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# IDENTIFICATION AND DEVELOPMENT OF TALENT IN YOUNG FEMALE GYMNASTS

by

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## ABSTRACT

**Identification and Development of Talent in Young Female Gymnasts**

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In the most recent survey, Performance Directors and Sports Scientists highlighted talent identification to be the top priority for research within Great Britain (Burwitz, 1999). However, the identification of talent is only the first stage of a continuous process of development through which sporting excellence may be realised. The contribution of talent identification to the attainment of excellence in Women's Artistic Gymnastics has yet to be conclusively determined. Moreover, as a result of the lack of longitudinal research in this area, the impact of growth and maturation upon the development of talent characteristics in the young female gymnast is not fully understood.

A longitudinal study was conducted to examine the identification and development of talent within a mixed ability sample of 48 young female gymnasts. Potentially prognostic talent characteristics from social-demographic, physical, perceptual-motor and psychological dimensions of performance were assessed in an 'initial' measurement session (September 1996). The 'future' performance of the gymnasts was assessed 17 months later (February 1998) using a composite index of competitive performance and technical skill acquisition. The performance of gymnasts was classified as successful or unsuccessful according to this index. The relationship between the 'initial' talent characteristics and 'future' gymnastic performance was examined using principal components analysis and logistic regression. Using a similar approach, the extent to which a reduced battery of talent characteristics was able to distinguish between the gymnasts and a group of 15 untrained control subjects was determined. Finally, to provide an insight into the longitudinal development of the talent characteristics, the initial test battery was administered to the gymnasts on two further occasions separated by a measurement interval of six months.

The results indicated that the profile of the young female gymnast is multidimensional. It is recommended that information should be analysed within each dimension of performance before being combined to produce a multidimensional profile. The physical characteristics were found to be the most prognostic indicators of talent and were recommended for inclusion in both the initial identification and subsequent monitoring processes. Support was also provided for the predictive validity of perceptual-motor characteristics, however, the contribution of these characteristics may be enhanced by further improvements in measurement reliability. Recommendations were drawn from the social-demographic and psychological dimensions concerning the most effective organisation of the training environment. The results from each dimension were combined to produce guidelines for the initial identification and subsequent development of talent within young female gymnasts.

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Special thanks to Mike for all his help and just for being there for me.

# DEDICATION

In memory of my mother, Joan Alwyne Wilkinson Prescott

(7th August 1931 - 14th July 1986)

This dedication is also extended to three very special people in my life,

Dad, Simon and Mrs Derry

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# GLOSSARY

| | |
|---|---|
| **1RM** | One repetition maximum. |
| **AFRD** | Average force of rate development. |
| **ANOVA** | Analysis of variance. |
| **AP** | Anterior-posterior. |
| **APF** | Ankle plantarflexion. |
| **BDJ** | Bounce drop jump. |
| **BIA** | Bio-electrical impedance. |
| **BMI** | Body mass index. |
| **BSGA** | British schools gymnastic association. |
| **BSP** | Body segment parameters. |
| **CDJ** | Counter drop jump. |
| **CM** | Centre of mass. |
| **CMJ** | Counter movement jump. |
| **COP** | Centre of pressure. |
| **DC** | Double leg stance eyes closed. |
| **DLT** | Direct linear transformation. |
| **DO** | Double leg stance eyes open. |
| **DZ** | Dizygotic. |
| **EI** | Ego involved. |
| **EMD** | Electro-mechanical delay. |
| **EMG** | Electromyography. |
| **FIG** | Federation Internationale de Gymnastique. |
| **FSD** | Full scale deflection. |
| **GEE** | General estimating equations. |
| **HXT** | Isometric hip extension. |
| **$IF_1$** | Moment of inertia about transverse (somersault) axis. |

| | |
|---|---|
| **$IF_3$** | Moment of inertia about longitudinal (twist) axis. |
| **IGA** | Identification of gymnastics aptitude. |
| **IRFD** | Isometric rate of force development. |
| **ISAK** | International society for the advancement of kinanthropometry. |
| **K-K** | Kinaesthetic-kinaesthetic. |
| **KST** | Kinaesthetic sensitivity test. |
| **LED** | Light emitting diode. |
| **LME** | Local muscular endurance. |
| **MIF** | Maximal isometric force. |
| **MIF1** | Maximal isometric force for the first muscle action. |
| **ML** | Medial-lateral. |
| **MRFD** | Maximal rate of force development. |
| **MTU** | Muscle tendon unit. |
| **MZ** | Monozygotic. |
| **NMPP** | Normalised mean power produced. |
| **NSO** | National sports organisation. |
| **PCA** | Principal components analysis. |
| **PHV** | Peak height velocity. |
| **PJH** | Peak jump height. |
| **PMV** | Peak mass velocity. |
| **POMS** | Profile of mood states. |
| **PRT** | Pre-motor reaction time. |
| **RFD** | Rate of force development. |
| **RMS** | Root mean squared. |
| **SEC** | Series elastic component. |
| **SEE** | Standard error of the estimate. |
| **SJ** | Squat jump. |
| **SO** | Single leg stance eyes open. |
| **SSC** | Stretch shortening cycle. |

| | |
|---|---|
| **TEOSQ** | Task and ego orientation in sport questionnaire |
| **TI** | Task involved. |
| **TNT** | The Testing for National Talent programme (Canada). |
| **TOYA** | The Training of Young Athletes project (UK Sports Council). |
| **TRT** | Total reaction time. |
| **TW2** | Tanner Whitehouse method. |
| **V-K** | Visual-kinesthetic. |

# CHAPTER 1

# INTRODUCTION

## 1.1 AREA OF STUDY

The systematic identification and development of talented athletes is of great interest to the sporting community. The review of future research directions commissioned by the Sports Council highlighted talent identification as one of the top ten problems facing performance sport in Britain (Reilly, 1992). A recent update of this report revealed that research in talent identification is now the number one priority (Burwitz, 1999). Interest in talent identification has been renewed in recent years due to a global intensification in the nature of elite sport. An increase in performance standards and a concomitant decrease in the age of the elite performer have ensured that the identification of talented youth is now an increased priority. The trend of intensification has been personified in Women's Artistic Gymnastics with World and Olympic Champions in their early teens, frequently pre-pubescent. The increase that has occurred in the technical skill level, in combination with the shortening career span of the elite female gymnast has ensured that the formula for success demands not only talent but also a well structured training programme from an early age. Ho (1987) estimated that in Men's Artistic Gymnastics it takes an average of 10 years for a beginner to become an elite international level athlete. Whilst the time frame for the development of the elite female gymnast is likely to be slightly shorter to reflect the mastery of four rather than six pieces of apparatus, a system capable of identifying potential gymnastic excellence must identify children at a younger age than would be necessary in most other sports. Without a systematic search for and identification of talent at an early age, by the time the gymnasts are identified by natural or self-selection they may not have the time to complete the training that is required to make international success a possibility.

The Training of Young Athletes Study (TOYA) reported the mean age at which British female gymnasts began participating in gymnastics to be 6.3 years with the onset of systematic training occurring at 8.6 years (Rowley, 1992a). This is significantly earlier than has been reported for most other sports. The results of the TOYA study also highlighted the lack of a systematic process to identify gymnastic talent in Great Britain,

citing self-selection as the most popular reason for children starting gymnastics. Indeed, 34% of respondents reported the child's own motivation as the reason for commencement of the sport. Therefore, in the absence of a systematic process to identify talent and guide children towards gymnastic participation, potentially talented and motivated children may fail to experience artistic gymnastics at an age early enough to permit the realisation of their potential.

While interest in talent identification is a recent phenomenon in the West, systems of identification have been established for many years as an integral part of sporting development in nations of the former Eastern bloc (Jarver, 1981). However, although the practical success of former Soviet athletes is uncontested, no quantitative estimation has been produced regarding the contribution of the talent identification process. The question of whether the identification of talent was of prime importance or whether the harsh training regimes were largely responsible for the extraordinary success of Soviet athletes remains unanswered. In addition, the scientific base underpinning the process of talent identification has been questioned and, in particular, doubts have been raised regarding the validity and reliability of the normative values used in Eastern European systems (Riordan, 1986, 1987a, b).

The major practical initiatives from the West emanated from North America with large scale programmes designed to identify gymnastic talent being developed in the 1970's and continuing into the 1980's. The most notable being the Testing for National Talent Programme (TNT) which was based upon the assessment of the competitive population of male gymnasts in Canada. However, the majority of these programmes met with failure which was attributed to the time and resource problems inherent in geographically diverse nations. More recently, Western nations such as Australia and France have implemented systems of talent identification and development which have achieved great success particularly in the minor Olympic Sports. However, as in most successful systems, the necessary integration of identification and development programmes has ensured that the particular contribution of talent identification to successful performances in mainstream sports such as gymnastics has not been conclusively determined.

## 1.2 PREVIOUS RESEARCH

A number of studies have applied unidimensional multivariate analyses to determine the profile of the elite athlete according to a single dimension of performance, most frequently the physical dimension (Tanner, 1964; Carter, 1982, 1984). Research specific to gymnastics shares this limitation with most studies focusing on the anthropometric and morphological characteristics of the elite female gymnast (Calderone, Leglise, Giampietro & Berlutti, 1986; Brüggemann & Böhmer, 1986; Claessens, Veer, Stijnen, Lefevre, Maes, Steens & Beunen 1991). There is a dearth of information concerning the perceptual-motor and psychological characteristics of elite gymnasts and their relationship to future gymnastic performance. Moreover, there have been few attempts to take a multidisciplinary perspective and consequently the majority of research has failed to adequately reflect the complex inter-disciplinary nature of the problem.

One notable exception was the study by Régnier & Salmela (1987) who applied the comprehensive model of talent detection and development proposed by Régnier (1987) to identify those variables which predicted success in Canadian male gymnasts. The relationship between test battery results and competitive score at the previous provincial championships was investigated using multiple linear regression analysis. The results highlighted the multidimensional nature of talent since in the majority of age groups a combination of talent characteristics from all four measured dimensions of performance (morphological, psychological, perceptual and organic) explained variation in performance better than talent characteristics from any single dimension. The study also reported that the profile of gymnasts varied according to their chronological age which confirmed that any process designed to identify gymnastic talent must consist of multiple stages. However, as in the majority of investigations, the authors were content to describe the relationship between talent characteristics and performance. There have been few attempts to take a prescriptive approach and investigate the relationship between talent characteristics and future sporting performance and since prediction is the crux of the talent identification and development process this may be considered a serious omission.

The potential importance of adopting a prescriptive approach can be illustrated by considering the results of a comprehensive mixed longitudinal investigation associated with the University of Western Australia Growth and Development Study (Blanksby,

Bloomfield, Ackland, Elliot & Morton, 1994). Significant differences in selected talent characteristics between swimmers and tennis players of various performance levels and controls did not appear until the later stages of puberty. As a result, the authors concluded that many talent characteristics previously assumed to have prognostic value were of limited utility in the identification of talent in pre and early pubertal children. However, since the classification of athletes was based upon their current level of sporting achievement, it was unclear whether future differences in performance between competitors and controls, which may be considered the true aim of talent identification, could be predicted using the pre-pubertal talent characteristics.

The majority of studies have employed the statistical technique of multiple regression analyses to investigate the relationship between proposed talent characteristics and current gymnastic performance (Grabiner & McKelvain, 1987; Singh, Rana & Walia, 1987). In contrast, Sol (1987) applied multiple linear regression in a retrospective study to determine the relationship between test battery results and the competitive performance of gymnasts six months later. A combination of 18 variables explained 92% of the variance in competitive performance, with 57% of the variance explained by the first two variables (left split and push up). While the prospective nature of the investigation may be considered a significant strength, the time period of prediction was short and therefore the extent to which the results may inform systems of talent identification is limited.

Finally, the majority of current research into talent identification has adopted a cross-sectional approach which assumes that the talent characteristics of older athletes previously resembled those of the younger athletes. This inherent assumption does not necessarily hold across the range of talent characteristics investigated. The failure to take into account the longitudinal nature of the talent process has resulted in the important effects of growth and maturation being neglected. A number of longitudinal studies have been conducted to investigate the development of fitness parameters within the growing child (Simons, Beunen, Renson, Claessens, Vanreusel & Lefevre, 1990). However, with the exception of the TOYA study and the University of Western Australia Growth and Development Study the development of fitness parameters within young athletic females has attracted little research interest. Since the main purpose of the TOYA study was to investigate the effects of intensive training in young athletes across a range of sports, talent characteristics were selected which were potentially important in gymnastics,

swimming, tennis and football. As a result, the implications of this study for the identification and development of gymnastic talent must be interpreted in the light of the generality of the assessment protocol. Several studies have investigated the development of talent within female gymnasts. However, given the small number of measurement observations and the large measurement intervals separating these observations, our understanding of the growth and development of talent characteristics within young female gymnast remains incomplete (Salmela, 1979; Jancarik & Salmela, 1987).

## 1.3 STATEMENT OF PURPOSE

In light of the limitations associated with previous research into talent identification, the extent to which talent characteristics may be used to predict future gymnastic performance has not been conclusively determined. In addition, the lack of longitudinal research has ensured that the impact of growth and maturation upon the development of talent characteristics in the young female gymnast is not fully understood. The present research seeks to contribute to the knowledge and understanding of talent identification and development in Women's Artistic Gymnastics and has three main purposes:

[a] To investigate the relationship between talent characteristics and future performance in young female gymnasts.

[b] To determine which talent characteristics are able to differentiate between gymnasts and untrained controls.

[c] To provide an insight into the longitudinal development of talent characteristics and their stability and sensitivity to development in the context of gymnastic training.

A mixed series study was designed to fulfil the first purpose of the research by addressing the following research questions:

*Which talent characteristics can be reliably measured in a mass screening situation?*

*Can the large number of potentially prognostic talent characteristics within each dimension of performance be reduced to a small number of talent components?*

*What is the relationship between talent components and future gymnastic performance within each dimension of performance?*

*What is the relationship between talent components and future gymnastic performance from a multidimensional perspective?*

A large number of characteristics identified as potential predictors of future performance will be assessed in a mixed ability group of young female gymnasts. The first aim of the research will be to examine the relationships between the characteristics and determine the underlying structure of the data in order to identify a smaller number of talent components. Statistical techniques will subsequently be applied to examine the relationship between the identified talent components and future gymnastic performance. The extent to which talent components are able to correctly classify gymnasts as successful or unsuccessful in terms of their future performance will be investigated within each dimension of performance and subsequently discussed from a multidimensional perspective.

The second purpose of the study is contained in the following research question:

*Which talent characteristics are able to differentiate between gymnasts and untrained controls?*

A similar analytical approach comprising data reduction and statistical modelling techniques will be used to determine which talent components are best able to distinguish between gymnasts and age-matched untrained control subjects. It is hypothesised that the components which differentiate between gymnasts and controls will differ from the components which distinguish between future successful and unsuccessful gymnasts. Empirical support for this hypothesis will have implications for the selection of talent components to be used in the initial identification and subsequent profiling of young female gymnasts.

In order to accomplish the third purpose of the study the investigation will seek to address the following questions:

*How stable are the talent characteristics over a 12 month period of development?*

*How do talent characteristics develop over time as children grow and mature within an environment of regular gymnastic training?*

An insight into the longitudinal stability of the talent components which distinguish between successful and less successful gymnasts will be ascertained by 'tracking' their development over a 12 month period. It is important to consider stability when determining the role of talent components within the continuous process of talent identification and development. Components included in the initial identification of talent must identify differences between children who are likely to be successful in gymnastics and those less suited to the sport which will persist irrespective of the effects of training and maturation. In contrast, a number of components will have an important role in differentiating between gymnasts of various ability which are influenced to a large extent by environmental stimuli. The systematic development of these less stable components through the creation of an optimal training environment is required to enable the realisation of potential.

## 1.4 CHAPTER ORGANISATION

**Chapter 2** reviews the literature relating to the identification of talent within sport with particular reference to artistic gymnastics. A number of the key issues which are generic to each dimension of performance will be examined.

**Chapter 3** provides an overview of the research design and introduces the techniques of investigation and statistical analyses which will be applied in subsequent chapters.

In **Chapter 4**, previous research investigating the role of social and demographic characteristics in the identification and development of sporting talent will be reviewed. The methods used in the present investigation for the collection, processing and analysis of social-demographic data will be outlined. Results will be presented and discussed to

highlight the relationship between social-demographic characteristics and future gymnastic performance. The extent to which social-demographic characteristics are able to differentiate between successful and unsuccessful gymnasts and between gymnasts and controls will be investigated. The longitudinal development of social-demographic characteristics over a 12 month period will also be reported.

**Chapters 5, 6** and **7** will adopt a similar univariate approach to consider the role of physical, perceptual and psychological characteristics respectively in the identification and development of gymnastic talent.

In **Chapter 8** the multidimensional nature of talent will be examined qualitatively by considering the relationship between the prognostic talent characteristics identified within each dimension of performance in Chapters 4-7. A summary of the main findings of the study will be presented and the implications for the identification and development of talent in young female gymnasts will be discussed. The limitations of the present study will also be highlighted along with suggestions for future research.

# CHAPTER 2

# REVIEW OF LITERATURE

## 2.1 INTRODUCTION

The development of sporting talent is a continuous process from the initial identification of a talented athlete through to the realisation of excellence upon the world stage. The talent process is made up of several component parts which are interdependent and complementary and cannot logically be viewed in isolation (Fisher & Borms, 1990). Since the development of sporting talent cannot be separated from the growth, maturation and development of the child an holistic approach will be adopted throughout this research. It is anticipated that via such an approach an appreciation of the true complexity of the talent process may be ascertained. Within this review, relevant sources of information will be critically appraised to reveal the current understanding of talent identification and development in sport. Specific reference will be made throughout to gymnastics.

The review of literature will be divided into eight sections and will consider the important questions which must be addressed in the design of any system to identify and develop talented athletes; the "why, who, where, how, when and what". The first section of the review will describe the talent process. The ethical issues that surround the talent process will be discussed and a rationale presented to justify the importance of systems of talent identification within contemporary sport. In the second section, the structure and organisation of international systems designed to identify sporting talent will be described. Commonalties across systems in terms of structure and organisation will be highlighted to address such questions as who should identify talented athletes and where should the process take place. The third and fourth sections will investigate the question of how best to identify sporting talent. The third section will review previous research initiatives with particular attention paid to the methodological and statistical aspects of research design. In the fourth section, the contribution of those conceptual models proposed to identify talented athletes will be reviewed. The fifth section of the review will elaborate upon some of the key issues raised thus far, which are inherent in the design of systems of identification.

The review will then focus upon the issues surrounding the development of talent characteristics within the growing child. Section six will provide an overview of the main theories of motor development. The critical concept of readiness for sport will be discussed in section seven with the aim of highlighting those factors to be considered when determining the most appropriate time to identify talented young athletes and introduce them to competitive sport. The final section of the review will comprise a description of existing test batteries designed to identify gymnastic talent to highlight those characteristics which are consistently or uniquely applied in the identification of talent within young female gymnasts.

**Overview**

The working definition of talent adopted in this research is that of:

> "a supra normal yet not completely developed giftedness for certain performances."
>
> (Borms, 1994)

This research is concerned with the process through which giftedness can be realised in order that the young female gymnast may achieve excellence in international competition. The systematic process designed to achieve this realisation is referred to as the 'talent process' and is depicted pictorially in Figure 2.1. The talent process can be divided into four component parts. The first component involves an extensive search whereby appropriate methods are applied to determine which individuals within a group can be regarded as talented.

The second stage of the process is to identify those children who, given their current state of development, demonstrate specific talent characteristics which lead with a substantial probability to superior performances in a certain sports discipline (Borms, 1994). These two components are sometimes combined together to form the conjugate component of talent detection (Régnier, Salmela & Russell, 1993; Borms, 1994). The subsequent development of sporting talent is the process through which talent is nurtured within an

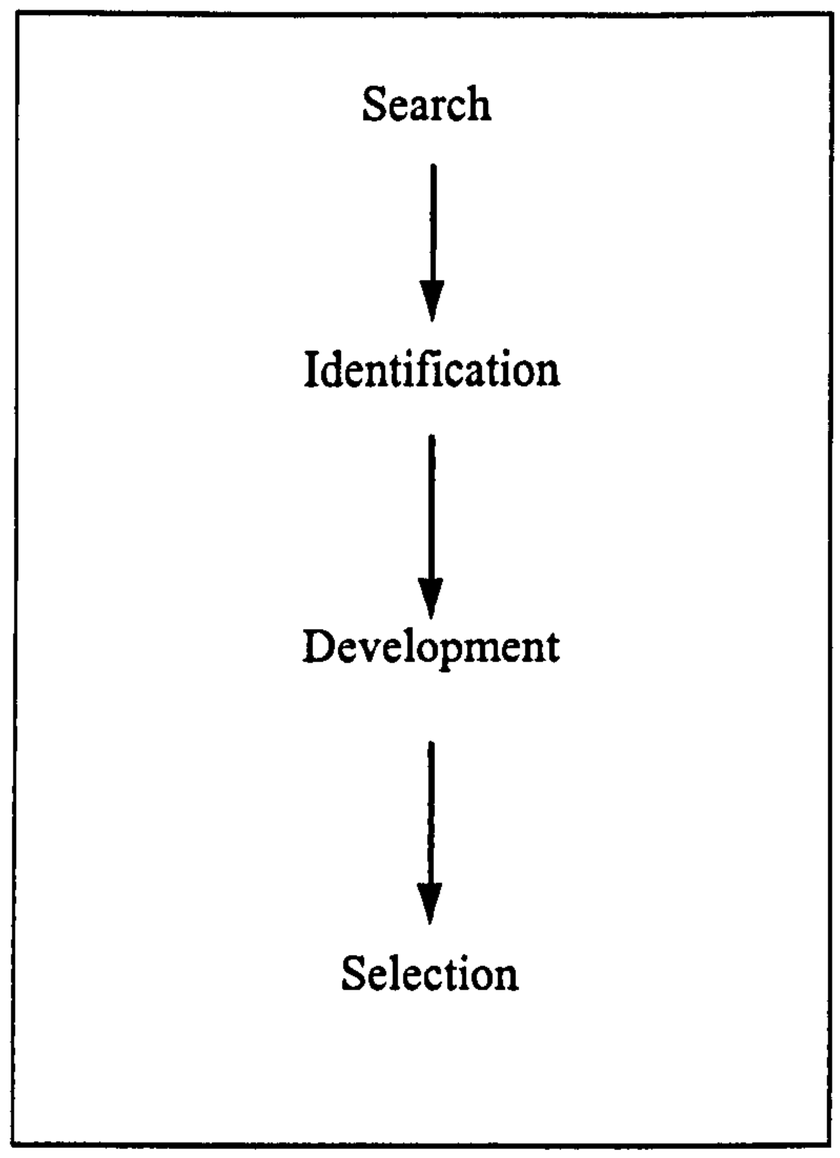



Figure 2.1. The talent process.

environment conducive to the realisation of potential. The final component of the process, talent selection, is distinct from identification and refers to a specific decision to choose an individual or team of individuals who can best carry out a task within a specific situational context (Régnier et al., 1993). Talent selection is characterised by short-term performance prediction and includes the choice of an individual or team to attend a major international event such as the Olympic Games. This description of the talent process is intended to provide an overview of an extremely complex phenomenon. In reality the identification and development of sporting talent is a continuous process of appraisal and re-appraisal which frequently takes many years to complete.

**Ethical issues**

The ethical issues which pervade the field of talent identification have been comprehensively reviewed (Salmela & Régnier, 1983; Salmela & Régnier, 1985 op cit. Klentrou, 1993; St-Aubin & Sidney, 1996). The motivations behind the implementation of a systematic talent process range from altruism through to nationalism and are frequently some combination of the two. In the context of talent identification, those with altruistic motivations would seek to employ the talent process for the benefit of the individual. It has been argued that when a child's abilities are matched to the demands of

a sport he or she will be more likely to experience success and derive personal enjoyment and satisfaction (Geron, 1978; Régnier et al., 1993; St-Aubin & Sidney, 1996). By contrast, those motivated by nationalistic concerns, employ the talent process for the benefit of the nation state. Former communist nations employed systematic processes of talent identification to maximise their medal gains at major sporting events and thus boost both national pride and global standing (Riordan, 1991). The nationalistic attitude of the former GDR was captured in the following statement by the former GDR Party leader, Eric Honecker:

> "Our state is respected in the world because of the excellent performance of our athletes."
>
> (Honecker (1976), p. 133 op cit. Riordan, 1987c p.126)

The adoption of a systematic talent process has been viewed by many as synonymous with the unnecessary elimination of athletes (St-Aubin & Sidney, 1996). Major ethical concerns centre upon the loss of the freedom of choice to participate in sport (Salmela & Régnier, 1985 op cit. Klentrou, 1993; Régnier et al., 1993; St-Aubin & Sidney, 1996). An associated concern is that the validity and reliability of such systems are insufficient and that truly talented athletes may be erroneously eliminated (St-Aubin & Sidney, 1996). In particular, concerns centre upon the adequacy of systems to detect talented athletes who may experience later biological maturation or who may possess an alternative profile to that specified within the model of the ideal athlete (Salmela & Régnier, 1985 op cit. Klentrou, 1993).

In reality, the vast majority of proponents of talent identification cite guidance rather than elimination as the main goal of their programmes, particularly with respect to very young athletes (Salmela & Régnier, 1985 op cit. Klentrou, 1993; Régnier et al., 1993; St-Aubin & Sidney, 1996). A guidance approach was strongly recommended by Bompa (1985) who suggested that all athletes expressing an enjoyment or 'love' of the sport should continue to participate but at a level commensurate with their ability. However, it may be considered appropriate to identify those children whose participation in programmes of intensive training may lead to the development of musculo-skeletal injuries or other health problems. While in extreme cases, withdrawal from sport may be recommended, it is more likely that athletes will be advised to participate at a less

intensive level. A longitudinal study of young tennis players focused upon aptitude, diagnosis and prognosis on the basis of an orthopaedic assessment. The primary motivation of the study was not the identification of talent per se, but rather the early detection of weak points in the skeletal system (Krahl, 1987). In addition, a guidance approach may prevent long term financial and temporal investments by those athletes who are unlikely to succeed at high levels of performance sport. Given the emotional and financial demands placed upon the families of elite and aspiring athletes this may be considered to be an important function of the talent process.

A further advantage of employing a systematic talent process is to increase the efficient use of limited resources (Régnier et al., 1993). The financial demands of elite sport are, and will continue to be, in excess of available funds. These resource constraints dictate that in the majority of sporting environments a finite number of athletes can progress through the sporting hierarchy. Therefore, decisions will be made as to which athletes make the transition to intensive training. Through the systematic organisation of talent identification and development the objectivity of such decisions can be increased (Klentrou, 1993).

The search for talent is not exclusive to the domain of sport, talented or gifted children exist across the social system, within academia, music and the arts. Independent of the medium of achievement, a common core of issues pervade (Bloom, 1985) which pertain to both the legitimacy and organisation of the process by which talented individuals are identified and subsequently developed. At the level of policy, the legitimacy and subsequent support of any process designed to identify and develop talent most frequently reflects attempts to reconcile the principles of egalitarianism and elitism which exist in democratic societies. The inconsistent manner in which those demonstrating a potential for excellence have received support at the level of policy reflects this failed reconciliation (Tannenbaum, 1993).

An example of the transient nature of the political support for academic giftedness was highlighted by Tannenbaum (1993), but is equally applicable to other fields. In the late 1950s the United States Government provided a massive injection of interest and funding in developing academically gifted children in response to the launch of Soviet Sputnik. This support subsequently declined in response to the concerns for social equality which

were characteristic of the post-Kennedy era. However, it has been recognised that in theory at least the problems in supporting excellence and providing equality are not necessarily incompatible:

> "A democratic society can pursue an egalitarian policy if it provides the fullest possible education for each person without regard to background and status... Under such a policy, all individuals will receive their democratic due, including those who are gifted and talented."
>
> (Brickman, 1979 p.329 op cit. Tannenbaum, 1993)

Those responsible for sport have an obligation to the gifted child to ensure they are given every opportunity to realise their potential. The adoption of a systematic talent process is one way to make this important and necessary step towards fulfilling that obligation.

## 2.2 INTERNATIONAL SYSTEMS

A number of international systems exist to identify and develop talented athletes. This review will consider the generic processes adopted by selected nations to identify sporting talent. This information will be supplemented by specific examples of the identification and development of talent in artistic gymnastics. To achieve this aim, information generated from two sources will complement the review of literature. Firstly, information from structured interviews with international expert coaches and secondly data derived from a questionnaire distributed to those federations who regularly achieved a top ten ranking in World and Olympic competitions (available on request from Loughborough University). In order to consider the merits of these systems it is important to recognise that the attitude of any nation towards its sporting talent is inherently linked to the social, political, economic and cultural climate (Riordan, 1991). The review will consider the contrasting approaches to talent identification adopted by communist and capitalist nations. While the limitations of adopting a bi-polar classification have been reported (Riordan, 1991) it is anticipated that such a division will highlight the key issues which merit consideration. While it has been acknowledged that the components of the talent process are inter-dependent, this section will focus primarily upon systems of identification.

## Communist countries

Whilst interest in talent identification is a recent phenomenon in the West, systematic processes of identification have been established for many years as an integral part of sporting development in nations of the former Eastern bloc (Jarver, 1981). The organisation of the talent process was not identical across communist nations, however, it was the similarities and subtle variations in the systems rather than the differences which prevailed (Hardman, 1992; Hardman & Fielden, 1994). The majority of communist systems were based upon and/or shared many features of the Soviet model (Rizak, 1986; Hardman, 1992). Therefore, the systematic process through which talent was identified and developed in the former Soviet Union will be briefly reviewed. Subsequently, similarities and differences between the Soviet model and the systems adopted in other Eastern European nations will be discussed.

The process of talent identification and development within the former USSR was a centrally planned system, organised across stages, which took several years to complete (Jarver, 1981). The initial stage of identification relied upon the programme of physical education in primary schools which was compulsory and placed a large emphasis on sporting activities. The success of the physical education system has been attributed to the National Fitness Programme (Ready for Labour and Defence, GTO) and the comprehensive ranking system (All Union Sport Classification) (Randt, 1993). These programmes provided a mass participation base from which potentially talented athletes could be identified (Riordan, 1991). Another significant factor which contributed to the success of talent identification in the former Soviet Union was the opportunity for competition (Zilberman, 1991), and in particular the role of the biannual Youth Spartakiade Games (Randt, 1993).

The process of talent identification and development in the former USSR relied upon the establishment of an 'ideal' model which was both sport and event specific (Jarver, 1981; Riordan, 1991). The models were derived from statistical data generated from elite Soviet and international athletes and included standards and rates of improvement to be attained by talented athletes at each particular level of development (Hardman & Fielden, 1994). The attainment standards were generally indexed according to biological rather than chronological age (Riordan, 1991). These 'ideal' models were applied to identify talent in

three inter-connected stages (Riordan, 1987a, 1987b; Peltola, 1992; Hardman & Fielden, 1994). The complexity and comprehensiveness of the assessments was increased across each successive stage.

The first stage, basic selection, aimed to determine who was likely to be successful in sport. This took the form of a mass screening of school children who were observed in primary schools by physical education teachers, who were well qualified in the art of talent detection (Jarver, 1981; Thompson & Beavis 1985). The assessments comprised simple field tests and included such indices as height, weight, speed and endurance, work capacity, power and sport specific tests (Riordan, 1986; Riordan, 1987a, Riordan, 1987b; Riordan, 1991). The second stage, preliminary selection, took place some 18 months later and sought to guide individuals towards a particular sport. Assessments at this stage included; progress in physical ability and sport specific tests, rate of physical growth, biological age and psychological aptitude (Jarver, 1981; Riordan, 1987a; Riordan, 1987b; Riordan, 1991). If children were eliminated from the programme at this stage they had the opportunity to be re-assessed approximately one year later, to limit the possibility of missing potentially talented athletes who were 'late developers' (Jarver, 1981; Riordan, 1987a; Riordan, 1987b; Riordan, 1991). In the third stage, final selection, children were guided towards a particular event or competitive discipline. This occurred some three to four years after their initial identification (Riordan, 1987a; Riordan, 1987b; Riordan, 1991) and was achieved using a comprehensive assessment of sports specific standards, rates of progress and indices of performance stability. In addition, physical capacity, event specific capacity and certain anthropometric and psychological indices were also included (Riordan, 1986; Riordan, 1987a, Riordan, 1987b; Riordan, 1991). The results of final selection determined whether children would be offered a place in a sports school in which they could combine their educational and sporting careers.

Prior to the demise of communism, most Eastern bloc nations were committed to the development of sporting excellence. Within these nations a network of organisations were involved in the identification and development of sporting talent which necessitated a large degree of cooperation between teachers and coaches (Randt, 1993). In some nations, such as the former GDR, schools were obliged to support talent identification initiatives (Kozel, 1995, 1996). However, in other nations the recommendations produced

regarding the identification of talent were simply guidelines with schools and/or clubs under no obligation to implement them. For example, guidelines were produced for talent identification by the Romanian Gymnastics Federation but many coaches did not implement these recommendations and instead selected gymnasts according to the club's own independent criteria (Stan, 1995). However, all data generated by the clubs was communicated to the central institute for the purposes of research. This central collation and processing of information appears to be characteristic of former communist systems.

A common feature of Eastern European nations was the provision of significant state support which enabled mass screenings for talented youth to be conducted by well-qualified professionals (Kozel, 1995). In line with the USSR model, Risak (1986) reported that screenings for talented children within the People's Republic of China occurred as a result of both subjective and objective evaluations by physical education teachers at all levels of the school system (Rizak, 1986). In contrast, Ho (1987) reported that coaches were responsible for the identification of gymnastic talent within China through the observation of physical education classes and discussions with school teachers. The primary role of coaches in screening for gymnastic talent was confirmed by Linderholm & Simon, (1988) and Stan (1995) in their accounts of Bulgarian and Romanian systems respectively. However, the extent to which gymnastic coaches were permitted to visit schools and kindergartens with the express purpose of identifying talented children is less clear. It appears that in a number of systems coaches performed a dual role of assisting teachers with physical education classes and identifying potentially talented children (Stan, 1995).

Within nations of the former Eastern bloc, the early stages of screening for gymnastic talent did not appear to be a highly scientific process and in many cases considerable importance was placed upon the coaches' 'gut feeling' (Karacsony, 1988; Linderholm & Simon, 1988; Stan, 1995). The main aim during the initial stage of identification was to determine the child's anthropometric profile, posture and the constitution of their musculature (Linderholm & Simon, 1988; Smolevski, 1992; Kozel, 1995; Mashi & Xhang, 1995). Medical examinations were also an integral part of the identification process and were used to detect latent/congenital illnesses and to provide an indication of the individual's capability for more intense training (Karacsony, 1988; Fisher & Borms, 1990; Mashi & Xhang, 1995). The extent to which the motor abilities of the child were

assessed was less consistent across systems. For example, Linderholm & Simon (1988) reported that simple tests of physical ability including balance, coordination, strength and flexibility were an integral component of the initial identification process in Bulgaria. In contrast, the Romanian system used tests of physical ability to monitor rather than eliminate children during the early stages of identification and development. The rationale being that as a result of the wide range of previous motor experiences such assessments were of limited utility within the initial screening process (Stan, 1995).

Periods of 'test' or 'probationary' training were incorporated within the majority of Eastern European systems. Observation of children's progress and responses to training during these periods was considered to be an important part of the identification process (Karacsony, 1988; Fisher & Borms, 1990; Mashi & Xhang, 1995). These training periods provided coaches with information regarding a child's ability to learn, their personality characteristics and social background and also exposed the athletes and their families to the demands of sporting life (Karacsony, 1988). Moreover, several sources alluded to the important role of probationary training periods in stimulating the child's interest in gymnastics (Fisher & Borms, 1990; Mashi & Xhang, 1995). The importance of developing interest and commitment in the early stages of participation was highlighted in the retrospective accounts of expert performers reported by Bloom, (1985). This aspect of talent development will be discussed in greater detail in chapter 4.

Once identified as talented, children were usually grouped and selected to enter a particular development programme according to their level of ability. In the systems of talent development operating within the People's Republic of China, the former USSR and GDR children were assigned to different schools or facilities on the basis of their level of sporting ability (Ho, 1987; Hartley, 1988; Hardman, 1992; The Sports Council, 1992). For example, within the former GDR children identified with an aptitude for a particular sport were directed to attend training centres which were the junior sections of sports clubs. However, children identified as possessing outstanding talent were directed to the Children's and Youth Sports Schools (K.J.S.S.) where their progress was assessed regularly according to normative data and training schedules (Hartley, 1988; Hardman, 1992). The differentiation of children according to ability also occurred in other Eastern European nations but on a different scale of magnitude. Rather than being assigned to different schools gymnasts were assigned to different groups within a particular training

facility. Irrespective of the means by which children were classified, the initial sizes of training groups were large but became progressively smaller as a result of systematic selection and attrition.

Within the majority of former communist nations detailed recommendations were produced in relation to the process of talent development. Guidelines were produced specifying the hours and type of training required at each stage of the development programme with particular emphasis placed upon the development of basic skills and physical preparation in the early years of training (Smolevski, 1992). Some recommendations were unique to a particular nation, for example, the Romanian Gymnastics Federation recommended that gymnasts should be instructed by a pair of coaches, one male and one female. From the personal accounts of expert coaches it was clear that talent identification was accorded primary importance within the nations of the former Easter bloc (Mashi & Xhang, 1995; Stan, 1995) and this was reflected in both the coach education system and the reward structure. For example, within the Chinese National Coaching Award system, the evaluation of gymnastic coaches was in part dependent upon their ability to identify talented children (Mashi & Xhang, 1995).

