$\dot{V}O_2$ max (ml/kg min.)	50 ± 0.9	39 - 62
$\dot{V}_I$ max (l/min.) (STPD)	53 ± 1.9	32 - 75
Ave. HR intensity (during routines)	73 ± 1.6	55 - 85
Peak HR intensity (during routines)	84 ± 1.9	49 - 100

increase in heart rate was observed on the balance beam while the most rapid increase in heart rate resulted from routines performed on the uneven parallel bars. The uneven parallel bar routines elicited an average heart rate intensity of 80 percent, while the heart rate response for the balance beam and floor exercise routines was approximately 75 percent of the maximum intensity. In addition, each routine resulted in a heart rate response of approximately 90 percent intensity by the end of the performance.

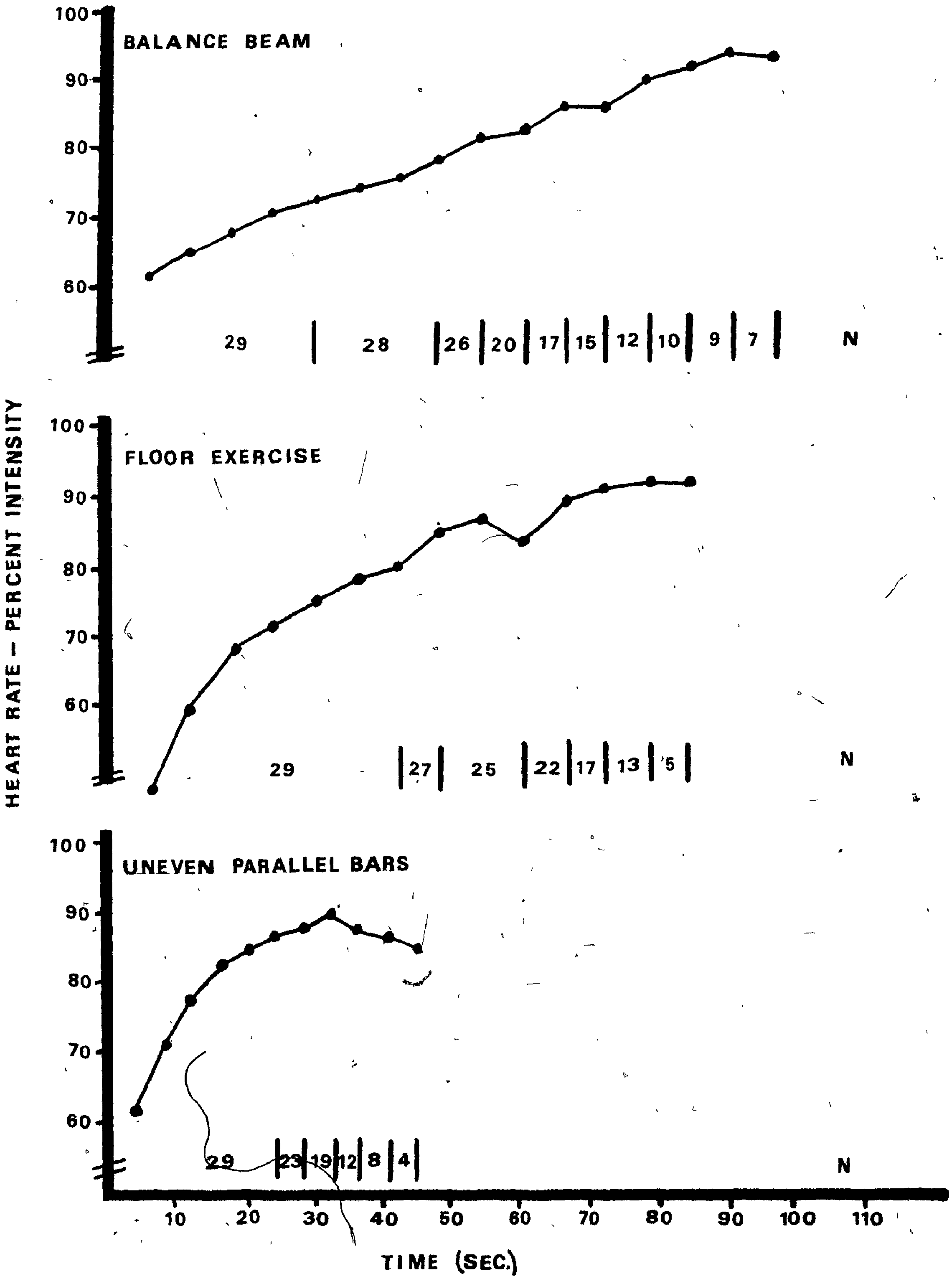


Figure 3. Average heart rate response during balance beam, floor exercise and uneven parallel bar routines.

4.3 HIGH ABILITY VERSUS LOW ABILITY GYMNASTS

For purposes of determining significant differences between gymnastic ability levels on the variables investigated in this study, the subjects were divided into two ability levels based on the all-around scores. Low ability gymnasts (n=17) were designated as those subjects who had all-around scores below 20 points, while high ability gymnasts (n=12) had all-around scores equal to or greater than 30 points. Experience, all-around, and individual event scores for high and low ability gymnasts are presented in Table 5.

Table 5. Experience, all-around and individual event scores for high and low ability gymnasts ($\bar{X}$ ±SE and Range).

Score	Low Ability (n=17)	High Ability (n=12)
Experience*	15.7 ± .77 (18.0-20.0)	53.1 ± 4.83 (33.0-95.0)
All-around	14.5 ± .62 (8.4-19.1)	32.9 ± .50 (30.0-35.0)
Vaulting	4.2 ± .23 (2.2-5.6)	8.3 ± .15 (7.4-9.0)
Uneven Parallel Bars	3.1 ± .19 (2.0-5.0)	8.2 ± .15 (7.1-8.7)
Balance Beam	3.7 ± .18 (2.0-4.8)	7.9 ± .11 (7.2-8.6)
Floor Exercise	3.5 ± .20 (2.0-4.7)	8.4 ± .15 (7.5-9.2)

*Experience = no. of years + ave. hours per week + no. of meets + ave. months per year.

Table 6 lists the results of t-tests computed between high and low ability gymnasts on the independent variables for which values are represented by a single measurement. Only one variable, agility, was found to be significant ($\alpha = .01$) between the two ability levels. The high ability gymnasts obtained significantly lower agility scores than the low ability gymnasts.

A two-way analysis of variance was computed for ability groups versus measurements on all the independent variables for which values were determined by a composite score of individual measurements. The ANOVA results and F-values for total skinfold, strength and total flexibility are presented in Tables 7, 8 and 9 respectively. Significant F-values ($\alpha = .05$) for between group variance were found in all three variables. The high ability gymnasts obtained significantly higher strength and flexibility scores and lower skinfold scores than the low ability gymnasts.

For the flexibility variable, significant F-values were also obtained for the main effects of flexibility measurements and for the interaction of ability groups by flexibility measurements. Because flexibility is joint specific, it would be expected that the measurements taken on different parts of the body will be significantly different from one another. Student-Newman-Keuls post-hoc analysis revealed that the high ability gymnasts obtained significantly higher flexibility scores than the low ability gymnasts on five of the measurements (active hip abduction for both legs, active hip flexion for both legs, and trunk flexion). The measurements for shoulder hyperflexion, shoulder hyperextension, and trunk extension, were not significantly different between the two ability groups. The significant interaction is explained by the fact that the high ability

Table 6. t-tests on regression variables between high (n = 12) and low (n = 17) ability gymnasts.

Variable	High Ability ($\bar{x} \pm SE$)	Low Ability ($\bar{x} \pm SE$)	t-value
Height (cm)	143 ± 2.1	148 ± 2.0	1.82
Weight (kg)	35 ± 1.6	38 ± 1.4	1.07
Anaerobic Endurance (sec.)	253 ±25.1	194 ± 14.8	-2.19
Maximum lactate (mg%)	73 ± 5.3	79 ± 2.6	1.07
$\dot{V}O_2$ max (ml/kg min.)	51 ± 1.5	48 ± 1.0	-1.64
Power (kgm/sec.)	97 ± 4.4	91 ± 4.3	-0.89
Agility (sec.)	9.7 ± 0.1	10.3 ± 0.1	3.76*

*(α =.01)

Table 7. ANOVA of skinfold measurements for ability groups versus individual skinfold measurements.

Source of Variation	df	Sum of Squares	Mean Square	F
Ability groups	1	504.5	504.5	5.34*
Skinfold	3	291.7	97.2	1.03
Ability groups x Skinfolds	3	653.4	217.8	2.30
Residual	104	9739.2	94.6	

* (F 1,104 df α = .05 = 3.93)

Table 8. ANOVA of strength for ability groups versus individual strength measurements.

Source of Variation	df	Sum of Squares	Mean Square	F
Ability groups	1	1.2	1.30	5.23 *
Strength	2	0.1	0.01	0.16
Ability groups x strength	2	1.3	0.63	2.82
Residual	78	17.3	0.22	

* ($F_{1,78df}$ α = .05 = 3.99)

Table 9. ANOVA of flexibility for ability groups versus individual flexibility measurements.

Source of Variation	df	Sum of Squares	Mean Square	F
Ability groups	1	16161.2	16161.2	72.92*
Flexibility	7	367203.9	52457.7	236.68**
Ability groups x flexibility	7	7576.9	1082.4	4.88**
Residual	208	46100.5	221.6	

* ($F_{1,208df}$ α = .05 = 3.92)

** ($F_{7,208df}$ α = .05 = 2.09) gymnasts obtained superior scores on all the hip measurements and trunk flexion but did not show this same superiority in measurements obtained for the shoulder joint and for trunk extension.

A two-way analysis of variance was computed for ability groups versus gymnastic events on the independent variable post-exercise lactate. The ANOVA results and F-values are presented in Table 10. A significant (α =.05) F-value was obtained for between group variance and following the examination of group means it was concluded that the high ability gymnasts obtained significantly higher post-exercise lactate concentrations than the low ability gymnasts. A significant (α =.05) increase in the resting lactate concentration (from 14± 1.0mg% to 25± 2.3mg%) was observed following the performance of the gymnastic routines. The lactate levels obtained following the routines, however, were not significantly different from each other, as indicated by the insignificant F-value obtained for the between events variance. Hence, all events elicited a similar physiological response in terms of lactate production.

Mean heart rate response and peak heart rates recorded during the performance of gymnastic routines along with the mean duration of each event are presented in Table 11. All events, except the uneven parallel bars event, were longer in duration for the high ability gymnasts as compared to the low ability gymnasts. The longer duration time for the vault observed for the high ability group can be explained by the fact that the approach to the vault used by this group of subjects was approximately 20 meters while the low ability group used an approach between 10 to 15 meters. In all cases except vaulting the mean and peak heart rates were higher for the high ability gymnasts than the low ability gymnasts.

Table 10. ANOVA of post-exercise lactate for ability groups versus gymnastic events.

Source of Variation	df	Sum of Squares	Mean Square	F
Ability groups	1	6161.4	6161.4	9.69*
Gymnastic events	2	454.9	227.5	0.36
Ability groups x events	2	136.2	68.1	0.11
Residual	78	48950.0	635.7	

* ($F_{1,78df}$ $\alpha = .05 = 3.99$)

A two-way analysis of variance was computed for ability groups versus gymnastic events on the independent variable average heart rate intensity during the routines. The ANOVA results and F-values are presented in Table 12. Significant ($\alpha = .05$) F-values were obtained for both main effects components, ability groups and gymnastic events, as well as for the interaction effects of ability groups by events. The high ability gymnasts obtained higher heart rate intensities during the performance of their routines than the low ability gymnasts. Following Student-Newman Keuls post-hoc analysis, statistically significant differences in heart rate intensity were observed between the ability groups for all gymnastic events except vaulting. In vaulting the high ability group obtained a lower mean heart rate intensity than the low ability group. Although this difference is insignificant it explains the acquisition of significant interaction. The high ability group invariably obtained the higher average heart rate intensities in all the other events. Figure 4

Table 11. Routine duration, mean HR and peak HR in the gymnastic events ($\bar{x} \pm SE$).

Event	Duration (sec.)	Mean HR (bpm)	Peak HR (bpm)
Vaulting			
Low Ability	4.6 ± 0.1	153 ± 2.2	161 ± 2.5
High Ability	5.3 ± 0.1	151 ± 5.0	163 ± 6.3
Uneven Parallel Bars			
Low Ability	87.5 ± 2.4	169 ± 3.6	181 ± 3.4
High Ability	28.5 ± 1.5	182 ± 2.5	195 ± 2.6
Balance Beam			
Low Ability	62.6 ± 4.2	160 ± 3.1	170 ± 2.9
High Ability	88.5 ± 5.0	181 ± 3.3	191 ± 3.6
Floor Exercise			
Low Ability	63.4 ± 3.5	164 ± 3.9	180 ± 3.2
High Ability	79.7 ± 2.5	175 ± 4.0	193 ± 3.1

graphically represents this observation. Further analysis revealed that the low ability group exhibited similar (statistically insignificant) heart rate responses in all events with one exception, the uneven parallel bar heart rate response was significantly higher than the vaulting response. On the other hand, for the high ability gymnasts three events, uneven parallel bars, balance beam and floor exercise, were all significantly higher in terms of heart rate response than the vaulting event. The greatest difference observed between the two groups was the heart rate intensity observed on the balance beam.

Table 12. ANOVA of exercise heart rate intensity for ability groups versus events.

Source of Variation	df	Sum of Squares	Mean Square	F
Ability groups	1	1732.6	1732.6	16.63**
Gymnastic events	3	5855.2	1951.7	18.74**
Ability groups x events	3	1086.2	362.1	3.48*
Residual	104	10834.1	104.2	

*(F1,104df α=.05 = 3.93)

**(F3,104df α=.05 = 2.69)

To further analyse the differences in heart rate response during routines between the ability groups, a mean heart rate was calculated for each six second period for the total duration of both balance beam and floor exercise routines and for every four second period for the uneven parallel bar routine. The average heart rate for each period was expressed as a percent of the maximum potential heart rate for both groups and plotted against time (Figure 5). Both groups began their routines at approximately the same heart rate intensity, but the high ability group showed a more rapid increase in heart rate and obtained a higher intensity in all routines.

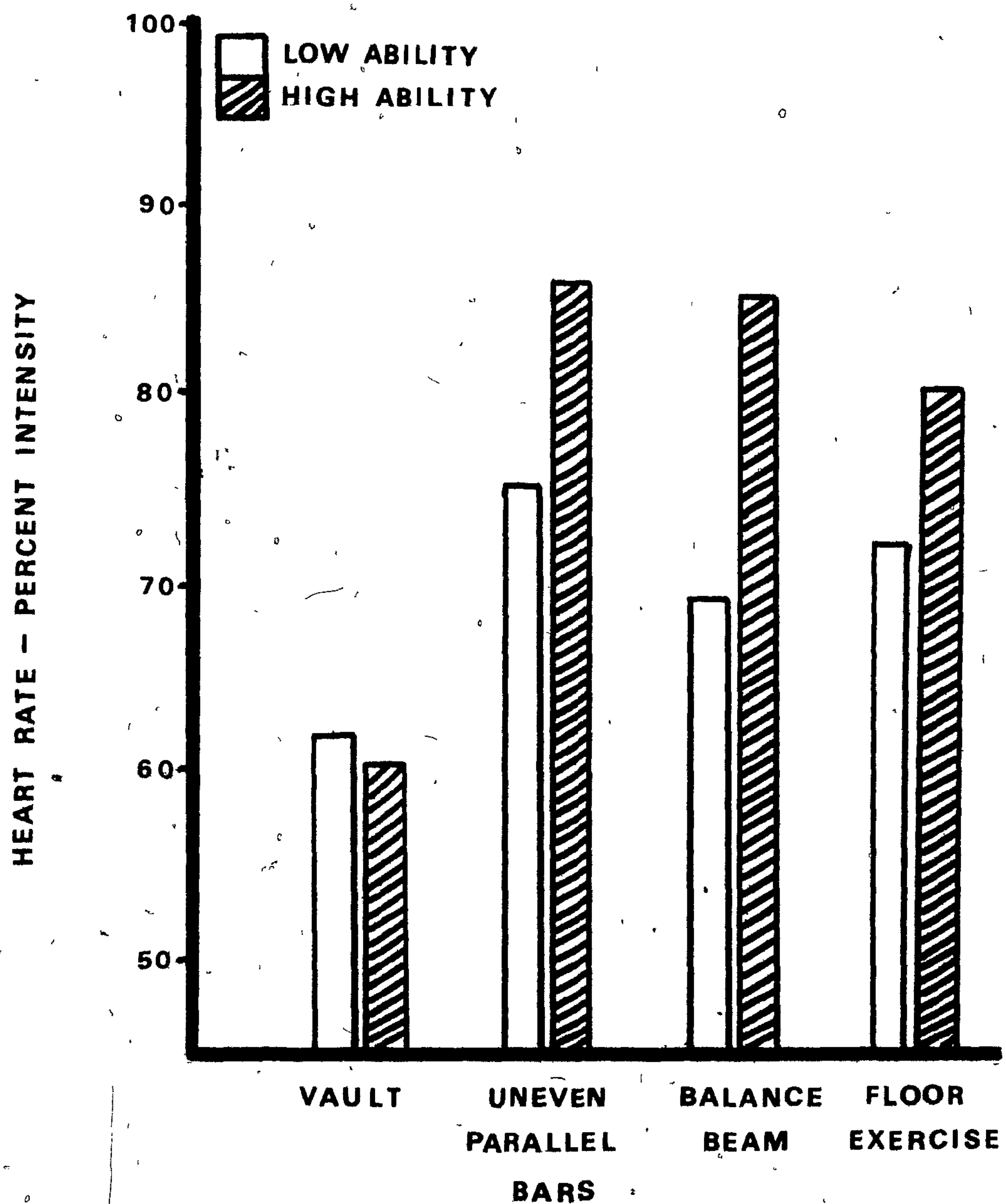


Figure 4. Mean heart rate intensities for each gymnastic event.

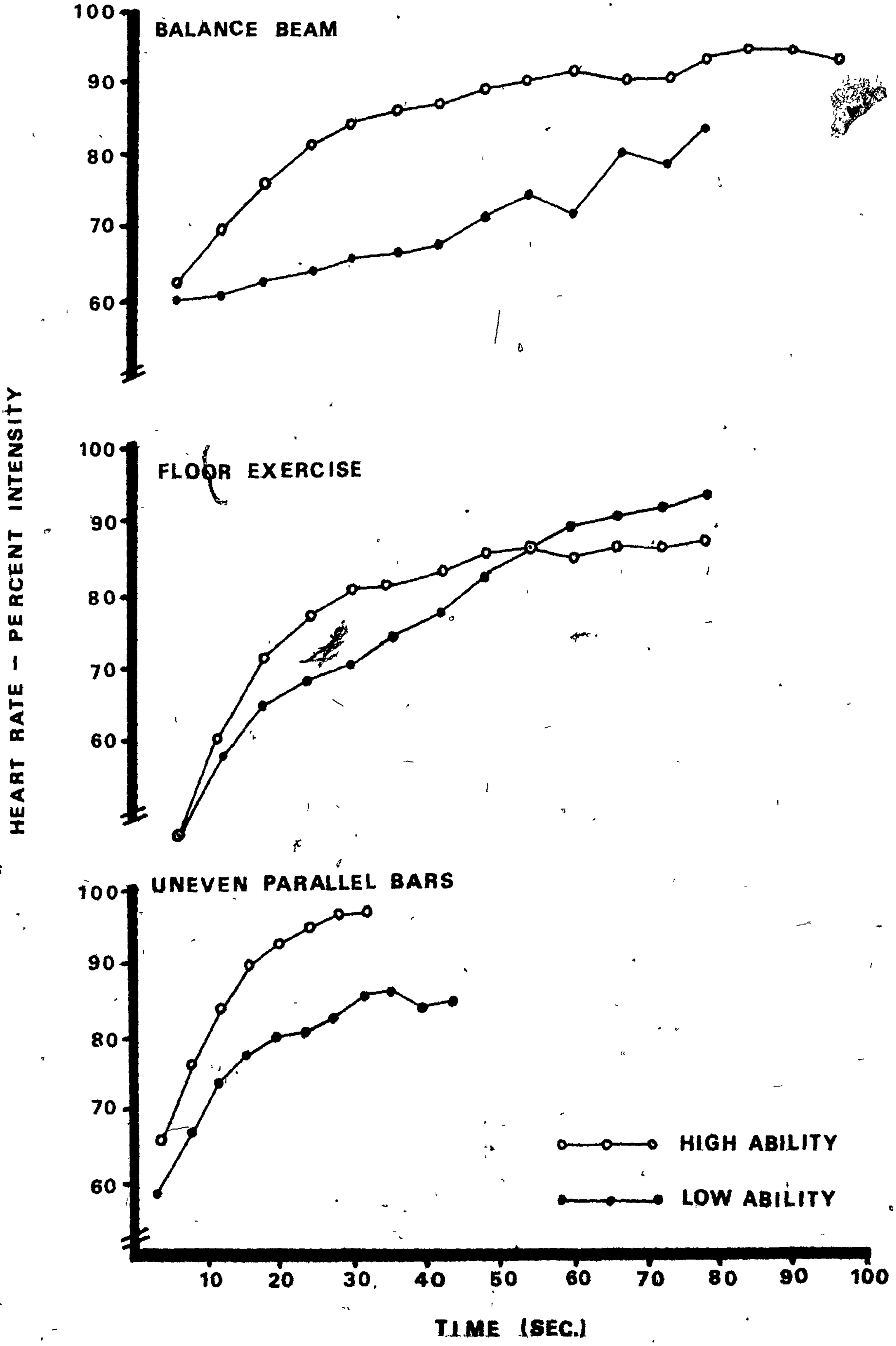


Figure 5. Average heart rate response during gymnastic routines for high and low ability gymnasts.

4.4 PREDICTION OF ALL-AROUND GYMNASTIC ABILITY AND ABILITY IN EACH EVENT

The dependent or criterion variables used to predict gymnastic ability in this study were all-around and individual event gymnastic scores. The significant (α=.05) correlations observed between the independent regression variables and all gymnastic scores are presented in Table 13. Three independent variables, weight, maximum lactate and power are not presented in the table because they did not result in any significant correlations with the gymnastic scores.

From Table 13 it can be seen that the experience variable had the highest correlations with all the dependent variables. The highest correlation observed was between experience and the all-around score (r=.895). Following experience, the independent variables most significantly and consistently correlated with all scores were flexibility, agility, total skinfold, and strength. It is interesting to note that although the measurements for anaerobic endurance and maximum aerobic capacity were not statistically significant between the two ability groups (see Table 6), both variables were significantly correlated with all-around gymnastic scores and individual event scores. Maximum aerobic capacity was significantly correlated with uneven parallel bar and floor exercise scores while anaerobic endurance was significantly correlated with all events except vaulting.

The significant (α=.05) inter-correlations between regression variables for all-around gymnastic ability are presented in Table 14. It is apparent that there were three independent variables in particular (total skinfold, agility and experience) that were significantly correlated with

Table 13. Significant correlations between regression variables and gymnastic scores.

Regression Variables	All-Around Score	Vaulting Score	Uneven bars Score	Beam Score	Floor Ex. Score
Height (cm)	-	-	-	.393*	-
Total Skinfold (mm)	-.637**	-.621**	-.638**	-.594**	-.653**
Anaerobic Endurance (sec.)	.364*	-	.384*	.388*	.377*
$\dot{V}O_2$ max (ml./kg.·min.)	.363*	-	.391*	-	.388*
Total Flexibility (degrees)	.762**	.762**	.731**	.762**	.750**
Agility (sec.)	-.652**	-.660**	-.620**	-.647**	-.648**
Strength (kg/kg body wt.)	.629**	.569**	.624**	.647**	.636**
Floor Exercise L.A. (mg%)	-	-	-	-	.523*
Uneven Bars L.A. (mg%)	-	-	.503*	-	-
Floor Exercise H.R. (% max.)	-	-	-	-	.385*
Balance Beam H.R. (% max.)	-	-	-	.651**	-
Uneven Bars H.R. (% max.)	-	-	.486*	-	-
Mean Exercise H.R. (% max.)	.515*	-	-	-	-

*(α=.05) **(α=.001)

Table 13. (Continued)

Regression Variables	All-Around Score	Vaulting Score	Uneven Bars Score	Beam Score	Floor Ex. Score
Mean Exercise L.A. (mg%)	.560*	-	-	-	-
Experience	.895**	.894**	.885**	.874**	.874**

*(α = .05)

**(α = .001)

Table 14. Significant correlations between the regression variables for all-around gymnastic ability.