To summarise, prior to the demise of communism most Eastern European nations were committed to the development of sporting excellence. They experienced significant state support which enabled mass screenings for talented youth (Kozel, 1995) to be conducted by well-qualified professionals. Physical education was compulsory within the primary school curriculum and emphasised sporting activities. This focus upon sport and specifically Olympic sports, was regarded to be a significant factor contributing to the success of such systems (Hardman & Fielden, 1994; Kozel, 1995). At the heart of communist systems was a centralised education system with sufficient flexibility to permit the development of talented individuals once identified (Thompson & Beavis 1985). However, while much of Eastern Europe operated the ladder rather than the pyramid principle, communist systems were underpinned by a mass base of participation created by comprehensive national fitness programmes (Hartley, 1988). Talent identification was conducted in a series of progressive stages during which the requirements were increasingly refined from the general to the specific (Hartley, 1988), with the majority of Eastern European systems incorporating periods of test training into the process of identification. Finally, the opportunities for organised competition and in

particular the Youth Spartakiade Games were considered to be an important aspect of the talent process (Hartley, 1988; Hardman, 1992; Randt, 1993; Hardman & Fielden, 1994; Kozel, 1995; Kozel, 1996).

Several practical problems have been associated with former Eastern bloc systems of talent identification. While the majority of criticisms have been directed against systems of the former USSR and GDR they are applicable to the majority of communist systems. One of the major criticisms centred upon the apparent inability to separate real from apparent potential (Riordan, 1987b; Riordan, 1991). By way of illustration, it was estimated that over 50% of children selected to enter sports schools failed to reach the level of performance they were predicted. (Jarver, 1981; Thompson & Beavis, 1985; Fisher & Borms, 1990; Riordan, 1991). Whilst the high level of planning and organisation of communist nations has been acknowledged, systems of the former Eastern bloc were by no means foolproof (Jarver, 1981; Peltola, 1992). The reliability and validity of testing procedures and in particular, the reliability of simple field tests has been questioned (Jarver, 1981). However, it was reported that reliability improved over successive stages of the identification process; rising from approximately 30% for initial testing to 77% when the rate of improvement over first 18 months of training was taken into consideration (Jarver, 1981; Riordan, 1986; Riordan, 1987a; Riordan 1987b). Concerns have been raised regarding the ethics of such systems. In particular, concerns have been raised regarding freedom of choice to participate in sporting programmes (Salmela & Régnier, 1985 op cit. Klentrou, 1993; Régnier et al., 1993; St-Aubin & Sidney, 1996). In addition, concern has centred upon the fate of those children eliminated from sporting programmes given the potential psychological consequences of enforced attrition. This may be of particular relevance given the large numbers of children who failed to fulfil their expected potential.

**Capitalist countries**

The identification of talent in North America and most other capitalist nations has traditionally been based upon the pyramid principle (Klentrou, 1993; Régnier et al., 1993). This was based upon the premise that when a multitude of young athletes train and compete at the lower levels of sport those with the most talent will automatically rise to

the top (Klentrou, 1993; St-Aubin & Sidney, 1996). Régnier et al. (1993) provided an insightful description of this approach:

> "the underlying method is to provide space and equipment for a number of athletes, let them practice for 10 years, and then skim the cream from the top"
>
> (Régnier et al., 1993 p. 308 )

In terms of medals per capita, the superior performance of nations employing a systematic process of talent identification, highlighted the inefficiency of the pyramid system (Salmela & Régnier, 1983, op cit. Klentrou, 1993; Bompa, 1985). Moreover, the costs of such a laissez-faire approach are particularly high for those sports in which participation may be intrinsically unattractive to the participant (Régnier et al., 1993). Western nations have traditionally lacked the large scale governmental funding enjoyed by many communist countries and hence have operated within the constraints of a maximal recruitment philosophy to pay for coaching and facilities (Bales, 1995). Initiatives to identify and develop talented athletes have evolved independently across sports with most opting to focus upon talent development rather than identification (Bales, 1995).

However, two Western nations, Canada and Australia, have made significant contributions to the field of talent identification in terms of both theoretical research and practical applications (Randt, 1993). With specific reference to gymnastics, two Canadian programmes deserve acknowledgement. The Testing for National Talent (TNT) programme (Salmela, Régnier & Proteau, 1979) was a significant research initiative which sought to identify those variables which predicted competitive performance in male gymnasts (Jancarick & Salmela, 1987). In addition, a major practical initiative, the GYMNAPT programme, was developed by the Canadian Gymnastics Federation to assist coaches with the detection and recruitment of young girls who demonstrated a natural aptitude for gymnastics (Klentrou & Bureaud, 1993). The GYMNAPT programme was based upon the successful Canada Fitness Awards Programme and provided practical guidelines for the identification of talent in Women's Artistic Gymnastics.

The Australian Talent Search Programme was a large practical initiative introduced to identify and develop talent for the 2000 Olympic Games in Sydney (Schembri, 1995). In

line with the Soviet model, the programme was divided into three stages, however, identification commenced much later, with the initial stage aimed at 14-16 year olds. The following eight sports were involved in the programme, athletics, canoeing, cycling, rowing, swimming, triathlon, waterpolo and weightlifting, (Hoare, 1996).

Stage one, the initial screening, was conducted in schools using an interactive computer programme, "sport search". Through a series of questions regarding the child's likes and interests and physical assessments the programme suggested a cluster of sports to which the child may be suited. Children with scores at or above the 98$^{th}$ percentile in one of the eight tests were referred to the next stage (Schembri, 1995). Stage two, advanced screening, was conducted at the State Institutes or Regional Centres and entailed a more detailed assessment of general abilities and sports specific tests, designed in consultation with the National Sports Organisations (N.S.O). The N.S.O. were subsequently responsible for the third stage of the process, talent development, which was conducted through the National Training Centre Programme.

Athletes identified through the Sports Search programme have experienced success at national and international events. The success of the programme could be attributed, in part, to the selection of participating sports (Hoare, 1998). Sports were chosen in which there were few international participants and/or the standard of elite performance was low. In addition, the period of time required to develop talent in the chosen sports was appropriate to achieve excellence in time for the Sydney Olympics (Hoare, 1998). One of the potential limitations of this system concerned the age at which the initial identification took place. This was considered to be too late for a number of sports including gymnastics and figure skating (Hoare, 1998). Furthermore, it was not clear whether any adjustment was made to account for the child's previous motor experience, which by the age of 14 may have significantly contributed to variations in performance. Moreover, it does not appear that any index of biological maturity was included in the programme, raising the possibility that the system may fail to detect potentially talented children whose performance is limited by their late maturation.

## Summary

The pyramid system, based upon the characteristic laissez-faire approach to the development of sporting excellence, has traditionally operated within the majority of Western nations. This is in sharp contrast to the large scale systematic programmes designed to identify talented athletes within nations of the former Eastern bloc. Numerous factors relating to the cultural and political differences between communist and capitalist societies have been cited to be responsible for the different approaches to the talent process (Riordan, 1991). However, the importance of economic factors and in particular the amount of financial support provided for such programmes cannot be underestimated. The extent to which the former communist systems of talent identification and development can transcend the changing political, social and economic boundaries accompanying the dissolution of the Eastern bloc remains to be seen. There is currently no systematic process through which talented athletes are identified in the United Kingdom. Athletes typically enter a sport because they are inherently motivated or are introduced to the sport by a parent or significant other individual (Hardman, 1992; Rowley, 1992a). There have been some isolated attempts to implement systems of talent identification, however these have been described as sporadic (Kane & Fisher, 1979). Many of these programmes were initiated by former Eastern European coaches and as such the cultural specificity of the programmes may be questioned.

Fisher & Borms (1990) classified approaches to talent identification and development as systematic or unsystematic. The systematic processes were further divided into 'systems related' and 'person related' models. The majority of communist nations have employed systems related models which are characterised by an active and systematic search for talent through the organisation of testing and competitive procedures. Most Western nations have adopted person related models in which talent emerges as a result of programmes of mass participation or sport for all. However, once identified, the structures are available through which talent may be developed. In contrast, the models adopted by developing nations were classified as asystematic since the structure and organisation of sport is insufficient to realise the talent of potentially gifted athletes (Fisher & Borms, 1990).

## 2.3 PREVIOUS RESEARCH INTO TALENT IDENTIFICATION IN SPORT

The recent review of research commissioned by the Sports Council outlined four major limitations associated with research into talent identification (Burwitz, Moore & Wilkinson, 1994). Firstly, due to the prevalence of unidimensional and multidimensional studies, the majority of research has failed to adequately reflect the complex inter-disciplinary nature of the problem. Secondly, research has traditionally been content to describe the relationship between talent characteristics and performance. There have been few attempts to take a prescriptive approach and incorporate an element of prediction into research designs. The third criticism was associated with the cross-sectional design frequently adopted in talent identification research. The failure to take into account the longitudinal nature of the talent process has resulted in the important effects of growth and maturation being neglected. Finally, it was suggested that most research has not been based upon a sound theoretical framework. As a result of this critical review a series of recommendations were outlined to guide the direction of future studies (Burwitz et al., 1994).

A major criticism of previous research in talent identification in sport concerns the observation that researchers have traditionally approached the problem from a unidimensional perspective (Régnier et al., 1993; Burwitz et al., 1994; Matsudo, 1996) and as such have failed to take account of the complex multidimensional nature of sporting talent (Klentrou, 1993). By adopting a unidimensional approach, the profile of the elite athlete has consistently been determined according to a single performance-dimension; for example the anthropometric dimension (Tanner, 1964; Carter, Ross, Aubrey, Hebbelinck, & Borms, 1982; Carter, 1984; Ackland, Schreiner & Kerr, 1996). Differences between various groups of athletes and controls have frequently been compared using a single dimension of performance. Comparisons have included athletes and non athletes (Aitken & Jenkins, 1998), groups of athletes from different sports (Eiben, 1981; Slaughter, Lohman, Boileau & Riner, 1981), athletes participating in a variety of events, roles or positions (McClean & Parker, 1989; Bale, 1991; Ackland et al., 1996), successful and unsuccessful participants (Mahoney & Avener, 1977) and expert and novice performers (Abernethy & Russell, 1987). Upon demonstrating significant differences between groups, researchers have frequently inferred that a particular variable or group of variables was a performance determinant (Régnier et al.,

1993). However, the limitations of such inferences were highlighted in the study by Poppleton & Salmoni (1991) which focused upon the identification of talent in elite swimmers. The results of ANOVA procedures highlighted that certain psycho-social variables (parental encouragement, parental expectations and father's success) distinguished between groups of swimmers and controls. However, further investigation using multiple regression analysis revealed that these variables were not predictive of performance expressed as swim time. This study raised important concerns regarding the attribution of causality and specifically the limitation of equating group differences with the prediction of athletic performance.

While other investigators have recognised that talent identification is a multidimensional phenomenon, the statistical techniques applied have not always been commensurate with the methodological design. For instance, several studies have applied univariate statistical analyses to a multivariate design with the contribution of each variable to performance being analysed independently. As a result, the nature and complexity of the interaction between the variables has been neglected (Régnier et al., 1993). For example, Mero, Jaakkola & Komi (1989) investigated the neuromuscular, metabolic and hormonal profiles of pre-pubertal tennis players. The performance of tennis players was compared with a group of control subjects with unpaired t-tests applied to determine inter-group differences. There are numerous other examples of the inappropriate application of univariate statistical techniques to multivariate designs (Meckel, Atterbom, Grodjinovsky, Ben-Sira, & Rotstein, 1995; Grant, Hynes, Whittaker & Aitchison, 1996). A more appropriate approach may be to take a multidisciplinary perspective and apply multivariate statistic techniques to consider the influence of a number of variables and to account for the relationships between the variables.

The term 'multivariate analysis' alludes concise definition. It has been used to refer to both multivariable and multivariate techniques (Hair, Anderson, Tatham & Black, 1995). Multivariable techniques involve the simultaneous measurement of a number of variables which can be analysed using methods which are essentially extensions of univariate statistical methods. In contrast, true multivariate techniques are uniquely designed to analyse the effects of multiple variables which, when assessed separately, cannot meaningfully be interpreted (Hair et al., 1995). Using true multivariate techniques it is possible to determine whether any of the measured variables, or the combination of

variables may be useful predictors of performance (Creagh & Reilly, 1995). Multivariate statistical techniques which have been applied most frequently in the explanation and prediction of sporting performance include multiple discriminant analysis (Silva, Shultz, Haslam, Martin & Murray, 1985; Régnier et al., 1993) and multiple linear regression (Poppleton & Salmoni, 1991; Claessens, Hlatky, Lefevre & Holdhaus, 1994).

The technique of discriminant analysis is used to estimate the relationship between a categorical dependent variable and a number of independent variables. This statistical technique may be applied in order to understand group differences or predict group membership (Hair et al., 1995). In contrast to univariate statistical techniques discriminant analysis enables multiple variables to be examined simultaneously (Spink, 1990). The study by Silva et al. (1985) highlighted the advantages of adopting a multidisciplinary multivariate approach. Silva et al. (1985) applied discriminant analysis to differentiate between qualifiers and non-qualifiers for the United States 1980 Olympic Wrestling Team. When seven psychological variables were included in the discriminant function, qualifiers and non-qualifiers could be differentiated with a classification accuracy of 78% (30% of variance explained). Physiological variables alone were able to differentiate with a classification accuracy of 60.9%, (21% of variance explained). However, when a multidisciplinary model was employed using 19 variables from three dimensions of performance, classification accuracy was increased to 89%, which corresponded to 75% of explained variance. To enhance parsimony, the authors applied a factor analysis and produced a six factor model which was still able to account for 71% of model variance. This study demonstrated that by taking a multidisciplinary perspective and combining factors from three dimensions of performance the predictive power of the model could be increased.

The multivariate technique of discriminant analysis has also been used to determine the optimal combination of variables to discriminate between various groups of athletes and controls. Poppleton & Salmoni (1991) applied a standard discriminant function to determine which variables were the most important discriminators between swimmers, athletes from other sports and non-athletes. The study revealed that ankle flexibility and swim competence were the measures which best discriminated swimmers from other children. Similar approaches have been adopted to investigate inter-group differences between: kayakers and canoeists (Misigoj-Durankovic & Heimer, 1992), elite male

gymnasts of different performance levels within the 'elite' category (Spink, 1990) and between successful and less successful elite female orienteers (Creagh & Reilly, 1995). However, discriminant analysis is unable to accommodate categorical independent variables. This may be a limitation when considering the extent to which demographic variables, for example, contribute to the future classification of gymnasts. An alternative method to discriminant analysis is logistic regression analysis which is able to accommodate categorical variables using 'dummy coding' procedures (as used in multiple linear regression). A further advantage of logistic regression over discriminant analysis concerns the distribution of the independent variables. Specifically, logistic regression is less affected by the non-normality of independent variables (Hair et al., 1995).

Multiple linear regression analysis has been the technique most frequently used to determine the relationship between various talent characteristics and sports performance (Poppleton & Salmoni, 1991; Yoshida, Udo, Iwai & Yamaguchi, 1993; Claessens et al., 1994; Sullivan, Knowlton, Hetzler & Woelke, 1994; Takeshima & Tanaka, 1995; Kioumourtzoglou, Derri, Tzetzis & Kourtessis, 1998). Poppleton & Salmoni (1991) used step-wise multiple regression analysis to predict the reported best swim performance times of 77 female swimmers aged between 8 - 17 years. Two measures of flexibility, athletic and swim competence were reported to be the most consistent predictors of swim speed. Claessens et al. (1994) investigated the relationship between anthropometric characteristics and performance of female athletes participating in Olympic modern pentathlon competition. The application of stepwise regression analysis revealed that 42.4% of the variance in performance could be explained by the following variables (sum of 10 skinfolds, biacromial breadth and humerus diameter).

Kioumourtzoglou et al. (1998) used multiple regression analysis to investigate the ability of selected perceptual and motor measurements to predict all around and event specific performances in two age groups of rhythmic gymnasts. Only those variables correlating significantly with performance were included in the multiple regression analysis. In the younger group of subjects, three measures (hand-eye coordination errors, whole body reaction time and depth perception) were able to explain 40% of variance in all around performance. In the older gymnasts dynamic balance, kinaesthesis and depth perception measures explained 55% of the variance in all around performance.

The studies of Poppleton & Salmoni (1991) and Claessens et al. (1994) were content to describe the relationship between predictor variables and current performance. However, the prediction of future performance is a key component of research into talent identification and therefore can be considered a serious omission. Performance prediction can be achieved through cross validation or by validating the results using an independent sample of athletes. For example, Cockerill, Nevill, & Lyons (1991) conducted a prescriptive study in which the Profile of Mood States inventory (POMS) was used to predict cross country running performance in a group of 81 experienced male athletes. A multiple regression model was established by plotting the finishing times against the six mood factors. The model which incorporated the interdependence of tension, anger and depression, was used to predict the rank order of finishing position for a second totally independent race. In this second race, a Spearman rank correlation coefficient of 0.74 was reported, which indicated that 54% of the variance was explained.

A further limitation of previous research into talent identification concerns the absence of a sound theoretical framework (Burwitz et al., 1994). Regression analysis has been the methodology of choice in the majority of studies which have investigated the relationship between talent characteristics and performance. However, despite recommendations that theoretical considerations should guide the choice of independent variables (Schumacker & Lomax, 1996), the selection of variables for inclusion in regression models has frequently been based upon statistical rather than theoretical criteria. In a number of studies, the selection of independent variables has been based upon the strength of correlation with the dependent variable (Régnier & Salmela, 1987; Chernechenko, 1982). Only a limited number of investigations have based the choice of independent variables upon theoretical criteria. In one such study, Poppleton & Salmoni (1991) based the choice of variables to be included in the regression model upon the framework of Bandura's (1986) theory of self-efficacy.

In addition to the choice of variables, the order in which variables have been entered into the regression equation has also lacked theoretical guidance. Such an atheoretical approach is exemplified in statistical regression approaches such as stepwise regression, in which the order in which a variable enters the regression equation is based solely on statistical criteria (Tabachnick & Fidell, 1989). Statistical regression has been adopted in a number of investigations seeking to predict aspects of sporting performance, with

stepwise estimation techniques being particularly prevalent (Poppleton & Salmoni, 1991; Yoshida et al., 1993; Claessens et al., 1994; Meckel et al., 1995; Takeshima & Tanaka, 1995; Grant, Craig, Wilson & Aitchinson, 1997). Statisticians have been critical of those studies which have employed stepwise regression to derive the best prediction equation for a particular phenomenon without regard for the meaning of the equation (Tabachnick & Fidell, 1989). However, the use of stepwise techniques may be considered appropriate in exploratory research where there is little existing theory (Menard, 1995). Alternative types of regression such as hierarchical regression require the order in which a variable enters the regression equation to be specified by the researcher, according to logical or theoretical reasons (Tabachnick & Fidell, 1989). However, there has been a distinct lack of hierarchical regression approaches in the studies designed to predict athletic performance.

The importance of longitudinal research in understanding the process of talent identification has been acknowledged (Bar-Or, 1975; Fisher & Borms, 1990). Cross-sectional studies designed to identify talent characteristics have frequently assumed that the characteristics of the mature athlete were once like those of the young child. The validity of this assumption is questionable given the considerable influence of growth and maturation and the influence of the genotype, the environment and the respective interaction effects (Bouchard & Malina, 1983a). However, longitudinal research is a time-consuming process and in dynamic sports such as gymnastics where performance requirements change regularly, research results may be invalid as soon as they are produced (Régnier et al., 1993). Therefore, studies with a mixed or multiple longitudinal design may be an appealing alternative to longitudinal research. In studies of this design, repeated measurements are taken on more than one cohort, with an overlap in ages between cohorts (Kemper, 1996). Such an approach was adopted by Bloomfield and colleagues. Data collected from the University of Western Australia Growth and Development Study were used to compare the characteristics of athletes competing at various levels of performance in swimming (Bloomfield, Blanksby & Ackland, 1990b) and tennis (Elliot, Ackland, Blanksby & Bloomfield, 1990) with those of age matched non-competitors over a five year period of investigation.

Bloomfield et al. (1990b) used a two factor ANOVA to compare swimmers and non-competitors at each pubescent stage of development. Several physical and physiological

variables were able to differentiate between groups from pre-pubescent stage one. However, several important measurements for successful swimming performance were unable to discriminate between elite and control populations until the later stages of pubescent development (Bloomfield et al., 1990b). Additional differences between groups appeared still later, after pubescent maturation. This study highlighted implications for talent identification in swimming that could not have been detected using traditional cross-sectional research. Certain stages of pubescent development were highlighted to be suitable for the application of talent identification strategies. It was concluded that talent identification initiatives for swimming performance, based upon physical and physiological parameters, would be of limited value prior to pubescent stage three.

Several practical initiatives have been conducted to collect longitudinal normative data for use in talent identification systems. In the GDR, a 25 year project was commenced in 1960 which involved 2,000 children. These children were monitored from 6 years of age, with the aim of establishing norms of physical development (Fisher & Borms, 1990). Matsudo (1996) reported the existence of a similar project in Brazil. The CELAFISCS project, initiated in 1974, measured indicators of physical fitness in a sample of 5,200 school children (2,600 from each gender) and 3,000 athletes of various sports and ability levels, for the purpose of establishing normative data.

Within Great Britain, a large scale survey was conducted to investigate the effects of intensive training on the young athlete. The Training of Young Athletes (TOYA) project was commissioned by the Sports Council in 1986 and sought to determine the benefits and risks of intensive training in four sports (gymnastics, football, swimming & tennis) (Rowley, 1992b). A total sample of 453 athletes were recruited, according to their year of birth, at successive two year intervals between 1971 and 1979. Physical, physiological, psychological and demographic characteristics were recorded over a three year period and comparisons made across sports and between elite and less elite groups within each particular sport. Within British sport the TOYA study remains unique in terms of the design and scope.

**Previous research into talent identification in gymnastics**

Research specific to gymnastics has tended to focus upon a single dimension of performance, with most studies concentrating on the anthropometric and morphological characteristics of the elite female gymnast. Calderone et al. (1986) and Brüggemann & Böhmer (1986) investigated the anthropometric and morphological characteristics of those gymnasts competing at the 1984 and 1986 junior European championships respectively. Similarly, Claessens et al. (1991a) examined the anthropometric characteristics of those gymnasts competing at the 1987 World Championships in Rotterdam. A comparison of results with appropriate reference data generated important information regarding the physical profile of the elite gymnast. Whilst anthropometric and other physical parameters have been the subject of frequent study, there is a dearth of information regarding the psychological and perceptual-motor characteristics of elite gymnasts and their relationship to performance. In addition, there have been few attempts to take a multidisciplinary perspective in order to gain a more complete understanding of the talent process.

Régnier et al. (1993) proposed the most comprehensive conceptual model of talent identification and development to date. An earlier version of this model (Régnier, 1987) was applied to the detection of talent in Men's Artistic Gymnastics (Jancarik & Salmela, 1987; Régnier & Salmela, 1987). These investigations were based upon the Testing for National Talent Programme, TNT (Salmela et al., 1979). The TNT Programme sought to identify those variables which predicted gymnastic performance through the administration of a comprehensive battery of tests to the total male gymnastic population of Canada (Jancarick & Salmela, 1987).

Régnier & Salmela (1987) adopted a multi-dimensional approach and sought to identify those variables which predicted success in Canadian male gymnasts. A total of 263 male gymnasts, aged between 10 - 26 years, were tested on 71 variables from four dimensions of performance (morphological, organic, perceptual and psychological). Using multiple linear regression analysis, the relationship between test battery results and competitive score at the previous provincial championships was investigated. For the majority of age groups, a combination of talent characteristics from all four dimensions of performance explained variation in performance better than talent characteristics from any single

dimension, thus reflecting the multidimensional nature of gymnastic talent. It was also reported that the profile of gymnasts varied according to their chronological age, with a different combination of variables best able to explain the variation in performance in each age group.

It has been reported that for the majority of age groups, 100% of performance variance could be explained using relatively few age specific multidimensional variables (Salmela, 1996). However, given the subjective nature of performance evaluation in gymnastics the validity of this conclusion may be questioned. It is possible to speculate that such a finding may be the result of an inappropriate application of multiple regression or the inappropriate partitioning of variance. In terms of partitioning the explained variance, perceptual variables provided the greatest contribution to performance prediction. These variables explained the greatest percentage of variance in four out of six age groups and made significant contributions in the remaining two age groups. At the other extreme, the role of psychological variables was limited. However, this was suggested to be the result of inappropriate specification or measurement rather than a reflection of the poor predictive validity of such variables.

In the original analysis, the study used an inappropriate ratio of variables to cases. The authors acknowledged this limitation and reduced the number of variables in the regression analysis to include only those variables which were significantly correlated with performance. Since the number of gymnasts in each age group was not reported, it is assumed that the sample was equally divided between the six age groups. Given this assumption, 44 subjects were present in each age group with approximately 20 variables entering the regression equation. Therefore, even after this adjustment for limited sample size, the suggested minimum ratio of cases to variables of 5:1 (Tabachnick & Fidell, 1989) was not achieved and remains a limitation.

Two further weaknesses are evident in the design of the study which reflect limitations of the research area in general. Firstly, the research was cross-sectional. Results indicated that a different combination of variables were required to identify talent throughout the career span. However, this finding was based upon the assumption that the profiles of gymnasts in the older age groups were once like the profiles of the younger gymnasts. In reality, the suggestion that predictors of performance vary according to the age of the

gymnast can only be confirmed using appropriate longitudinal research. In addition, the study was descriptive and sought to describe the relationship between the gymnast's talent characteristics and current competitive performance. There have been few attempts to apply longitudinal studies to address the question of prediction of future gymnastic performance and since prediction is the crux of the talent process this has been a serious omission.

Jancarik & Salmela (1987) in part addressed the issue of prediction by re-evaluating the talent characteristics of those gymnasts involved in the initial TNT programme who qualified for the Senior National Team some seven years later. Changes in test performances of the gymnasts over time were evaluated. Similarly, the test results of the gymnasts at the time of re-measurement were compared to the results of the appropriate age group gymnasts in the original study. The investigation reported the longitudinal stability of talent characteristics and highlighted temporal changes in the contribution of the various talent characteristics to performance. The size of the sample involved in this study was small, comprising nine of the 263 male gymnasts involved in the original TNT sample. Perhaps as a result of the restrictions imposed by sample size the study did not retrospectively examine which of the initial variables were best able to predict future performance of gymnasts some seven years later.

The majority of studies investigating the relationship between proposed talent characteristics and gymnastic performance employed multiple regression analyses (Grabiner & McKelvain, 1987; Singh, Rana & Walia, 1987; Sol, 1987). In a retrospective study Sol (1987) applied the Bisdom/Sol aptitude test to a group of female gymnasts. The battery comprised flexibility, strength and neuro-motor tests which were shown to demonstrate adequate reliability and independence. Multiple linear regression was conducted to determine the relationship between test battery results and competitive performance six months later. A combination of 18 variables explained 92% of the variance in competitive performance, with 57% of the variance explained by the first two variables (left split and push up). In this study the time period of prediction was deliberately kept short to minimise the 'misleading influence' of training effort. However, given that the realisation of potential is inherently linked to the process of training this may not be the optimal strategy. An alternative approach would be to

quantify the training effect and include this parameter in the model, either as a covariate or as an additional independent variable.

In a similar research design Singh et al. (1987) applied the technique of multiple regression analysis to examine the relationship between performance scores on 17 tests of strength and flexibility, and competition results attained two months later. Using the stepwise technique, 73% of the variance in competitive performance was explained by four factors; rope climb, leg split, standing vertical jump and hand grip. However, in common with the majority of studies which have employed regression analysis to explain or predict competitive performance, no indication was provided of any attempt to validate the results using an independent sample of gymnasts. Finally, Grabiner & McKelvain (1987) investigated the relationship between power output scores and the national ranking of gymnasts using multiple regression analysis. Results revealed a regression equation which accounted for 44.02% of the variance associated with rank.

**Contemporary research initiatives**

The nature of contemporary research initiatives emanating from North America appears to have moved away from investigations to determine the importance of innate abilities and is currently orientated towards the social and environmental aspects of talent development, with an emphasis upon environmental determinism (Salmela, 1996). The major qualitative research project conducted by Bloom (1985) can be considered an important precursor to this reorientation. Bloom (1985) retrospectively examined the development of talent in young expert performers across a broad range of performance domains. The main focus of attention was on the social context of talent development with particular attention to the role of significant others in the development of talent. As a result of this investigation, Bloom (1985) questioned the role of innate abilities as prerequisites in the development of expert performance. Ericsson, Krampe & Tesch-Römer (1993) provided further theoretical and empirical support for the perspective of environmental determinism. Ericsson and colleagues suggested that long term adaptations to deliberate practice were uniquely responsible for the development of expert performance (Ericsson et al., 1993; Ericsson & Charness, 1995). The theoretical

framework of environmental determinism and the social and environmental factors upon which this framework is based will be considered in greater detail in chapter 4.

In a stimulating article entitled "Innate talents: reality or myth?" Howe, Davidson & Sloboda (1998) discussed at length the evidence both supporting and opposing the talent account of expertise development. The talent account was interpreted to hold that expert performance is the consequence of possessing innate talent or ability. Due in part to a rather restrictive working definition, the review concluded that the talent account is unable to appropriately explain the development of domain specific expertise. However, numerous responses to the article suggested that such a discrete polarization of the debate by Howe et al. (1998) was inappropriate (Csikszentmihalyi, 1998; Heller & Ziegler, 1998) and moreover did not reflect the status-quo of current theorising in the area (Schneider, 1998). The interpretation of expertise development as the long term interaction between innate individual differences and environmental opportunities is considered by many to be a more appropriate solution (Csikszentmihalyi, 1998; Freeman, 1998; Feldman & Katzir, 1998; Schneider, 1998).

The threshold model for exceptional performance (Schneider, 1993a) and the partial compensation model may be considered inherently appealing approaches which have attempted to reconcile the issue of polarity. The central feature of the threshold model was the concept of a critical level of ability. It was suggested that if the level of ability was close to or beyond this threshold value, peak performance would be determined by individual differences in non-cognitive variables such as commitment, endurance concentration or motivation (Schneider, 1993a, 1998). However, problems associated with the definition of critical or threshold scores (Schneider, 1993a) may limit the utility of this approach particularly considering the multidimensional nature of sporting ability. In contrast, the partial compensation model indicated that the acquisition of expertise reduces the contribution of basic aptitude to a greater extent as the amount of domain knowledge increases (Schneider, 1998).

The generic model of Gagné (1993) conceptualised the interdisciplinary nature of exceptional human performance (Figure 2.2).

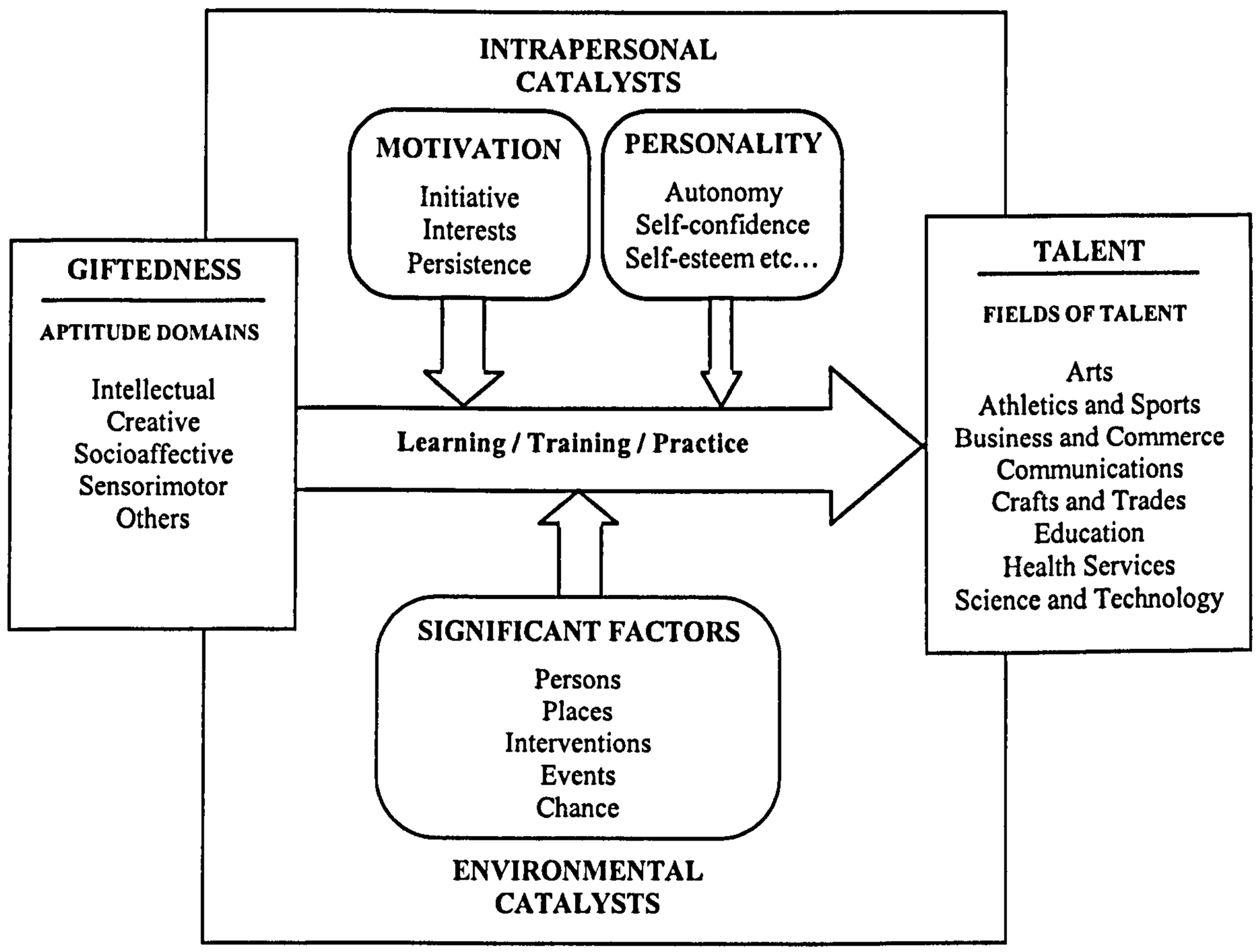



Figure 2.2. Gagné's differentiated model of giftedness and talent (adapted from Gagné, 1993).

The model embodied an implicit differentiation between the constructs of giftedness and talent. Giftedness was considered to be an above average level of competence in naturally developed abilities within one or more domains of human aptitude. In contrast, talent was defined as the level of performance in those systematically developed abilities or skills which constitute expertise in a particular field of human activity (Schneider, 1998; Gagné, 1993). The model proposed that talent emerged via the application of aptitudes to the mastery of skills; where aptitudes were regarded as natural human abilities which determined the ease and rapidity with which certain skills can be learned. Although aptitudes are largely genetically determined, the emergence of talent was mediated by the influence of intrapersonal and environmental catalysts in addition to systematic learning, extensive practice and training (Gagné, 1993).

## 2.4 CONCEPTUAL MODELS OF TALENT IDENTIFICATION

It is clear from previous sections that the extent to which the process of talent identification is possible and desirable has been the subject of considerable debate (Howe

et al., 1998). This section of the review will focus upon those theoretical models which have proposed a fundamental role for innate abilities in the acquisition of sporting expertise. A number of conceptual models have been proposed to identify the determinants of sporting performance and to produce guidelines for the identification and development of sporting talent. Due to the complexity of the phenomenon, no generic model has been universally accepted.

Bar-Or (1975) suggested that the protocol for the prediction of athletic performance should be divided into five stages. In the first stage, a multidimensional perspective was recommended through which the current status of the athlete could be assessed in terms of anthropometric, physiological, genetic and psychological characteristics. An estimate of current athletic performance was also performed during this stage. In the second stage, test results were indexed according to the biological maturity of the child using the proposed 'developmental index'. The third stage required the child to participate in a short training programme through which the individual's responsiveness to training could be evaluated. During the penultimate stage of the protocol, the child's family history was investigated with specific reference to height and level of fitness. Finally, as a result of information derived in the four previous stages the prediction of athletic performance was achieved using the technique of multiple regression.

The use of genetic factors as a predictor variable is an unusual feature of the model. Genetic factors are commonly used to weight talent characteristics according to the extent to which they are determined by the heredity. The validity of using genetic factors as a predictor of future performance requires investigation. The author does not provide any clear indication of how the model may be best applied in a practical situation. In particular, the protocol lacks clarity regarding the definition of athletic performance. This can be considered to be a limitation particularly with respect to those sports which lie towards the open end of the skills continuum. In addition, there is no mention of a procedure through which the validity of the model may be tested. This may be resolved by adding an additional sixth stage during which the results of the regression equation can be cross-validated or alternatively validated using an independent sample of athletes.

Jones & Watson (1978) proposed a multidimensional framework for the prediction of athletic performance. In the model, prediction of performance was divided into four consecutive stages which are depicted in Figure 2.3.

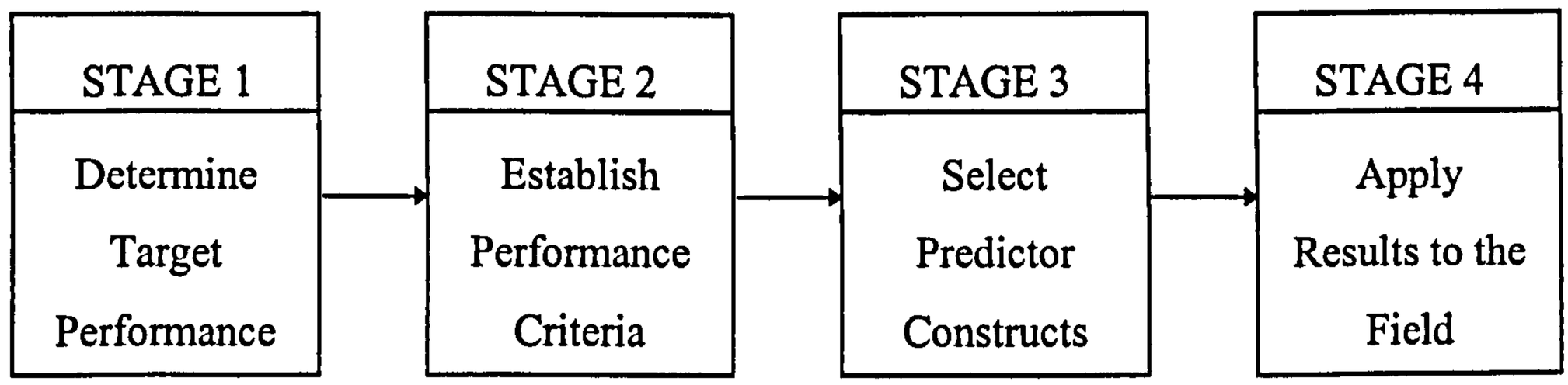



Figure 2.3. Stages in the prediction of athletic performance (adapted from Jones & Watson, 1978).

In the first stage of the process, target performance was determined through the identification of the critical objectives of a sport. Where necessary, performance could be divided into a number of appropriately weighted sub-clusters in order to accurately reflect performance demands. In stage two, the criteria which defined high level performance were established by a team of experts representing a number of performance disciplines. An element of forward thinking or prognosis was suggested to be an important component of this second stage. In the third stage of the process, predictor variables were identified. It was suggested that athletic performance was dependent upon three constructs: physical capacities, skill abilities and personal dispositions. The relative importance of each construct in the prediction of performance was determined using the technique of multiple regression. Finally, the model was applied 'in the field' to the prediction of sporting performance. As one of the earliest attempts to conceptualise the process of performance prediction this model provided a major contribution in terms of understanding the phenomenon of talent identification. The importance attributed to the determination of performance criteria was particularly important and continues to be a key feature of contemporary models (such as Régnier et al., 1993).

The contribution of Geron (1978) was not to produce a model but rather to review the strategies adopted in the psychological assessment of giftedness in sport. A key finding of Geron's review was the recognition that the factors which influence elite performance

and the factors which define giftedness cannot be considered synonymous. The review revealed that a number of factors which determined elite performance could be developed through training and therefore stressed the need to differentiate those factors largely influenced by the environment from those innate factors which constitute giftedness. Moreover, given that genetic and environmental control was reported to vary across the life span, the importance of identifying the most appropriate age to measure specific characteristics was highlighted. In accordance with the review, the general strategy proposed for the psychological assessment of sport giftedness was reported to consist of three stages. In the first stage, a sport specific profile was determined, in the second stage the contribution of genetic and environmental factors to the components of the profile was estimated and in the final stage the age at which the genetic influence was most pronounced was determined.

In what has been described as one of the most complete talent detection models in the literature (Régnier et al., 1993), Harré (1982) highlighted the critical role of the training process in the identification of talent. Harré suggested that the suitability of an individual for sport could only be determined through regular participation in a programme of sports training. Therefore, the initial objective of any talent identification system was cited to be the establishment of training programmes. Functions of the training process were numerous and included the detection of talent, the development of the child's abilities, personality and interest in the sport and the enhancement of the body's responsiveness to the demands of training. The model also emphasised the role of the social environment and in particular the interest and support of significant others were considered to be important factors in the detection of talent.

Harré (1982) highlighted a number of theoretical principles to be considered in the identification of sporting talent. The first principle related to the importance of identifying talent over a series of stages. It was recommended that the process begins with the identification of a general athletic ability with selection for a particular class of sports occurring at subsequent stages. The second theoretical principle concerned the selection of critical performance factors. Critical factors were suggested to be those which depended largely on heredity such as anthropometric characteristics and certain physical abilities. The role of previous experience in determining the physical manifestation of such factors was recognised, however, it was not considered to be a

confounding variable given the uniform programme of sports instruction in the former GDR. The third theoretical principle highlighted the importance of evaluating talent in accordance with the child's level of biological maturation. However, no indication was given regarding how best to achieve this evaluation (Régnier et al., 1993). The fourth and final principle highlighted the importance of adopting a multi-disciplinary perspective which included such factors as the activity of the child and their interest and attitude to sport.

The process through which to identify sporting talent was divided into two stages. The first stage consisted of mass screenings to identify those children who possessed the principal or critical performance factors considered to be essential for future development. It was stressed that these factors must be easy to identify and must provide an indication of both the level and disposition of the young athlete. The main determinants of performance were considered to be height and weight, running speed, endurance, coordination, games ability and athletic versatility. It was suggested that additional information should be collected in relation to previous sporting performances, with these results interpreted in the light of the child's athletic history. The second stage of the process was to determine the aptitude of a selected individual in terms of the development of sports specific critical performance factors. Sporting aptitude would be confirmed through a training programme taking into account the previous training, maturity and age of the child. Harré (1982) recommended that aptitude was evaluated according to the following four weighted indicators: current performance level, rate of improvement, tolerance to training loads and performance stability and improvement.

The theoretical contribution of the model in highlighting a number of key issues is undisputed. However, the practical applications of the model to sport may be limited. In particular the mechanism through which critical performance factors can be identified was not elaborated. This is a key element of any process designed to identify talent and as such is an important omission (Régnier et al., 1993). In a similar way, the theoretical limitations of indexing talent according to chronological age were highlighted, however, no indication was provided as to how variations in biological maturity status can be detected and incorporated into the process of talent detection.

Russell (1987a) proposed a theoretical model for the selection of tests to be applied in the detection, selection and perfection of athletic talent. However, for the purposes of this review only the detection component of the model will be considered. It was proposed that the design of any talent detection instrument must be based upon a thorough knowledge of performance determinants. Therefore, an investigation to identify those tasks fundamental to successful performance was considered to be an essential component of talent detection. Russell (1987a) suggested that such an investigation could best be achieved via a statistical factor analysis of the sport or through subjective task analysis. The detection of talent could subsequently be conducted by determining which young athletes best matched the identified performance demands (Russell, 1987a). Morphological, organic, perceptual-motor, psychological and situational variables were usually included in batteries of tests designed to detect talent.

The original model was subsequently refined with the aim of encouraging coaches to establish simple test batteries for the purposes of detecting sporting talent (Russell, 1988). Russell (1988) highlighted several important issues which demand consideration when establishing a talent detection instrument. Firstly the issue of trainability; it was recommended that in addition to the current status of the athlete, the ease or rate at which this status could be improved should also be considered. The second important issue referred to the need to consider the level of biological maturity of the athlete. Russell (1988) identified several practical methods through which the maturity status of the athlete could be determined. Finally, the importance of accounting for the child's previous experience was emphasised. While the influence of previous experience upon the current status of the athlete was acknowledged, it was considered to be particularly important in determining rate of improvement. The models alluded to the importance of adopting a stage-like approach to the detection of talent. However, they neglected to consider the influence of genetic and environmental factors upon the selection of variables at different ages.

In a subsequent paper, Régnier et al. (1993) proposed the most comprehensive conceptual model of talent detection to date. The model comprised a talent detection instrument which could be directed toward the establishment of sport specific models. The generic model has been applied to the detection of talent in the sports of gymnastics (Jancarik & Salmela, 1987; Régnier & Salmela, 1987) and baseball (Régnier, 1987). The detection

instrument was based upon the dynamic nature of sporting performance. The authors recognised the importance of detecting talent over a series of progressive stages. It was acknowledged that different performance determinants may be important at various stages of the development process and that these determinants may be influenced by the growth, development and level of training of an individual. As an alternative to longitudinal research Régnier et al. (1993) adopted the sliding populations approach shown in Figure 2.4.

For example, the first talent detection instrument determined which individuals from a pool population of 10 year old children were likely to reach the target population of 13 year old athletes. Simultaneously the second instrument determined which individuals from a pool population of 13 year old children were likely to reach the target population of 15 year old athletes. By combining cross-sectional and longitudinal perspectives into a single methodological approach, sliding populations enabled stage-specific talent detection instruments to be determined simultaneously throughout the range of performance development. The age of the children and the number of years which define the gap between pool and target populations are sports specific and must be determined according to the age at which peak performance occurs (Salmela & Régnier, 1983).

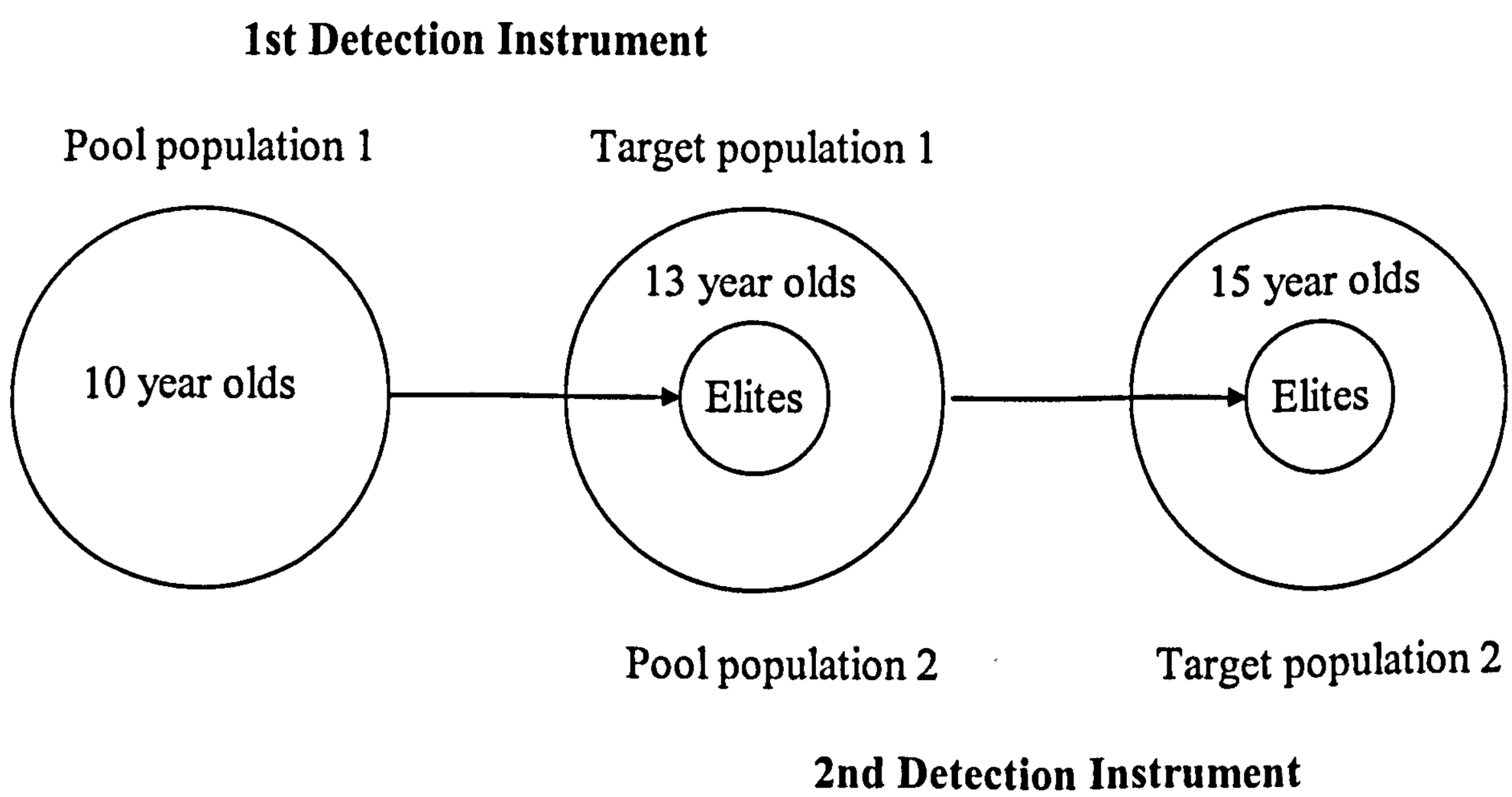



Figure 2.4. An illustration of detection instruments using the sliding population approach (adapted from Régnier et al., 1993).

The process of establishing a talent detection tool was divided into five stages. In the first stage, the performance criteria relevant for each target population were determined. During the second stage, the potential determinants of performance for each stage were identified. A multidimensional perspective was recommended during this stage, with emphasis placed upon the identification of variables which exhibited a high degree of stability. The third stage consisted of the measurement of the performance determinants in samples of both the pool and target populations. In the penultimate stage a discriminant analysis was performed to determine which variables best discriminated between the pool and target populations. A classification equation was produced to estimate the probability that any member of the pool population will reach the target population (Régnier et al., 1993). During this stage the stability of the variables was taken into account via the application of an heredity index. The fifth and final stage of the detection instrument comprised a regression analysis to predict which of those variables identified from the discriminant analysis best predicted performance of the target population according to the criteria of performance highlighted in stage one. Using this regression equation, it was possible to evaluate the probability of success of an athlete from a new sample of the pool population (Régnier et al., 1993).

This model has made a significant contribution to the understanding of talent detection. It is the first model to elaborate upon the methodological and statistical components involved in designing a detection tool. Several limitations need to be highlighted in relation to specific aspects of the detection instrument. However, it is due to the comprehensiveness of the model that such specific points of criticism can be raised. The first point relates to the absence of any process to evaluate the detection instrument. It may be appropriate to include a sixth stage, in which the accuracy of the model in predicting future performance may be evaluated. This may best be achieved through the technique of cross-validation or by using an independent sample and validating the model accordingly. The appropriateness of the target population is also an issue in determining the validity of the model. This approach is based on the assumption that the elite sample of the target population demonstrate a level of performance or a set of performance determinants which are appropriate or optimal for that particular age group. However, the quality of the target population may fluctuate over time. A more appropriate approach may be to determine normative values which are consistent irrespective of the quality of the target population. In addition, modifying the normative data according to changes that

may occur in the nature or demands of the sport, may ensure that the detection tool is a proactive rather than a reactive instrument. While the authors acknowledged the important influence of growth and maturation, the level of biological maturity was not evaluated in the model. This is likely to be an important limitation of the model, particularly in those sports where early maturation constitutes a definite performance advantage. The final limitation is concerned with the extent to which the multivariate techniques of regression and discriminant analysis are appropriate in the context of performance prediction.

Matsudo (1996) used standard deviation units (z scores) to compare the performance characteristics of elite athletes with the mean value of a sample of the general population in order to determine which characteristics were important in the determination of athletic performance. Using this method Matsudo (1996) identified certain critical or fundamental variables upon which the z scores of elite athletes were large in relation to the population mean. In the interpretation of these critical variables, four factors were highlighted for consideration; the functional maturation curves of the various characteristics, the sexual maturation status of the athlete, nutrition levels and the level of sports activity and previous sporting experience. The authors themselves raised certain limitations with the model, of particular relevance was the inability of the model to deal with those variables which are not normally distributed. Furthermore, the model does not appear to take into account the level of stability of the critical variables in terms of the contribution of the genetic and environmental factors to performance. Although the model controls for individual rates of maturation, the utility of sexual indices will be limited in sports such as gymnastics in which elite performers are generally pre-pubescent. At a more conceptual level, there appears to be no theoretical basis for the choice of critical variables. They are chosen as a result of statistical criteria with no causal relationship demonstrated between such variables and sporting performance.

Information on a number of additional models has been derived from the comprehensive review of talent detection and development in sport presented by Régnier et al., (1993). The model proposed by Havlicek, Komadel, Komarik & Simkova (1982) represented a conceptualisation of ideas, summarised in the form of ten principles for talent detection. While the majority of these principles have arisen in the models reviewed in the previous section, two principles merit further discussion. Firstly, the authors were critical of early

sports specialisation and rather advocated a broad approach to talent identification. They suggested that initial specialisation should occur in a particular group of sports, which they referred to as a 'sports family'. The second contribution of the model concerned the role accorded to genetic factors in the identification of talent. The authors indexed talent characteristics according to the degree of heredity and subsequently prioritised the predictive contribution of each talent characteristic according to its respective stability.

Gimbel (1976) proposed that the initial identification of talent should take place in schools according to the morphological, physical and psychological factors underlying performance. According to this screening, children should then be guided towards an appropriate 12 - 24 month instructional sports programme. A prognosis is made at the end of the training programme on the basis of which the young athlete may be orientated towards either intensive training or recreational sport. Gimbel recognised the problems caused by variations in the maturity status of athletes and proposed an additional year of training for late maturing athletes. However, the financial and logistical implications of providing such an extensive catch-up period are likely to limit its practical utility (Régnier et al., 1993).

Dreke (1982) proposed a three phase approach for the detection of talented athletes. In the first stage of the process (pre-selection) assessments were conducted to determine general health status, academic achievements, sociability, somatotype and agility. In the second stage (verification), the measured somatotypes were compared with profiles for particular sports and the athlete underwent a series of tests to determine their general physical ability. The final stage (detection) comprised a short training programme to determine the physical and psychological responses to training.

An interesting aspect of Bompa's (1985) model concerns the absence of psychological factors from the detection instrument. Performance was therefore defined according to three groups of factors; motor capacities (perceptual and motor skills, endurance strength and power), physiological capacities and morphological attributes. The factors to be used in a sport-specific detection instrument and their relative contributions to performance were determined as a result of a task analysis and from the opinions of recognised experts. The selected factors were measured in a large number of children and weighted accordingly. This approach affords the opportunity to verify the model using multiple

regression analysis. This feature is noticeably absent in the majority of conceptual models.

## 2.5 KEY ISSUES

From the preceding overview several important issues can be delineated which must be considered in the design of any system to identify and develop sporting talent. Firstly, the importance of viewing talent identification as a multidimensional, multistage and prognostic process will be discussed briefly. Subsequently, a more comprehensive review will consider the role of genetic factors and the influence of biological maturity upon the process of identification.

### Multiple dimensions

The majority of initiatives, both theoretical and practical, have viewed talent identification as a multidimensional phenomenon (Bar-Or, 1975; Jones & Watson, 1978; Harre, 1982; Havlicek et al., 1982; Russell, 1988; Régnier et al., 1993; Borms, 1994; Matsudo, 1996). Previous research has confirmed that sporting performance can best be explained using a combination of characteristics from a number of performance dimensions (Régnier & Salmela, 1987). Moreover, studies have demonstrated the need to adopt multivariate statistical techniques which are commensurate with a multidimensional research design (Silva et al., 1985). Characteristics from the following dimensions of performance have been suggested to contribute to the prediction of sporting performance: biomechanical, biochemical, physiological, psychological, neuromotorical and social (Fisher & Borms, 1990).

The multidimensional nature of sport produces an effect referred to as the compensation phenomenon, which implies that elite sporting performance can be achieved in individual or unique ways through different combinations of skills, attributes and capacities (Feldman, 1986 op cit. Régnier et al., 1993). The compensation phenomenon has hindered the development of talent detection instruments in some sports. For example, a multidimensional test battery was applied in the search for talent in tennis. The compensation phenomenon was cited to be responsible for the absence of a universal

tennis ability and as a result the purpose of the test battery was changed from detection to diagnosis (Rieder, 1987). It has been suggested that the influence of the compensation phenomenon may be particularly prevalent at specific times in an athlete's career. For example, Régnier & Salmela (1987) reported that a large number of variables were required to explain the variance in competitive performance for those groups of gymnasts aged between 12 - 16 years. The authors inferred that this may be due to the effect of the compensation phenomenon which may be particularly significant in the heterogeneous adolescent population. The potential for an individual to compensate for a deficiency in performance further emphasises the importance of adopting an interdisciplinary approach through which the nature of the relationships between talent characteristics and sporting performance may be fully understood (Russell, 1987a, 1988; Matsudo, 1996).

**Multiple stages**

The majority of international systems have adopted a multi-stage approach to the identification and development of talented athletes (Jarver, 1981; Fisher & Borms, 1990; Hartley, 1988; Karacsony, 1988; Linderholm & Simon, 1988; Mashi & Xhang, 1995; Stan, 1995). Empirical support for such an approach can be derived from the investigation of talent in elite male gymnasts (Régnier & Salmela, 1987). The study indicated that for each age cohort a different combination of talent characteristics was best able to explain the variance in gymnastic performance. Although the cross-sectional nature of the study limited any firm conclusions, the results of this study support the proposal that any process designed to identify gymnastic talent should be organised over multiple stages. Dividing the talent process into a series of stages, progressing from the initial selection for sport through to the selection and development for a particular sport or event, is suggested to be a basic principle of any systematic process (Hartley, 1988; Fisher & Borms, 1990). One of the main advantages of adopting a multistage design may be to enhance the reliability with which future performance may be predicted. It has been reported that the reliability of prognosis is inversely proportional to the length of time for which it is intended to be valid (Bartmus, Neumann & Marées, 1987) with forecasts of aptitude considered to be reliable for 2 - 4 years (Bauersfeld, 1985 op cit. Fisher & Borms, 1990).

## The role of training

It is generally accepted that the achievement of sport mastery requires exposure to a programme of goal directed training or deliberate practice over a period of many years (Balsevich, 1996; Ericsson et al., 1993). Periods of probationary or test training are considered an essential component in a number of conceptual models (Bar-Or, 1975; Dreke, 1982; Harré, 1982) and in the majority of international systems. Three main reasons have been cited for the incorporation of training periods into the systematic process of talent identification. Firstly, an evaluation of training permits the assessment of an athlete's ability for motor learning which is considered to be an important prognostic factor in the development of sporting talent (Balsevich, 1970 op cit. Balsevich, 1996; Karacsony, 1988). A number of international systems, most notably the former GDR, considered the evaluation of change as well as status to be important in selection with particular attention being paid to the speed of adaptation and learning (Fisher & Borms, 1990). Secondly, the training process was considered to be important for evaluating those characteristics which cannot be determined using a battery approach. It was assumed that the assessment of personality qualities and behavioural traits, including attitudes and responsiveness to training, was best performed by coaches as a result of their prolonged interaction with gymnasts during the training process (Karacsony, 1988; Fadeev, 1993). Finally, exposure to a programme of training provided gymnasts and their families with an insight into the demands of training and specifically the pleasures and difficulties of sporting life (Karacsony, 1988).

## Previous motor experience

In the evaluation of performance status for the purposes of talent identification, it is important to take into account the child's previous motor experience. This is particularly important in the initial stage of identification where the variability in previous motor experience is likely to be large. If a child has been exposed to a systematic training programme, the results of screening will represent the sum of genotype, training and sensitivity to training (Matsudo, 1996). However, in the absence of previous systematic training, initial screening results will more closely reflect the child's genetic profile (Matsudo, 1996). The confounding effect of previous motor experience may be particularly significant when initial identification is completed at a relatively late age. For

example, in the Australian Sports Search programme, initial identification did not occur until at least 13 years of age by which time previous motor experience may have significantly contributed to variations in performance status. In addition to the influence upon performance status, previous experience has been suggested to influence the rate of improvement or the variation in sensitivity to exercise training (Russell, 1988; Bouchard, Malina & Pérusse, 1997).

Various methods have been proposed to resolve this issue. In the former GDR, test results were related to the amount of training experienced (Fisher & Borms, 1990). An alternative, more passive approach, was adopted by the Romanian Gymnastics Federation (Stan, 1995). Although ability assessments were recorded at the initial stage of identification, such tests were not used for the purpose of selection until after one year of training, when it was assumed the effects of any previous motor experience could be discounted. The majority of attempts to account for previous motor experience have focused upon quantitative criteria with little or no account taken of the quality of previous motor experience. The development of indices of previous motor experience which combine quantitative and qualitative criteria may be an element of the talent process worthy of future investigation.

## Prognosis

The need to incorporate an element of forward thinking or prognosis into talent detection systems has been highlighted (Régnier et al., 1993). It is important to consider how changes in both the requirements of the sport and the profile of competitors will influence the nature and development of talent characteristics. In Women's Artistic Gymnastics, the Code of Points produced by the Federation Internationale de Gymnastique is amended after every Olympic cycle to direct the development of the sport over the subsequent four year period. However, the review of international systems revealed a general consensus that such changes have the most dramatic effect upon the development of elite gymnasts and that the impact upon the process of identification is minor (Linderholm & Simon, 1988; Smolevski, 1992; Stan, 1995).

## Genetic factors

In making a long term prediction of the future performance capability of an individual it is necessary to identify which determinants of future performance are largely influenced by heredity. Such determinants will demonstrate a high degree of stability over time and can be considered to have high predictive power (Kovar, 1981 op cit. Matsudo, 1996). Several conceptual models have contended that those variables largely determined by heredity should be accorded a primary or exclusive role in the identification of future talent (Geron, 1978; Harre, 1982). However, there are a number of variables which play an important role in determining the profile of the young athlete which are influenced to a large extent by environmental factors. Therefore, the most appropriate strategy may be to include all variables which have a theoretical role in the prediction of future performance and to index the characteristics according to the extent to which they are determined by heredity (Havlicek et al., 1982).

Heritability ($h^2$) is defined as the proportion of phenotypic variance that can be attributed to genetic differences (Cummings, 1994; Klissouras, 1997). One method through which the genetic contribution to overt phenotypic variance can be determined is via the study of relatives, for example, twins or family members (Malina, 1986b). The rationale underlying this method is based upon Fisher's theorum which suggests that the degree of similarity exhibited by individuals is proportional to the number of genes they have in common (Fisher, 1918, op cit. Bouchard & Malina, 1983a). Monozygotic (MZ) twins have identical heredity, sharing 100% of genes, while dizygotic (DZ) twins share on average 50% of genes (Cummings, 1994; Bouchard et al., 1997; Klissouras, 1997; Vogel & Motulsky, 1997). In twin studies, a comparison is made of the phenotypic variance of MZ and DZ twins exposed to similar environmental conditions. It follows that if a variable is largely determined by heredity MZ twins should be more alike than DZ twins, but if a variable is largely determined by environmental factors, within pair differences should be approximately equal (Régnier et al., 1993). Differences in intra-pair correlations between MZ and DZ twins have been used to estimate heritability and thus determine the relative strength of the genotype via the application of a number of statistical formulae [for example, Clark ($\sigma^2_{DZ} - \sigma^2_{MZ} / \sigma^2_{DZ}$), Neuman ($\sigma_{MZ} - \sigma_{DZ} / 1 - \sigma^2_{DZ}$) and Falconer $2(\sigma_{MZ} - \sigma_{DZ})$ (Klissouras, 1997)]. The heritability index indicates the strength of genetic influence. The greater the difference in intra-pair

correlations between MZ and DZ twins, the closer the index is to unity and the stronger the assumed contribution of the genotype. More recently, statistical techniques such as path analysis have been applied to decompose correlations between relatives to estimate the components of phenotypic variance (Bouchard et al., 1997).

Heritability values reflect the extent to which heredity affects the variation of an attribute in the population from which it is derived, given the environmental conditions present during measurement (Pérusse, Lortie, Leblanc, Tremblay, Theriault & Bouchard, 1987; Cummings, 1994; Klissouras, 1997). It is not possible to obtain a single heritability value for a particular trait or to apply population values to any particular individual (Bouchard et al., 1997). Heritability indices have mistakenly been equated with determinism. Klissouras (1997) emphasised that high heritability estimates do not suggest that the environment has little or no effect. Rather high values imply that after individuals have acquired their personal limits of a trait given the appropriate environmental/training conditions, there will still be significant inter-individual variability which is genetic in origin (Klissouras, 1997).

Bouchard & Malina (1983a) proposed a general model which enabled the partitioning of phenotypic variance. In this model, total phenotypic variance was viewed as the sum of genetic and environmental sources of variation plus the interaction between the genotype and the environment and a random error component. Given a series of assumptions, the genotype-environment interaction component implies that the sensitivity of an individual to environmental influences is genotype dependent (Bouchard, 1986). According to the model, an individual with a favourable genotype may respond in a positive manner towards a particular environmental stimulus such as a well structured training environment. The effect of the interaction between genetic and environmental factors has been the centre of much research attention, but has not been conclusively determined (Bouchard et al., 1997). Large inter-individual differences in the responsiveness to training have been reported across a series of tasks which include aerobic capacity, endurance performance and anaerobic performance (Bouchard, Shephard, Stephens, Sutton & McPherson, 1990). The evidence cited most frequently to provide support for a genetic contribution to trainability concerns responses to the training of aerobic capacity (Prud'Homme, Bouchard, LeBlanc, Landry & Fontaine, 1984). However, after a review

of relevant literature, Klissouras failed to derive support for the contention that the trainability of maximal aerobic power is genotype dependent (Klissouras, 1997).

With respect to anaerobic performances there is evidence to suggest that extent of the genetic contribution to training induced improvements is a function of task duration. Simoneau, Lortie, Boulay, Marcotte, Thibault & Bouchard (1986) subjected 14 pairs of MZ twins to a 15 week training programme of high intensity intermittent exercise. While the response of long term anaerobic performance (power output in 90 seconds) was largely genetically determined, the responsiveness of short term anaerobic performance (power output in 10 seconds) appeared to be only minimally affected by genotype. Research examining the contribution of the genotype to motor learning has been less extensive. In a study of 9 - 13 year old children, Sklad (1975) reported that the rate of learning in four motor tasks (plate tapping, foot tapping, mirror tracing and ball tossing for accuracy) was generally more similar in MZ than DZ twins, confirming the contribution of the genotype. A further study investigated the relative importance of genetic and environmental influence on learning a rotary pursuit task (Fox, Hershberger & Bouchard, 1996). A total of 64 MZ pairs and 32 same sex DZ twins who had been reared apart completed 25 trials over three successive days. The intra-class correlations for the change in performance were greater in MZ than DZ twins indicating significant genetic effects in the rate of learning.

Considerable research attention has been devoted to evaluate the adequacy of a simple additive model in explaining the phenotypic variance. In connection with the Leuven Longitudinal project, Maes, Beunen, Vlietinck, Lefevre, Bossche, Claessens, Derom, Lysens, Renson, Simons & Eynde (1993) used path analysis to investigate the heritability of health and performance related fitness in a sample of 91 twins (mean age, 10.3 years ± 0.3). Using the maximum likelihood estimation method, the authors evaluated the ability of two alternative models to explain the phenotypic variance and covariance among certain parameters of physical fitness in the twins. A simple model (EG) which estimated the effect of genetic and environmental factors was compared with a more complex model (ECG) which separated common and specific environmental factors. Results indicated that while the more complex model resulted in a slightly superior model fit, the difference was not statistically significant. However, it was suggested that the role of common environmental factors may approach significance as sample size was increased. Maes,

Beunen, Vlietinck, Neale, Thomis, Eynde, Lysens, Simons, Derom, & Derom (1996) extended the study to include 105 twin pairs and their parents. For the majority of fitness parameters a simple additive model consisting of genetic and specific environment factors explained the majority of phenotypic variance. Despite such support, the validity of the simple additive model has not been conclusively determined.

It appears that the assumptions governing the determination of heritability from twin data are frequently violated and as a result heritability estimates should be interpreted as an indication of the contribution of the genetic component (Vogel & Motulsky, 1997). Estimates derived from twin studies are considered to indicate the upper limit of heritability estimates (Bouchard et al, 1997). It has been suggested that data derived from studies of family members, particularly those encompassing the extended family may be more representative of the population than data derived from twin studies (Bouchard et al., 1997).

A review of the heritability estimates reported in the literature reveals considerable variation for the majority of performance parameters. The value of such estimates appears to be a function of the nature of relationship under investigation. For example, heritability estimates calculated from relationships between family members tend to be lower than those derived from twin studies (Maes et al., 1993). Indeed, estimates of heritability reported by Pérusse et al. (1987) and Pérusse, Leblanc & Bouchard (1988) were much lower than those derived using the traditional twin model and those reported by Maes and colleagues who applied the various path models to the analysis of twin data (Maes et al., 1993, 1996). Moreover, within the technique of path analysis, heritability estimates vary according to model specification. Additional factors which may be responsible for the discrepancies between estimates include sample size (Pérusse et al., 1988; Maes et al., 1996), data reliability (Bouchard & Malina, 1983a) and the extent to which underlying assumptions have been violated (Maes et al., 1996).

Longitudinal studies have been conducted to 'track' the stability of talent characteristics over time. It has been suggested that stability represents an indirect measure of heritability and the extent to which the variable is influenced by genetic factors (Kovar, 1981; Régnier, 1987). Tracking studies involve periodic measurements of one or more characteristics over a long period of time, usually between 3 and 10 years (Klentrou,

1993; Régnier et al., 1993). Correlation coefficients can then be computed between the measurements taken at the various time intervals to determine the extent to which each variable evolves in a constant and predictable manner (Klentrou, 1993). For a characteristic to be termed 'stable' individuals must maintain the same relative rank, position or percentile position over time (Malina, 1990; Lefevre., Beunen, Claessens, Lysens, Maes, Renson, Simons, Eynde & Vanreusel, 1993; Malina, 1996b). Correlations between repeated measurements have frequently been used to calculate a tracking index (Malina, 1996b) including autocorrelations, partial correlations and inter-age correlations covering various age periods and time intervals (Beunen, Ostyn, Simons, Renson, Claessens, Eynde, Lefevre, Vanreusel, Malina & Hof, 1997). More recently the technique of generalised estimating equations (G.E.E.) has been proposed as a method of tracking subjects. It has been applied in longitudinal analyses in the Amsterdam Growth and health study to track the development of risk factors for coronary heart disease (Twisk, Kemper, Mellenbergh & Mechelen, 1996; Twisk, 1997). However, the use of this technique is restricted to large sample sizes.

There is relatively little information available regarding the longitudinal stability of parameters of physical performance in girls from early childhood through to adolescence. Since talent identification involves a series of long-term performance predictions beginning in early childhood, future research in this area will be extremely valuable. An additional concern relates to the extent to which results from population studies can be applied to samples of potentially elite athletes. It cannot be assumed that the level of stability of a variable in the general population is equivalent to that in a sample of highly skilled athletes. The z-score approach adopted by Matsudo (1996) highlighted that many of the variables which distinguish talented athletes were located towards the extremes of the distribution. It has been suggested that parameters may demonstrate increased stability at the extremes of the distribution which may result in improvements in tracking (Matsudo, 1996).

Lefevre et al. (1993) investigated the stability of health and performance related fitness parameters between late adolescence and adulthood in a sample of male subjects participating in the Leuven Growth Study. The extremes included those boys who at 18 years of age were at or below the 10$^{th}$ percentile or at or above the 90$^{th}$ percentile. Approximately 30% of subjects remained in the lowest decile for subcutaneous skinfold

measurements between 18 and 30 years of age. For tests of physical and motor performance, 28 - 75% of individuals remained at or above the 90th percentile over the 12 year period of study. However, given that the tracking estimates were for male subjects between the ages of 18 - 30 years, the relevance of the results for the purposes of talent identification in Women's Artistic Gymnastics is limited. In addition, although the stability of tracking parameters at the extremes of the population were reported no direct comparison was made to the stability estimates obtained for the total sample or for the central portion of the distribution.

To further investigate the stability of tracking at the extremes of the distribution Matsudo, Andrade, Andrade, Araujo & Matsudo (1997) reported the results of tracking height and standing vertical jump in 49 girls followed longitudinally over a period of 10 years. At the outset of the study, the mean age of the girls was 10.67 ± 2.02. Autocorrelations were reported for the total sample of girls and for three sub groups (a. = < -1 SD: b. = -1 SD = x = +1 SD: c. = > +1 SD). Autocorrelations were the highest in the extreme sub-groups and were significantly different from those in the central part of the distribution ($p<0.1$). These results led Matsudo et al. (1997) to conclude that stability is higher at the extremes of the distribution, which can be viewed positively by those wishing to predict the future performance of talented athletes.

In one of the few longitudinal studies tracking the development of performance in young athletes, Montpetit & Cazorla (1982) op cit. Klentrou (1993) conducted a longitudinal study of swimmers tested between 11 and 16 years of age. Correlations between the initial and final measurements demonstrated a high degree of stability for anthropometric measurements (r = 0.700 - 0.864), flexibility measurements (r = 0.609 - 0.760) and strength measurements (0.717 - 0.780). The results of this study and the suggestion that tracking of physical performance may be enhanced at the extremes of a population may be viewed favourably in the context of talent identification research. However, further research will be required to support these tentative suppositions.

In conclusion, estimates of heritability or stability may be used to estimate the contribution of the genotype to phenotypic variance for the purpose of indexing talent characteristics. If estimates of heritability are to be used, it will be necessary to rely upon

values published in the literature. It is unlikely that published values will accurately reflect the specificity of talent characteristics or the age and physical profile of the current sample of gymnasts. In addition, the large variability in published heritability estimates does not facilitate the selection of a single value. It may be more appropriate to calculate estimates of stability from the longitudinal tracking of talent characteristics. The stability of talent characteristics may be determined in the present study using rank order correlations and compared to values reported in the literature.