	Height	Weight	Skinfold	$\dot{V}O_2$ max.	Flexibility	Strength	Power	Ave. H.R. (%max)	Ave. L.A. (mg%)	Agility	Experience
Height		.893**	-	-	-	-	.643**	-	-	-	-
Weight			.492*	-	-	-	.803**	-	-	-	-
Skinfold				-.570*	-.608**	-.495*	-	-	-	-.538*	.693**
$\dot{V}O_2$ max.					-	-	-	-	-	-	.432*
Flexibility						.546*	-	-	-	-.527*	.663**
Strength							-	-	.485*	-.542*	.641**
Power								-	-	-	-
Ave. H.R. (%max.)									.532*	-	.523*
Ave. L.A. (mg%)										-.517*	-
Agility											-.523*
Experience											

*(α=.01) **(α=.001)

five of the other independent variables. Total skinfold measurements were closely related to $\dot{V}O_2$ max., flexibility, strength, agility and experience. The agility and experience variables were significantly correlated with all these variables. In addition, the average heart rate intensity during the performance of routines was significantly related to experience and average post-exercise lactate was correlated with agility.

Multiple correlation coefficients (R), coefficients of determination (R^2), change in R^2, simple R's, beta values, F-vaules and regression equations for the prediction of gymnastic ability are presented in Tables 15 through 19. The multiple correlation coefficient (R) is an index of the relative strength of the relationship between the independent variable(s) and the dependent variable while the coefficient of determination(R^2) is a measure of prediction accuracy and the strength of linear association. The value of R^2 indicates the proportion of variation in the dependent variable that is explained by the independent variable(s). The change in R^2 column indicates the relative contribution or significance of the addition of an independent variable into the regression equation. The beta values are standardized regression coefficients that indicate the relative importance of each of the independent variables as predictors of the dependent variable. An independent variable was added to the regression equation if it significantly ($\alpha = .05$) improved the prediction accuracy.

Since the independent variable "experience" is neither a physical, physiological or anthropometric variable, two regression equations have been computed for each dependent variable. The first equation in each

Table 15. Prediction of all-around gymnastic ability.

Without the experience variable in the regression analysis.

Variable	R	R^2	Change in R^2	Simple R	Beta
X_1 Flexibility	.762	.581	.581	.762	.600
X_2 Agility	.817	.667	.087	-.652	-.135
X_3 Endurance	.856	.733	.066	.364	.302
X_4 Power	.884	.781	.047	.166	.224
X_5 Post-Exercise Lactate	.903	.816	.035	.560	.222

F

$Y' = -18.69 + .550\ (x_1)\ -2.416\ (x_2) + .370\ (x_3) + .128\ (x_4)\ \underline{+}.173\ (x_5)$ 20.42*

* ($F5,23\ \alpha = .05 = 2.64$)

Experience variable added into the regression analysis.

Variable	R	R^2	Change in R^2	Simple R	Beta
X_1 Experience	.895	.802	.802	.895	.618
X_2 Height	.928	.861	.059	-.334	-.431
X_3 Power	.947	.898	.037	- .166	.391
X_4 Skinfold	.969	.940	.041	-.637	-.277

F

$Y' = 70.93 + .271\ (x_1) - .496\ (x_2) + .223\ (x_3) - .178\ (x_4)$ 92.34*

* ($F4,24df\ \alpha = .05 = 2.78$)

Table 16. Prediction of vaulting ability.

Without the experience variable in the regression analysis.

Variable	R	R^2	Change in R^2	Simple R	Beta
X_1 Flexibility	.762	.581	.581	.762	.446
X_2 Power	.823	.677	.096	.227	.600
X_3 Skinfold	.875	.766	.089	-.621	-.419
X_4 Height	.903	.815	.048	-.245	-.318

$Y' = 5.89 + .952\ (x_1) + .796\ (x_2) - .626\ (x_3) - .852\ (x_4)$ — F: 26.35*

* (F4,24df α = .05 = 2.78)

Experience variable added into the regression analysis.

Variable	R	R^2	Change in R^2	Simple R	Beta
X_1 Experience	.894	.799	.799	.894	.630
X_2 Flexibility	.922	.850	.051	.762	.237
X_3 Agility	.937	.879	.028	-.660	-.206

$Y' = 8.80 + .643\ (x_1) + .504\ (x_2) - .858\ (x_3)$ — F: 60.28*

* (F3,25df α = .05 = 2.99)

Table 17. Prediction of ability on the uneven parallel bars.

Without the experience variable in the regression analysis.

Variable	R	R^2	Change in R^2	Simple R	Beta
X_1 Flexibility	.731	.534	.534	.731	.414
X_2 Endurance	.794	.630	.096	.384	.339
X_3 Lactic Acid	.846	.715	.085	.502	.285
X_4 Power	.877	.769	.054	.151	.302
X_5 Skinfold	.906	.821	.052	-.638	-.313

$Y' = -8.87 + 1.05\ (x_1) + .115\ (x_2) + .476\ (x_4) - .556\ (x_5)$ F 21.16*

* ($F5,23df\ \alpha = .05 = 2.64$)

Experience variable added into the regression analysis.

Variable	R	R^2	Change in R^2	Simple R	Beta
X_1 Experience	.885	.782	.782	.885	.609
X_2 Height	.920	.846	.064	-.343	-.432
X_3 Power	.938	.880	.034	.151	.379
X_4 Skinfold	.960	.922	.042	-.638	-.279

$Y' = 19.01 + .739\ (x_1) - .138\ (x_2) + .598\ (x_3) - .495\ (x_4)$ F 70.57*

* ($F4,24df\ \alpha = .05 = 2.78$)

Table 18. Prediction of ability on the balance beam.

Without the experience variable in the regression analysis.

Variable	R	R^2	Change in R^2	Simple R	Beta
X_1 Flexibility	.762	.580	.580	.762	.471
X_2 HR Percent Intensity	.852	.726	.146	.651	.361
X_3 Endurance	.901	.812	.086	.388	.277
X_4 Agility	.921	.849	.036	-.647	-.229

$$Y' = 1.08 + .102\,(x_1) + .637\,(x_2) + .798\,(x_3) - .970\,(x_4)$$ F 33.61*

* ($F_{4,24}$df $\alpha = .05 = 2.78$)

Experience variable added into the regression analysis.

Variable	R	R^2	Change in R^2	Simple R	Beta
X_1 Experience	.874	.764	.764	.874	.694
X_2 Height	.925	.856	.092	-.393	-.428
X_3 Power	.944	.891	.036	.117	.212
X_4 Agility	.955	.911	.020	-.647	-.173

$$Y' = 24.85 + .718\,(x_1) - .116\,(x_2) + .285\,(x_3) - .732\,(x_4)$$ F 61.52*

* ($F_{4,24}$df $\alpha = .05 = 2.78$)

Table 19. Prediction of ability in floor exercise.

Without the experience variable in the regression analysis.

Variable	R	R^2	Change in R^2	Simple R	Beta
X_1 Flexibility	.750	.563	.563	.750	.450
X_2 Post-ex. L.A.	.817	.668	.105	.523	.231
X_3 Maximum L.A.	.856	.733	.065	-.393	-.231
X_4 $\dot{V}O_2$ max	.897	.805	.071	.388	.369
X_5 Power	.914	.836	.031	.160	.440
X_6 Height	.943	.888	.052	-.334	-.376

$$Y' = -.196 + .112\,(x_1) + .372\,(x_2) - .370\,(x_3) + .200\,(x_4) + .677\,(x_5) - .117\,(x_6)$$

F 29.20*

* $(F_{6,22df}\ \alpha = .05 = 2.55)$

With the experience variable added into the regression analysis.

Variable	R	R^2	Change in R^2	Simple R	Beta
X_1 Experience	.873	.763	.763	.873	.556
X_2 Height	.907	.822	.060	-.334	-.462
X_3 Agility	.927	.860	.038	-.648	.083
X_4 Power	.939	.882	.022	.160	.470
X_5 Skinfold	.959	.920	.037	-.653	-.397

$$Y' = 15.85 + .660\,(x_1) - .144\,(x_2) + .406\,(x_3) + .725\,(x_4) - .690\,(x_5)$$

F 52.68*

* $(F_{5,23df}\ \alpha = .05 = 2.64)$

table is the result of regression analysis computed without the inclusion of the experience variable. While the coefficients of determination are high (range .815 to .888) and significant ($\alpha = .05$) for all the equations, it is apparent that a greater portion of explained variation is obtained with the inclusion of the experience variable. The coefficients of determination ranged from .879 to .940. Examination of the residuals indicated that all the regression equations computed were relatively free from abnormalities. Residuals were plotted and are graphically presented in Appendix A, Figures A through E for regression equations computed without the experience variable and in Figures F through J for regression equations computed with the experience variable. The implications of the regression equations as predictors of gymnastic ability will be discussed in the next chapter.

CHAPTER V

DISCUSSION

5.1 ANTHROPOMETRIC CHARACTERISTICS

Gymnasts, on the average, tend to be smaller in size and leaner than the normal population and also smaller and leaner than other athletic groups (Bosco, 1964; Drazil, 1971; Novak et. al., 1968; Pool et al., 1969; Sinning and Lindberg, 1972). Several investigators came to this conclusion based upon studies conducted with late adolescent and college age gymnasts. Whether these characteristics persist in children and early adolescent groups has not been determined.

In the present study, the gymnasts had an average height of 146 cm and a weight of 37 kilograms. There were no significant differences between the high and low ability gymnasts on these two measures. Contrasting these measurements, previous investigators (Adams et al., 1961; Seliger et al., 1971 and Brown et al., 1972) have reported substantially higher values of height and weight for athletic and non-athletic girls in the same age group. Adams et al. (1961) after evaluating 52 girls, reported average height values of 148 cm, 158 cm and 163 cm for ages 11, 12 and 13 years respectively. The average weight was also higher, ranging from 44 kg for the 11 year olds to 55 kg for the 13 year olds. In a similar study evaluating the 12 year old population in Czechoslovakia (n=294), Seliger et al. (1971) reported an average height of 150 ±6.4 cm and an average weight of 40 ±6.1 kilograms. Also, when comparing the gymnasts in the present study to other athletic groups of the same age, it has been reported that girls participating in cross-country running were larger with an average height of 152 cm and a weight of 45 kg (Brown et al., 1972).

The most extensive study of skinfold measurements for all age groups was the Tecumseh Community Health Study (Montoye, 1970). In this particular study 343 girls, 11 to 13 years of age were evaluated. The average total of four skinfold measurements in the Tecumseh girls ranged from 58 mm for 11 year olds to 66 mm for 13 year olds. After measuring the same skinfolds in this study, the gymnasts had an average total skinfold measurement of 32 mm with a range from 18 mm to 84 milimeters. When compared to the average population the subjects were much leaner, as their total score placed them between the 5th and 20th percentile on the lean end of the scale (i.e. the 5th percentile representing the leanest subjects). In addition, the high ability gymnasts were significantly leaner than the low ability gymnasts. The mean value of 23 ±1.0 mm for the high ability group was not represented on the percentile table, indicating that they were extremely lean, while the low ability group had a score of 39 ±3.8 mm which placed them in the 20th to 35th percentile of the Tecumseh population. It is concluded, therefore, that the female gymnasts in this study were smaller in size and leaner than the average female population of the same age group, and that the high ability participants were leaner than their less skilled counterparts.

5.2 PHYSICAL CHARACTERISTICS

The results of the power test used in the present study were higher than the values reported by Godfrey (1974). The mean power score for the subjects in this study was 62 kg-m./sec. with a range from 50 to 89 kg-m./sec. whereas the average power scores reported by Godfrey (1970) ranged from about 34 kg-m./sec. for 11 year old girls to 58 kg-m./sec. for 13 year old girls. Godfrey's investigation of maximum anaerobic power in children utilized the original Margaria power test. The only difference between the two tests is that in the Margaria power test, subjects run up a flight of steps taking two steps at a time, while in the Margaria-Kalmen test, subjects ascend the stairs at maximum speed taking three steps at a time. It has been reported that a greater power output is achieved with the three step test (Mathews and Fox, 1976). This could account, in part, for the higher scores obtained by the gymnasts. It has also been suggested that training for, and performing gymnastic type movements requires the recruitment of the fast twitch, high glycolytic fibers and perhaps their subsequent development (Sale, 1976). The fast twitch fibers are preferentially recruited for performing short, high intensity work bouts (Mathews and Fox, 1976). It is quite possible, therefore, that the gymnasts in this study obtained higher power scores due to the effects of gymnastic activity on the improvement of fast twitch muscle fiber capacity.