**Biological maturation**

The level of biological maturation of a young athlete is an important issue to consider in the identification and development of sporting talent (Fisher & Borms, 1990; Matsudo, 1996). In the case of a young male athlete early maturation may constitute a performance advantage and thus identified 'talent' may be a manifestation of early biological maturation rather than superior sporting ability. However, it is the failure to select potentially talented athletes as a result of their late maturation that is of particular concern to those seeking to identify sporting talent. As a result, several conceptual models have reported the need to evaluate performance according to biological rather than chronological age (Bar-Or, 1975; Harré, 1982; Matsudo, 1996). However, the significance of biological maturation as a factor in the identification of talent in young female gymnasts remains to be quantified.

Substantial evidence presented in the literature has confirmed that chronological age is a weak indicator of biological maturity (Beunen, 1993). There is considerable variation in maturity status between individuals of the same chronological age (Beunen & Malina, 1996) with variability being most pronounced around the time of the adolescent growth spurt (Malina & Bouchard, 1991). Discrepancies between chronological and biological age of up to 30 months have been reported in the literature (Fisher & Borms, 1990). In youth sport most indicators of training and competitive performance are expressed in relation to the child's chronological age. Given the known inter-individual variability in biological maturation and the fact that talent characteristics vary in their rate of development throughout childhood and adolescence, biological maturation has been raised as an issue in the development of both international systems and conceptual models

designed to identify sporting talent (Bar-Or, 1975; Harré, 1982; Thompson & Beavis, 1985; Riordan, 1991; Matsudo, 1996). In spite of the widespread recognition of the issue few solutions have been suggested to deal with the inherent variability in biological maturity.

Biological maturity can be assessed using sexual, morphological, dental and skeletal criteria (Beunen, 1989; Malina & Bouchard, 1991; Beunen, 1993; Beunen, 1996). Sexual criteria include stages of pubic hair, breast and genital development (Tanner, 1962, 1989). The age of the first partition (age at menarche) is also a popular index but its utility is limited by the problems associated with the retrospective recall of information (Malina, 1988a). Sexual criteria have frequently been applied to study maturation in athletes (Peltenberg, Erich, Bernink, Zonderland & Huisveld, 1984; Rowley, 1992b). However, they provide discrete information during the adolescent period only (Beunen, 1989; Malina, 1989; Beunen, 1993) and are therefore of limited use in the initial identification of talent which requires predictions from early childhood.

The most frequently used indicator of biological maturity is skeletal age (Beunen, 1989, 1993, 1996). There are three main methods of estimating skeletal maturity; the Atlas technique (Greulich & Pyle, 1959) and two bone specific approaches (Tanner, Whitehouse, Cameron, Marshall, Healy & Goldstein, 1983; Roche, Wainer & Thissen, 1975a; Roche, Chumlea & Thissen, 1988). The techniques vary in the methodological approach and measurement criteria used, however, the principle in which a hand-wrist or knee radiograph of a child is matched to a set of criteria is common. Each method relies upon the radio opaque nature of cartilage and bone which provides information on the shape of bones and the degree of ossification which are indicative of skeletal maturity. It has been suggested that in children under the age of seven years a radiograph of the knee will provide additional information regarding changes in maturational status (Roche et al., 1975a; Roche, 1980). Estimates of skeletal maturity are useful as they are valid throughout the whole period of growth (Malina & Bouchard, 1991; Beunen, Malina, Lefevre, Claessens, Renson, Eynde, Vanreusel & Simons, 1997; Beunen, Malina, Lefevre, Claessens, Renson & Simons, 1997). In addition, they have been reported to have a high measurement resolution, which enable estimations to be made to the nearest 0.1 year (Malina & Bouchard, 1991 op cit. Beunen et al., 1997a).

Morphological or somatic indicators include 'height age', age at peak height velocity (PHV) and percentage of predicted adult height. Height and/or height age (the age at which the child's height is equal to the height of the average child) were used as indices of biological maturity in the talent identification system of the former GDR (Fisher & Borms, 1990). However, these indices are limited as they confound maturity with size (Beunen, 1989; Beunen, 1993). Age at PHV derived from fitting growth curves is a valid method but is limited due to the requirement for longitudinal data (Malina, 1989; Malina & Bouchard, 1991; Beunen, 1989, 1993, 1996). Finally, the method of expressing stature as a percentage of predicted adult height is potentially useful. It is based on the premise that it is possible to identify whether the tall stature of an individual is due to genetic pre-programming or a function of early maturation (Malina & Bouchard, 1991; Malina & Beunen, 1996b; Beunen et al., 1997b). However, defining adult height has proved problematic. Traditionally, three methods have been used (Bayley & Pinneau, 1952; Roche, Wainer & Thissen, 1975b; Tanner et al., 1983) which require estimates of actual height, chronological age, skeletal age, and sometimes parental height and age at menarche (Beunen, 1993). The main difficulty in predicting adult height is deriving an estimate of skeletal age which has traditionally only been available through invasive procedures. It is possible to estimate adult stature using the height of a child's parents. In this way the range of adult stature in which 95% (± 2 SD) of a couple's female children will be expected to fall as adults can be predicted (Tanner, 1989). Strictly speaking the method of predicting target height requires the centiles of mid-parent height however, the final height for female children has been estimated using the following formula:

$$\text{Final Height} = \frac{\text{maternal height} + (\text{paternal height} - 13\,\text{cm})}{2} \qquad \text{Rogol (1996)}$$

Where 13 cm represents the average difference in stature between the sexes. Furthermore, Tanner (1989) reported that for female children predicted final height ± 9 cm would produce the target range in which the adult height of 95% of female children would be expected to fall. Other non-invasive methods of predicting adult stature have been proposed which include the Khamis-Roche Method (Khamis & Roche, 1994) and the method derived from the Leuven Longitudinal Study (Beunen et al., 1997b).

The Khamis-Roche method comprises a stature prediction model which was developed using data derived from the Fels longitudinal study in Southwest Ohio. Three predictor variables were used to produce the following regression equation:

$$\text{Predicted adult stature} = \beta_0 + \beta_1\text{stature} + \beta_2\text{weight} + \beta_3\text{midparent stature}$$

The Khamis-Roche method is applicable to white American children free from pathological conditions affecting stature and aged between 4.0 - 17.5 years. The method results in a slight deterioration in accuracy and validity compared to the modified Roche Wainer Thissen method. The average 90% error bounds for female children were estimated to be approximately 1.7 inches. In the Beunen-Malina method (Beunen et al., 1997b) age specific regression equations were calculated using data derived from a sample of Flemish boys aged 13 - 16 years participating in the Leuven Longitudinal Study. The equations included five predictor variables (current stature, sitting height, triceps skinfold, subscapular skinfold and chronological age). Standard error estimates of 3.0 - 4.2 cm were reported which compared favourably to the established TW2 method (Tanner et al., 1983). The applicability of these non-invasive methods has not been extensively validated using independent samples. However, it is anticipated that as such methods gain widespread acceptance they may be incorporated into talent identification systems.

A number of studies using a variety of maturity indicators have demonstrated that female gymnasts tend to mature later than non-athletic children and the majority of their athletic peers (Beunen, Claessens & van Esser, 1981; Märker, 1981; Bar-Or, 1988; Baxter-Jones, Helms, Baines-Preece & Preece, 1994). Malina (1994b) reviewed a number of studies reporting the skeletal maturation of female gymnasts. Although the majority of research was cross-sectional in nature, the review indicated that the relationship between chronological age and skeletal age was not consistent throughout childhood and adolescence. No clear trend was observed in the difference between skeletal age and chronological age during early and middle childhood, from 6 through to 10 years of age (Galaraga, Segredo, More & Guerra, 1982 op cit. Malina, 1994b; Eiben, Pantó, Gyenis & Fröhlich, 1986). However, from late childhood through to adolescence, several studies reported that female gymnasts demonstrated a skeletal age which was lower than their

chronological age (Beunen et al., 1981; Eiben et al., 1986; Theintz, Howald, Allemann & Sizonenko, 1989; Claessens et al., 1991a). Theintz et al. (1989) estimated the skeletal age of 34 elite female gymnasts who had a mean chronological age of 12.6 ± 1.1. The mean skeletal ages were estimated at 11.0 ± 1.3 using the Greulich-Pyle (1959) method and 11.8 ± 1.4 using the TW2 method (Tanner et al., 1983). It was concluded that the skeletal age of the gymnasts was moderately lower in relation to swimmers and non-athletic controls. A similar trend was reported by Beunen et al. (1981) in a study of 23 National level Belgian female gymnasts aged between 11.4 - 21.4 years. For those gymnasts who had not reached skeletal maturity, skeletal age determined according to the TW2 method was reported to be lower by an average of 1.5 years. Claessens et al. (1991a) determined skeletal maturity in 113 elite female gymnasts using the TW2 method. Skeletal age was lower by 1.9 years in relation to the chronological age of the gymnasts. However, empirical support for the later skeletal maturation of gymnasts during adolescence has not been unanimous. Novotny (1981) revealed that the chronological and skeletal ages of Czechoslovakian gymnasts were comparable at 12.4 and 16.5 years of age (Novotny, 1981 op cit. Malina, 1994b). Additionally, Calderone et al. (1986) reported a close correspondence between the average values of skeletal age (14.2 ± 1.05) and of chronological age (14 .0 ± 0.90) for those female gymnasts competing at the 1984 Junior European Championships. A summary of research findings illustrating the relationship between skeletal age and chronological age in female gymnasts is presented in Figure 2.5.

A similar relationship is revealed when indicators of sexual maturation are considered. The majority of investigations have used age at menarche as the index of sexual maturity (Beunen, 1989). Numerous studies have reported a later onset of menarche in gymnasts. In a longitudinal study designed to investigate the effects of intensive training in young British athletes (TOYA), Baxter-Jones et al. (1994) reported that gymnasts attained menarche at 14.3 ± 1.4 years which was significantly later than swimmers and tennis players and also significantly later than the median age of menarche of the UK population, reported to be 13 years (Tanner, 1989).

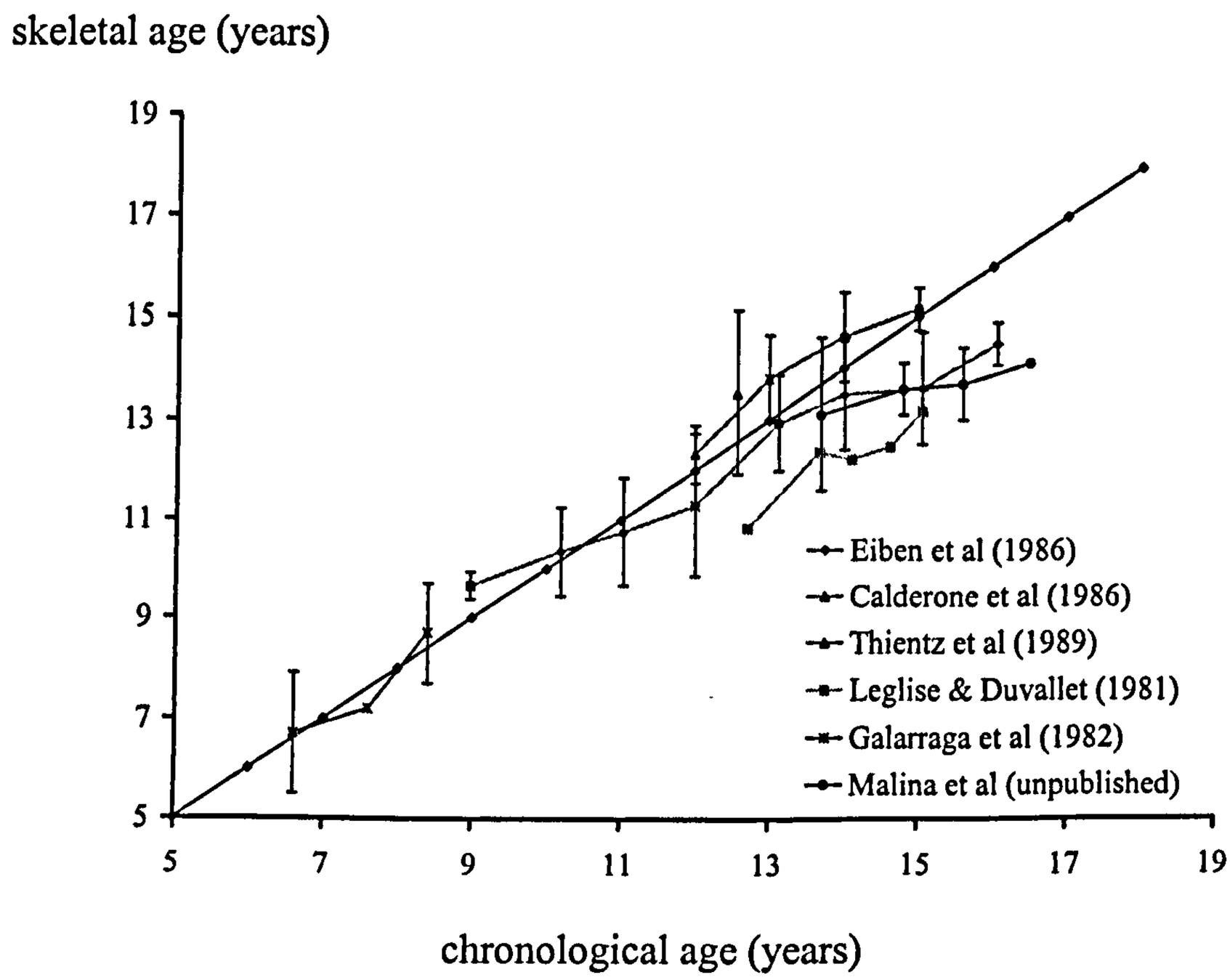



Figure 2.5. The relationship between skeletal age and chronological age in elite female gymnasts (adapted from Malina, 1994b).

In the most extensive study of menarche in elite gymnasts Claessens, Malina, Lefevre, Beunen, Stinjen, Maes & Veer (1992) reported a markedly late onset of menarche for a sample of 201 gymnasts who competed in the 1987 World championships. Using the status-quo method and probit analysis, median menarcheal age was estimated to be to be 15.6 ± 2.1 years which in comparison with a reference sample of Flemish girls, 13.2 ± 1.2 years, represented a difference of 2.4 years. However, since the minimum age limit for participation in major international competitions required that gymnasts were 14 in the year of the competition, this sample did not include girls under 13 years of age. Therefore, the reported age at menarche is likely to be biased towards an older age (Malina, 1994b). Menarche has been demonstrated to occur late in comparison to reference populations in samples of elite Hungarian (15.04 ± 0.62, Eiben et al., 1986); Dutch (Peltenberg et al., 1984); Belgian (15.13 ± 1.70, Beunen et al., 1981); Swiss (14.5 ± 1.2 years, Theintz et al., 1989) and East German gymnasts (15.04 ± 1.06, Märker, 1981). Studies of secondary sex characteristics confirm that as a group, elite female gymnasts experience later sexual maturation (Peltenberg et al., 1984; Malina, 1994b; Baxter-Jones, 1994b) which is most pronounced after 10 years of age (Peltenberg et al., 1984; Malina, 1994b). It is noteworthy that higher level gymnasts appear to experience

later maturation in various indices when compared with those gymnasts competing at lower levels of the sport (Peltenberg et al., 1984).

In females, late maturation is associated with smaller body dimensions. Late maturing girls have on average long legs for their stature, relatively narrow hips, less weight for height and a generally linear physique (Tanner, 1962; Malina, 1994b; Beunen & Malina, 1996; Malina, 1996a; Beunen et al., 1997a). The somatic characteristics associated with late maturation were found in a sample of elite female gymnasts whose skeletal maturity was lower than a reference population by 1.3 - 1.9 years (Claessens et al., 1991a). These gymnasts were found to be remarkably smaller and lighter and to have significantly narrower hips than a reference population of Flemish girls. However, no differences were observed in the leg length to stature ratio between the gymnasts and controls.

Differences between early and late maturing girls in terms of height, weight and biiliac diameter are apparent from 6 years of age (Richey, 1937 op cit. Beunen, 1989; Shuttleworth, 1937 op cit. Beunen, 1989). However, differences in the somatic characteristics of individuals of contrasting maturity status are reported to be small in childhood. These differences increase in magnitude until puberty, reaching a maximum around the time of peak height velocity (Beunen, 1989, 1993, 1996; Beunen & Malina, 1996; Beunen et al., 1997a). While the majority of somatic differences disappear by 16 years of age, the greater weight for height ratio of early maturity girls persists into adulthood (Tanner, 1962 op cit. Beunen, 1989).

The results of several investigations have confirmed that for many motor skills early maturing boys have a performance advantage over their average or late maturing peers (Beunen & Malina, 1996; Malina, 1996a; Malina & Beunen, 1996a). However, less is known about the relationship between maturity status and motor performance in girls. Beunen et al. (1997a) examined the relationship between skeletal maturation and physical fitness in a sample 6 - 16 year old girls participating in the Leuven Growth Study. The associations between maturity status and the various parameters of physical fitness were examined using zero order correlations at each chronological age. In general, correlations were low with the exception of physical working capacity, vital capacity and static strength. Correlations between flexibility, balance, explosive jumping activities and maturity status were low or non-significant throughout childhood and adolescence.

Interestingly, negative correlations were reported for indices of functional strength (bent arm hang, sit-ups and leg lifts).

Age specific step-wise regression analyses were employed to further examine the contribution of skeletal age, chronological age and parameters of body size to physical fitness. The order of entry of independent variables was determined according to statistical criteria, specifically the strength of correlations with the dependent variable. With the exception of indices of static strength, skeletal age was found to be a poor predictor of fitness parameters, explaining only 1 - 4% of the variance in most dependent variables. While interaction terms demonstrated greater predictive power they were still unable to explain more than 10% of the variance for most fitness parameters, moreover, skeletal age was rarely included in the interaction terms.

In a four year longitudinal study, Little, Day & Steinke (1997) measured parameters of physical performance annually in a sample of 61 girls. The girls were classified as early, average or late maturers according to their menarcheal age. The influence of maturity status upon performance at each chronological age was evaluated using analysis of variance (ANOVA) with repeated measures. In agreement with the results of Beunen et al. (1997a) there were few performance differences between contrasting maturity groups at each chronological age. Maturity status did not appear to have a significant influence upon flexibility, running speed, bent arm hang or standing vertical jump. Moreover differences in power output, as derived from performance in the standing vertical jump, were significant at only one chronological age (11 years). At this age the power output of earlier maturing girls was significantly greater than that of later maturing girls. This is not unexpected given that differences in maturity status are maximal at or around the age of peak height velocity (Malina & Bouchard, 1991) which in girls occurs at approximately 11 - 12 years of age (Malina & Beunen, 1996b). Three measures of static strength, mean grip strength, arm strength and back strength and a composite measure, total strength were recorded. Interestingly, with only one exception there were no significant differences in static strength between maturity groups. As a consequence of normalisation for body weight the static strength of the lighter late maturers was significantly greater than that of early or average maturers.

The results of these studies indicate that in girls physical and motor performance is largely independent of biological maturity with the possible exception of static strength. (Beunen & Malina 1996; Malina, 1996a; Beunen et al., 1997a; Little et al., 1997). The positive relationship between biological maturity and isometric strength highlighted by Beunen et al. (1997a) is in accordance with previous research (Malina, 1988a; Beunen, 1989; Beunen & Malina, 1996). The negative relationship between maturity status and certain parameters of muscular endurance and functional performance may be interpreted in the light of body composition changes associated with biological maturity (Beunen, 1989; Malina & Beunen, 1996a). Such parameters require the individual to work against their own body weight and thus the increase in fat mass associated with maturation may have a detrimental effect upon performance (Tanner, 1989).

With the possible exception of static strength, early biological maturation does not appear to constitute a performance advantage in girls. Moreover, as a direct result of differences in body composition, late maturing girls may demonstrate superior levels of performance in muscular endurance and functional strength parameters. Therefore, for the purposes of talent identification it is suggested that only measures of isometric or static strength need to be indexed according to biological maturity status. Research is required to quantify the value of indexing isometric strength over and above the benefits derived from normalising strength according to body weight. Since elite gymnasts are likely to lie towards the extremes of any reference population, research will be required to confirm the validity of the relationship between maturity status and performance in young female gymnasts.

The somatic profile characteristic of the late maturing female is associated with high level or elite performances in Women's Artistic Gymnastics (Claessens et al., 1991a). It has been suggested that gymnasts and other female athletes are selected to participate in sports as a result of possessing such characteristics (Malina, 1983). With the development of non-invasive methods of estimating maturity status via the percentage of adult stature attained (Khamis & Roche, 1994; Beunen et al., 1997b) maturity status may be used as a talent characteristic. However, such a proposal must be considered in the light of medical concerns, specifically, the possibility that late maturing athletes may be more susceptible to overuse injuries as a result of an immature skeleton. It has been reported that excessive training in combination with disrupted menstrual function may result in decreased bone mineral density and an increased risk of sustaining stress fractures (Drinkwater, Nilson,

Chestnut, Bremner, Shainholz & Southworth, 1984; Bailey & Rasmussen, 1996; Malina, 1996a; Micheli, 1996). To conclude, the role of biological maturation in the identification of talent may be limited to indexing values of static strength to control the performance advantage of early maturing girls. However, it is anticipated that non-invasive indices of maturity status will play a large role in the development of talent. Specifically, such information will be useful in establishing guidelines for the acquisition of skills and the regulation of training load.

The next section of the review will focus upon the issues surrounding the development of talent characteristics within the growing child. The discussion will begin by considering several theories of motor development. It is anticipated that an understanding of the theoretical approaches within motor development research will assist in interpreting the longitudinal changes which occur in the talent characteristics over the duration of the study.

## 2.6 THEORIES OF MOTOR DEVELOPMENT

Motor development has been defined as:

> "the changes in motor behaviour over the lifespan and the processes which underlie these changes."
>
> (Clark & Whitall, 1989)

This recent definition encapsulates the underlying debate between product and process which has plagued the field of motor development. With few exceptions, early theoretical approaches focused upon the product of motor development with researchers content to describe and document the changes in motor behaviour within the 'average child'. Only recently have some contemporary theorists recognised the importance of understanding both the product and process of motor development. As a result there has been renewed research interest in the mechanisms of change and more specifically how and why development occurs. The aim of this section is not to provide a comprehensive review of theories of motor development but rather to highlight some of the most significant

theoretical perspectives through which the motor development research presented in subsequent chapters may be interpreted.

## Maturational theories

Maturational theories were the dominant theoretical orientation during the first half of the twentieth century (Clark & Whitall, 1989). This theoretical approach stressed the fundamental importance of neural maturation in interpreting the motor development of infants and children. Specifically, the maturation of the central nervous system was suggested to determine behavioural changes in an essentially causal manner (Hopkins, Beek & Kalverboer, 1993). Environmental factors were considered to contribute minimally to the development of motor skills (Haywood, 1993). The majority of maturational research focused upon the product of motor development and generated a significant amount of valuable descriptive information and normative data which catalogued the sequential development of motor behaviour in infancy and early childhood.

Two of the major proponents of the maturational approach were Gesell (1928, 1946) and McGraw (1935, 1945). Although both were classified as maturationalists each adopted a specific approach to the investigation of motor development as highlighted by Hopkins et al. (1993). McGraw was primarily concerned with the establishment of causality in the relationship between the structural development of the nervous system and the acquisition of motor skills. Through a primarily intra-task approach McGraw documented changes in the nature of movements from the initial emergence of a skill through to its stabilisation within the child's movement repertoire. The acquisition and development of motor skills was thought to be correlated with the maturation of the motor cortex (Clark & Whithall, 1989; Hopkins et al., 1993).

The most frequently documented aspect of McGraw's work was her 1935 co-twin study, in which she investigated the effects of early training upon the development of specific motor skills. Only one twin was trained in a range of fundamental and slightly more obscure motor skills. The influence of early experience was found to be skill dependent and appeared to be most beneficial for the novel motor skills such as roller skating

(Magill & Anderson, 1996). From the results of this study McGraw concluded that skill development was the result of an interaction between neural maturation and the specific experiences of the child. (Clark & Whithall, 1989). In contrast to the direct causal relationship proposed by McGraw, Gesell (1946) considered motor development as an internal process of self-organisation (Hopkins et al., 1993). Although Gesell (1946) acknowledged the contribution of neural maturation to motor development, other factors were also considered to be important, in particular body morphology was accorded a key role (Clark & Whithall, 1989).

While the contribution of early maturational theorists has been acknowledged, criticism has been directed towards subsequent proponents' reliance upon descriptive data (Seefeldt & Haubenstricker, 1982). The period of time 1946 - 1970 has been described as the normative/descriptive period (Clark & Whitall, 1989). During this period a number of investigators sought to generate normative data and to describe average performance within various age groups (Haywood, 1993). The descriptive movement continued into the 1970's, with a shift in emphasis towards the identification of fundamental movement patterns (Seefeldt & Haubenstricker, 1982). In a review of research, Branta, Haubenstrucker & Seefeldt (1984) concluded that there was a consensus among researchers that movement skills develop in an orderly manner. However, while the sequence of development was confirmed to be largely invariant there was clear variability between children with respect to the rate of developmental change (Newell, 1986).

**Piaget's theory of cognitive development**

Piaget (1969) studied the development of cognitive thought processes through the observation of children's behaviour (Gallahue & Ozmun, 1995). Children were assigned to developmental stages according to their ability or inability to solve specific tasks or problems devised to detect changes in cognitive functioning (Thomas, Thomas & Gallagher, 1993). The notion of developmental stages was considered to be one of Piaget's major contributions to the field of child development (Haywood, 1993). Piaget proposed four stages of development; sensorimotor (0 - 2 years), pre-operational (2 - 7 years), concrete operations (7 - 11 years) and formal operations (12 + years) which were based upon qualitative structural changes in cognitive functioning (Haywood, 1993).

Piaget contended that five qualities were associated with the stages, most critically they were universal for all children and formed an invariant sequence of development (Thomas, 1996). The interaction between an individual and the environment was considered to be an important principle underpinning cognitive theories of development (Haywood, 1993). Piaget proposed that cognition developed as a result of adaptation to the environment and was subsequently intellectualised via the processes of accommodation and assimilation. One of the major criticisms levelled at Piaget's theory of cognitive development is the apparent difficulty in assessing exact changes in cognitive processing. Therefore, the precise identification of a child's cognitive functioning during the transition between stages has been problematic (Thomas et al., 1993). In response, Neo-Piagetian theorists have produced formulae to quantify the cognitive capacity demanded by each task to enable a more precise definition of a child's progression within a stage. However, the mathematical complexity of such formulae has precluded their widespread use.

**Information processing approach**

In the information processing approach the brain is modelled as a computer (Clark & Whitall, 1989) with the human regarded as a processor capable of storing, retrieving and transforming information (Gabbard, 1992). Motor behaviour is interpreted in terms of perceptual-cognitive processes. Specifically, sensory input is perceived at an executive level whereupon this information is transformed into numerous commands which are issued to individual muscles, the effector system, in order to produce coordinated movements. Information processing theories are hierarchical in nature with the dominant central nervous system responsible for the apriori determination of movement coordination (Clark & Whitall, 1989). Motor development proceeds as the hierarchy increases in complexity in terms of the programmes, subroutines and schemata contained within it (Hopkins et al., 1993). The information processing approach has been criticised as a static approach with the determinants of change remaining constant across the lifespan. Change is viewed as a quantitative phenomenon, for example, the speed of processing is increased with age in the developing child. As a result, theories of information processing are suggested to be unable to adequately explain motor development and the generation of new movement patterns (Hopkins et al., 1993).

However, the most cited criticism pertains to the problem of storing the vast amount of information required to produce the movement repertoire of the adult human.

Kugler, Kelso & Turvey (1982) published a seminal paper which has subsequently been described as a watershed in the re-conceptualisation of motor development (Whitall, 1995). Located within the broader ecological perspective, numerous labels have been applied to describe this theoretical approach or components of the approach: for example, dynamical systems theory (Clark & Whitall, 1989; Haywood, 1993; Whitall, 1995; Magill & Anderson, 1996; Seefeldt, 1996) and the natural physical approach (Hopkins et al., 1993; Davids, Handford & Williams, 1994). In a review of the Kugler et al. (1982) paper, Whitall (1995) delineated three important themes. The first two themes will be considered together as they comprise the dynamical systems approach. The final theme relates specifically to the perception-action perspective and will be considered as a unique perspective.

**Dynamical systems approach**

The dynamical systems approach was based upon the classical theory of Bernstein (1967) which proposed that the degrees of freedom associated with the human multi-joint system are constrained into self-organising synergies or coordinative structures (Kugler, Kelso & Turvey, 1980). According to proponents of the dynamical systems approach coordination emerges as a consequence of this process of self-organisation rather than by apriori determination by the central nervous system as suggested by the information processing approach (Clark & Whitall, 1989). The dynamical systems approach is essentially interdisciplinary with the contribution of all maturing subsystems considered to be of equal importance (Whitall, 1995; Gallahue & Ozmun, 1995; Seefeldt, 1996). Motor control within the human organism is therefore regarded as a self-organising process through which a number of subsystems function together dynamically to produce coordinated and controlled movements.

According to the dynamical systems approach developmental change is interpreted in terms of the principles of non-linear dynamics (Whitall, 1995). Movements are defined in terms of 'collective variables' which represent the nature of change within the system.

These variables are expressed in terms of mathematical or physical models with the behaviour of the system emerging as a result of the physical properties specified within the model (Hopkins et al., 1993). Developmental change occurs as a result of changes within a specific sub-system which cause the collective variable to become unstable and a shift to occur to a new behavioural state (Whitall, 1995). At any particular age, the slowest sub-system to mature acts as a catalyst for the transition and is therefore termed the rate controller (Hopkins et al., 1993; Magill & Anderson, 1996). For example, Thelen has identified strength in the extensor muscles together with the development of postural control to be the rate limiting parameters controlling the onset of walking in infants (Thelen, 1986; Thelen, Ulrich & Jensen, 1989 op cit. Whitall, 1995). According to this theoretical approach, inter-individual differences in motor development can be interpreted as a function of the maturation rate of various sub-systems. The dynamical systems approach has most frequently been applied to the development of phylogenic skills, however the possibility of interpreting the acquisition of gymnastic skills according to this perspective is inherently appealing.

**Perception-action perspective**

The final theme delimited from the paper by Kugler et al. (1982) was based upon the ecological approach developed by Gibson (1979) op cit. Whitall (1979). According to this perspective, perceptual and motor systems have evolved concurrently and therefore cannot be studied independently (Haywood, 1993; Whitall, 1995). The perspective proposed that an individual's perception of an object is interpreted in relation to their own body dimensions. As a result of this interpretation a particular movement pattern is afforded. Motor development is considered to proceed as a result of the changes in affordances which occur as the individual grows and attains greater motor proficiency. Both the dynamical systems approach and the more broad ecological perspective focus upon the process rather than the product of development (Clark & Whitall, 1989; Gallahue & Ozmun, 1995) which may be considered an important strength of these approaches. By focusing upon the concept of constraints, Newell (1986) reflected the interdisciplinary nature of the dynamical systems approach. Newell proposed that the interaction of constraints relating to the organism, the environmental and the task influenced the emergence of movement coordination.

## 2.7 READINESS

One aspect of the development of the athletic child which is particularly important in identification and development of talent concerns the issue of readiness. This concept has traditionally been investigated from a maturationalist perspective, however, there is considerable scope to apply contemporary theoretical approaches to facilitate a more complete understanding of the phenomenon.

> "Readiness relates to the ability of the individual to successfully handle the demands of an instructional and learning situation."
>
> (Malina, 1993)

The concept of readiness can be applied to many facets of human development including the identification and development of sporting talent. An understanding of readiness is clearly necessary to determine the most appropriate age at which to identify talented youngsters and introduce them to sport. Two specific questions have been raised in relation to readiness for sport. Firstly, when is a child ready to learn sports skills? and secondly, when is a child ready to compete in sport? (Magill & Anderson, 1996). One of the major proponents of readiness in youth sport, Robert Malina, interpreted the concept as the relationship between the ability of a child and the demands of a specific task or activity (Malina, 1986a, 1993). Malina developed the readiness state given in Figure 2.6 stating that readiness occurs when the ability of a child is commensurate or exceeds the task demands of a sport. Likewise, unreadiness will prevail when the ability of a child is exceeded by the demands of a sport. (Malina, 1988b; 1993).

| | |
|---|---|
| **readiness** | ability ≥ demands of a sport |
| **unreadiness** | ability < demands of a sport |

Figure 2.6. The readiness equation (adapted from Malina, 1993).

Malina (1993) considered the ability of the child to be a multidimensional construct comprising a biosocial matrix of growth, maturation and development (Figure 2.7).

Malina also alluded to the importance of the child's own perception of readiness as an important area for future study (Malina, 1988b).

Since readiness is viewed as a dynamic phenomenon, those factors which influence ability and in turn readiness are subject to change as the child grows, matures and develops and as a result of the child's adaptation to the demands of the sport (Malina, 1993). Therefore decisions must be taken throughout the training process to determine the child's readiness to enter each successive phase of development. The decision to advance a child has traditionally been the subjective decision of the coach. Frequently coaches rely upon children's overt attempts at skills to facilitate this decision (Seefeldt, 1996). However, in technical sports such as gymnastics where the level of risk and associated fear are high spontaneous attempts are unlikely to be forthcoming. Thus coaches need to be aware of prerequisite factors which indicate readiness.

BIOSOCIAL MATRIX OF CHARACTERISTICS

| GROWTH | MATURATION | DEVELOPMENT |
|---|---|---|
| • size | • skeletal | • cognitive |
| • physique | • sexual | • emotional |
| • composition | • somatic | • social |
| • systemic | • neuromuscular | • motor |

SELF-CONCEPT

PERCEIVED READINESS FOR SPORT

Figure 2.7. The biosocial matrix of ability (adapted from Malina, 1993).

An alternative model of readiness which recognised the importance of identifying antecedent variables was proposed by Seefeldt (1980). A pictorial representation of the model is provided in Figure 2.8. The model suggested that certain antecedents were required before a novel task could be accomplished. The level of proficiency of basic tasks was suggested to influence the efficiency and effectiveness of the child in acquiring more demanding tasks and ultimately influence the completion of the developmental repertoire (Seefeldt, 1980). It was suggested that in order to facilitate the development of

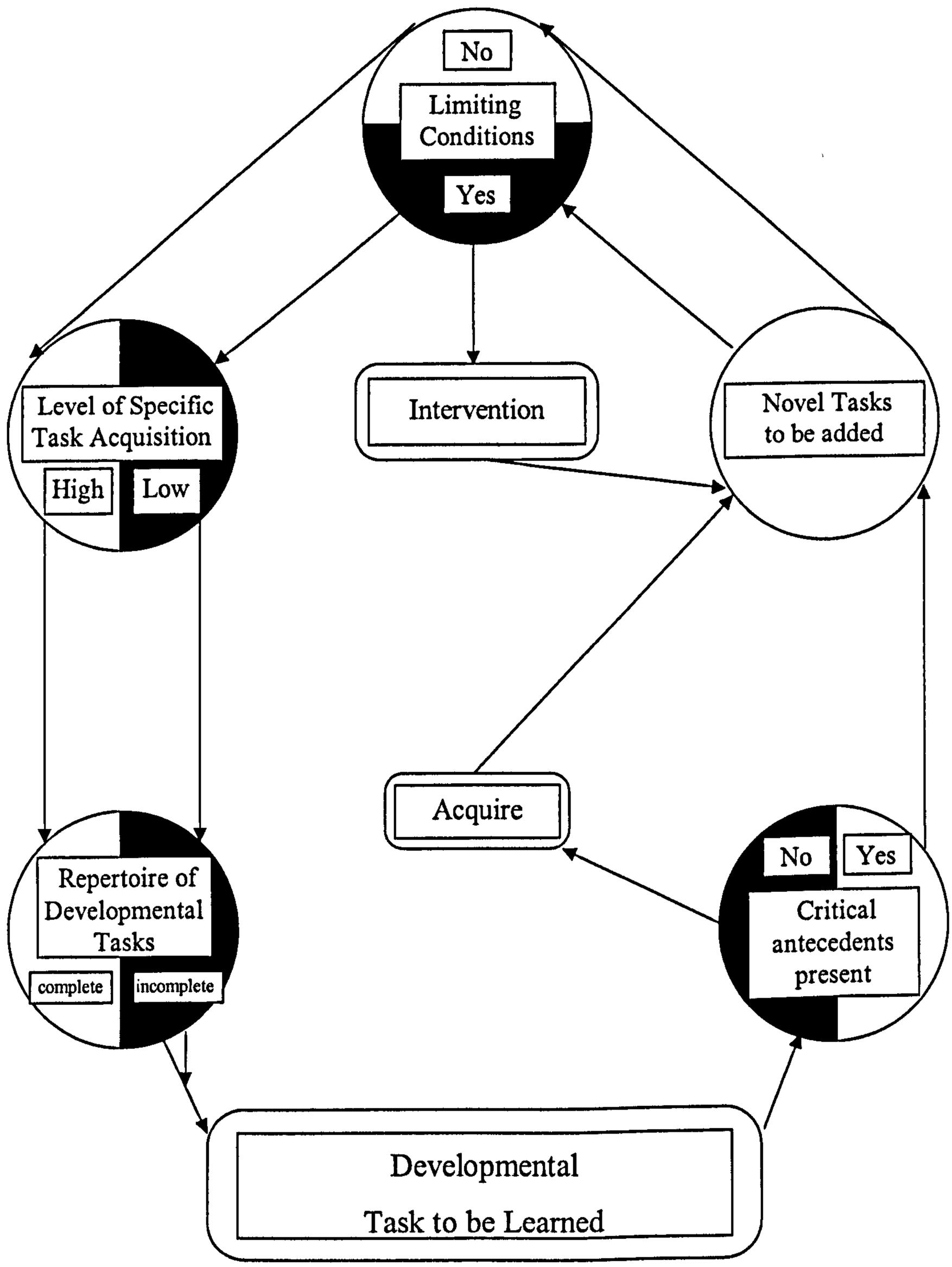



Figure 2.8. Model for the acquisition of fundamental movement skills (adapted from Seefeldt, 1980).

motor skills, the coach must be aware of the antecedent variables which underpin readiness, they must recognise behavioural signs which indicate readiness and provide an environment conducive to skill development (Seefeldt, 1996).

Readiness has most commonly been perceived in terms of physical, biological or motor factors (Karacsony, 1988). The demands of the sport are suggested to include the

objectives, tasks and rules (Malina, 1993). However, social, cognitive and emotional factors are also essential components of the readiness equation (Smoll & Smith, 1996; Karacsony, 1988). It is likely that the frequent lack of concern for social and emotional readiness have contributed to the phenomenon of burn-out in youth. An example of the detrimental effects of neglecting such factors was highlighted by Karacsony (1988). He suggested that in attempting to achieve rapid and spectacular success in gymnastics, coaches in Hungary were responsible for psychological and physical exhaustion experienced by gymnasts.

> "When bringing through a champion at too young an age, one can make use of juvenile abilities, but these abilities do not match the maturation of body and mind."
>
> (Karacsony, 1988)

More recently, an optimal readiness model for skill learning has been proposed (Magill & Anderson, 1996). Three factors, maturation, prerequisite skills and motivation were suggested to be responsible for determining when a child is optimally ready to learn a new skill. The model suggested that in order to acquire skills an individual requires an appropriate level of maturation, certain pre-requisite skills and the motivation to learn. The relative importance of these three factors in determining readiness was considered to be a function of the individual learning the skill and the nature of the skill to be learned. Whilst motivation was considered to be an essential component of readiness (Scott, 1986; Magill & Anderson, 1996) it was acknowledged that the required level of motivation could develop as a function of the learning process. Hence, it was recommended that skill development should not be delayed as a result of insufficient levels of intrinsic motivation (Magill & Anderson, 1996).

The second question to be addressed is of particular concern to those sceptical of the benefits of youth sport and concerns the child's ability to handle the physical, motoric, social and emotional demands of competition (Malina, 1988b). The distinction between the demands of participation and competition and the associated readiness requirements have been widely recognised (Malina, 1986a; Lee, 1988; Magill & Anderson, 1996; Passer, 1996). Although competitive readiness is recognised to be a multifaceted phenomenon it has frequently been considered in relation to the psychological pressures

associated with youth sport. Passer (1996) considered the issue of competitive readiness with particular reference to two psychological factors; the development of social comparison and cognitive readiness. As a result of a comprehensive review of research on child development Passer (1996) recommended that participation in competition should be delayed until the mid-late elementary school years (7 - 8 years of age). It was suggested that by this age children are reported to have acquired the ability and the desire to compare themselves socially. In addition, the information processing, attributional processes, and skill in interpreting the reactions of significant others will be sufficiently developed. Passer (1996) warned of the potential risks associated with participating in a competitive programme too early, which included low perceived competence, increased levels of competitive anxiety and decreased self-esteem.

**Critical or sensitive periods**

Closely linked to the notion of readiness is the concept of critical or sensitive periods. A critical period has been described as;

> "an optimal time for the emergence of certain behaviours and is a point in development when an individual is unusually receptive to influences by environmental or other mitigating factors."
>
> (Gabbard, 1992)

Given this definition of critical periods, they can be considered to represent times of optimal readiness (Magill & Anderson, 1996). While the distinction between critical and sensitive periods is not always clearly stated it has been suggested that the term sensitive period refers to a more modifiable and less irreversible phenomenon in which the degree of importance of the resulting change is not specifically implied (Scott, 1986). Critical periods in behavioural development were initially identified in non-human species, examples included the phenomena of imprinting in birds (Lorenz, 1935 op cit. Scott, 1986) and primary socialisation in mammals (Scott, 1945; Scott & Marston, 1950 op cit. Scott, 1986). Within human subjects, research has included an examination of critical periods in the accumulation of body fat in relation to the onset of obesity (Cioffi, 1978 op cit. Scott, 1986; Brook, 1972 op cit. Scott, 1986; Scott, 1981) and in the acquisition and

organisation of language (Lenneberg, 1967 op cit. Scott, 1986). Scott (1986) proposed that critical periods were a common feature of all developmental processes, however, the duration and importance of a critical period was dependent upon the rate of change of the process. According to the theory of critical periods, modifications in the organisational processes can be most easily achieved during periods of rapid development, which have been referred to as optimal periods (Scott, 1986; Bornstein, 1989).

The bi-directionality of the modification of organisation has been acknowledged (Scott, 1986; Bornstein, 1989). The terms vulnerability or vulnerable periods were coined to refer to critical periods in which the agent produced unfavourable effects on the organising process. Bornstein (1989) produced a framework of description and explanation to guide research into sensitive periods suggesting that at least 14 structural characteristics were essential in order to comprehensively describe sensitive periods. These 14 characteristics were divided into four sets of parameters relating to; temporal and intensive contours of the sensitive periods (timing and change); mechanisms involved in the sensitive period change; consequences of the sensitive period and the evolutionary and ontogenic time scales with respect to sensitive periods (modifiability and variability). The second part of the framework involved consideration of two levels of causal interpretation, namely why do sensitive periods arise and how are sensitive periods regulated?

In the context of motor development, critical or sensitive periods can be defined as finite periods during which a child is most sensitive to learning a particular skill (Haywood, 1993). It is important to determine whether critical periods exist within the lifespan during which the child displays 'optimal readiness' to learn a specific skill (Magill & Anderson, 1996). It is also important to consider what are the consequences of failing to introduce skills during such critical periods in terms of the degree of success of future performances.

Critical periods are considered to be periods of optimal readiness during which those factors which are considered to be critical to the performance of a specific skill are present. Such factors include the child's maturational level, the environment and previous learning experiences (Magill & Anderson, 1996). It has been suggested that during critical periods skill learning is both more effective and efficient than at other periods

during the lifespan (Magill & Anderson, 1996). However, it has been suggested that in addition to quantitative assessments, important information about the effects of sensitive periods may also be gained by adopting a more qualitative approach (Haywood, 1993).

It is well known that children acquire basic motor skills in an invariant sequence but that the rate at which children progress through the developmental sequence is highly variable (Seefeldt, 1996). The readiness of a child to acquire sports skills is dependent upon several factors including the level of maturation of various systems. The development of a motor skill will not proceed until each system has advanced sufficiently, regardless of the training process (Haywood, 1993). Additional factors such as the acquisition of antecedent skills, the nature of the environment and the motivation of the individual are also of paramount importance in determining readiness. The determination of a readiness model for Women's Artistic Gymnastics will be an essential aspect of any process designed to identify and develop talent. The first stage of the process will require a thorough consideration of the task demands of those core skills required in gymnastics. From such an analysis it would be possible to determine the level of maturation required in each system, the necessary antecedent skills and the optimal environmental conditions required to facilitate skill development.

It is essential that any attempts to determine periods of optimal readiness are viewed from an inter-disciplinary perspective with particular consideration of the medical implications for the growing child. Critical or sensitive periods are frequently associated with periods of rapid development (Scott, 1986; Bornstein, 1989). However, these are the very times when the growing child is most likely to sustain skeletal damage (Bailey, McCulloch & Wedge, 1990). The authors demonstrated that the age at peak incidence of distal radius fractures in children coincided closely with the age of peak height velocity. The authors suggested that this observation may be due to a temporary period of relative weakness at the time of peak velocity of linear bone growth which resulted from the dissociation between linear bone growth and bone mineralisation which occurred during the adolescent growth spurt (Bailey, McCulloch & Wedge, 1990).

In an attempt to provide a framework for the development of fundamental and pre-requisite skills, Durandt & Salmela (1994) produced an athlete development model for Women's Artistic Gymnastics. The lifespan of the female gymnast was divided into five

stages of development (Early childhood up to 6 years; pre-pubertal 6 - 11 years; early pubertal 11 - 13; late pubertal 12 - 16 and post-pubertal 15 + years). A description of the physical, motoric, perceptual cognitive and social/psychological changes that occur within each stage of development was provided together with suggested implications for the gymnast in terms of general development and with respect to the acquisition of specific skills. This model is currently the most comprehensive attempt to incorporate the multidimensional concept of readiness into a model of sports development.

## 2.8 GYMNASTIC IDENTIFICATION BATTERIES

This final section is based upon a comprehensive review of literature produced by Klentrou (1993) which described the following gymnastic test batteries: Vankov (1978); Kozlov & Koljuxov (1979); Salmela, Régnier & Proteau (1979); Rozin & Mukambetov (1980); Weber (1982); Carzola & Margueritat (1986); Radoulov (1986); Rozin (1986); Sol (1987); Hartley (1988); Risack, Plum & Sturbois (1988); Poelvoorde & Levarlet-Joye (1990). The aim of this section is to identify those tests or assessments which were common across batteries. Also, where appropriate, unique or original features of specific batteries will be discussed. The reader is referred to Klentrou (1993) for details of specific test batteries.

### Physical characteristics

In most systems, the initial stage of identification was based upon the coaches' observations of posture and basic anthropometric measurements, such as height and weight (Radoulov, 1986; Hartley, 1988). In addition, ratios of height to weight have also been used for selection purposes (Hartley, 1988; Stan, 1994). Hartley (1988) estimated that in the initial phase of identification approximately 25% of all 5 year old children in the GDR were expected have an appropriate height to weight ratio for selection. Charts outlining the optimum height for gymnasts of all ages and levels of ability were devised by the Romanian Gymnastics Federation (Stan, 1994). According to their current height, gymnasts were classified into the following categories; 'optimum', 'possible' and 'improbable' which indicated the likelihood of future gymnastic success. In these charts,

the range of optimum heights was narrow for the youngest gymnasts but became progressively broader as the age of the gymnasts increased.

Additional anthropometric criteria have been specified at the stage of initial selection. For example, the system of selection in the former GDR included body proportions such as arm length and the relationship between hip and shoulder width (Hartley, 1988). One of the most comprehensive anthropometric batteries was proposed by Radoulov (1986) which consisted of 11 anthropometric criteria. The battery was devised for 5 - 6 year old gymnasts and included the following measurements: height, sitting height, leg length, arm length, hip width, weight, height to weight index, trunk to height ratio, leg to height ratio, arm to height ratio and hip to height ratio. Posture was regarded as a significant factor in the selection of gymnasts within the former USSR. Postural screening was designed to identify those children demonstrating alignment problems in the knee joint and both incomplete extension or hyper-extension in the elbows and knees. Particular attention was paid to deviations of the spinal column including lateral deviations (scoliosis), abnormal concavity forward in the thoracic region (kyphosis) and abnormal convexity forward in the lumbar region (lordosis) (Kelly, 1995).

In the majority of test batteries, subsequent stages of identification focused upon aspects of general and specific physical condition (Vankov, 1978). Factors such as strength, speed-strength, muscular endurance, power, flexibility, agility, and balance were frequently measured. Tests of general physical condition were included to assess general aspects of fitness and performance. In contrast, tests of specific physical condition were devised to assess the specific physical requirements of each piece of apparatus. For example, tests were designed to assess the strength and speed-strength qualities in the flexor and extensor muscles of the shoulders and upper body, high levels of which are essential in contemporary bar work (Fadeev, 1993).

Coaches traditionally assumed that muscular strength was an important component of talent in gymnastics. This assumption has been supported by studies which have demonstrated a high correlation between measures of strength and high level gymnastic performances (Radoulov, 1986). Assessments of both static and dynamic strength have been considered important in the identification of talent (Rozin & Mukambetov, 1980). The battery proposed by Fadeev (1994) included multiple assessments of static strength

across a range of joint actions considered to be important in Women's Artistic Gymnastics. However, relative strength, normalised according to body weight, was suggested to have greater predictive validity, given the nature of gymnastic skills (Suchilin, Head of VNIPI Sport, personal communication). Fadeev (1994) determined static strength using dynamometry, however, in the majority of test batteries static strength was estimated from functional measurements. These functional measurements required the gymnast to maintain a set body configuration, such as the half lever hang or flexed arm hang, for as long as possible (Rozin, 1979; Risack et al., 1988).

The majority of test batteries also included assessments of local muscular endurance. These were usually estimated according to the number of repetitions of a particular conditioning exercise. Exercises commonly used to assess muscular endurance included chin-ups, pressups, leg lifts, sit-ups, V-sits and reverse leg lifts (Weber, 1982; Radoulov, 1986; Bajin, 1987; Sol, 1987; Risack et al., 1988; Poelvoorde & Levarlet-Joye 1990). However, given that the majority of contemporary asymmetric bar work is completed on straight arms, the utility of specific bar-based exercises involving flexion/extension of the elbow joint, such as chin-ups, has been questioned (Stan, 1995). The more recent test batteries have focused upon tests which involve flexion and extension of the shoulder joint (Carzola & Margueritat, 1986; Fadeev, 1993, 1994).

It is interesting to observe that in a number of test batteries, a range of tests were used throughout the age range to assess the same quality/ability. In some cases, this may reflect the increases in physical capacities which are expected to occur with age. For example, standard press-ups were used to assess muscular endurance in 7 year old gymnasts while raised press-ups were used in the assessment of 8, 9 and 10 year old gymnasts (Fadeev, 1993). In addition, differences may be incorporated to reflect an age-related increase in the technical proficiency of gymnasts. This was confirmed by a number of test batteries in which physical assessments became increasingly skill based as the age of the gymnast increased. For example, repeated upstarts were introduced in the battery of Fadeev (1993) at ages 9 and above. The progression towards skill based assessments increased the level of specificity of tests.

Tests of speed-strength were included in a number of batteries. These tests used similar exercises to those reported for muscular endurance but measured the number of

repetitions completed in a specific period of time, usually 10 - 15 seconds (Fadeev, 1993; Stan, 1994). A useful protocol which combined the assessment of muscular endurance and speed-strength was proposed by Stan (1994). Six of the tests included in the battery were of this design. In this protocol, the gymnast was required to complete as many repetitions of an activity, as quickly as possible, in 60 seconds. The number of repetitions were recorded after 10/15 seconds to indicate speed-strength, 30 seconds to indicate strength-endurance and finally at 60 seconds to indicate endurance-strength.

Tests most frequently applied to assess muscular power included the standing long jump (Vankov, 1978; Rozin, 1979; Salmela et al., 1979; Radoulov, 1986; Bajin, 1987; Sol, 1987; Poelvoorde & Levarlet-Joye, 1990; Fadeev, 1993) and the standing vertical jump or jump and reach test (Vankov, 1978; Bajin, 1987; Sol, 1987; Fadeev, 1993). Attempts were made to normalise performances in jumping tests according to the height of the gymnast. Age specific coefficients were produced for both standing long jump and vertical jump (Bajin, 1987). Some batteries included assessments of plyometric power using a rebound jump or drop jump protocol (Salmela et al., 1979; Carzola & Margueritat, 1986; Risack et al., 1988; Poelvoorde & Levarlet-Joye, 1990). Finally, a number of batteries included assessments of plyometric endurance using consecutive rebound jumps (Vankov, 1978; Carzola & Margueritat, 1986; Radoulov, 1986).

Flexibility was also regarded as an important aspect of talent detection in young female gymnasts (Radoulov, 1986). Moreover, assessments of both active and passive flexibility were considered important (Salmela et al., 1979; Rozin & Mukambetov, 1980; Bajin, 1987). Flexibility or range of movement was most frequently assessed in the shoulder joint, hip joint, hamstrings, lower back, wrists and ankles. The majority of assessments, such as the bridge, were specific to gymnastics and therefore their utility in the initial detection of talent has been questioned (Klentrou, 1993). Tests were frequently scored subjectively in relation to scaled criteria, with marks deducted for faults in body posture or alignment (Fadeev, 1993).

After a thorough review of existing batteries, Klentrou (1993) concluded that the following factors were most frequently employed in the initial detection of gymnastic talent: height, weight, side splits, 20 metre run, leg lifts, standing long jump and agility tests. As expected, the range of tests commonly included in the final test battery was

more comprehensive and included the following attributes: height, weight, body proportions, 3 splits, bridge, shoulder flexibility, 20 metre run, chin-ups, standing long jump, consecutive rebounds and balance.

**Perceptual-motor characteristics**

Two components of balance ability were included in talent detection batteries. Firstly, dynamic balance, which was usually assessed using variants of a beam walking test (Peltenberg, Erich, Bernink & Huisveld, 1982; Rozin, 1986; Risack et al., 1988; Poelvoorde & Levarlet-Joye, 1990). In addition, tests of static balance have included assessments in both upright and inverted stances (Vankov, 1978; Salmela et al., 1979; Rozin, 1986; Régnier & Salmela, 1987; Sol, 1987; Poelvoorde & Levarlet-Joye, 1990). The importance of coordination in Women's Artistic Gymnastics is widely acknowledged. However, only a limited number of tests have been devised to assess coordination for the purpose of talent detection (Régnier & Salmela, 1987; Fadeev, 1993). Fadeev (1993) assessed coordination according to two criteria; the extent to which movements could be linked together smoothly and with good timing (transition) and the accuracy with which a movement or the individual phases of a movement could be perceived and reproduced (differentiation) (Fadeev, 1994). These qualities were assessed using a routine which required gymnasts to perform a quick succession of arm and leg movements. The complexity of the exercise was set according to the age and experience of the gymnasts.

Tests of kinaesthetic ability were included in only two of the test batteries reviewed (Régnier & Salmela, 1987; Fadeev, 1994). In the battery outlined by Fadeev (1994), kinaesthetic acuity was first assessed at 9 years of age. The gymnast lay in a supinated position and produced successive flexions at the hip joint. The aim of the test was to repeatedly increase the angle of flexion within a 45° - 90° range. Points were awarded for the number of successive increases in hip flexion angle. The ability to perceive muscular force was assessed in gymnasts from 7 years of age using a similar protocol (Fadeev, 1994). From the gymnast's performance in three maximal standing broad jumps targets were set at 50% and 75% of the maximum jump. The aim of the test was to gradually increase jump length within this quartile. Points were awarded for the number of

successive increases in jump length within the target range. The perception of timing test established by Fadeev (1994) required the gymnast to move between the following positions as the coach counted aloud for 16 seconds: standing position, squat support, lying support, squat support, standing position. The gymnast was then required to repeat the exercise in half the time (8 seconds) without the verbal assistance of the coach. After a set amount of practice, the time for this performance was recorded, with points deducted for any deviations from 8 seconds. The final component of kinaesthetic ability, rotation sense, was included in only one of the test batteries reviewed, the comprehensive battery proposed by Régnier & Salmela (1987).

**Psychological characteristics**

The final set of assessments frequently included in test batteries related to the personality and behavioural qualities of the gymnast and included such characteristics as will-power, daring, determination, patience and personal discipline (Rozin, 1986). The battery of Fadeev (1994) was typical of the way in which such qualities were assessed in nations of the former Eastern bloc. The personality qualities of a gymnast were assessed according to the perceptions of the coach who had observed the training process for a minimum period of one year. The following qualities were assessed through questionnaire responses using a likert scale: purposefulness, self-confidence, ability to concentrate, capacity for improvement and willingness to learn. The coach also evaluated behavioural qualities by indicating for a series of questions which of three behavioural responses was the most characteristic of each gymnast. Points were awarded according to the chosen response. Although personality factors were considered to be important in the identification and development of gymnastic talent, such information was frequently used to supplement the information derived from physical tests (Chernechenko, 1982).

In most batteries of talent detection, model characteristics were produced for each talent characteristic (Chernechenko, 1982; Fadeev, 1993). The performance of each gymnast was evaluated according to these ideal or 'model' characteristics and the decision to select the child to enter a programme or progress to the next level of training was taken accordingly. The comparison of the gymnast's performance to model characteristics also facilitated the identification of any strengths and weaknesses in the profile. In the

GYMNAPT programme normative data were established and indexed according to percentile standards (Klentrou & Bureaud, 1993). However, in the majority of test batteries, a score was awarded for the gymnast's performance on each particular test according to the comparison with normative data. Selection was frequently made according to the total score a gymnast achieved across a range of characteristics. An interesting variation to this system was adopted in the Canadian Talent Identification Programme. In this programme a success score was established for strength and flexibility which prevented a gymnast being able to compensate for poor performance in the strength tests with excellent flexibility scores and vice versa (Bajin, 1987).

The results of tests designed to identify gymnastic talent within the former Soviet Union were indexed according to their level of validity (Chernechenko, 1982). The maximum score for each parameter was dependent upon the strength of the correlation between test results and technical performance (Chernechenko, 1982; Fadeev, 1993). For example, in the assessment of 7 year old gymnasts, press-ups were awarded a maximum score of 10 points whereas chin-ups, which demonstrated a lower correlation with technical performance, were awarded a maximum score of seven points. Integral parameters were determined for each set of talent characteristics, such as muscular strength, by summating the results of individual assessments (Chernechenko, 1982; Fadeev, 1993). These integral parameters were found to have a greater prognostic value than the results of individual tests (Chernechenko, 1982). Age specific summary parameters were also established using regression analysis with weightings for the integral parameters of force, force-velocity, coordination and flexibility.

## 2.9 SUMMARY

In the preceding review, the four major limitations associated with previous research into talent identification (Burwitz, Moore & Wilkinson, 1994) were discussed. It was suggested that future research should be multi/interdisciplinary, predictive, longitudinal and based upon a sound theoretical framework. The development of sporting talent cannot be separated from the growth, maturation and development of the child. Therefore, a longitudinal approach is advocated to investigate the manner in which the chosen talent characteristics develop in the young female gymnast. The review highlighted a number of conceptual issues relating to the longitudinal nature of the talent

process which must be incorporated into the research design. In particular, the stability of talent characteristics and the biological maturity status of each individual child were outlined as important factors to be considered. It is anticipated that by adopting a longitudinal approach it may be possible to determine which characteristics define an individual as talented and how the development of those characteristics determines the readiness of children to enter each successive phase of gymnastic development.

# CHAPTER 3

# RESEARCH DESIGN

## 3.1 OVERVIEW OF THE RESEARCH DESIGN

The aim of this chapter is to provide an overview of the research design adopted and the modifications needed to address the three main purposes of the research outlined in Chapter 1. Particular reference will be made to the organisation of the practical study and the statistical analysis of results. The study was approved by the Ethical Advisory Committee of Loughborough University. A copy of the ethical submission (reference R97/26) and details of approval are provided in Appendix 3.1. The parent or guardian with legal responsibility for the gymnast was required to provide details of his/her child's medical history and a written statement of informed consent for participation in the study. A copy of the medical history questionnaire, informed consent form and information for subjects is provided in Appendix 3.2. Ethical approval was also sought to assess biological maturity status using skeletal age determined from an anterior-posterior radiograph of the left wrist. It was proposed that this aspect of the study would be conducted by the Consultant Orthopaedic Surgeon for British Gymnastics, Mr J. Aldridge. However, the Ethical Advisory Committee of Warwickshire Orthopaedic Hospital expressed concern about the exposure of children to radiation given that there were no direct benefits to the individual, as a result the procedure was excluded from the study.

## 3.2 TALENT CHARACTERISTICS AND FUTURE GYMNASTIC PERFORMANCE

As outlined in Chapter 1 the first purpose of the research was to examine the relationship between talent characteristics and future gymnastic performance and thereby determine the extent to which talent components were able to correctly classify gymnasts as successful or unsuccessful in terms of their future performance. A battery of tests was designed to measure the talent characteristics considered to have potential utility in predicting future gymnastic performance. The test battery was administered to determine the initial talent characteristics in a mixed ability sample of 45 female gymnasts, 9-11

years of age. The assessment of 36 club gymnasts took place over 3 days in September 1996 with 10 gymnasts from the National Under 12 Squad being assessed in a single session in January 1997. This assessment coincided with the first training session after squad selection. For the purpose of statistically modelling future performance, the gymnasts were combined to produce a single group, thereby increasing the size of the sample and the power of statistical tests. The performance of the gymnasts was assessed in February 1998 using a composite measure which combined competition score and technical skill acquisition (Figure 3.1).

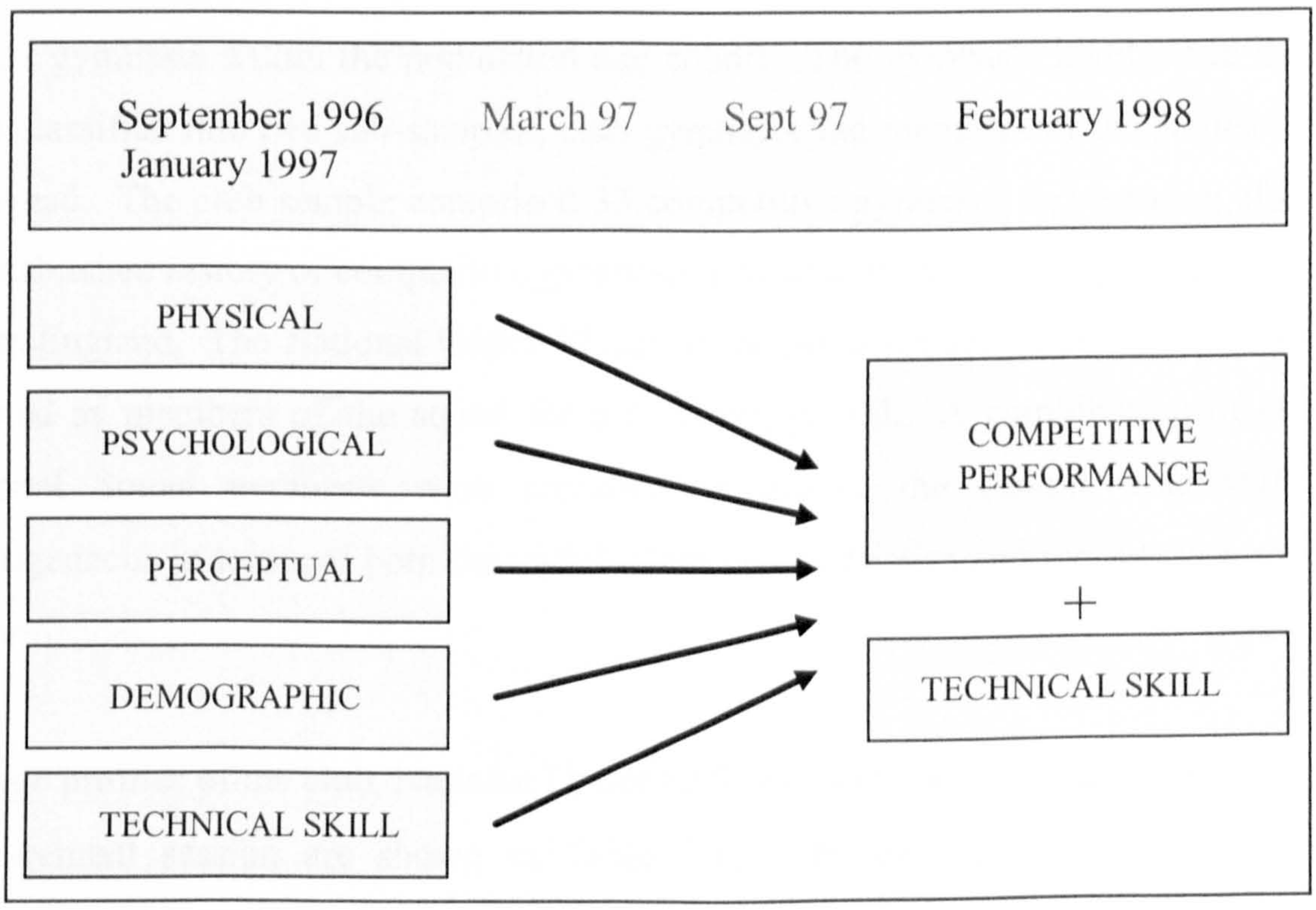



Figure 3.1. Overview of the research design used to examine the relationship between talent characteristics and 'future' performance in young female gymnasts.

While it is acknowledged that talent is a multidimensional phenomenon, the statistical constraints imposed by the small sample size precluded a multidimensional modelling approach to be adopted in the first stage of data analysis. Within each dimension of performance the initial talent characteristics were reduced to a smaller number of talent components using the data reduction technique of 'principal components analysis'. The relationship between the initial talent components and future gymnastic performance, classified as successful or unsuccessful, was examined using logistic regression analysis. The multidimensional nature of the relationship was subsequently examined by considering the relative importance of the initial talent components from each

performance dimension previously identified as significant predictors of future performance.

All clubs with representatives in the 1996 National Grade Finals were invited to participate in the study. Due to geographical constraints and the considerable time commitment required from subjects, it was not possible to obtain a truly random sample. Six clubs agreed to participate in the longitudinal investigation and representatives of the National Under 12 Squad were recruited for a single data collection session. Within the imposed constraints the sample was considered to be representative of competitive young female gymnasts within the population age cohort. The gymnasts involved in the study were classified into two sub-samples, club gymnasts and members of the National Under 12 Squad. The club sample comprised 33 competitive gymnasts representing clubs with an established history of competitive gymnastics located in various geographical locations across England. The National Under 12 Squad sample consisted of 10 gymnasts recently selected as members of the squad for a 6 month period. A combination of club and National Squad gymnasts were recruited to ensure the sample was sufficiently heterogeneous in terms of both the initial talent characteristics and the future competitive performances.

The age profiles of the club, National Under 12 Squad and combined samples at the initial measurement session are shown in Table 3.1. The decimal age of gymnasts was determined using tables. For classification purposes, the gymnasts' age on the day of measurement was rounded to the nearest year. For example all gymnasts with a decimal age between 8.50 and 9.49 years were classified as 9 year olds. During the time interval between the initial measurement sessions (September 1996 - January 1997) and the assessment of future performance (February 1998) 10 club gymnasts or 23.3% of the combined sample retired from the sport and therefore dropped out of the study. The data obtained from these gymnasts were not included in the statistical analyses. Table 3.2 shows the mean decimal age at the first testing session of those gymnasts who completed the study and therefore whose data were included in the principal components and logistic regression analyses.

Table 3.1. The age profile of gymnasts during the assessment of initial talent characteristics

| | Club (Sept96) | | U12 (Jan 97) | | Combined | |
|---|---|---|---|---|---|---|
| | (n) | mean ± SD | (n) | mean ± SD | (n) | mean ± SD |
| all age groups | (n=33) | 9.40 ± 0.54 | (n=10) | 10.28 ± 0.49 | (n=43) | 9.61 ± 0.64 |
| 9 year olds | (n=20) | 9.03 ± 0.26 | (n=1) | 9.44 | (n=21) | 9.05 ± 0.27 |
| 10 year olds | (n=13) | 9.98 ± 0.27 | (n=6) | 10.15 ± 0.33 | (n=19) | 10.03 ± 0.29 |
| 11 year olds | | | (n=3) | 10.81 ± 0.05 | (n=3) | 10.81 ± 0.05 |

Table 3.2. The age profile of the sample of those gymnasts who completed the study at the initial measurement session

| | Club (Sept96) | | U12 (Jan 97) | | Combined | |
|---|---|---|---|---|---|---|
| | (n) | mean ± SD | (n) | mean ± SD | (n) | mean ± SD |
| all age groups | (n=23) | 9.35 ± 0.51 | (n=10) | 10.28 ± 0.49 | (n=33) | 9.63 ± 0.66 |
| 9 year olds | (n=16) | 9.06 ± 0.26 | (n=1) | 9.44 | (n=17) | 9.08 ± 0.26 |
| 10 year olds | (n=7) | 10.02 ± 0.27 | (n=6) | 10.15 ± 0.33 | (n=13) | 10.08 ± 0.28 |
| 11 year olds | | | (n=3) | 10.81 ± 0.05 | (n=3) | 10.81 ± 0.05 |

**Talent characteristics**

Characteristics were selected for inclusion into the test battery as a result of a theoretical review, the analysis of elite international gymnasts, and a review of the existing literature and world systems of talent identification. A questionnaire was designed and administered to 10 nations who regularly experienced success in international gymnastic competition, to gain an insight into those talent characteristics measured most frequently in the selection procedures of successful gymnastic nations (available on request from Loughborough University). The test battery is depicted in Figure 3.2 and included talent characteristics from physical, perceptual, psychological and social-demographic

dimensions of performance. All assessments were laboratory based with the exception of tests for local muscular endurance. A pilot study was conducted to determine the feasibility of the assessment battery with an age-matched sample of young female gymnasts. A test-retest study was employed to determine the reliability of the initial talent characteristics. Details of the pilot and test-retest studies are provided in Sections 3.5 and 3.6 respectively.

| PHYSICAL | PERCEPTUAL | PSYCHOLOGICAL | DEMOGRAPHIC |
|---|---|---|---|
| anthropometry<br>inertia<br>strength<br>muscular endurance<br>power<br>flexibility | kinesthesis<br>balance<br>postural sway | goal orientation<br>sport enjoyment<br>perceived competence<br>motivational climate | gymnastic facility<br>training time<br>training intensity<br>coach education<br>geographical location |

Figure 3.2. Test battery of initial talent characteristics.

**Administration of the test battery**

Administration of the test battery required six trained 'measurers' and four additional personnel and took approximately 4 hours to complete for 10 subjects. Gymnasts were accompanied by a coach and/or parent who remained present for the duration of the testing. The measurement session was divided into two rotations. Gymnasts worked in groups of 3-4 during the first rotation and in pairs during the second rotation.

The order of isometric strength tests, jumps and sways was balanced across subjects to control for order effects. Further details of the randomisation procedure and details of the methodology of individual tests is provided in subsequent chapters.

| | | |
|---|---|---|
| Rotation 1: | station 1 | anthropometry |
| | station 2 | isometric strength |
| | station 3 | self-concept questionnaire |
| | station 4 | demographic questionnaire |
| Rotation 2: | station 1 | inertia & goal orientation questionnaire 1 |
| | station 2 | jumps & sways |
| | station 3 | functional & clinical flexibility & goal orientation questionnaire 2 |
| | station 4 | perception of force & matching, goal orientation questionnaire 3 and competitiveness questionnaire |
| | station 5 | balance, perception of rotation, timing and pointing |

**Assessment of gymnastic performance**

Previous investigations have used competition score as the sole index of performance (Régnier & Salmela, 1987; Sol, 1987). However, given that young female gymnasts are continually acquiring and competing new skills, competitive instability is to be expected and therefore this index alone was considered to be inappropriate. As a result gymnastic performance was assessed as a composite measure which combined the gymnasts' level of technical skill acquisition and competition performance.

**Technical skill acquisition**

The technical skill level of gymnasts was assessed according to the recommendations for skill development produced by the Performance Director for Women's Artistic Gymnastics in Great Britain, Adrian Stan (Stan, 1994). The recommendations consist of age-specific skill development targets for gymnasts of various competitive levels (club, county, regional, national, international) for five areas (vault, bars, beam, floor, choreography). The mean decimal age of the gymnasts on the date of the competition was 10.96 ± 0.58 years and therefore the skill development targets for 11 year old gymnasts aspiring to be national standard were chosen. Details of the assessment protocol together with examples of blank and completed assessment charts are included in Appendix 3.3.

To increase the objectivity of measurement, the assessments were completed by an experienced high performance coach who was also a National Judge and had no role in the laboratory based assessment of talent characteristics. The purpose of the assessment, to assess the stage of skill development, was explained to the gymnasts and coaches. Gymnasts were asked to perform at the level they were currently training and not to attempt skills of which they had no previous experience. Gymnasts were asked to perform each skill twice with their performance being assessed according to the following scoring system:

0 gymnast has no awareness /experience of the skill

1 gymnast has developed an awareness and understanding the concept of the skill but has not attempted the skill or progressions for the skill

2 gymnast attempts progressions for the skill or parts or phases of the skill in isolation

3 gymnast performs the complete skill with support of the coach or additional matting as required

4 gymnast completes the skill unassisted but frequently makes major mistakes

5 gymnast is able to complete the skill unassisted within a combination or routine

6 gymnast is able to complete the skill 'perfectly' as in a competition situation

The scoring system permitted the assessor to downgrade the level of development for a particular skill as necessary. For example, if a gymnast performed a skill unassisted but extremely poorly, the assessor was permitted to 'downgrade' the skill level from 4 to 3 to reflect the level at which the skill could be performed safely. The gymnast's awareness and understanding of skills was assessed verbally.

**Competition performance**

A National level competition sponsored by the English Sports Council (Sport England) was organised to assess competitive performance. The competition was judged according to the FIG modified code (1997-2001) with panels of four Brevet/National judges per apparatus. Details of the competition rules and requirements for the FIG modified code are provided in Appendix 3.4. Competition attendance was disappointing with only 17 of

the 33 gymnasts who completed the study participating. The remaining gymnasts failed to compete citing injury, illness and holidays as reasons for non-participation. However, scores were derived for seven of the non-participants who competed in the British Schools Gymnastics Association Junior Championships two weeks later which was also judged according to the FIG modified code. The relationship between technical skill acquisition and competition score was obtained for those gymnasts who competed in IGA and BSGA competitions using linear regression. Competition scores for the nine non-participants were estimated using the regression equation presented in Figure 3.3.