The results of the agility run indicated that gymnastics may have a positive effect on leg strength and subsequently speed. The mean score for 11 to 13 year old girls in this study was 10.0 seconds with a range from 9.3 to 11.9 seconds. According to the AAHPER norms, these results placed the gymnasts in the 90th percentile or greater, depending on their age. In this test the high ability group obtained significantly (α=.001) faster running times than the low ability group. A mean score of 9.7 seconds, with a range from 9.3 to 10.0 seconds, for the high ability group placed the group in a percentile ranking greater than 95 percent. The low ability group, on the other hand, obtained a mean agility score of 10.3 seconds with a range from 9.5 to 11.9 seconds. These values placed the low ability group in a range from the 30th to 90th percentile.

Measurements for strength obtained from the subjects in this study substantiate the conclusion of a previous article which stated that strength is one of the outstanding characteristics of highly trained gymnasts (Bosco, 1970). The mean strength score for all subjects in this study was 1.2 ±0.1 kg/kg body weight. The high ability gymnasts obtained a significantly (α=.05) higher strength score than the low ability gymnasts. The mean strength score was 1.4 ±0.1 kg/kg body weight for the high ability group while the low ability group had a mean score of 1.1 ± 0.1 kg/kg body weight. Strength scores for two out of the three movements measured, shoulder extension and trunk extension, were significantly different at the .05 level between the two ability groups, while values for hip extension were not significantly different. The shoulders and back are two areas in which strength is vitally important for the performance of gymnastic routines. It was not surprising, therefore, that values obtained for shoulder and trunk extension were significantly higher for the high ability group. While strength in the hip area is also considered very important by many coaches, most gymnastic type movements involve forceful hip flexion rather than hip extension (i.e. in performing a kip). This could possibly explain the similar values obtained by both groups for the measurement of hip extension. Most strength training for the hip area is probably focused on improvement of hip flexion.

In another investigation, Cumming (1970) reported a much higher strength score of 3.4 kg/kg body weight for female gymnasts, however, his subjects were of college age and the score was calculated from a composite of five different tests than those used in this study. Because of the differences in these two studies and the lack of other investigations measuring strength in female gymnasts it is difficult to assess the strength score of the subjects in this study.

Anaerobic endurance as measured in this study has not been investigated in other studies, to this authors knowledge. Because of the highly anaerobic nature of gymnastics, however, it would be expected that anaerobic endurance is an important physical trait to possess and that highly trained subjects would have a greater capacity. It might also be expected that the capacity of anaerobic endurance would be of greater importance in the uneven parallel bars, balance beam and floor exercise routines which are longer and more intensive events than vaulting.

The mean anaerobic endurance times for high and low ability gymnasts (194 ±14.8 seconds for low ability and 253 ±25.1 seconds for high ability), were not statistically different. Despite this lack of significance, anaerobic endurance had a low but significant ($\alpha = .05$) correlation with the all-around gymnastic score, as well as for the uneven parallel bars, balance beam and floor exercise scores. Insignificant differences between the two groups for this variable can be explained by the fact that the high ability group obtained a wide variation in scores and as a result a large standard error (±25.1). Analysis of individual data revealed that two subjects in the high ability group scored significantly lower than the rest of the girls in that group. When the scores for anaerobic endurance are considered on an individual basis, however, as in correlation analysis, it becomes apparent that in a significant number of cases, scores obtained for anaerobic endurance are significantly and positively related to gymnastic scores. Further implications of anaerobic endurance will be discussed later in the section regarding the prediction equations for gymnastic ability.

The testing protocol used to measure flexibility was unique to this investigation and as a result there were no other studies with which a comparison of flexibility results could be made. As stated previously, the individual test items and methodologies utilized during the present study were specifically selected because of their importance in gymnastic performance. From the authors' previous experience it can be stated that the subjects in this study possessed above average flexibility in many, if not all, of the areas measured.

Results of the flexibility measurements obtained on the gymnasts in this study support the statement by Clarke (1975) which claimed that both the number of years of participation and the ability level of athletes have an effect on flexibility. While both ability groups demonstrated a high level of flexibility, the high ability gymnasts obtained a mean total score of 825 ±11.9 degrees of motion, while the low ability gymnasts had a score of 683 ±22.5 degrees. This difference in scores was significant at the .001 level. It is apparent that this difference in flexibility is due to the training techniques used and the significantly greater amount of time utilized for the development of maximum range of movement in the better competitors. Optimal improvements or maintainanee of flexibility requires a minimum of 30 minutes of sustained stretching exercises each day (Bates, 1976). Flexibility training is part of the daily routine for subjects in the high ability group. A high degree of range of motion is obtained for specific joint areas (i.e. the hips) by forcing the body into extreme positions and maintaining this strenched position for a specified amount of time. Low ability gymnasts consistantly reported fewer practice days and practice hours per week. This fact alone probably accounts for their lower flexibility scores.

After an investigation of the individual measurements, it was apparent that all the measurements were significantly different between the ability groups except for shoulder hyperextension, shoulder hyperflexion, and trunk extension. It was reported by Mathews and Fox (1976) that shoulder flexibility in athletes is generally below average as compared to the normal population. They concluded that this lower range of movement is most probably due to an increase in muscular strength in this area. The shoulder is a weak joint structurally and the primary stabilizing factor is the surrounding musculature. Increases in strength are not necessarily associated with a concomitant loss in range of motion if flexibility training is practiced in conjunction with the strength exercises (Clarke, 1975). In this study the high ability gymnasts did not obtain flexibility measures that were lower than those obtained by the low ability gymnasts but instead there was no significant difference between the two groups. Therefore, although the high ability gymnasts have been found to possess a greater amount of shoulder strength than low ability gymnasts the range of motion was retained due to flexibility training. A possible explaination for the lack of significant difference for the measurement of trunk extension between the ability groups could be that even low ability participants in gymnastics develop a high degree of trunk flexibility due to their participation in the sport.

5.3 PHYSIOLOGICAL CHARACTERISTICS

A comparison of the maximum physiological measurements obtained by various investigators for heart rate, oxygen consumption and blood lactate concentration are presented in Table 20. Studies for both boys and girls ages 11 to 13 years are included in the table because it has been shown that there are no sex differences for maximum heart rate and lactate concentration at this age (Astrand, 1951). In addition, there are no significant differences in maximum oxygen consumption values and other physiological responses to maximum exercise in children before the beginning of puberty (Astrand, 1951; Wilmore and Sigerseth, 1967; and Godfrey, 1974).

The mean maximum heart rate obtained in the present study (197 ±8.0 beats/min.) was comparable with most of the values reported by the other investigators, but was slightly lower, though probably not significantly different, than the maximum rates obtained by Astrand, 1952 (205 beats/min.), Hermanse and Oseid, 1971 (203 beats/min.) and Saltin and Thoren, 1968 (200beats/min.). This discrepancy in maximum heart rate values was probably due to differences in measurement techniques. Comparisons of maximum heart rate as determined by a 10-second ECG recording and the technique of Astrand (palpation of the first 10 to 15 beats of the

Table 20. Maximum heart rate, oxygen consumption and blood lactate concentration in children ages 11 to 13 years.

Investigators	n (sex)	Age (years)	Heart Rate (beats/min)	$\dot{V}O_2$ max (ml/kg·min)	Lactate max (mg%)
Astrand, 1952	19 (boys)	12-13	205	57	78
	13 (girls)	12-13	207	50	-
Wilmore and Sigerseth, 1967	22 (girls)	12-13	194	49	-
Saltin and Thoren, 1968 (unpubl.)	6 (boys)	12	200	55	66
Shepard, et al., 1969	10 (boys)	11	193	48	73
	15 (boys)	12-13	193	46	69
	6 (girls)	10-12	199	39	109
	13 (girls)	10-12	196	39	72
Seliger et al., 1971	294 (girls	12	198	38	-
Hermanse and Oseid, 1971	10 (boys)	11.5	203	55	-
	10 (boys)	12.5	203	58	-
Weber, 1974	12 (boys)	13	196	44	75
Eriksson, ~~1972~~	16 (boys)	11	200	49	77
Present Study, 1978	29 (girls)	11-13	197	50	77

carotid artery following exercise) showed errors in Astrands' technique as great as 22 beats/min. with a mean of 10 beats/min. (Golberg et al., 1966).

In the present study 14 out of the 29 subjects, or 48 percent, obtained maximum heart rates of 200 beats/min. or greater. The highest heart rate recorded was 213 beats/minute. After determining the maximum heart rate of 136 children between the ages of 1 and 16 years, Goldberg et al., (1966) reported that only eight subjects obtained heart rates above 205 beats/minute.

Heart rate in this study were recorded during the graded bicycle ergometer test and during the performance of gymnastic routines to determine the maximum rate. Twelve subjects out of 29 reached higher maximum heart rates during the performance of their routines than during the graded bicycle test, and nine of these subjects were high ability gymnasts. In addition, the maximum heart rates were obtained on different routines. Of the 12 subjects who obtained maximum heart rates during a gymnastic routine, seven were perfoming on the uneven parallel bars, three on the balance beam and two in floor exercise.

The maximum values for oxygen consumption were in agreement with those reported by Astrand, 1952, Wilmore and Sigerseth, 1967, Shepard et al., 1969, Weber, 1974, and Eriksson, 1972, lower than three investigators reporting values for boys (Astrand, 1952, Saltin and Thoren, 1968, and Hermanse and Oseid, 1971) and higher than two investigators reporting values for girls (Shepard et al., 1969 and Seliger et al., 1971). The investigation by Seliger et al. (1971) was quite extensive as 294 girls, age 12 years were evaluated. This study established a good population norm for this age group. Comparing the past results to those of the present study, it can be concluded that gymnasts between the ages of 11 and 13 years have similar maximum oxygen uptake values to those of the normal population. In addition, the gymnasts in this study had higher aerobic capacities than the female gymnasts investigated by Sprynarva and Parizkova, 1969 (42.5 ml/kg·min.) and Cumming, 1970 (43.1 ml/kg·min.) (see Table 1.).

The mean values for maximum aerobic capacity obtained by the two ability groups are not significantly different. The high ability gymnasts had a $\dot{V}O_2$ max of 51 ml/kg·min. as compared to the low ability gymnasts value of 48 ml/kg·min. The subject with the highest aerobic capacity of 62 ml/kg·min. was one of the top gymnasts in the study. This same observation was reported by Novak et al., (1968) after an investigation of male gymnasts. In Novak et associates study, the top gymnast had an aerobic capacity of 60 ml/kg·minute.

The present study obtained a mean maximum blood lactate concentration of 77 ±14.3 mg%. This value was similar to the other values listed in Table 20. Astrand, (1951) reported that in children of the same age, there were no sex differences between the values obtained for maximum blood lactate concentrations. In addition while you would expect maximum lactate levels to be greater than 100 mg% for adults, the normal maximal range for children ages 11 to 13 years is between 72 and 88 mg% (Godfrey, 1974). The probable cause for a lower lactate production in children could be due to the rate limiting enzyme, PFK, which displays an activity which is 40 percent of the activity for adults. The low and high ability gymnasts obtained similar maximum lactate values when tested on the bicycle ergometer.

The mean heart rates observed during the performance of gymnastic routines for subjects in this study were considerably higher than the mean values reported by Seliger et al., (1970). In that investigation, the mean heart rates were 133, 134, and 130 beats/min. during vaulting, uneven parallel bar and balance beam routines respectively. The difficulty level of the routines was not reported. In the present study, the mean heart rate response for all subjects in these same events was 152, 175 and 169 beats/minute. In another study (Faria and Phillips, 1970), the mean heart rate observed for children 7 to 13 years old while vaulting was 153 beats/min., a value which was in close agreement with the response of 152 beats/min. observed in this study. However, the average heart rate during floor exercise activity was 158 beats/min. as compared to 169 beats/min. observed in the present investigation.

It was apparent that the gymnasts in this study obtained significantly higher heart rate averages, while performing their routines, than gymnasts investigated in other studies. The differences in physiological responses observed between the two ability groups was equally apparent and significant. Average heart rate intensities (high ability 78 percent, low ability 70 percent), peak heart rates (high ability 89 percent, low ability 81 percent) and post exercise lactates (high ability 33mg%, low ability 19mg%) were all found to be significantly ($\alpha = .01$) higher in the more experienced, high ability gymnasts. The difference may be explained by the higher difficulty element present in the routines of the highly trained group. Hence, a high degree of difficulty produces a higher gymnastic score and placed a greater physiological demand on the subject.