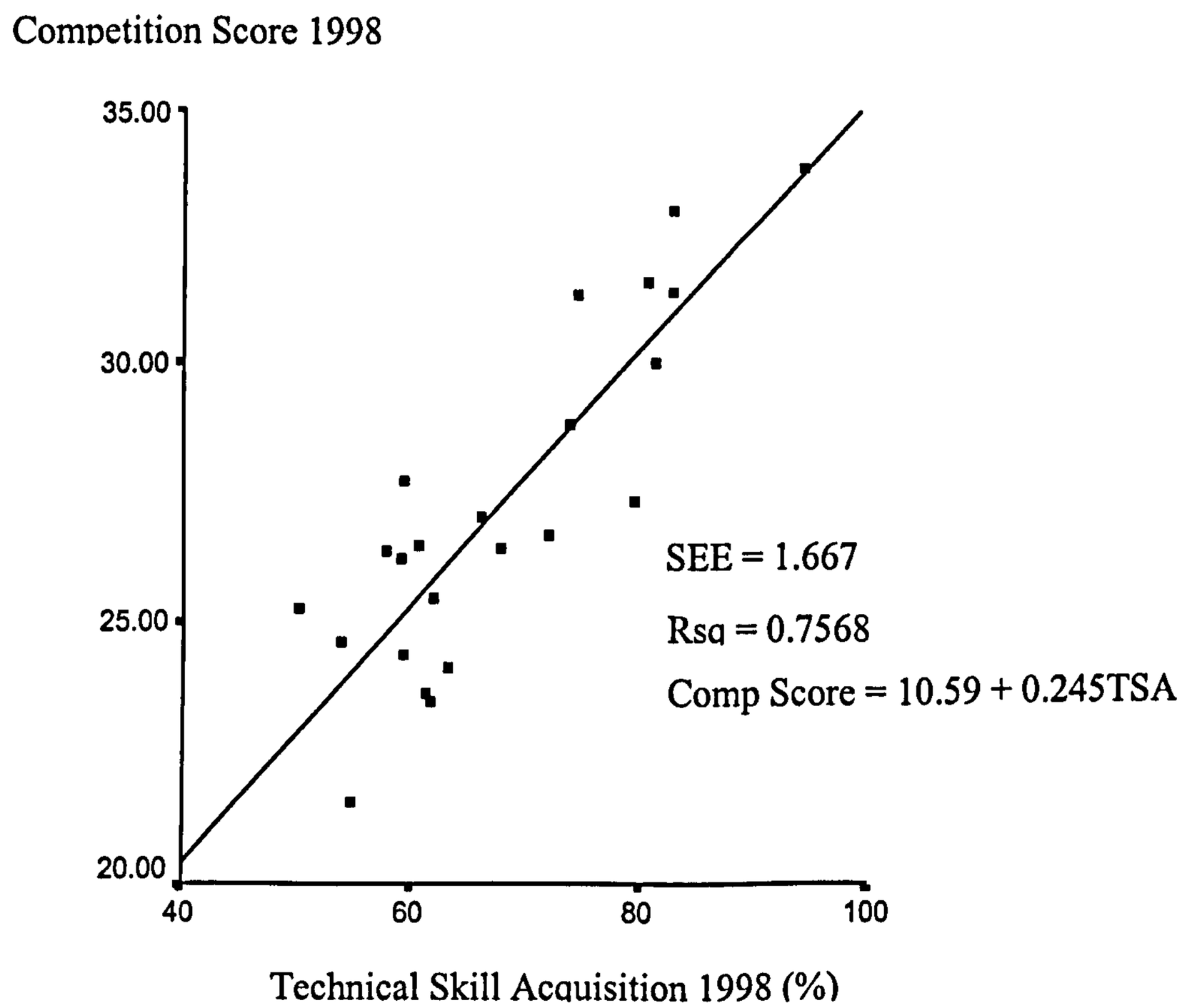



Figure 3.3. Linear regression between competition score and technical skill acquisition.

The F ratio for the regression model was significant at the 1% level which indicates that the proportion of variance explained by the regression model is significantly greater than the proportion of variance explained using the mean competition score. The statistical power of the F ratio calculated at the 1% level of significance was greater than 99% (Cohen, 1988). The adjusted coefficient of determination ($R^2$) provides an estimation of the explanatory power of the regression equation and suggests that approximately 75.6% of the variation in competition score about the mean is explained by the technical skill acquisition score. The standard error of the estimate (SEE) is a measure of prediction

accuracy that represents the average estimate of the error for all points about the regression line. In the present example, 95% of scores will be expected to lie within ±3.267 of the predicted score (±1.96*SEE).

Raw competition scores were expressed as a percentage of the score of the highest scoring gymnast. The scores for technical skill acquisition were adjusted similarly. The performance of gymnasts was classified as successful or unsuccessful according to the average percentage score. A score of 80% was defined as the cut off point with gymnasts scoring 80% or greater being defined as successful and gymnasts scoring less than 80% defined as unsuccessful. Within Great Britain, the 80% cut off level is used to determine whether gymnasts follow the elite or club programme. All members of the National under 12 Squad were classified as successful performers at the end of the study together with two of the club gymnasts. Performances of the gymnasts in competition supported the results of this classification. Details of the performance scores are provided in Appendix 3.5.

**Records of training**

Coaches were required to complete a training diary for each gymnast for the two weeks following each data collection session. The training diary was anticipated to provide a record of the nature of training, its frequency, duration and intensity. However, the precision with which these diaries were completed varied between coaches and hence the information was considered to be of limited use.

**Additional information**

To supplement the information generated from the assessment battery, all participants were required to provide details of any injuries sustained during the study, diagnosis, treatment and training time lost as a direct result of the injury. In the event of retiring from the sport, gymnasts were asked to complete a retirement form outlining their reasons for retiring. The coach and parent of the gymnast were also asked to provide their perception of why the gymnast had retired. Only a limited number of retirement forms were completed.

## Statistical analysis

Statistical analysis was completed using SPSS 8.0 for Windows.

### *Missing data*

In principal components analysis, missing data for a single talent characteristic results in the exclusion of that case for all talent characteristics, therefore missing data were estimated according to the following procedures. Missing data from club gymnasts in September 1996 were estimated from the values obtained in March 1997 corrected for the average difference between the March 1997 and September 1996 measurements. Where data were missing from the National Under 12 Squad gymnasts and no subsequent data were available, the missing data were replaced with the mean of the National Under 12 Squad sample. Finally, local muscular endurance data missing from club and squad gymnasts were estimated from the values obtained in September 1997 corrected for the average difference for the relevant group between September 1997 and September 1996 measurements.

### *Data screening*

Tabachnick & Fiddell (1989) reported that departures from normality may result in degradation of the factor solution, therefore the data were screened for skewness and kurtosis. Positively skewed data were transformed using a logarithmic transformation and negatively skewed data were reflected prior to logarithmic transformation. The normality of the transformed data was subsequently examined. Where skewness and kurtosis were reduced to acceptable levels the variables were retained in their transformed state, however, where non-normality persisted the variables were excluded from all subsequent analyses.

### *Principal components analysis*

Using a combination of raw and transformed data, principal components analysis was conducted to reduce the large number of reliable variables to a smaller number of components. In order to ensure an appropriate ratio of variables to cases, the talent characteristics within the physical and perceptual dimensions were initially grouped into

categories with separate analyses conducted within each category. To confirm the suitability of each data set for principal components analysis the correlation and partial correlation matrices were examined (Hair et al., 1995). The extent to which inter-correlations were present within the data was quantified using the Bartlett test of sphericity and the Kaiser-Meyer-Olkin measure of sampling adequacy. Upon confirmation of an appropriate data structure, an initial factor solution was computed using the latent root criterion with components identified with an eigenvalue greater than one. The initial factor solution was rotated using orthogonal rotation (varimax criterion). Orthogonal rotation was considered to be appropriate given that the aim of data reduction was to produce a set of independent components for subsequent entry into a logistic regression model (Hair et al., 1995).

The components were interpreted and mean scores derived for each component computed according to the magnitude and sign of the factor loadings. The raw variables were standardised using the z transformation and each standardised variable was assigned a weighting for each component. Variables with an absolute loading greater than 0.6 on a component were assigned a weighting of 1 with the sign of the weighting the same as the sign of the loading. Therefore all variables with a component loading greater than +0.6 were assigned a weighting of +1 and all variables with a component loading less than -0.6 were assigned a weighting of -1. All other variables were assigned zero weightings. The standardised raw scores were multiplied by their weighting and averaged to compute a mean score for each component. The use of raw scores simplified the interpretation of components and was considered appropriate given that the mean of several samples will approximate a normal distribution even if the population from which the samples are drawn deviates from normality (central limit theorem, Vincent, 1995). The use of a mean scale was selected in preference to the calculation of factor scores given the potential reduction in the size of the test battery that may be achieved while retaining the meaning of the rotated components. Moreover, the summated scale has been reported to be easily replicated in future samples (Hair et al., 1995).

*Logistic regression analysis*

Logistic regression examines the relationship between one or more independent variables and a dichotomous dependent variable. For example, in the current investigation logistic

regression will be used to determine which linear combinations of talent components can be used to classify gymnasts as either successful or unsuccessful. The problem with expressing the probability of an event occurring as a linear function is that predicted values for the probability may lie outside the range [0,1]. If instead the probability of an event occurring is expressed as the ratio of an event occurring to the probability that the event does not occur, the range of possible values for this function becomes $(0,+\infty)$. This function is called the 'odds' that an event will occur and may be calculated as follows:

$$\text{Odds}(Y=1)=\frac{P(Y=1)}{1-P(Y=1)} \qquad (3.1)$$

where: P(Y=1) is the probability that Y will equal 1 (the gymnast will be successful) (Menard, 1995).

However, expressing the odds as a linear function may also lead to predicted values less than zero. Therefore, the next step which is taken produces a function whose values range from $-\infty$ to $+\infty$. By taking the natural logarithm of the odds we have a function that tends to $-\infty$ as the odds decrease from one to zero (that is a probability of less than 0.5) and increases to $+\infty$ as the odds increase above one (probabilities greater than 0.5). Therefore, there is no longer the problem of estimating values which exceed the limits of the function. The log of the odds (logit (Y)) is the dependent variable within the logistic regression and is expressed as a linear combination of the independent variables. From the logit, the probability of an event occurring may be estimated. By exponentiating the logit and using the relationship between the odds and the probability, the probability of an event occurring may be expressed as follows:

$$P(Y=1)=\frac{1}{1+e^{-z}} \qquad (3.2)$$

where P(Y=1) = the probability of a gymnast being successful

and z = logit (Y) the linear combination of the independent variables

(Menard, 1995).

Therefore, for any values of the independent variables, given the logit we may calculate the probability of an event occurring. All probabilities will lie between 0 and 1 on the logistic regression curve shown in Figure 3.4. Within logistic regression, a probability threshold is established to enable cases to be classified in accordance with the dichotomous dependent variable. In the present investigation, the threshold was set at 0.5. Therefore those gymnasts with an estimated probability of future success equal to or greater than 0.5 were classified as 'successful' while those with an estimated probability of future success less than 0.5 were classified as 'unsuccessful'.

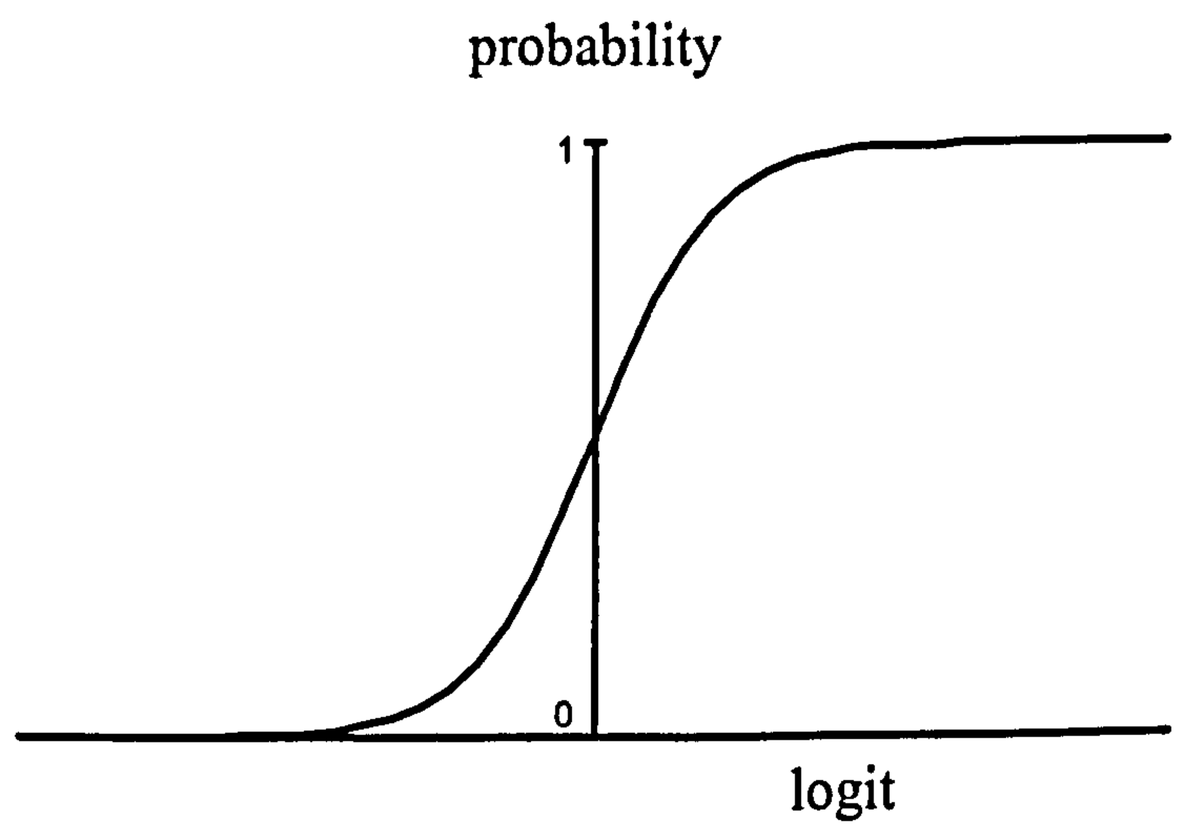



Figure 3.4. The 'S' shape of the logistic function.

Unlike linear regression which uses the ordinary least squares approximation to estimate the parameters within the regression model, logistic regression relies upon the method of maximum likelihood estimation. This method involves the construction of the 'likelihood function', which expresses the probability or likelihood that the observed data will be obtained given the values of the unknown parameters (Kleinbaum, 1994; Menard, 1995). Through the process of iteration, the method of maximum likelihood determines the values of the regression parameters which maximise the probability that the observed data set will be obtained (Hosmer & Lemeshow, 1989; Kleinbaum, 1994). By convention the likelihood is expressed as -2*log (likelihood) and therefore large values indicate that the model does not fit the observed data closely. The extent to which the inclusion of independent variables improves the fit of the model may be determined by assessing the change in the log likelihood.

Within each dimension of performance, logistic regression analyses were conducted to investigate the relationship between the identified talent components and future gymnastic

performance. The extent to which the talent components were able to correctly classify the future performance of gymnasts as successful or unsuccessful was also determined. In regression analysis, five cases for each independent variable is considered to be the minimum acceptable ratio (Tabachnick & Fiddell, 1989). To maintain this ratio within the physical and perceptual-motor dimensions separate regression models were produced within each category of variables. The components included in the final regression model within each category were subsequently treated as independent variables to produce a single model for each dimension.

Prior to conducting the logistic regression analysis the degree of multicollinearity among the independent variables was estimated. Multicollinearity refers to the extent to which the independent variables within a regression model are correlated (Pedhazur & Schmelkin, 1991). High levels of multicollinearity in logistic regression tend to inflate the standard errors of the regression coefficients and may result in the failure of even large regression coefficients to attain statistical significance (Menard, 1995). Models were examined for multicollinearity by conducting a series of linear regressions with each independent variable in turn treated as the dependent variable and regressed against all other independent variables included in the model (Menard, 1995; Hair et al., 1995). An estimate of tolerance, which indicates the amount of variance in the particular independent variable which is not explained by the linear combination of all other independent variables in the model was obtained by calculating $1-R^2$. In line with recommendations by Menard (1995) tolerance values less than 0.2 were considered unacceptable. It was anticipated that the selection of orthogonal rotation in the principal components analysis would limit the likelihood of multicollinearity problems.

Examination of the age profiles presented in Table 3.3 reveals that the successful gymnasts were older than the unsuccessful gymnasts. In order to control for age differences in the logistic regression analysis a forced entry procedure was adopted with standardised decimal age 'forced' to be the first variable entered into the regression model. The remaining components were entered using stepwise procedures and the extent to which the talent components improved the fit of the model or reduced the error of prediction over and above the effect of decimal age was determined.

Table 3.3. The age profile of successful and unsuccessful gymnasts at the initial measurement session

| successful gymnasts mean ± SD (years) | Unsuccessful gymnasts mean ± SD (years) |
|---|---|
| 10.03 ± 0.74 (n=12) | 9.28 ± 0.63 (n=21) |

Both forwards and backwards stepwise methods of entry were conducted for each regression model. Only those interactions deemed theoretically appropriate were considered for entry into the regression model. The backward stepwise entry procedure was included to enable suppressor effects as described by Menard (1995) to be identified. In line with recommendations by Bendel & Afifi (1977) independent variables were included/retained in the model if the change in the likelihood-ratio was statistically significant at the 20% level. It is acknowledged that this conservative significance level may increase the incidence of type I errors, however, the threshold was considered to be appropriate given the exploratory nature of the investigation.

The validity of the logistic regression model may be evaluated according to the extent to which the model 'fits' the data or is able to accurately predict that an event will or will not occur. The results of model fit and prediction accuracy frequently but not necessarily produce equivalent results (Menard, 1995). The main aim of the current study is to correctly classify gymnasts as successful or unsuccessful in terms of their future performance and therefore indicators of the predictive efficiency of the model will be accorded primary importance. The goodness of fit for each regression model will be estimated in terms of the proportional reduction in the log likelihood ($R^2_L$) (Menard, 1995). In accordance with the main goal of talent identification, to classify individuals according to their likelihood of future success, a number of indices will be calculated to determine the accuracy with which each regression model is able to correctly classify the future performance of gymnasts. For each model, classification tables will be presented together with a quantitative estimate ($\lambda$) of the predictive efficiency of the model, calculated according to the following equation:

$$\lambda = ((c+d)-(c+b))/(c+d) \qquad (3.3)$$

where:

b = number of cases incorrectly classified in the largest group

c = number of cases incorrectly classified in the smallest group

d = number of cases correctly classified in the smallest group

Lambda indicates the extent to which errors of misclassification are reduced by the inclusion of each independent variable or block of independent variables. The statistical significance of $\lambda$ may be determined by calculating the d statistic, which approximates a normal distribution (Menard, 1995):

$$d = \frac{\left(\frac{c+d}{N} - \frac{c+b}{N}\right)}{\sqrt{\frac{\left(\frac{c+d}{N}\right) * \left(1 - \frac{c+d}{N}\right)}{N}}} \qquad (3.4)$$

For the final model produced within each dimension of performance the relative importance of each independent variable will be ascertained. Where appropriate each variable in isolation will be increased and decreased by one standard deviation to determine its effect on the probability of being classified as successful or unsuccessful.

## 3.3 CLASSIFICATION OF GYMNASTS AND CONTROLS

A similar analytical approach was adopted to investigate the extent to which the talent characteristics were able to distinguish between gymnasts and untrained control subjects. A reduced version of the assessment battery comprising selected physical and perceptual-motor characteristics was administered to a group of 15 age matched control subjects. The reliability of the measurements was confirmed for control subjects using test-retest procedures in an associated study (Gill, 1999). As outlined in Section 3.2 principal components analyses and logistic regression were conducted to determine the extent to which the derived talent components explained variability in the data (model fit) and were able to correctly classify gymnasts and untrained controls (predictive efficiency). The mean ages of the gymnasts and control subjects were similar, however the forced entry

procedure described in Section 3.2 was retained in the light of the relatively large standard deviations (Table 3.4).

Table 3.4. The age profile of the combined population of gymnasts and the control subjects at the initial measurement session

| gymnasts<br>mean ± SD (years) | Controls<br>mean ± SD (years) |
|---|---|
| 9.61 ± 0.64<br>n=(21) | 9.73 ± 0.71<br>(n=15) |

## 3.4 LONGITUDINAL STABILITY

The final purpose of the study was to provide an insight into the longitudinal development of talent characteristics and their stability and sensitivity to development in the context of gymnastic training. Gymnasts in the club sample completed the battery of laboratory based tests in September 1996 and on two further occasions (March 1997 and September 1997 respectively) each separated by a six month interval. The field based assessments (technical skill acquisition and local muscular endurance) were completed at the beginning of the practical study and approximately 12 months later. The field based testing took approximately three months to complete with the majority of assessments taking place during evenings and weekends. For both field and laboratory based assessments the order of testing was balanced between subjects during the initial measurement session. This order was retained in all subsequent assessment sessions. The measurement team was identical in all three measurement sessions.

Details of the mean decimal age of gymnasts in the club sample at each of the laboratory based testing sessions are provided in Table 3.5. One gymnast was a member of the Under 12 National Squad but attended all three measurement sessions with her club, therefore her data were included in the longitudinal component of the investigation. Only data from those gymnasts who completed the study were included in the longitudinal analysis.

Table 3.5. The age profile of gymnasts at each of the laboratory measurement sessions

| | Sept 96 | | March 97 | | Sept 97 | |
|---|---|---|---|---|---|---|
| | (n) | mean ± SD | (n) | mean ± SD | (n) | mean ± SD |
| combined sample | (n=24) | 9.38 ± 0.53 | (n=24) | 9.90 ± 0.50 | (n=24) | 10.38 ± 0.53 |

**Statistical analysis**

*Missing data*

Within the statistical procedures used to assess the longitudinal stability of the talent components, missing data for a single talent component resulted in the exclusion of the case for that talent component only and therefore no adjustments were made to estimate or replace missing data.

**Longitudinal stability**

Longitudinal stability, defined as the maintenance of relative ranks, was determined using Spearman's rank order correlations. Autocorrelations were computed between talent components measured in September 1996 and March 1997 (time 1 and time 2), March 1997 and September 1997 (time 2 and time 3) and September 1996 and September 1997 (time 1 and time 3). The strength of the correlations was assessed according to the classification proposed by Malina (1996b) with correlations defined as low (<0.30), moderate (0.30-0.60) and high (>0.60).

## 3.5 PILOT STUDY

A pilot study was conducted to examine the extent to which the test battery, assessment protocol and instructions were suitable for the population of young female gymnasts under investigation. A sample of five competitive gymnasts completed the battery of tests on two separate occasions with an interval of 72 hours separating the measurement sessions. After the first testing session modifications were made to the test battery in

response to observations by the measurement team to enhance the validity and reliability of assessments. The modified test battery was completed by gymnasts in the second measurement session and retained in its entirety for all testing sessions included in the main investigation.

## 3.6 TEST-RETEST RELIABILITY

Reliability was assessed in a sample of ten gymnasts using a test-retest protocol with a 72 hour interval between measurement sessions. The mean decimal age of the gymnasts involved in the reliability study was 9.81 ± 0.77 years. Test-retest reliability of physical and perceptual-motor characteristics was estimated using a modification of the limits of agreement method (Bland & Altman, 1986) as recommended by Nevill (1999, personal communication). To overcome the problem of heteroscedasticity commonly observed in ratio data, the raw test-retest data were logarithmically transformed (Nevill, 1997; Atkinson & Nevill, 1998). The mean difference and standard deviation of the differences between the logarithmically transformed test and retest scores were reported to indicate the systematic bias and variability respectively. In line with the recommendations by Nevill (1999, personal communication) physical variables were considered to demonstrate adequate reliability if bias did not exceed 0.05 and variability was not greater than 0.12. To reflect the nature of the data within the perceptual-motor dimension the threshold level required to conclude adequate reliability was more conservative. All variables failing to demonstrate an acceptable level of bias or variability were classified as unreliable and excluded from all subsequent analyses.

## 3.7 SUMMARY

The research design described above will be used to examine the relationship between talent characteristics within the social-demographic, physical, perceptual-motor and psychological dimensions of performance. Within each chapter specific modifications will be made in accordance with the nature of the data. Details of these modifications will be provided, with justification, in the relevant sections.

# CHAPTER 4

# SOCIAL & DEMOGRAPHIC CHARACTERISTICS

## 4.1 INTRODUCTION

Over the past two decades there has been considerable research interest in the process of talent identification and development and in the contribution of social and environmental factors to the development of elite athletes across a range of sports (Bloom, 1985; Hemery, 1991; Rowley, 1992a; Rowley & Baxter-Jones, 1995; Ericsson et al., 1993; Salmela, 1994). In a series of studies, elite athletes, their parents and coaches have retrospectively provided personal accounts of talent development (Bloom, 1985; Hemery, 1991). This case study approach has highlighted remarkable similarities in the process of talent development and in particular in the social environment experienced by elite athletes and expert performers across a diverse range of talent fields. The TOYA study was one of the few studies to apply quantitative and qualitative techniques to investigate the social environment of current junior athletes (Rowley, 1992a; Rowley & Baxter-Jones, 1995). In the first investigation, the participation motives and socio-demographic characteristics of junior athletes training in football, swimming, tennis and gymnastics were compared. Subsequently, the athletes were divided into four groups and the differences between highest and lowest achieving groups were investigated. Collectively, these studies have raised awareness of the prognostic value of social and environmental factors in the identification and future development of talent.

The interest in social factors has led to the decline in the popularity of models of talent identification based upon innate talent characteristics. A considerable amount of contemporary research has reflected this shift towards empirical determinism, with particular emphasis directed towards determining the importance of deliberate practice (Ericsson et al., 1993). Although research studies have not directly examined the role of deliberate practice in gymnastics, training time has been reported to be positively associated with attainment in Rhythmic Gymnastics (Hume, Hopkins, Robinson, Robinson & Hollings, 1993) and an important predictor of current performance at all age groups in Men's Artistic Gymnastics (Russell, 1987a, 1988; Salmela, 1994).

The social situation and in particular the home environment has been reported to be a critical factor in the development of sporting talent (Bloom, 1985; Fisher & Borms, 1990). In addition, factors associated with the training environment including the quality, proximity and availability of the training venue and the quality of the coach are regarded to be important considerations (Russell, 1987a; 1988; Singer & Janelle, 1999). However, most studies which have investigated the identification and development of talent in Women's Artistic Gymnastics have neglected to include social and demographic characteristics (Russell, 1987a, 1988). Instead, authors have merely alluded to the importance of these factors when the more 'scientific' characteristics failed to differentiate between various groups of gymnasts (Lindner, Caine & Johns, 1991; Claessens & Lefevre, 1998). The purpose of this chapter is to examine the relationship between selected social, situational and demographic characteristics and future performance in young female gymnasts. In addition, the extent to which these characteristics are able to differentiate between gymnasts classified as successful and unsuccessful competitors will be examined.

## 4.2 REVIEW OF LITERATURE

In his seminal study, Bloom (1985) retrospectively examined the process of talent development in 120 American expert performers via a series of structured and semi-structured interviews with the performers and significant others. Six categories of performers were included in the study representing three domains of expertise; athletic (swimmers and tennis players), artistic (concert pianists and sculptors) and cognitive (research mathematicians and research neurologists). Each performer was judged according to a number of criteria to be one of the top 25 performers in the world within their respective talent field. Despite being drawn from such diverse fields, Bloom (1985) reported remarkable similarities in the process of talent development and proposed three phases of talent development, which were classified as the early, middle and later years. Rather than distinct periods, the phases were conceptualised 'as signposts along a continuous path' (Bloom, 1985) The phases have been used as a conceptual framework in subsequent research to permit a clearer understanding of the process of talent development and the transitions an athlete experiences from the initiation of the sporting career through to its termination at retirement (Salmela, 1994). A brief overview of the

original phases proposed by Bloom is provided below with the salient features of each phase summarised in Table 4.1.

The main feature of the early years was that children derived a positive experience of the talent field. This phase was best described as a period of recreation, fun and excitement in which the interests of the child were encouraged and they became engrossed in the activity. The parents were supportive of the child's interests and played an important role in organising the child's time, encouraging practice and although frequently by chance, they selected a suitable mentor. The initial teacher was selected on the basis of his/her ability to work with children, indeed personality and interpersonal skills were regarded to be a far more important consideration than technical ability or coaching prowess:

> 'The criterion at this point was the teacher's ability to work with children. The parents wanted the beginning teacher to teach the fundamentals of the field in an enjoyable way. They wanted children to learn, but the children's interests were to be encouraged, not squelched by a teacher who was too "harsh" or too "demanding" ... being "good with children" was more important than the teacher's technical expertise.'
>
> (Sloane, 1985 pp.452).

This pattern was subsequently confirmed in a study of elite male tennis players in Sweden, the majority of whom initially worked with a coach who possessed good interpersonal skills rather than a high level coaching qualification (Carlson & Engstrom, 1988 op cit. Fisher & Borms, 1990). However, Bloom reported that in most cases, the first coaches were proficient teachers of the basic requirements of the sport and were adept at using praise and reinforcement to secure rapid progress. Towards the end of the early years the children became increasingly committed to the talent field. They derived inspiration from their successes and from the acclaim of their parents, but the motivation for participation changed from a desire to please significant others which was characteristic of the early years and became increasingly internal.

Table 4.1. Phases of the talent development model (Bloom, 1985)

| | Situation | Athlete | Parent | Coach/mentor |
|---|---|---|---|---|
| Early years | enter talent field by chance<br>positive experience<br>fun, play & enjoyment | learn to love the field<br>motivated to please others<br>competitive<br>pursued other activities | valued the talent area<br>emphasised the work ethic<br>child centred<br>encouraging and supportive | good with children<br>foster interest and excitement<br>motivate with approval/praise |
| Middle years | | increased commitment<br>increased training time<br>increased effort<br>sacrificed other activities | increased commitment<br>time, finance and emotional support<br>became sporting families | good technical knowledge<br>demanding<br>perfectionist<br>respected |
| Later years | | complete commitment<br>extreme intensity & hard work<br>increasingly self directed | less direct influence<br>moral and supportive role | master within the field<br>rigid disciplinarian<br>demands respect and authority<br>more collaborative relationship |

The middle years were characterised by an increased commitment to the talent field. The serious training began in earnest and the demands upon the individual increased in terms of the time spent practising the activity and the increasingly technical nature of the training. Typically parents sought a new teacher at the beginning of this second phase who was acknowledged to be proficient in the talent field. The relationship between coach and performer changed from a warm loving bond to a relationship based upon respect, authority and discipline. Parents assumed a less direct role in the process of talent development, but made an enormous contribution in terms of both emotional and financial support and their willingness to restructure their lives to accommodate their child's sporting schedule. The child became engrossed in the talent field and were expected to prioritise their participation and to pursue training at the expense of other competing activities. Children began to define their identify in terms of their talent field, regarding themselves for example, as 'swimmers' rather than children who swam.

In the later years, the performers were completely committed to their talent field, spending tremendous amounts of time practising and perfecting specific aspects of their performances. The performers were often enrolled with master teachers, who in the athletic field for example had a history of working with great athletes and champions. These coaches demanded an enormous amount of effort from the performers in terms of training time and attention to detail. The performers progressively began to contribute to the decisions and the relationship between performer and teacher became increasingly based upon mutual respect. The role of the parents was mainly to provide the continued financial and emotional support to the performer.

The home environment and in particular, the characteristics of the parents were considered to be important factors in the development of talented performers. The parents of the expert performers studied by Bloom (1985) appeared to share three main characteristics in common. Firstly, they valued the talent area in which their child would eventually excel and actively encouraged their child's participation and progress in this area. Secondly, they were strongly committed to the work ethic and conveyed its beliefs to their children. They stressed the importance of hard work and doing one's best irrespective of the activity. Finally, the families of the expert performers were remarkably 'child centred', to such an extent that they were prepared to reschedule their lives to accommodate and support their child's talent.

In a similar qualitative investigation Hemery (1991) conducted a series of semi-structured interviews with elite international competitors who were or had been classified as the best performers in their chosen sport or event. Three steps or phases consistently emerged from these interviews which were in broad agreement with the phases of talent development identified by Bloom (1985). Firstly, the athletes were introduced to sport as an activity that was fun and which they found inherently enjoyable. In the second stage of development, the basic skills of the sport were introduced in an un-pressurised environment. It was not until the third stage that the athletes were 'pushed' to succeed and in the majority of cases the pressure to achieve primarily came from the athletes themselves. It was particularly evident from the retrospective accounts detailed by both Bloom (1985) and Hemery (1991) that the athletes who went on to reach the top of their field did not experience the intense demands of training and the pressures of competitive sport until they were caught up in the activity and had fostered an internal commitment to the event or discipline in which they would later excel. Both studies also highlighted the importance of the home environment and in particular the support and encouragement provided by parents with a clear distinction between supportive and 'pushy' parents (Hemery, 1991).

Weiss & Hayashi (1995) published a descriptive account of American gymnasts aged 7-16 years, focusing specifically on the interest, encouragement and support provided by their parents. The study provided support for the conceptual framework proposed by Bloom (1985). Specifically, the gymnasts and their families appeared to demonstrate behaviour that was characteristic of the middle years. The training demands were high with gymnasts training on average 19.1 ± 9.8 hours per week, moreover, the commitment to gymnastics was clearly evident with 70% of female gymnasts focusing on gymnastics to the exclusion of all other sports. The characteristics of the 'middle years' were particularly evident in the behaviour of some but not all families with a considerable family commitment being apparent in between 50-70% of the families interviewed. For example almost 50% of gymnasts reported that their parents changed the family's itinerary to accommodate their training and competition schedule. The commitment of individual parents was also particularly apparent with approximately 70% of parents perceiving that their home and personal lives revolved around the sport.

**Socialisation into sport**

The social learning perspective (Bandura, 1977) and the social role-social systems approach (Kenyon & McPherson, 1973) are the two main theoretical models which have been applied to understand the process through which children are socialised into sport (Weiss & Hayashi, 1995; Greendorfer, 1992). Social learning theorists contend that socialisation into sport is the result of learned behaviours which are acquired through observation and modelling and are reinforced by significant others. The social role-social systems approach may be considered an extension of social learning theory which recognises that the values and beliefs held within a particular social system such as the family contribute towards an individual learning roles. Research has demonstrated a positive association between the nature and extent of children's participation in sport and the beliefs and values held by their parents (Eccles & Harold, 1991). Despite the distinctions between social learning theory and social roles-social systems perspectives, both theoretical approaches stress the important role of significant others in the socialisation of children into sport and emphasise the role of peers, teachers and in particular parents as important socialising agents (Weiss & Hayashi, 1995).

In line with the social role-social systems perspective, research by Bloom and colleagues indicated that the parents of expert performers valued the field of expertise in which their children eventually excelled but did not necessarily value their specific event or discipline. For example, most parents of elite swimmers valued achievement within competitive sport without necessarily valuing swimming (Bloom, 1985). This may be considered particularly significant given the role of parents as socialisation agents who play a central role in introducing children to sport (Rowley, 1992a; Greendorfer, 1992; Brustad, 1996). A descriptive study by Weiss & Hayashi (1995) confirmed that the parents of aspiring gymnasts 'valued' achievement sport. Specifically, most of the gymnasts fathers (94.7%) and almost three quarters of their mothers (73.7%) showed an interest in sport which their children described as 'moderate to high'.

Parents have been described as primary socialising agents (Brustad, 1996). The results of the TOYA study revealed that 33% of gymnasts became involved in the sport as the result of a decision by one or both parents, most frequently by the child's mother. The important role of the parents in introducing children to gymnastics was confirmed by

Karacsony (1988) who reported that in 59% of elite male gymnasts training at the Hungarian School of Physical Education, the parents were responsible for the decision to commence gymnastics. The important role of the parents was suggested to be in part due to the young age at which children enter organised gymnastic programmes within the former Eastern Europe. In support, studies which have examined participation motives from a developmental perspective have reported that the social approval of significant others is a particularly salient source of motivation in young children (Wankel & Kreisel, 1985; Brodkin & Weiss, 1990). The child's self-motivation also played an important role in the socialisation into gymnastics accounting for the decision to participate in 32% and 17% of gymnasts in British and Hungarian samples respectively (Karacsony, 1984 op cit. Karacsony, 1988; Rowley, 1992a). It was of interest to note that the TOYA study reported no significant differences in socialisation between gymnasts classified as high and low achievers (Rowley & Baxter-Jones, 1995).

It may be hypothesised that the positive regard in which the parents of the athletes held sport may be related to their general awareness of the field and in particular their previous experience of sport as participants. Bloom (1985) reported that most parents of expert performers participated in sport at a younger age, however, the extent to which parents participated in the sport in which their children excelled was more varied. For example, only 30% of the swimmer's parents swam competitively in contrast to approximately 80% of tennis families in which at least one parent could be described as an 'avid' tennis player (Bloom, 1985). Similarly, 79% of the parents of the young female gymnasts involved in the TOYA study had previously participated in sport although only 6% took part specifically in gymnastics. Research by Hemery (1991) supported these observations since more than 66% of the expert performers succeeded in a sport in which neither of their parents had previously participated.