Even though the low ability subjects were putting a maximal effort into the performance of their routines, the level of cardiovascular adjustment did not compare to the more vigorous and difficult performances of the high ability group. This relationship between the difficulty level of the routine and cardiac response was also observed by Montpetit (1972) after monitoring male gymnasts while performing novice, junior and senior routines.

From the lactate results it seems apparent that training the anarobic lactate system would be of greater importance for girls with a high level of ability whereas this type of training would not be as necessary for the average high school participant. For the high ability group, the post exercise lactate concentration following a single floor exercise routine on the average was 37 mg%, while the lactate concentration after uneven parallel bar routines was 39 mg%. Repeating exercises of this intensity a total of eight to ten times each, (which is quite normal during a training session) would theoretically produce very high blood lactate levels if sufficient rest periods are not allowed between each repetition (Astrand and Rodahl, 1977). The ability to tolerate high levels of lactate would enable a gymnast to practice longer and more productively without feeling greatly fatiqued.

5.4 THE USE OF REGRESSION EQUATIONS TO PREDICT GYMNASTIC ABILITY

In order to obtain prediction equations, the measurements of selected physical, physiological and anthropometric variables were analysed to evaluate their relative contribution in the prediction of gymnastic scores. Two regression analysis, one with and one without the inclusion of the experience variable, were computed for all-around gymnastic ability and for each event. According to the rating of Weber and Lamb (1970) the coefficients of determination (R^2) for all the regression equations computed with or without the experience variable showed "high" to "very strong" relationships in the strength of their prediction accuracy. The range for R^2 in the equations computed without the experience variable was from .815 for vaulting ability to .888 for the prediction of floor exercise ability. With the addition of the experience variable, prediction accuracy increased as the amount of explained variance ranged from 88 percent for vaulting ability to 94 percent for all-around ability.

When experience was excluded from the analysis, the flexibility variable was consistantly selected as the first variable to enter the regression equation and therefore was the single best predictor for gymnastic success. The flexibility variable alone explained from 53 to 58 percent of the variance in the dependent variables. However, when the experience variable was included into the regression analysis it was selacted as the best single predictor, explaining from 76 to 80 percent of the variance in the dependent variables. The other variables selected as significant predictors of ability were quite different, depending on whether or not the experience variable was included in the analysis. This was explained by the fact that many of the variables, such as total skinfold, flexibility, strength and agility are highly correlated with experience and were therefore partialled out of the regression analysis when experience was included. Hence, the experience variable actually represented a compilation of many of the individual variables.

Upon analysing the individual regression equations computed with the exclusion of the experience variable, it was apparent that a few regression variables were repeatedly selected as strong predictors for all-around ability and ability in each of the events. Following the inclusion of the flexibility variable into each of the equations the next variables most often selected were power, anaerobic endurance and post-exercise lactate concentrations. Each of these variables was selected in three out of the five regression equations. The variables of agility, total skinfold, and height were also important predictors for gymnastic ability as they were each significant in two of the prediction equations. Three other variables were selected on only one occasion. These variables were average heart rate intensity for the balance beam, and the maximum lactate and maximum aerobic capacity, both for floor exercise.

The relative importance of most of these variables for gymnastic success is quite apparent, however, a few variables deserve some discussion. The variables of post-exercise lactate and average heart rate intensity were closely related to the difficulty level of the routines and their selection as significant predictors indicated the importance of including high difficulty movements to obtain a high score. The values for anaerobic endurance and power were both measured utilizing leg exercise. It would be incorrect to assume that these measurements were representative of other parts of the body (i.e. the arms). It is therefore difficult to explain the importance of both of these variables in the uneven parallel bars event. Because of these findings it would be interesting to measure the muscular endurance and power capacity of the arms to further investigate the importance of these variables in the uneven parallel bars event. Although the floor exercise event is quite brief (approximately one minute to one minute 30 seconds), it is not surprising that the variable of maximum aerobic capacity was chosen as an important predictor of success in this event. As Astrand (1967) stated, "when large muscle groups are very active for a minute of longer the individuals aerobic work capacity is to a high degree decisive for his capacity."

As with the first set of equations that were computed, it was interesting to note that again only a few variables were repeatedly selected as significant predictors when regression analysis was performed with the addition of the experience variable. Following the experience variable in importance the other significant predictors of gymnastic ability were power, height, agility, total skinfold and flexibility.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

The purpose of this investigation was to ascertain the relative importance of selected physical, physiological and anthropometric variables in predicting all-around gymnastic ability and ability in each of the individual events. To accomplish this task it was important to analyse the differences between two distinct ability groups on all of the measurements obtained in order to determine which variables most clearly distinguished the high ability gymnast from the low ability gymnast. A review of related literature revealed that some studies had investigated the ability of various physical and anthropometric variables to predict gymnastic ability. There were, however, no studies indicating the significance of physiological capacities on gymnastic ability. An awareness of important physical, physiological and anthropometric characteristics that distinguish the high ability gymnasts from the low ability gymnasts will provide a helpful training guide and evlauation tool for the gymnastic coach.

A total of 29 female, all-around gymnasts between the ages of 11 and 13 years, were evaluated on 13 variables: (1) height, (2) weight, (3) total skinfold, (4) anaerobic endurance, (5) flexibility, (6) power, (7) strength, (8) agility, (9) maximum aerobic capacity, (10) maximum lactate, (11) heart rate response during gymnastic routines, (12) post exercise lactate and (13) experience. Maximum aerobic capacity was determined with a graded, discontinuous, bicycle ergometer test. The Margaria-Kalmen power test was utilized to measure alactic power. Values for maximum lactate and anaerobic endurance were obtained from a short, exhaustive bicycle ergometer test. Each subject pedalled at a rate between 60 and 70 rpm and a resistance corresponding to six percent of her body weight in kilograms. Maximum lactate was determined from a blood sample drawn five minutes following the termination of the test. Anaerobic endurance was designated as the total time in seconds that the subject was able to maintain the prescribed workload. Total body strength was evaluated with a cable-tension test battery developed by Clarke and Monroe. In all, three movements (shoulder extension, hip extension, and trunk extension) were evaluated and totalled for a composite score in kg/kg body weight. Flexibility was determined using a Leighton Flexometer and an eight item test battery. A composite score in total degrees was calculated from the following measurements; (1) active hip abduction - both legs, (2) active hip flexion - both legs, (3) shoulder hyperflexion and hyperextension and (4) trunk flexion and extension. The AAHPER 30 foot shuttle run was used to evaluate agility. Each subjects height and weight were determined with a standard scale and skinfolds were taken on four sites (triceps, subscapular, abdominal and suprailiac) and totalled for a composite score. Heart rate was monitored during the performance of each routine via radio telemetry. After determining each subjects maximum and resting heart rate, the Karvonen formula was used to calculate average heart rate intensity for each event. Post-exercise lactates were determined from blood samples drawn five minutes following each routine, except vaulting. An enzymatic procedure was used to analyse each blood sample. A criterion score for the experience variable was determined from a questionnaire. The questionnaire evaluated four factors; (1) years of formal gymnastic training, (2) number of meets in which the subject had competed, (3) average number of hours of practice per week and (4) number of months per year devoted to gymnastic practice. All-around and individual event gymnastic scores were standardized based on difficulty level and used as a measure of the subjects ability level. High ability subjects had all-around scores equal to or greater than 30 points while low ability gymnasts had all-around scores below 20 points.

Analysis of variance and t-test procedures were utilized to determine significant differences between the ability groups in all the variables measured. High ability gymnasts obtained significantly (α =.05) lower scores for agility and total skinfold and higher scores for flexibility, strength, average heart rate intensity and post-exercise lactate than the low ability gymnasts. Further analysis of each gymnastic event revealed that there were significant (α =.05) differences in the physiological response to the performances in terms of heart rate intensity but no differences in lactate concentration were observed. For high ability gymnasts, average heart rate intensity during vaulting was significantly lower than the other events. The low ability gymnasts obtained similar heart rate responses for all the gymnastic events with one exception, the uneven parallel bar routine elicited a significantly higher heart rate response than vaulting.

Five of the independent variables, experience, flexibility, agility, total skinfold and strength were found to be significantly (α=.05) and consistently correlated with all of the dependent variables. The experience variable showed the highest correlation with all of the gymnastic scores (range r=.87 to r=.90). Inter-correlations were computed between the independent variables. Three variables, (total skinfold, agility and experience) were significantly correlated with five other independent variables. Prediction equations for all-around ability and individual events were computed with and without the experience variable entered into the regression analysis. Coefficients of determination ranged from R^2=.815 to R^2=.888 when the experience variable was excluded from the analysis. The flexibility variable was found to be the single best predictor of ability. With the experience variable included in the analysis, R^2 ranged from .879 for vaulting ability to .940 for all-around ability. In this situation the experience variable was the most significant predictor in each equation.

6.2 CONCLUSIONS

Based upon the results obtained and within the confines of the limitations of this study, the following conclusions seem justified:

(1) High ability gymnasts are significantly leaner, stronger, more agile and more flexible than low ability gymnasts.

(2) The performance of gymnastic routines elicits a moderate to high heart rate response (61 to 80 percent intensity) and high ability gymnasts obtain significantly higher heart rate intensities than low ability gymnasts.

(3) Significant increases in resting lactate are observed following the performance of gymnastic routines and high ability gymnasts obtain significantly higher levels than low ability gymnasts.

(4) The gymnastic events elicit significantly different physiological responses in terms of heart rate intensity, but similar responses in terms of post-exercise lactate.

(5) Multiple regression equations have been developed that may be used to predict all-around gymnastic ability and ability in each of the events.

The results of this study suggest implications for the selection and training of potential gymnasts. A short test battery could easily be constructed using the regression coefficients that were found to be significant predictors of gymnastic ability. Results from the administration of the test battery can be used by coaches to evaluate ability and/or determine areas of weakness. Aside from measuring post-exercise lactate measurements, heart rate response and maximum aerobic capacity, each of the variables can be evaluated with a short simple test procedure.

Girls selected for gymnastics training should be small in size and very lean. Other physical capacities that are particularly desirable to possess and train are flexibility, power, anaerobic endurance and maximum aerobic capacity. While there are undoubtedly many other factors which contribute to gymnastic ability it is apparent that these variables have been shown to be significant contributors to performance success.

6.3 RECOMMENDATIONS

Many of the test batteries and measurement procedures were used for the first time in this study and in most cases for the first time on gymnasts. Recommendations for changes in these tests and for future studies are as follows:

(1) Because of the great extent of arm exercise involved in gymnastics, development of tests to measure anaerobic endurance and power in the arms or upper body would be significant contributions to the evaluation of gymnastic ability.

(2) Although differences between the two ability groups for maximum lactate were insignificant, further investigation into the anaerobic capacity of gymnasts is warrented. Gymnastics is a highly anaerobic activity and it would be expected that more experienced gymnasts would have significantly greater anaerobic capacities.

(3) Maximum aerobic capacity was found to be a significant predictor of ability in the floor exercise event. Becuase of the small sample size in this study, further investigation into the importance of aerobic capacity in gymnasts is warrented.

(4) To establish the validity of the regression equations formulated in this study, another sample of approximately 30 gymnasts should be measured on the significant predictor variables to test the ability of the regression equations to predict all-around gymnastic scores and individual routine scores.

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APPENDIX A

SCATTER DIAGRAMS OF REGRESSION RESIDUALS

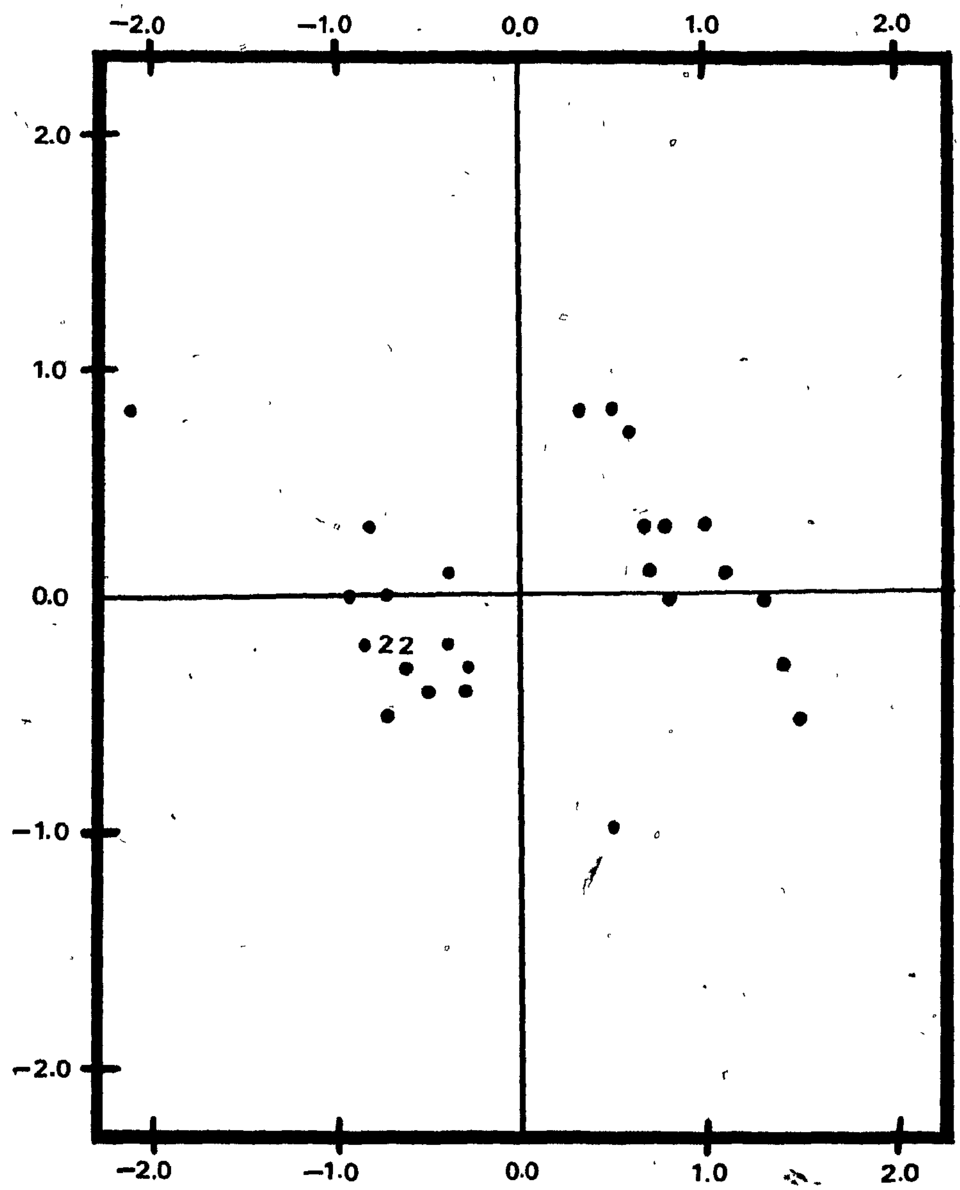

Figure A. Standardized residual (ordinate) versus the predicted standardized all-around score (abscissa), **without the inclusion of the experience variable**

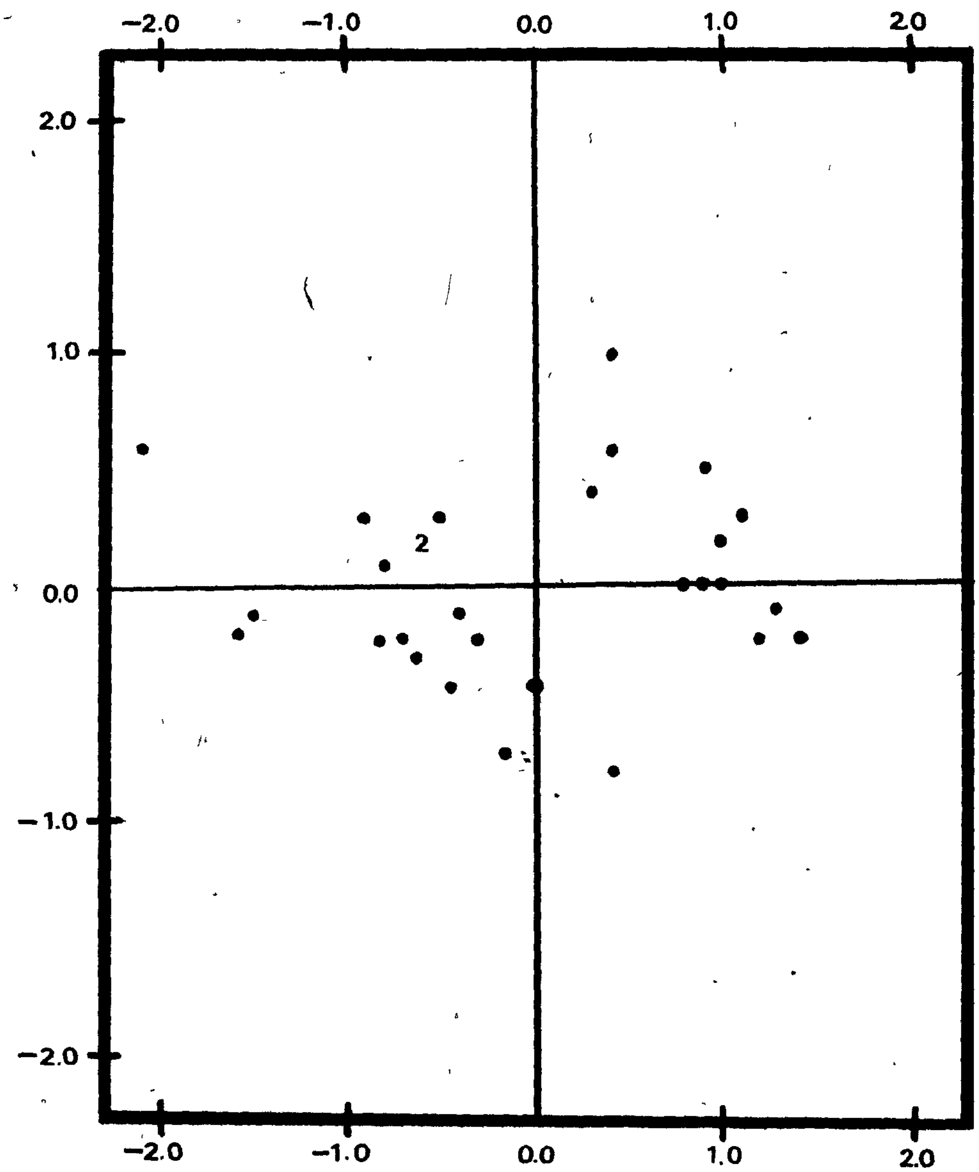

Figure B. Standardized residual (ordinate) versus the predicted standardized vaulting score (abscissa), **without the inclusion of the experience variable.**

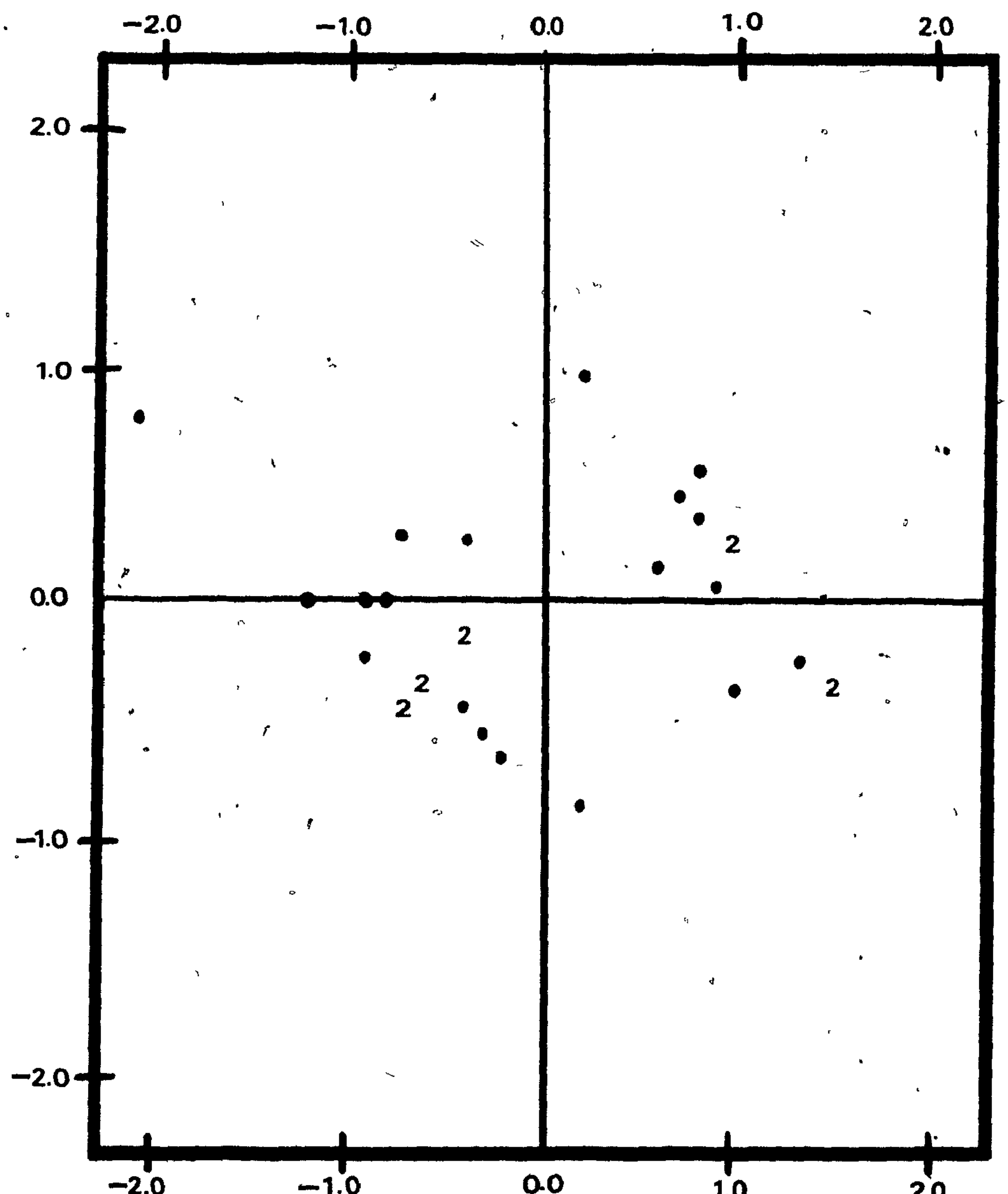

Figure 7. Standardized residual (ordinate) versus the predicted standardized uneven parallel bar score (abscissa), **without the inclusion of the experience variable.**

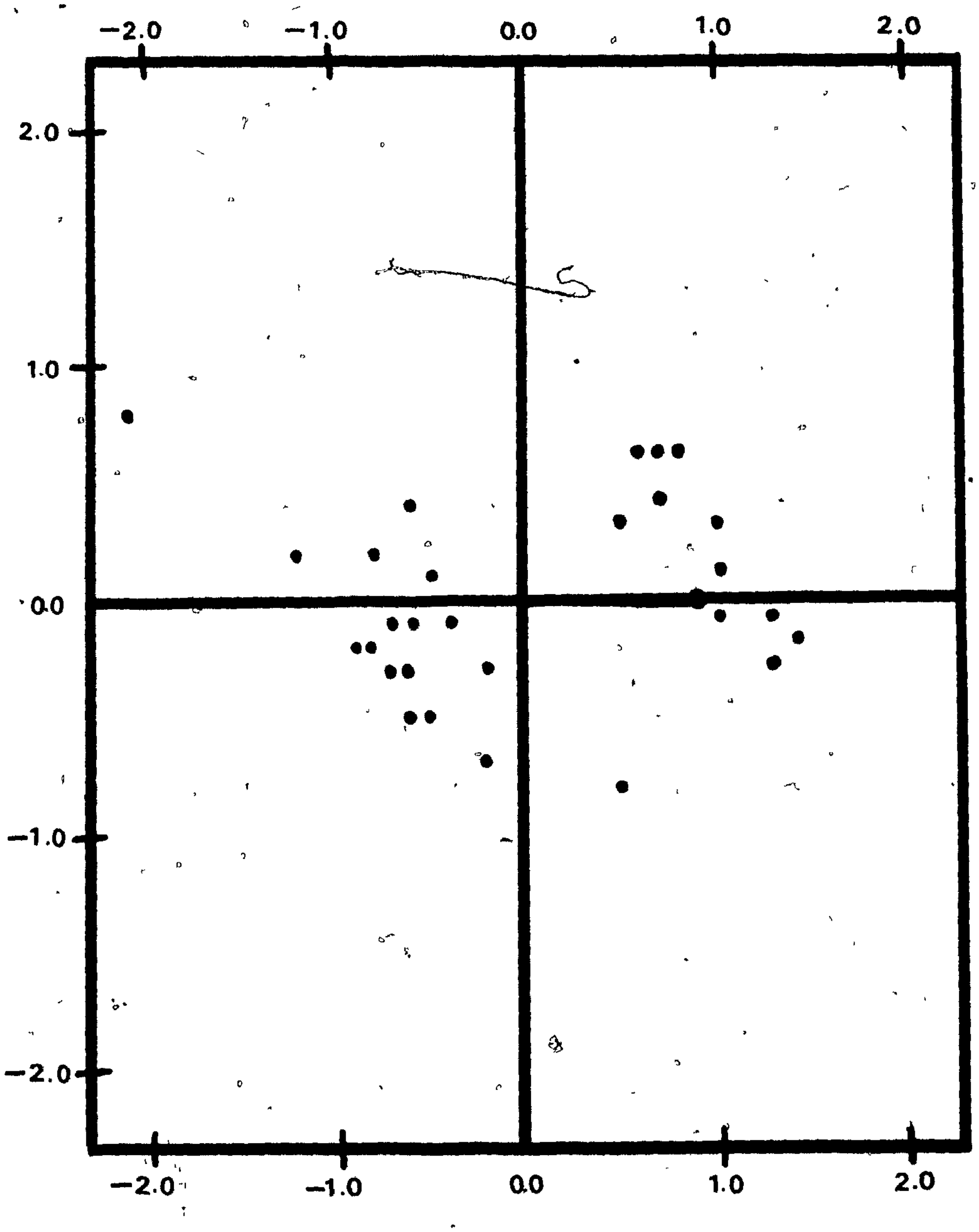

Figure D. Standardized residual (ordinate) versus the predicted standardized balance beam score (abscissa), without the inclusion of the experience variable.