Women's Artistic Gymnastics is characterised by a short career span and therefore gymnasts are required to become involved in the sport at a young age. This 'early specialisation' may be considered a requirement to permit the three phases evident within Bloom's research to take place. In particular to enable the period of playful fun and excitement which Bloom considered to be so essential in the early years to foster the athletes commitment to the sport. The early entry or 'specialisation' into gymnastics was confirmed in the TOYA study, with the mean age at which gymnasts commenced the

sport reported to be 6.3 years. The gymnasts made the transition to the intensive training, characteristic of the middle years, at approximately 8.6 years therefore, it may be assumed that gymnasts spent approximately 2.3 years in the phase described by Bloom (1985) as the early years. The need for early specialisation at a young age has been questioned (Starosta, 1996). However, on closer inspection, most criticisms are directed towards the early onset of intensive training and the focus upon a single sports activity to the exclusion of all others, neither of which are characteristics features of the 'early years'.

Results of the TOYA study indicated that unlike their initial introduction to gymnastics which was most frequently due to the parents or the self-motivation of the child, the coach was primarily responsible for making the decision to progress to intensive training. The coach made the decision in 49% of cases, the other main factor was self-motivation with the child making the decision to commence intensive training in 34% of cases (Rowley, 1992a). The parents did not appear to have a major role in the transition to more intensive training, taking responsibility for the decision in only 4% of cases. This pattern of responses was consistent irrespective of the future skill level of the gymnasts with no significant differences reported between gymnasts subsequently classified as high and low achievers (Rowley & Baxter-Jones, 1995). The limited influence of the gymnast's parents is in contrast to the findings reported by Bloom (1985) but is likely to reflect the structure of the gymnastic environment and in particular the decision by many gymnastic coaches to restrict the access of parents to training sessions.

In summary, previous studies which have retrospectively investigated the socialisation of elite athletes into performance sport indicated the absence of any systematic process through which these talented performers were identified. The introduction of elite athletes into their talent field was characterised by chance and was largely dependent upon the values held by the parents and/or the motivation of the child (Bloom, 1985). This suggests that the decision to enrol in sport, the timing of enrolment and the choice of coach is a process of 'trial and error' which is to a large extent dependent upon the parental values, opportunities within the local area and the awareness of parents that such opportunities exist.

**Deliberate practice**

Guided by the research of Bloom (1985), the major proponents of the empirical determinism approach to the acquisition of expert performance were the research group led by Anders Ericsson. Ericsson et al. (1993) published a seminal paper which questioned the importance of innate abilities and moreover challenged traditional perceptions of talent identification and development. Ericsson et al. (1993) proposed a theoretical framework through which the development of expert performance in various achievement domains could be interpreted. The central premise of the framework was the notion that long term adaptations to deliberate practice were uniquely responsible for the development of expert performance (Ericsson et al., 1993; Ericsson & Charness, 1995). Ericsson et al. (1993) proposed that an individual's performance was monotonically related to the amount of time that individual was engaged in deliberate practice (Salmela, 1996). Although the concept of deliberate practice was never concisely defined it was suggested to incorporate:

> "those activities which have been found most effective in improving performance"
>
> (Ericsson et al., 1993)

In a review of Ericsson's research, Singer & Janelle (1999) highlighted that the three features which define deliberate practice were a well-defined and challenging task, the provision of informative feedback and opportunities to repeat skills and correct mistakes.

In an attempt to quantify the requirements for deliberate practice, Ericsson et al. (1993) suggested at least 10 years or 10,000 hours of deliberate practice were required for the acquisition of expert performance. This appears to be in broad agreement with empirical studies which have documented the sporting careers of athletes (Ericsson et al., 1993). Moreover, it is in line with the findings of Ho (1987) who estimated that in Men's Artistic Gymnastics it takes on average 10 years for a beginner to become an elite international level athlete. Ericsson et al. (1993) proposed that the development of expert performance occurs within a set of constraints which must be overcome for an individual to achieve expert performance. The three constraints specified within the theoretical framework were resource, motivation and effort. The resource constraint highlighted that individuals

require access to certain resources including facilities, equipment and coaching. The motivation constraint encapsulated the recognition that deliberate practice was not an inherently motivating activity, but rather was viewed as a means for the advancement of future performance. Finally, the effort constraint outlined that deliberate practice requires the application of effort and that an optimal amount of deliberate practice balances demands of training and recovery. The incorporation of such constraints within the theoretical framework precludes the possibility that all individuals will achieve the level of expert performance. One of the factors which differentiates the approach of Ericsson et al. (1993) from previous theoretical perspectives is the acknowledgement that deliberate practice is necessary but not sufficient for the attainment of domain specific expert performance (Schneider, 1993a).

Ericsson et al. (1993) reported the results of two studies in support of the theoretical framework. The studies compared current and previous levels of deliberate practice between three groups of elite adult violinists and groups of amateur and expert pianists respectively. The two groups of violinists, who demonstrated the highest levels of performance, practised three times more than the least skilled violinists. The comparison between amateur and young elite pianists was more pronounced, with the amount of deliberate practice undertaken by the young elite pianists in excess of ten times greater than that undertaken by the amateur pianists. The retrospective recall of previous levels of deliberate practice produced a similar pattern of results. These observational studies provided indirect support for the postulation that differences in performance are directly related to the accumulation of deliberate practice (Ericsson et al., 1993).

Various investigators have extended aspects of Ericsson's original theory and as a result have provided evidence in support of the proposed theoretical framework. A series of qualitative studies have been conducted to investigate the role of expert sports coaches. As a result of a thorough investigation of the knowledge structure of expert gymnastics coaches Côté, Salmela, Trudel, Baria & Russell (1995) developed a theoretical model, the coaching model, to represent the process through which expert coaches realised their objectives of developing elite or 'expert' performers. Using a similar methodological approach Salmela (1996) completed in-depth interviews with a total of 21 expert Canadian coaches working in various team sports. Salmela (1996) applied the framework outlined by Ericsson et al. (1993) to examine the current practices of expert coaches. The

study highlighted that a primary role of expert coaches was the organisation of deliberate practice. Moreover, the role of coaches as facilitators was highlighted, with specific emphasis upon establishing strategies to enable athletes to overcome effort and motivational constraints. The results of the study revealed that attitudes and actions of expert coaches provided support for the theoretical model outlined by Ericsson et al. (1993).

While studies have applied the theoretical framework proposed by Ericsson et al. (1993) to investigate the development of expertise in specific domains of performance, empirical testing within the context of performance sport continues to be lacking (Salmela, 1996). However, partial support for the framework can be derived from the study by Schneider, Bös & Rieder (1993) which investigated the prediction of future performance in young elite tennis players and confirmed the contribution of deliberate practice to the development of expert performance. However, the omission of the basic ability construct resulted in a failure of the model to fit the empirical data thus reiterating the importance of individual differences in basic motor abilities. Indirect support for the importance of deliberate practice may be derived from the TOYA study in which the number of training hours per week discriminated between gymnasts defined as high and low achievers with the high achievers training significantly more hours per week ($p<0.01$) (Rowley & Baxter-Jones, 1995). The study by Hume et al. (1993) also highlighted the association between deliberate practice and performance in Rhythmic Gymnastics. Training hours, expressed in terms of current training and the cumulative training, was the factor most significantly correlated with attainment in Rhythmic Gymnastics.

Further support for the importance of deliberate practice may be derived from research associated with the Testing for National Talent Programme conducted in Canada. Russell (1987a, 1988) reported that out of the five performance dimensions studied, demographic variables best explained gymnastic success. This finding was further discussed by Salmela (1994) who described that during the preliminary analysis of the TNT data 'the number of training hours per week' accounted for approximately 80% of the variance in competitive performance within each age group. However, this variable was interpreted as a nuisance variable masking the emergence of other characteristics and was subsequently discarded. Salmela (1994) described how the importance of training hours as a prognostic variable was only reconsidered after the re-emergence of theoretical

interest in demographic factors in the light of Ericsson's research by which time the original data were no longer available for re-analysis. However, for two reasons this study can at best provide qualified support for the importance of deliberate practice. Firstly, the male gymnasts involved in the TNT programme were likely to have been pre-selected, through natural or systematic means during previous phases of their gymnastic careers. Therefore training hours may be hypothesised to be less likely to predict/explain the same amount of variance in heterogeneous samples of young gymnasts. Secondly, no attempt was made to quantify the nature or quality of training which is an important consideration (Ericsson et al., 1993; Ericsson & Charness, 1994; Ericsson, 1996 op cit. Singer & Janelle, 1999). The decision to exclude demographic and other situational factors is not uncommon within research in the field of talent identification and development. For example, Sol (1987) deliberately limited the time frame between the initial measurement of the talent characteristics and the evaluation of performance of study to limit the influence of training. In the light of the research on deliberate practice a more appropriate strategy may be to quantify training and to include it as a potentially prognostic talent characteristic.

The previous discussion alluded to the importance of considering both quality and quantity of training in an attempt to quantify deliberate practice. However, most evidence cited in support of the importance of deliberate practice has focused upon the quantity of training (Schneider, et al., 1993; Rowley & Baxter-Jones, 1995; Salmela, 1996; Hodges & Starkes, 1996 op cit. Singer & Janelle, 1999). It may be suggested that studies wishing to investigate the contribution of deliberate practice to the development of sporting talent would benefit from adopting a more detailed quantification of the training stimulus. With respect to gymnastic training this may require multiple indices pertaining to the duration, frequency, volume and intensity of training (Gajdos, 1987). Moreover, given the importance of the quality of training, a more qualitative approach may be pertinent to indicate the content and nature of training via the use of training diaries (Ericsson et al., 1993). However, the additional information that may be gained by adopting a qualitative approach must be considered against the likelihood of subject compliance.

## Seasonal birth distribution

Participants in youth sport are generally organised into competition groups or classes according to their chronological age. In a number of sports, athletes whose birth dates fall in the early part of a competition year have been reported to have a performance advantage (Baxter-Jones & Helms, 1994; Baxter-Jones, 1995). Given that in most sports talent is identified as a direct result of competitive performance this may influence the likelihood of an individual being labelled as talented. The sports which have reported a positive association between birth date and athletic achievement are those in which early biological maturation is considered an advantage including football, tennis, swimming and cricket (Dudink, 1994; Baxter-Jones, 1994b). In contrast, no significant biases were observed in the seasonal distribution of birth dates in male or female gymnasts participating in the TOYA study (Baxter-Jones, 1995). The absence of a positive association is not unexpected given that later biological maturation represents a distinct performance advantage in elite gymnasts (Beunen et al., 1981; Märker, 1981; Bar-Or, 1988; Baxter-Jones et al., 1994b). However, results of the TOYA study revealed a non-significant trend towards birth dates falling in the early part of the selection year for female gymnasts. The reasons for this trend are unclear but may be hypothesised to be in part due to the greater amount of training completed by the older gymnasts born in the early part of the selection year.

## Finance

A number of studies have reported the financial costs of participating in youth sport at the elite level (Rowley, 1992a; Weiss & Hayashi, 1995; Kirk, Burke, Carlson, Davis, Glover & O'Connor, 1997 op cit. Tan, 1998). Kirk et al. (1997) investigated the economic impact of taking part in six sports at the junior level in Australia. The financial contribution of parents was described as substantial, with the family's income cited as an important and possibly prohibiting factor in determining children's involvement in sport (Kirk, 1997 op cit. Tan, 1998). Within the TOYA study, Rowley (1992a) and Rowley & Baxter-Jones (1995) examined the financial implications associated with talent development. The parents of the gymnasts reported that they spent on average approximately 5.7% of their annual income on supporting their child's sport. As a consequence of this expenditure more than half the families involved in the study

experienced some degree of financial strain, with 50% of gymnasts' parents reporting mild or moderate hardship and a further 4% reporting severe hardship (Rowley, 1992a). In a subsequent publication, Rowley & Baxter-Jones (1995) reported that the cost of gymnastics was dependent upon the level of skill attained by the gymnast with the parents of gymnasts classified as high performers spending on average £1523 which was significantly different to the amount spent by the parents of low performers (£797). Similar results were reported by Weiss & Hayashi (1995) in a study of 7-16 year old American gymnasts. Parents reported that they spend on average 5% of their annual income on gymnastics although the range of percentage expenditure was quite dramatic (2-25% of annual income). Moreover, the majority of parents perceived gymnastics to be a financial burden, however, it did not appear to be a serious financial strain upon these families with 86% of parents indicating that gymnastics was 'some or a little' financial burden.

**Travel**

Finally, parents also make an important contribution to their child's sporting development by devoting time to transport their children to and from training and competition. This contribution may be particularly significant for those parents who live a considerable distance away from the training facility and must remain at or around the facility for the duration of the training session. The TOYA study provided the clearest insight into the transportation demands faced by the parents of young female gymnasts in Great Britain. In most cases the parents drove or commuted with their children to training. The average distance to training was 16 miles and the mean time taken to reach the training facility was 42 minutes. Rowley (1992a) did report evidence of parents sharing rota with approximately one fifth of gymnasts' parents citing involvement in such schemes. There were no significant differences between high and low achievers in terms of the distance travelled to the training facility (Rowley & Baxter-Jones, 1995).

## 4.3 METHODS

A series of questionnaires were designed for administration to gymnasts, parents and coaches to ascertain information regarding the social and demographic characteristics of

gymnasts and their families. Prior to the commencement of the longitudinal investigation, the questionnaires were piloted to investigate clarity and content. In response to the results of the pilot investigation the questionnaires were revised and re-checked. All questionnaires included a combination of forced choice and open-ended responses.

*Gymnast Questionnaire*

Questionnaires were administered in the initial data collection session during the first rotation of testing. A member of the research team assisted each gymnast to complete the questionnaire. The researcher read out the questions, clarified any problems with interpretation and filled in the responses. The questionnaire took approximately 20-30 minutes to complete and covered the following topics: personal details, gymnastic history, gymnastic training, gymnastic competition, friends, interests and activities. A copy of the questionnaire is provided in Appendix 4.1.

*Parental Questionnaire*

At the end of the initial data collection session coaches were given questionnaires to distribute to the gymnasts' parents together with a stamped addressed envelope in which to return the completed questionnaires. The parental questionnaires were self-report measures which covered the following areas: gymnastic history, gymnastic interests, family, travel and finance, enjoyment and interests, aspirations, parental/grandparental stature data. A copy of the questionnaire completed by the parents of those gymnast involved in the study is provided in Appendix 4.2.

*Coach Questionnaire*

The coaches were required to complete a self-report questionnaire during the initial measurement session. The questionnaire covered three main issues: enrolment and training, programming and talent identification. A copy of the questionnaire completed by coaches is provided in Appendix 4.3.

*Training Diaries*

Coaches were required to provide information concerning the nature, frequency, duration, volume and intensity of each gymnasts training for a two week period following each data collection session. In an effort to minimise the time demands upon the coaches and encourage a consistent method of recording, training diaries were produced. Coaches were requested to complete the diaries for a two week period in close proximity to the measurement session which they considered to be representative of the gymnasts level of training at that point in time. The coaches were requested to return the completed diaries by post, follow-up calls were made to encourage the completion and return of the diaries. An example of a completed training diary is provided in Appendix 4.4.

## 4.4 RESULTS

The response rate for parental questionnaires was good with approximately 90% of parents returning completed questionnaires. Of these completed parental questionnaires 86.7% were completed by the gymnasts' mother. The response rate for the training diaries was less positive and despite numerous follow-up calls, training diaries were completed and returned for approximately 48% of gymnasts. Moreover, the quality of the completed responses was variable and therefore the only index which could be derived from the diaries with any level of confidence was the number of training hours completed per week.

### 4.4.1 DESCRIPTIVE DATA

**Socialisation into sport**

Parents reported that the mean age at which gymnasts commenced the sport was 5.28 years. The bar chart presented in Figure 4.1 indicates that most children enrolled in gymnastics at between 4 to 6 years of age.

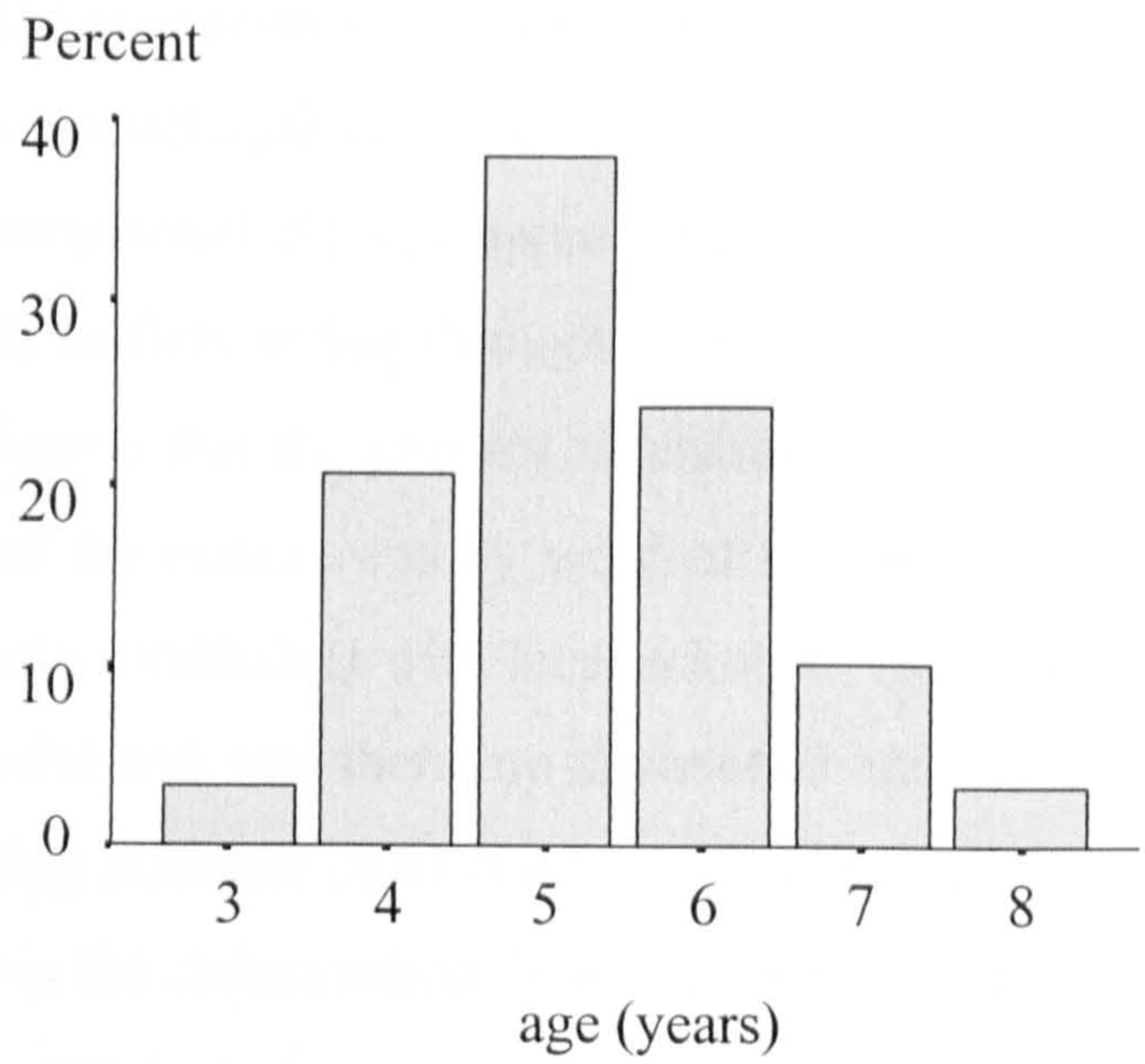



Figure 4.1. Parental estimates of the age at which children began gymnastics.

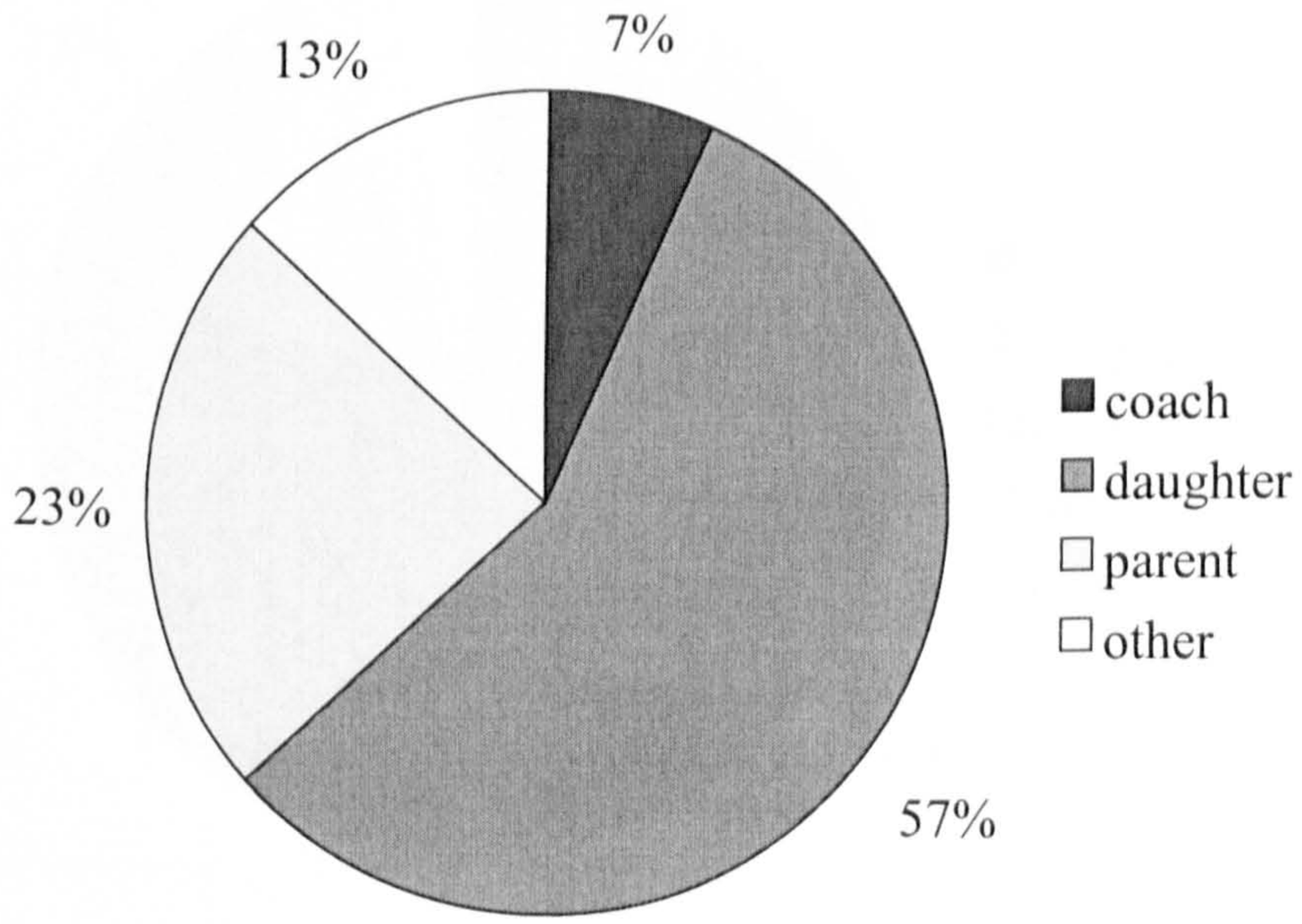



Figure 4.2. Percentage distribution showing which individual(s) were responsible for the decision to commence gymnastic training.

According to parental reports, 56% of gymnasts were personally responsible for the decision to enrol in gymnastics. Parents also appeared to be important socialisation agents, making the enrolment decision in 23.3% of cases. A summary of these results is presented in Figure 4.2.

Responses to the 'coach' questionnaire indicated that in 83% of the clubs involved in the study, junior gymnasts initially joined the club via recreational classes. In terms of the active promotion of recreational classes, approximately one quarter of coaches reported that they advertised via leaflets and/or through advertisements placed in the local press. However, coaches indicated that the primary mechanism through which members of the public became aware of the classes was by word of mouth. Two coaches reported that links had been previously established with local schools. However, one school-club link had not proved successful and was therefore abandoned and the other link involved the school simply distributing information to children regarding screening sessions to be held at the club. Therefore, in the clubs studied there was little evidence of a systematic search for talented children to participate in gymnastics.

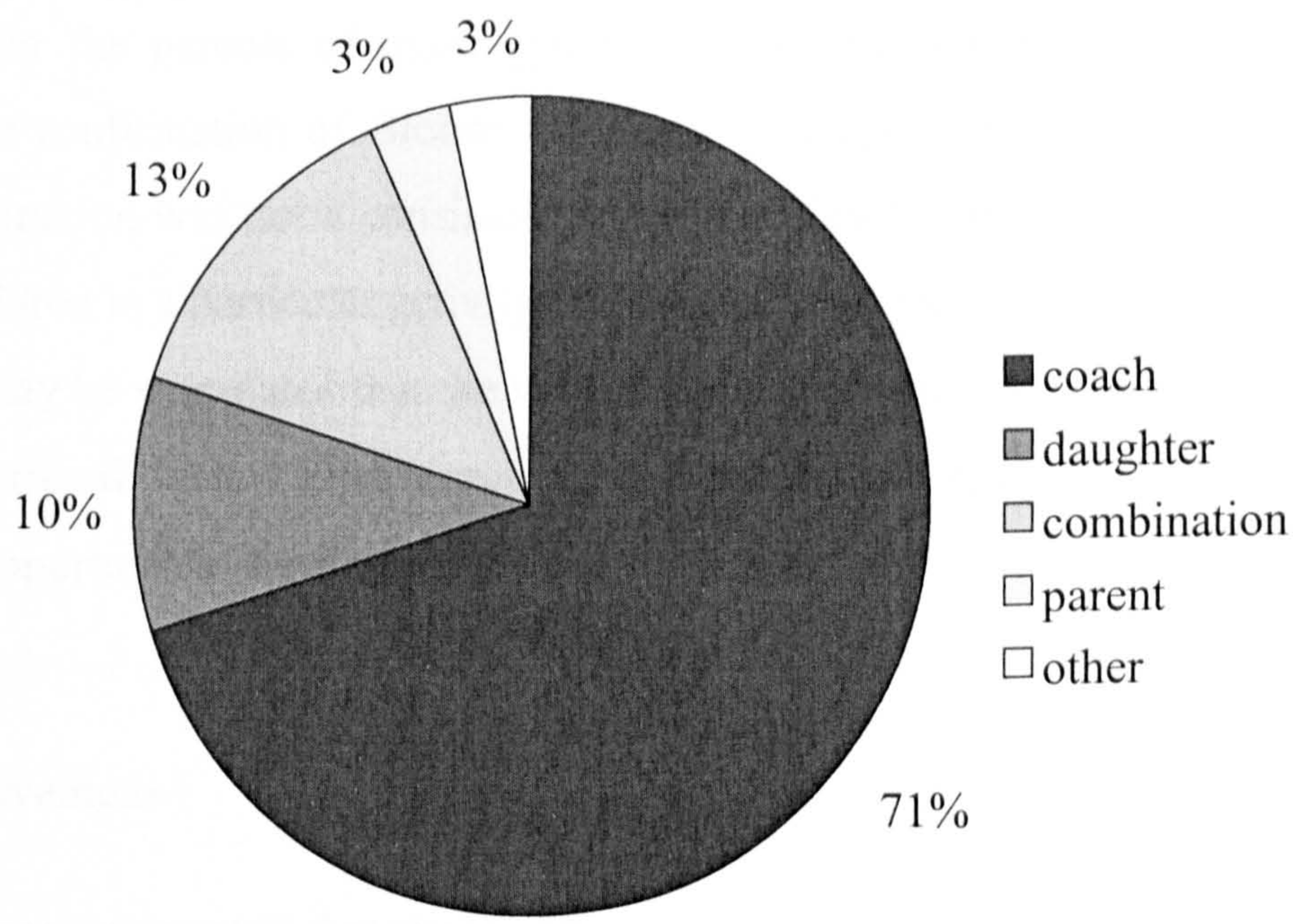



Figure 4.3. Percentage distribution showing which individual(s) were responsible for the decision to progress to more serious training.

The majority of children made the transition to 'more serious' training at 6 or 7 years of age, where more serious training was defined subjectively with the minimum criterion stipulated as at least three training sessions per week. The mean age at which the transition occurred was 6.53 years, approximately 1.25 years after the initial commencement of the sport. According to responses on a 5 point likert scale, ranging from too young to too old, 80% of parents were happy with the age at which this transition occurred. While none of the parents felt that 'more serious' training began too

early, 20% of parents considered their daughters to be too old when this transition occurred. As highlighted in Figure 4.3, coaches were primarily responsible for making the decision that gymnasts progress to more serious training. Parents played a relatively minor role in the transition decision, indeed only one parent reported being responsible for the transition decision. This parent was also the head coach and therefore it may be speculated that the decision was made in the parent's capacity as coach rather than as parent.

Almost half of the gymnasts' parents had previously participated in gymnastics at school (46%). However, only two respondents or 6.6% of parents had participated in extra-curricular gymnastics, both of whom were involved at the club level. This was in line with the findings of Rowley & Baxter-Jones (1995) who reported similar patterns of prior participation for the parents of those gymnasts involved in the TOYA study. These results provide confirmation of Bloom's qualitative research which indicated that prior parental participation was not a consistent factor associated with the choice of parents to enrol their children in a particular activity. In line with the contentions made by Bloom & colleagues it may be speculated that the value attached to 'sport' as a field of achievement may be the critical factor in determining the extent to which parents will provide socialisation opportunities for their children.

**Parental involvement**

Parental responses suggested that these gymnasts are in the phase of talent development described by Bloom (1985) as the 'middle years'. A large proportion of the family's time appears to be focused around the training and competitive pursuits of their children. For example, all parents reported that they 'always' watched the competitions in which their daughter competes and surprisingly 73.3% indicated that they 'usually' attended competitions in which their daughter did not participate. Competitions were accorded primary importance in the family schedule with 96.7% of parents indicating that gymnastic competitions took priority over other family events. However, for many families training was considered to be less of a priority, with 53.3% of parents reporting that training always took priority.

According to 63% of parents, gymnastics interfered with family activities, with the main problem reported to be the time demands associated with training and competition. With respect to family structure, 90% of gymnasts had at least one brother or sister. Of those families with multiple siblings, 20% of parents reported that as a result of the family's commitment to gymnastics the activities of the non-gymnastic siblings were restricted. Once again the main reason cited for this restriction was the time demands associated with gymnastic training and competition.

Finally, 73% of parents perceived that gymnastics limited the extent to which the gymnasts themselves were able to participate in other interests or activities. However, despite parental concerns, 45.5% of gymnasts reported that they regularly participated (at least once per week) in another sport, most frequently swimming. The results of cross tabulations revealed that 57% of 'unsuccessful' gymnasts and only 25% of 'successful' gymnasts participated in other sports. The exclusive focus of the successful gymnasts reflects the high level of commitment which characterises the 'middle years' (Bloom, 1985).

**Finance**

The fees for gymnastics training ranged from £22.50 to £60.00 per month with the average cost of training estimated to be £45.60 per month. It is recognised that this estimate does not represent the true cost of participation with additional expenditure required to cover the cost of insurance, affiliation, equipment, competition fees and travel expenses. The questionnaire responses indicated that the majority of parents considered the cost of gymnastics training to be acceptable. Parents were asked to rate the cost of gymnastics training in relation to other sports, with responses classified according to a five point likert scale ranging from very cheap to very expensive. ,In total, 40% of parents thought that the cost of gymnastics was 'about right' with approximately one third of respondents indicating that gymnastics was cheap in relation to other sports. Moreover, the analysis of the open ended responses revealed that of the 63% of parents who indicated that gymnastics interfered with other family activities only one parent (3.3%) cited financial cost as a reason why gymnastics was considered prohibitive.

## Travel

The distance travelled by gymnasts to their usual training facility ranged from 1-114 miles with a mean distance of 23.5 miles. However, with the exception of two gymnasts who travelled 105 and 114 miles respectively all gymnasts lived within a 30 mile radius of the gym in which they usually trained. Moreover, 70% of gymnasts lived within an 8 mile range of the training facility. The results of cross tabulations did not suggest any relationship between successful and unsuccessful gymnasts in terms of the distance travelled or the time spent travelling to training. The mean travel time was just under 25 minutes, which translated to approximately 50 minutes travel time per day or given that most gymnasts trained five times per week, resulted in approximately 4 hours 10 minutes of travel time per week. However, in line with the results for travel distance, 60% of gymnasts spent 15 minutes or less travelling to their usual training facility. Only two of the parents reported that they always had to wait in or around the facility while the gymnasts completed their training with 56.7% reporting that they sometimes had to wait. Few parents (13.3%) perceived this to be a major inconvenience. The incidence of parents sharing travel arrangements was higher than reported in the TOYA study with approximately one third of parents citing involvement in a rota scheme.

## Parental aspirations

In a series of open ended questions parents were asked to indicate what they hoped their children would achieve in gymnastics and what they would gain from their gymnastic experience. In terms of achievements, several parents cited specific goals or performance standards they hoped their daughter would achieve which included competing for Great Britain and participating in the Olympic Games. However, a large proportion of parents cited no specific goals or targets but rather highlighted their preference for self-referenced goals which included reaching their potential, fulfilling their own goals or merely doing their best. These responses may be interpreted in terms of Goal Perspective Theory to be indicative of a task orientation (Nicholls, 1984, 1989). The potential impact of parental goal orientations will be discussed in detail in Chapter 7. Of the qualities parents hoped their children would derive from their gymnastic experience, discipline or self-discipline was cited most frequently (27% of parents). This may reflect the importance and value parents place upon the work ethic. A similar percentage of parents recorded responses

associated with fitness, with a further 10% of parents emphasising enjoyment, and the enhancement of self-confidence.

**Seasonal birth distribution**

To examine the influence of seasonal birth distribution, gymnasts were classified into four quartiles according to their date of birth. Figure 4.4 indicates that relatively few gymnasts were born in the first quarter of the calendar year with the greatest number of gymnasts born in the third quartile. This trend was particularly marked in the successful gymnasts as shown in Figure 4.5. These results are in contrast to the findings of the TOYA study reported by Rowley & Baxter-Jones (1995) in which a non-significant trend was reported for female gymnasts towards birth dates falling in the early part of the selection year. Reasons for the differences between these studies may be attributed to sampling variations.

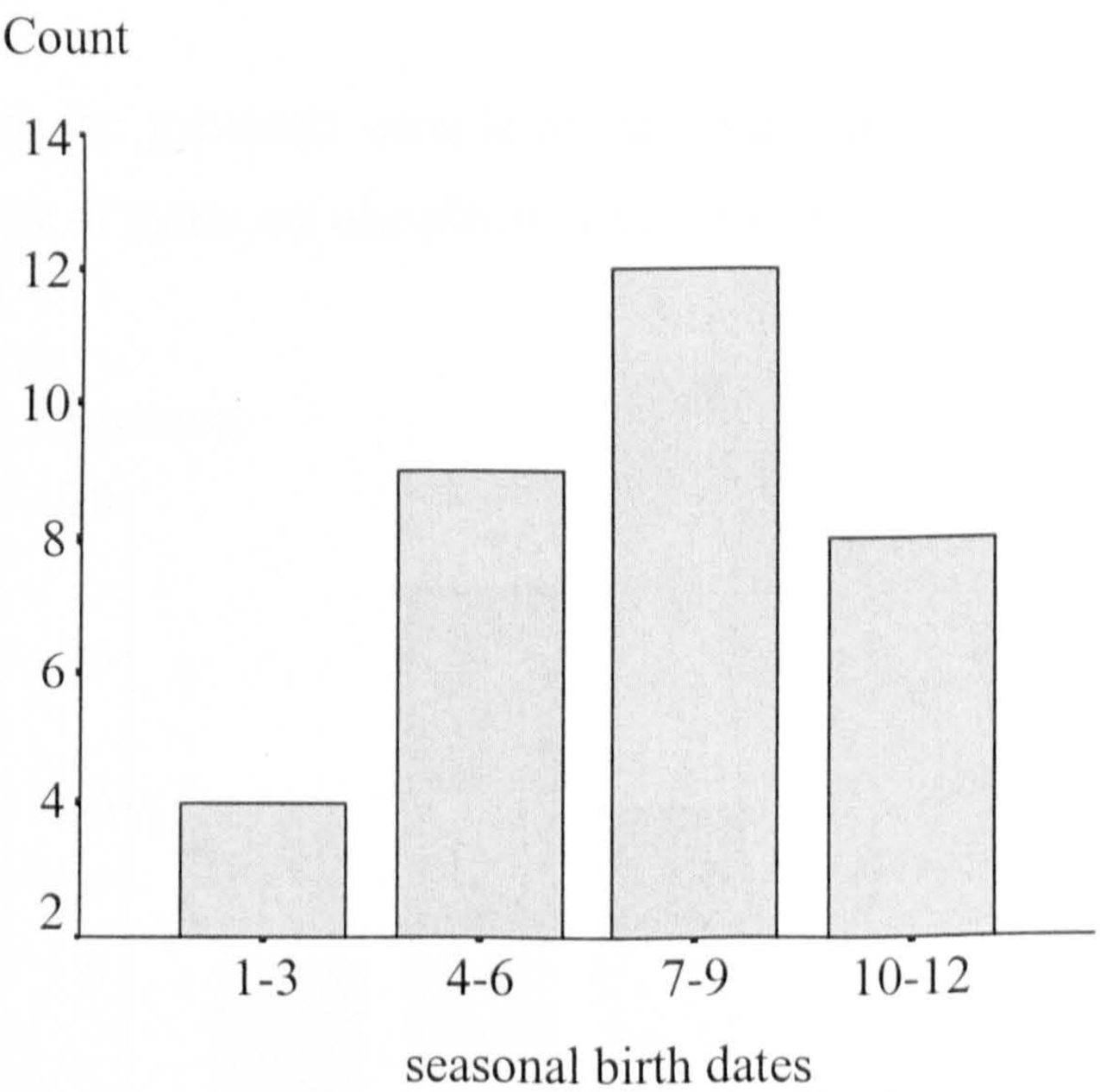



Figure 4.4. Seasonal distribution of birth dates for the sample of gymnasts who completed the study (successful and unsuccessful gymnasts pooled).