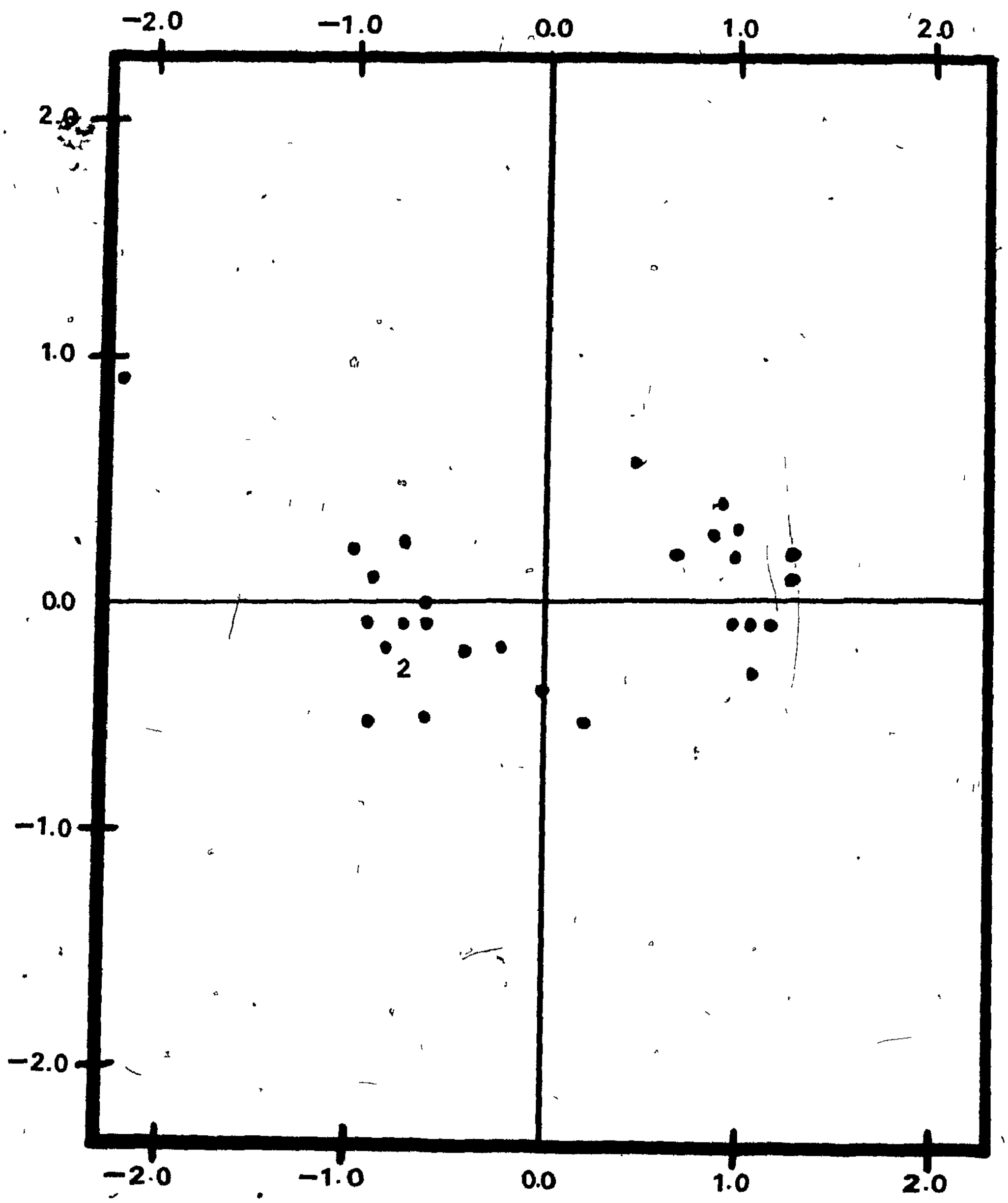

Figure E. Standardized residual (ordinate) versus the predicted standardized floor exercise score (abscissa), **without the inclusion of the experience variable.**

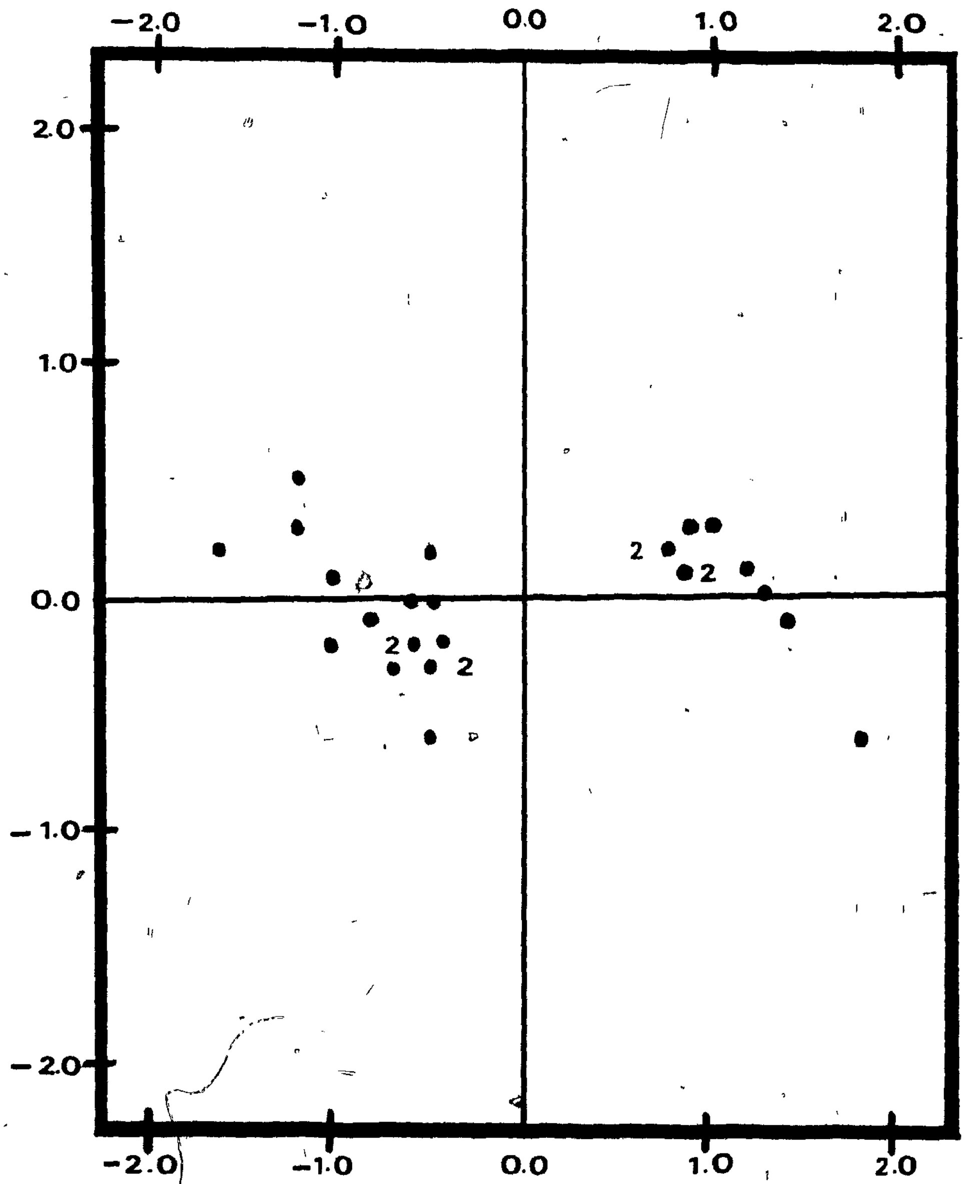

Figure F. Standardized residual (ordinate) versus the predicted standardized all-around score (abscissa), **with the experience variable included.**

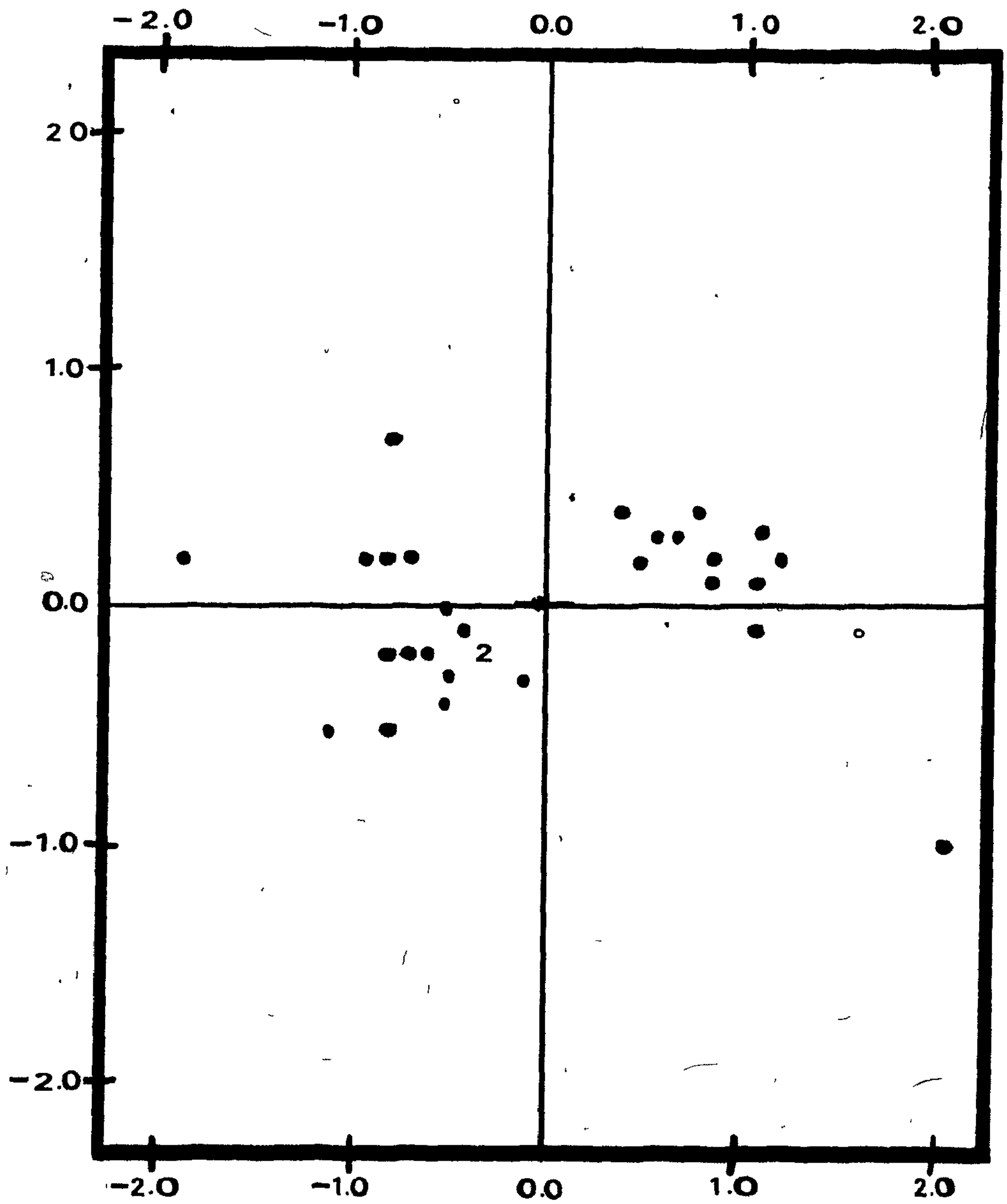

Figure G. Standardized residual (ordinate) versus the predicted standardized vaulting score (abscissa), with the experience variable included.

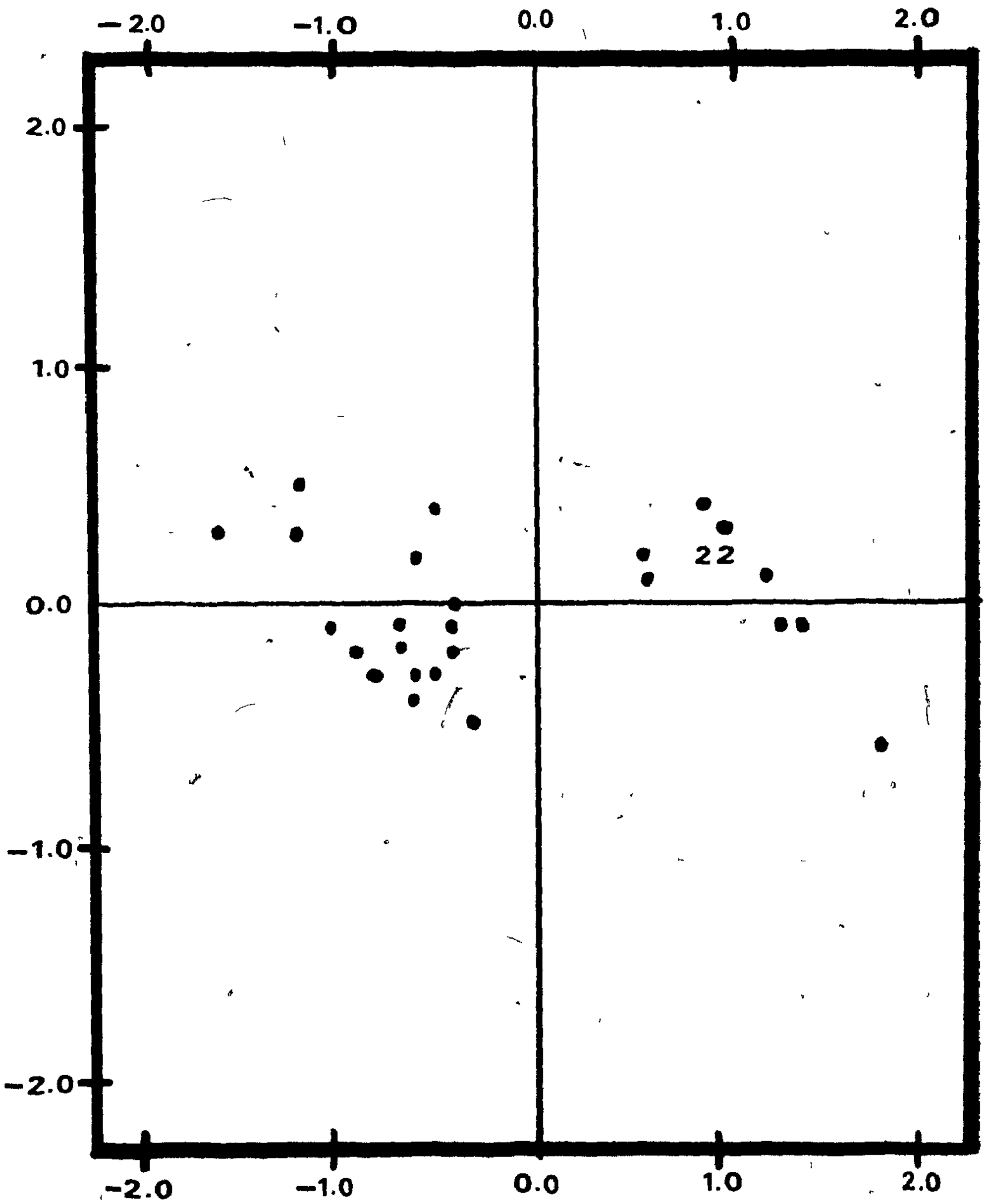

Figure H. Standardized residual (ordinate) versus the predicted standardized uneven parallel bar score (abscissa), **with the experience variable included.**

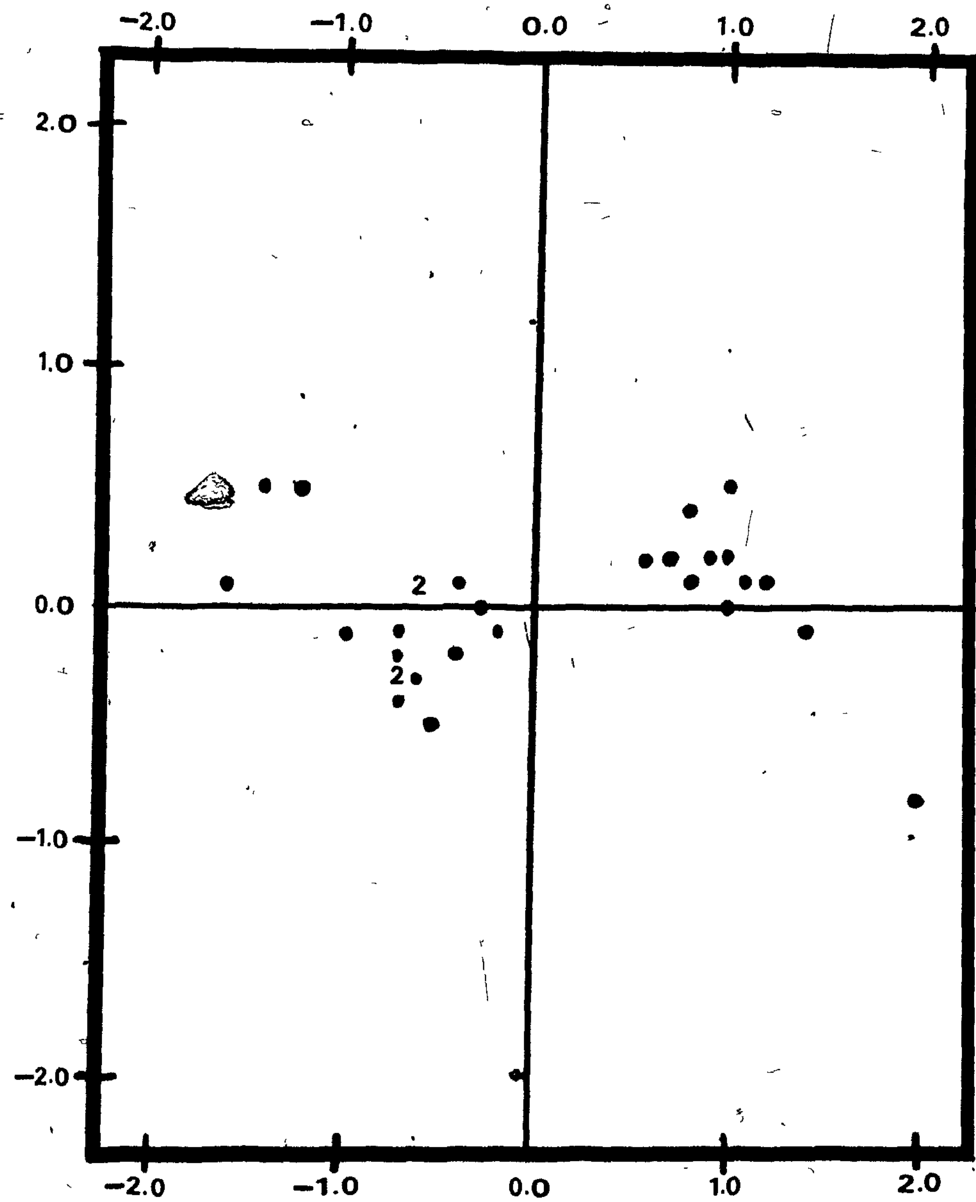

Figure 1. Standardized residual (ordinate) versus the predicted standardized balance beam score (abscissa), **with the experience variable included.**

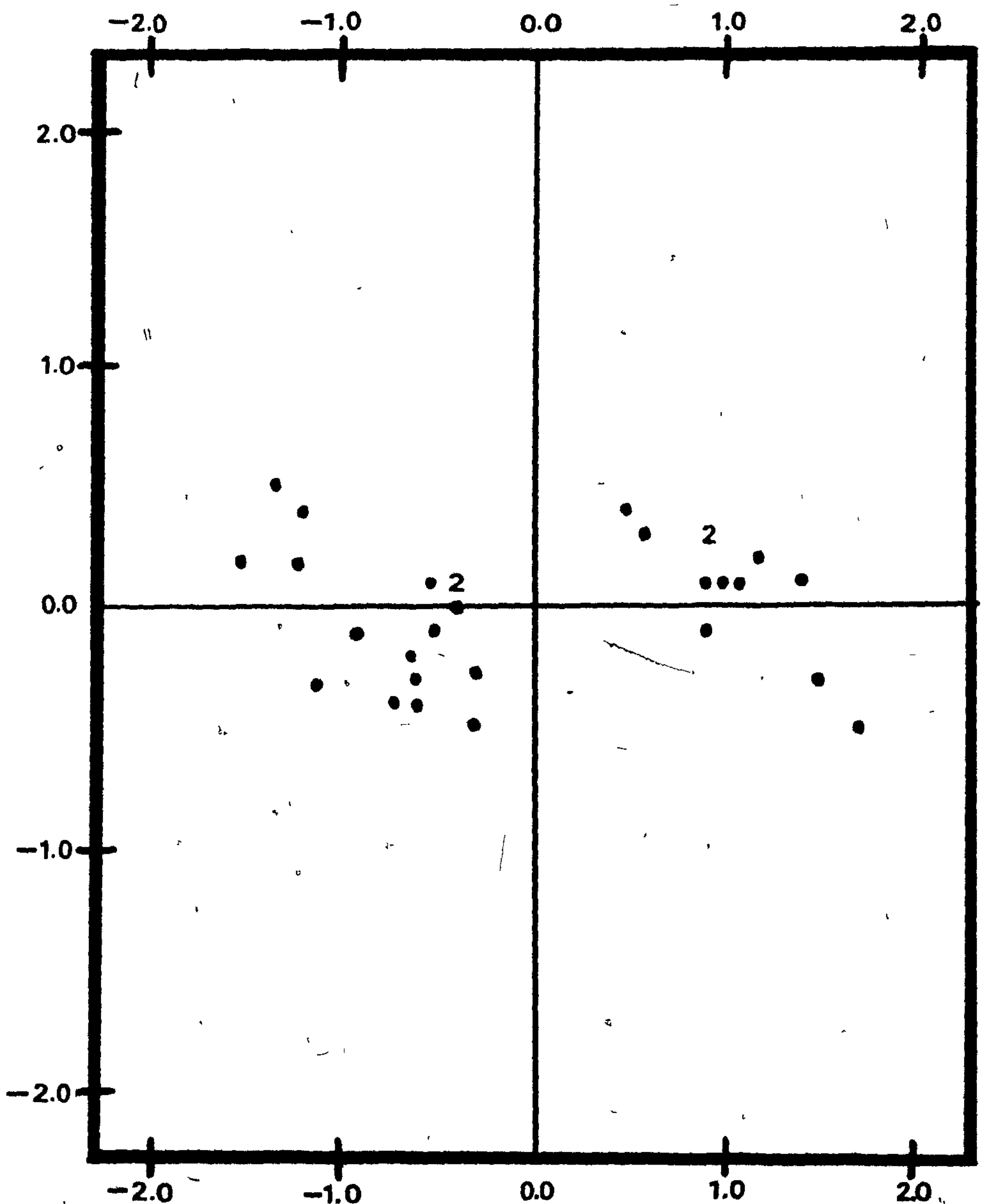

Figure J. Standardized residual (ordinate) versus the predicted standardized floor exercise score (abscissa), **with the experience variable included.**