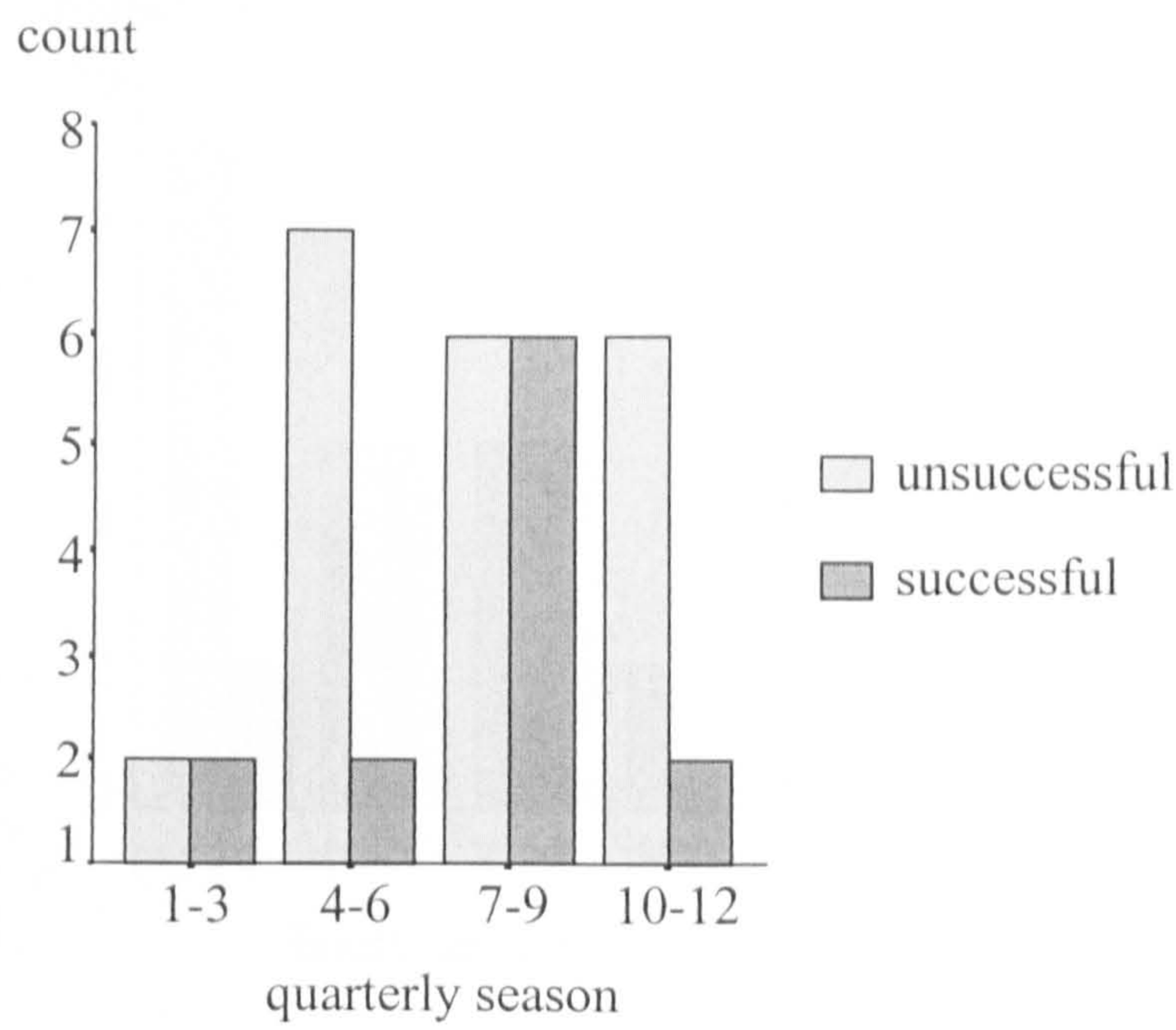



Figure 4.5. Seasonal distribution of birth dates for successful and unsuccessful gymnasts.

**Training**

Figure 4.6 shows that the gymnasts completed between 4 and 7 training sessions per week, with the majority of gymnasts completing either 5 or 6 sessions.

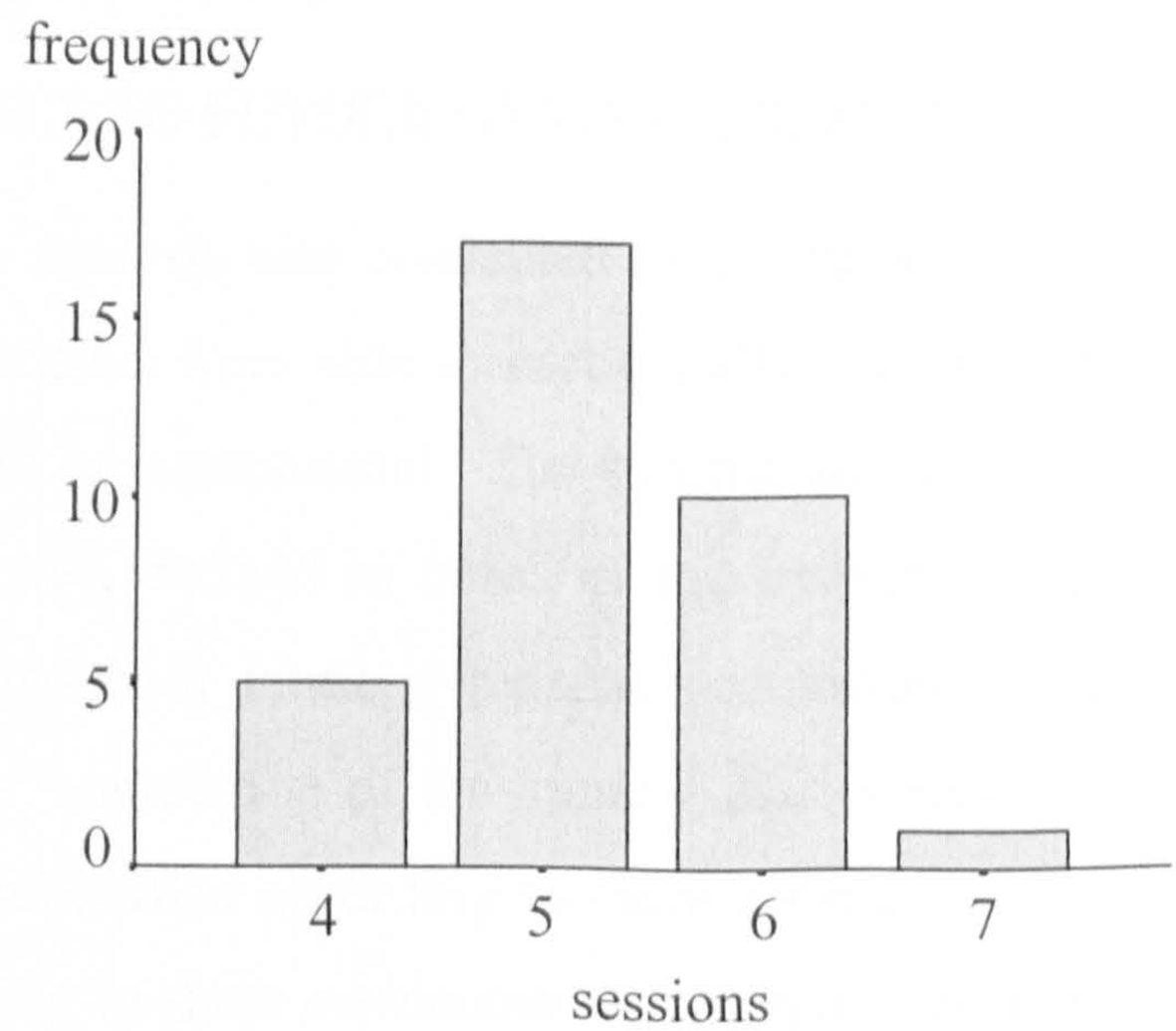



Figure 4.6. Training sessions per week for the pooled sample of gymnasts.

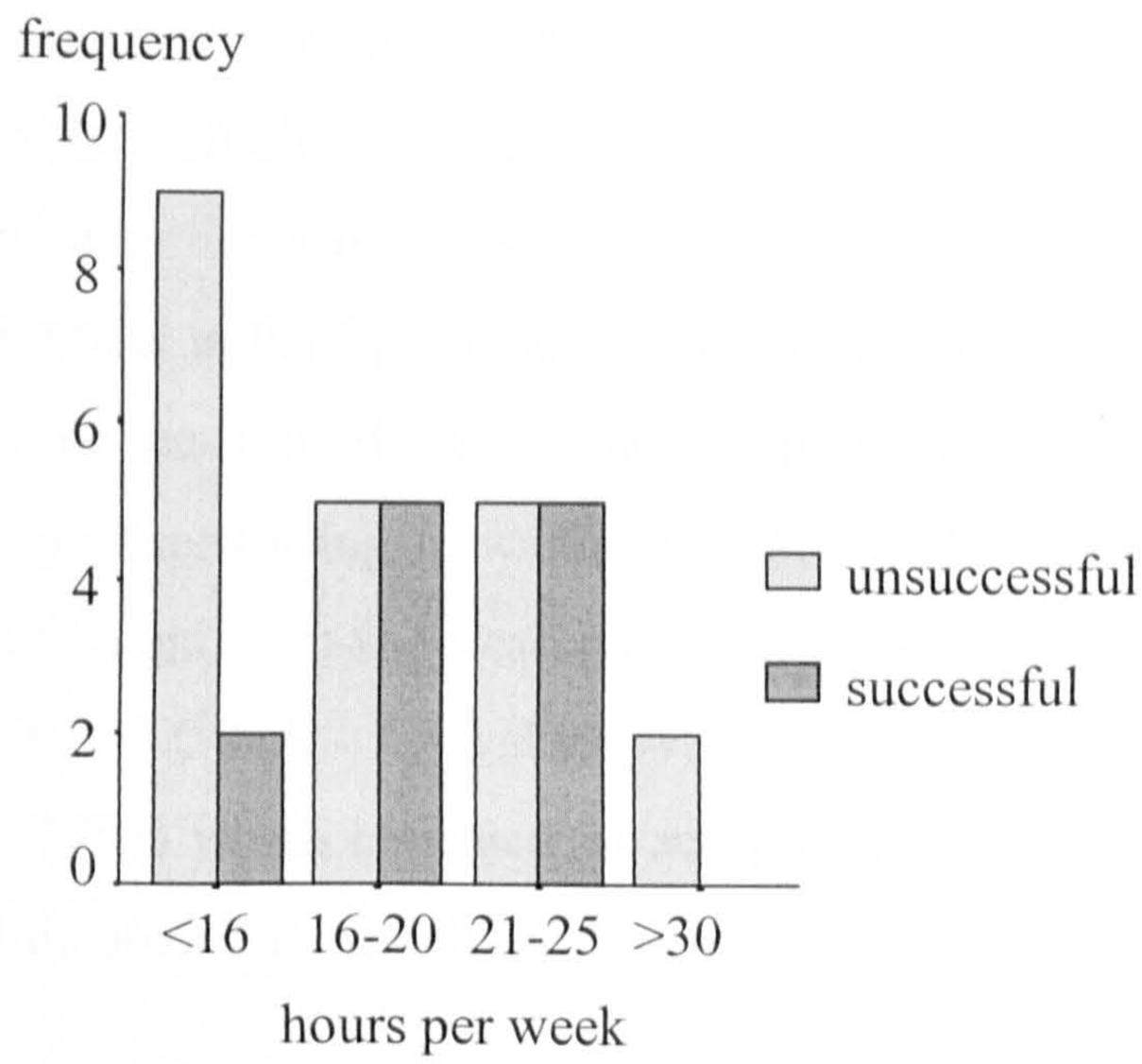



Figure 4.7. Training hours per week for the pooled sample of gymnasts.

The hours trained ranged between 10 and 36 per week with a mean of 19.2 hours. It was interesting to note that the most successful gymnasts did not appear to train the most hours (Figure 4.7). However, these figures provide no indication of the differences in training intensity between gymnasts. Responses on a five point likert scale indicated that the majority of gymnasts felt they were completing an appropriate amount of training.

### 4.4.2 RELATIONSHIP TO FUTURE GYMNASTIC SUCCESS

A Logistic regression analysis was conducted to determine the extent to which selected demographic characteristics were able to successfully classify the future performance of gymnasts as successful or unsuccessful. The specific aim was to determine the extent to which deliberate practice, defined in terms of the frequency, intensity and duration of training, was associated with future gymnastic performance. However, as previously described the coaches' completion of the training diaries was not sufficiently precise to permit training to be classified according to these criteria. Therefore, training stimulus was estimated according to three continuous demographic characteristics, the number of training hours per week, parental estimates of the number of years of training the gymnast had completed and parental estimates of the number of years of 'systematic/intensive' training the gymnast had completed.

The contribution of demographic characteristics was examined in terms of the extent to which the fit and predictive efficiency of the model were enhanced over and above the contribution of decimal age. To achieve this, standardised decimal age was forced into the logistic regression model in the first 'block' of variables with the components within each category entered in the second block using stepwise procedures. An identical regression model was produced using forwards and backwards stepwise entry methods indicating the absence of significant suppressor variables/effects. The range of estimated tolerance values was 0.290-0.842. All values were above the critical value of 0.20 suggested by Menard (1995) which indicated an acceptable level of multicollinearity in all categories of social-demographic variables.

Decimal age

When standardised decimal age was included as the sole independent variable, the following regression model was produced:

$$\text{Logit(successful)} = 1.1091(\text{zdecage}) - 0.6931$$

With the inclusion of standardised decimal age, the log likelihood (-2*LL) was reduced by 7.425 which was significant at the 1% level ($p<0.006$). This indicated that in comparison to the inclusion of a constant term only in the model, decimal age significantly reduced the log likelihood and therefore improved the fit of the logistic regression model. However, when expressed in substantive terms, this corresponded to an $R^2_L$ of 0.172 which indicated that the fit of the model was still relatively poor. The classification table presented in Table 4.2 shows that 75.8% of gymnasts were correctly classified. Predictive efficiency, expressed quantitatively through the calculation of Lambda ($\lambda$), was 0.333 which indicated that the inclusion of standardised decimal age as an independent variable reduced the error of classification by approximately one third. However, the reduction in misclassification did not attain statistical significance at the 5% level ($p<0.074$). In conclusion, the positive coefficient associated with standardised decimal age indicated that the probability of being classified as successful was greater for older gymnasts. However, the poor model fit and non-significant reduction in predictive

efficiency suggested that factors other than decimal age are likely to be important in determining future success within this particular sample of young female gymnasts.

Table 4.2. Classification table for the logistic regression model including standardised decimal age as an independent variable

| | unsuccessful | successful | correct |
|---|---|---|---|
| Unsuccessful | 17 | 4 | 80.95% |
| Successful | 4 | 8 | 66.67% |
| | | overall | 75.76% |

Demographic characteristics

Following the forced entry of standardised decimal age, the three demographic characteristics relating to training status were entered in the second block or the regression model using stepwise procedures. The variable training hours demonstrated positive skewness and was therefore transformed logarithmically before being included in the model. The change in the log likelihood (-2*LL) associated with the entry of demographic characteristics in block two did not attain statistical significance and the demographic characteristics were therefore excluded from the model. The final model was therefore identical to that reported above when decimal age was included as the sole independent variable. The tolerance values reported above indicated evidence of multicollinearity among the demographic characteristics, which was expected given the inclusion of two highly correlated independent variables 'years of gymnastic training' and 'years of systematic training' within the regression model ($r=0.791$ $p=0.000$). Therefore, the logistic regression analysis was repeated using two independent variables, ln(training hours) and years of gymnastic and/or systematic training. The results were identical to those obtained when all three independent variables were included in the model. The observation that variables associated with the training status of the gymnast were unable to distinguish between gymnasts whose future performance was defined as successful or unsuccessful was in contrast to the findings reported for rhythmic gymnasts (Hume et al., 1993) and for artistic gymnasts in the TOYA study (Rowley & Baxter-Jones, 1995). The differences between studies may be a function of sampling variations and specifically the age differences between gymnasts across the three samples. The results of the present

investigation did not provide support for the importance of deliberate practice as hypothesised by Ericsson et al. (1993).

## 4.5 DISCUSSION

This chapter sought to describe the social and demographic characteristics of a 'pooled' sample of successful and unsuccessful female gymnasts and to examine the relationship between the aforementioned characteristics and future gymnastic performance. According to parental estimates, children began participating in gymnastics at a mean age of 5.32 ± 1.06 years. In the majority of cases (57%) the child was personally responsible for the decision to commence gymnastic training. Parents were the 'significant other' most involved in the socialisation of children into gymnastics and made the participation decision in 23% of the sample. This confirms the results of previous research which has highlighted the important role parents play in introducing children to sport (Karacsony, 1988; Rowley, 1992a; Brustad, 1996). In line with findings published in the TOYA study, the result of the present investigation indicated that coaches play a minimal role in the decision of the child to begin participating in gymnastics (Rowley, 1992a; Rowley & Baxter-Jones, 1995). Responses to the 'coach' questionnaire confirmed that the majority of coaches did not actively recruit 'talented' children rather they relied upon talented gymnasts entering the sport as participants of the recreational classes. This approach corresponds to a local version of the 'pyramid' principle (Klentrou, 1993; Régnier et al., 1993) as described in Section 2.2 in that lots of children participate in recreational classes and the most talented stand out and are 'selected' to participate in more intensive training. Although this policy is not optimal in terms of talent identification and development it may in part be attributed to financial constraints which force clubs to operate within a philosophy of maximal recruitment (Bales, 1995).

According to Bloom (1995), the process through which potentially elite athletes enter the sport in which they will eventually excel is characterised by chance. Two findings within the present investigation provided indirect support for this contention. Firstly, the observation that coaches had little influence in the decision of children to enrol in gymnastics. Secondly, it was observed in the present study that the majority of gymnasts live in close proximity to the training facility. Approximately 70% of the gymnasts resided within an 8 mile radius of the gymnasium with 60% of parents reporting that they

spent 15 minutes or less travelling to their child's gymnastic club. Therefore, it may be concluded that in line with Bloom (1985) the initial training facility was selected on the basis of convenience rather than the performance standards of the club.

Coaches were mainly responsible for introducing the onset of more serious or systematic training, and were responsible for this decision in 49% of gymnasts involved in the TOYA sample and in 71% of gymnasts involved in the present study. It was also interesting that only 3% and 4% of parents in the present study and in the TOYA study respectively made the decision that their child would progress to more intensive training. This observation was in contrast to the results of Bloom (1985) and most probably reflects the nature of gymnastic training and the strict restrictions on parental access which appears to be the policy of many gymnastics clubs within Great Britain. With few exceptions, talent identification in gymnastics was operationally defined by coaches to consist of the selection of children to progress to 'more serious' training from the pool of children who enter their facility to participate in recreational classes. This talent pool is limited to those children who live within a convenient distance, whose parents value sport and who are aware of the local facility. This element of chance may in part be self-serving to the extent that the parents who are motivated to enrol their children in recreational classes are likely to value sport and therefore likely to provide support the pursuit of achievement within this domain. However, given that it is the value of 'sport' as a global entity which appears to be an important factor in socialisation and that parents are faced with a variety of sports in which to enrol their children it is inevitable that a number of potentially talented youngsters who may have appropriate parental support fail to experience gymnastics at all or at a young enough age to permit the phases inherent within Blooms conceptual framework to take place.

Bloom (1985) considered the first phase of talent development, described as 'the early years', to be an extremely important stage during which children developed a long term commitment to their chosen sport. The parents' choice of coach appeared to be critical with coaches selected on the basis of their interpersonal characteristics and their ability to work well with young children (Bloom, 1985; Carlsson & Engstrom, 1988 op cit. Fisher & Borms, 1990). A consistent feature of the development of expert performers was that their early experiences of the sport in which they would later excel were positive and as a result of these early experiences they became committed to the sport. The majority of

retrospective accounts provided by elite athletes cited their early years to be a period of fun, excitement and recreation in which their love of the sport was developed and nurtured. It also appears that through good fortune most of the coaches who worked with these young expert performers were also proficient teachers of basic skills.

It is argued that given the importance of the early years in providing a positive experience and developing the essential technical skills required by the gymnast, the selection of the coach cannot be left to chance. However, in reality, many gymnastic clubs rely on a limited number of volunteer coaches and experienced coaches are rarely assigned to work with the youngest gymnasts. All too frequently, beginners are not assigned a particular coach, but are supervised by whichever of the coaching team is available. If they are assigned a regular coach, it is often an enthusiastic parent with little technical experience or perhaps of greater concern a young coach who may be keen to stamp their authority on the group. It may be concluded that the technical proficiency and in particular their inter-personal skills of the gymnasts' first coach will be a critical aspect of any system designed to develop talent in young female gymnast and one which should not be left to chance. It is also recommended that within such a system the coaches selected to work with beginners are provided with appropriate training and guidance to develop the social and technical skills they require to ensure that young female gymnasts are given an optimal experience in the early years.

A characteristic feature of Women's Artistic Gymnastics is the early age at which children begin participating in the sport. The proponents and opponents of youth sport continue to debate the ethics and the efficacy of early specialisation in the literature (Coakley, 1986, 1993) however, little attention is devoted to the nature of 'training' at these young ages. It is argued that by specialising early, at 5-6 years, young female gymnasts are able to enjoy the early years and experience a period of 'structured play' prior to the onset of more systematic training as competition is introduced at approximately 8 years of age. The time required to realise a young gymnast's potential appears to be relatively fixed and therefore it is of concern that if gymnasts are not introduced to the sport from a young age coaches may try to condense their development accordingly. It is likely that the early years will be the phase most frequently sacrificed, but in neglecting this stage of development coaches may be omitting a crucial component of the talent development process. It is essential that coaches are made aware of the

important function of the early years and that their enthusiasm for progress does not threaten the long term involvement of children in the sport.

The questionnaire responses indicated that gymnasts were in the 'middle years' described by Bloom (1985) which were characterised by a large commitment to the sport with family life revolving around the training and competitive pursuits of the gymnasts. Retrospective accounts have indicated that a high level of parental support is a critical factor in the development of elite athletes (Bloom, 1985; Hemery, 1991; Carlson & Engstrom, 1988 op cit. Fisher & Borms, 1990). Empirical support was derived for this contention in the TOYA study. Specifically, Rowley & Baxter-Jones (1995) found that the families of gymnasts demonstrated significantly greater levels of adaptability and cohesion in comparison to age matched controls ($p<0.001$) with no differences reported between the families of high and low performers. Although parental support was not directly addressed, the parents of the gymnasts involved in the present study appeared to be remarkably 'child-centred.' Their self-reported behaviours indicated a high level of commitment and support particularly with respect to the competitive pursuits of their children. For example 100% of parents reported that they attended all gymnastic competitions in which their daughter participated, with 96.7% of parents prepared to rearrange the family schedule to accommodate gymnastic competitions. In contrast, a smaller percentage of parents (53.3%) indicated that they would rearrange the family's schedule to fit in with their daughter's training. This figure was closer to the gymnasts' estimate of parental behaviour reported by Weiss & Hayashi, (1985) and most probably reflects the fact that latter authors' did not distinguish between the willingness of parents to accommodate competition and training. A number of studies have highlighted the critical distinction between parental support and parental pressure (Bloom, 1985; Hemery, 1991; Carlson & Engstrom, 1988 op cit. Fisher & Borms, 1990) with parental pressure associated with negative emotional responses including enhanced stress (Scanlan & Lewthwaite, 1988).

Finally, the parents of expert performers have been reported to hold a value system which emphasised the importance of hard work and accomplishment. This was described by Bloom (1985) as the 'work ethic' and was conveyed to children from a young age. Many of the parents of gymnasts involved in the present study appeared to hold a similar value system as reflected by their responses to the question of what they hoped their children

would 'gain' from their gymnastic experience. The most prevalent response to this open-ended question was associated with discipline or self-discipline which was cited by 27% of parents. It was also interesting to observe that when parents were asked to indicate what they hoped their children would 'achieve' in gymnastics a large proportion of parents cited self-referenced goals which included: reaching their potential, fulfilling their own goals or merely doing their best. These responses were interpreted to indicate evidence of a task orientation (Nicholls, 1984, 1989). Motivational climates consistent with this particular goal perspective have been associated with adaptive motivational strategies and behaviours and will be considered more thoroughly in Chapter 7.

The training loads experienced by gymnasts in the present study were characteristic of the intensive training required during the middle years. Gymnasts trained an average of $19.2 \pm 5.54$ per week which was in line with the $19.1 \pm 9.8$ hours per week reported by Weiss & Hayashi (1995) for a mixed ability sample of American gymnasts with a similar age profile. In both samples the standard deviations were large indicating a high level of variability in training loads. Indeed, the range of training hours reported in the present study was considerable with gymnasts training between 10 and 36 hours per week. Given this variability it was surprising that variables associated with the training status of the gymnast were unable to distinguish successful gymnasts from their less successful peers and did not provide support for the importance of deliberate practice as hypothesised by Ericsson et al. (1993). Several reasons may be posited to account for the absence of this association. Firstly, it is possible that the representation of the training stimulus, in terms of the total number of hours trained each week, may not be sufficiently sensitive to detect the qualitative differences in training that exist between successful and unsuccessful groups. It is possible that while successful and unsuccessful gymnasts train for a similar total time, the successful group may use their training time more effectively and work at a greater training intensity than their less successful peers.

Secondly, it may be speculated that the relationship between training hours and future gymnastic success may be best represented by a non-linear relationship. Although the mechanisms are not well understood, excessive volumes of training have been associated with debilitating effects upon performance, physical health status and the risk of 'burnout' from youth sports (Gould, 1993; Mandelbaum, 1993). In particular, the appropriateness of the volume of training experience by those young female gymnasts in the present study

who trained in excess of 35 hours per week must be seriously questioned. The potential for a non-linear relationship is consistent with the theoretical framework proposed by Ericsson et al. (1993) and in particular the acknowledgement that an optimal amount of deliberate practice balances the demands of training and recovery.

The final reason proposed to explain the lack of an association between the selected demographic characteristics and performance may be the result of the young age of the gymnasts involved in the present study. It may be speculated that differences in performance level associated with training volume are the result of a cumulative effect over a number of training years. Therefore, the relationship between indices of training status and performance will only begin to emerge in the later stages of a gymnast's career when the differences in cumulative training time between successful and unsuccessful gymnasts are magnified. While the possibility of this relationship is acknowledged, such measures will have limited value in the context of talent identification.

The present study also sought to investigate the salience of potential barriers to participation. As a result of the findings reported in previous research, information was generated concerning the financial costs of participation and the demands of transportation (Rowley, 1992a, Rowley & Baxter-Jones, 1995; Weiss & Hayashi, 1995; Kirk, 1997 op cit. Tan, 1998). Questionnaire responses indicated that parents did not perceive the financial costs or transportation demands associated with their daughters' participation to be prohibitive. However, the present sample consists of those gymnasts who remain in the sport because their parents are able and prepared to support their cost of their participation. The cost of gymnastics training may well be prohibitive to those families in the lower socio-economic classes.

## 4.6 SUMMARY

The results of the present chapter indicate that within Great Britain there is currently no consistent pathway through which potentially talented children are identified and introduced to the sport of gymnastics. Talented gymnasts are not systematically identified, rather they emerge through a series of chance occurrences. Once the talented gymnast has 'emerged', the support structures are in place within the club system to develop and nurture the talent effectively. This approach is characteristic of the 'person

related' model described by Fisher & Borms (1990). However, in the absence of a systematic approach to talent identification a potentially large number of children who may have the necessary attributes, parental support and the desire to succeed in Women's Artistic Gymnastics may fail to experience the sport at all or at an age early enough to permit their potential to be realised. Therefore, it is suggested that British Gymnastics may benefit from a National system of talent identification and development to provide a continuous pathway through which gymnasts may progress from initial identification through to the ultimate achievement of excellence.

It is important that any system of identification and development fits within the framework for development proposed by Bloom (1985) and incorporates the three phases of development defined as the 'early', 'middle' and 'later' years. Considerable retrospective evidence has been presented to indicate that the child's early contact with the sport must be both a positive and pleasurable experience (Bloom, 1985; Hemery, 1991; Carlson & Engstrom, 1988 op cit. Fisher & Borms, 1990). Therefore, it is important that the those coaches selected to work with the youngest gymnasts are technically proficient but most importantly are good with children and are able to foster the love and commitment to the sport that is essential during this phase of development. It is clear that at each stage of development the coach will be required to possess a specific balance of technical and interpersonal skills to instruct and support the gymnast. It is anticipated that few coaches will be able to provide this expertise and support across the entire period of development. It may therefore be appropriate for teams of coaches to work together to prepare and support the gymnasts. However, this will demand a high level of cooperation and support within the coaching team, particularly during the periods of transition as gymnasts transfer between coaching staff.

The present chapter has highlighted the importance of the home environment and the need for parental support (Bloom, 1985; Hemery, 1991; Carlson & Engstrom, 1988 op cit. Fisher & Borms, 1990; Fisher & Borms, 1990). It is essential that throughout the early and middle years the gymnasts remain within their family environment. Therefore, it is recommended that any system of talent identification and development should be regionally based. Moreover, in light of the critical distinction between parental support and parental pressure it will be important to provide programmes of education to inform parents of the most appropriate mechanisms of support.

The results of the current chapter and consideration of the literature will be used to design a system of talent identification and development within Great Britain. The formulation of guidelines relating to this system will be outlined in Chapter 8. The following chapters will examine the relationship between talent characteristics within the physical, perceptual-motor and psychological dimensions of performance with a view to establishing a National guidelines for the identification and development of gymnastic talent.

# CHAPTER 5

# PHYSICAL CHARACTERISTICS

## 5.1 INTRODUCTION

Physical variables have been the most frequently measured facet of talent identification programmes. Numerous studies have sought to establish the physical profile of the elite athlete (Hawes & Sovak, 1994; Claessens et al., 1994). However, the majority of research has been content to provide a description of this profile. The purpose of this chapter is to determine the relationship between selected physical variables and future gymnastic performance. In accordance with theoretical considerations and a review of current world systems of talent identification the following categories have been identified as potential indicators of talent in young female gymnasts: anthropometry, body composition, inertia, isometric strength, power, local muscular endurance and flexibility. Through the application of exploratory principal components analysis and logistic regression analysis this chapter aims to determine the extent to which physical variables are able to correctly classify the future performance of gymnasts as successful or unsuccessful. In addition, the longitudinal development of these physical variables will be evaluated during the 12 month period of training. It is anticipated that by determining the stability and pattern of development of physical variables their role in the profiling of young female gymnasts will be more clearly understood. Finally, the extent to which physical characteristics are able to distinguish between gymnasts and controls will be investigated.

## 5.2 REVIEW OF LITERATURE

### 5.2.1 ANTHROPOMETRY

Investigations of the anthropometric characteristics of champion athletes have been a feature of almost every Olympic Games and many other major World and European competitions (Borms & Hebbelinck, 1984; Claessens et al., 1991a). The results of these studies have highlighted that Olympic athletes have an anthropometric profile that is distinct from the profile of a reference population matched for age and gender (Carter,

1984). Tanner (1964) suggested that there was a strong relationship between the mechanical and physiological requirements of a sports event and the physique of successful participants. Tanner subsequently transcended the level of description to infer causality, suggesting that physique and body composition may predispose individuals to express particular athletic abilities. The majority of early studies considered Olympic athletes as a single homogeneous group (Carter et al., 1978; Hirata, 1966), focusing most frequently upon the anthropometric characteristics of male Olympians (Claessens et al., 1991a). It was not until the 1960's that the anthropometric characteristics of the elite female athlete and moreover the elite female gymnast, became the object of scientific research (DeGary, Levine & Carter, 1974; Hirata, 1979a; Carter, Ross, Aubrey, Hebbelinck & Borms, 1982).

In addition to the identification of sport specific anthropometric profiles, it has been suggested that athletes specialising in particular events or occupying positions within a given sport may also exhibit distinct anthropometric characteristics. (Carter et al., 1978; Carter, 1984). Carter & Ackland (1994) highlighted that in terms of relative body dimensions, specific profiles were reported among world class athletes competing in various aquatic sports. In a similar manner, differences have been proposed in the anthropometric characteristics of those gymnasts attaining high competition scores in a single event (Schmidt, 1987; Salmela; 1979; Petiot, 1987). Salmela (1979) reported that the anthropometric profiles of American male single event specialists varied according to their preferred apparatus. Floor exercise specialists had a short compact frame suitable for power tumbling and multiple rotations about the transverse axis. By contrast, pommel horse specialists tended to be tall and lean with elongated extremities to enable the hips to remain well above the hand support during circling movements. The investigation of those anthropometric characteristics best suited to performance in a single event is of particular interest given the restructuring of competitive events by the Federation Internationale de Gymnastique (FIG). Individual Apparatus World Championships were introduced into the gymnastic calendar with entry for these events not restricted to qualification via four or six piece competition. Moreover, there are opportunities for single event specialists to compete in Team World Championships since nations are required to select four gymnasts from a team of six to compete on each piece of apparatus. Nevertheless, the greatest prestige is still associated with all around gymnastic performance. For a gymnast to be successful over all events the anthropometric profile is

likely to comprise a combination of the characteristics which are favourable in each event and as such, the specific profile of the "all around" gymnast is likely to prove more difficult to identify.

Table 5.1 presents a summary of the studies conducted at major international events to determine the anthropometric characteristics of elite gymnasts. The majority of these studies have failed to report full anthropometric profiles, indeed, several studies reported only the height and weight of competitors (Hirata, 1979a; Gajdos, 1984; Hadjiev, 1992). Table 5.2 presents a summary of the content of those studies which have reported data over the range of anthropometric variables which are of interest in the context of identifying talent. The majority of studies applied to determine the anthropometric profile of the elite female gymnast have been cross-sectional in nature. Cross-sectional studies are valuable for generating data on a large sample of gymnasts to enable statistical comparisons with an appropriate reference population. However, they are limited in that they only provide information at one specific point in time. It is not valid to assume that the anthropometric profiles of older gymnast were once like those of younger gymnasts, thus inferences regarding intra-individual trends in the longitudinal development of the anthropometric variables must be viewed with caution. An additional limitation of studies conducted at major international events concerns the specific environmental influence which may distort the determination of a sport specific anthropometric profile. Certain characteristics, such as skinfold measurements, are highly susceptible to environmental influences and may have artificially low values at the point of competition to enable the gymnast to achieve peak performance. The maintenance of such extreme values may not be required throughout the training cycle.

There are innate difficulties associated with the analysis of the data collected from an international sample. Considerable international variation exists in anthropometric parameters (Eveleth & Tanner, 1990). With respect to inter-continental variation in body size, Asian gymnasts have been reported to be smaller and lighter than gymnasts of European ancestry (Claessens et al., 1991a). These findings were confirmed by Hadjiev (1992), with those Asian gymnasts competing at the Barcelona Olympic games having remarkably low values for height and weight in comparison with other competitors.

Table 5.1. International investigations of anthropometric characteristics

| Title | Date | Sample | Authors |
|---|---|---|---|
| | | | |
| **Olympic Games** | | | |
| Amsterdam | 1926 | 19 Male | Dybowska & Dybowski (1929) |
| London | 1948 | 15 Male | Cureton (1951) |
| Tokyo | 1964 | 122 Male & 102 | Hirata (1966) (1979b) |
| Mexico City | 1968 | 28 Male & 21 | DeGaray et al. (1974) |
| Munich | 1972 | 126 Male & 106 | Hirata (1979a) (1979b) |
| | | 5 Female | Novak et al. (1976) (1977) |
| | | 10 Female | Malina et al. (1984) |
| Montreal | 1976 | 101 Male & 93 Female | Hirata (1979a) (1979b) |
| | | 103 Male & 99 Female | Gadjer op cit. Lopez et al. (1979) |
| | | 11 Male & 15 Female | Carter et al. (1982) |
| Los Angeles | 1984 | 75 Female | Staub (1986) |
| Barcelona | 1992 | | Hadjaev (1992) |
| | | | |
| **World Champs** | | | |
| Varna | 1974 | 126 Male & 106 | Zaharieva et al. (1979) |
| | | 105 Female | Gajdos (1980) |
| Budapest | 1983 | 169 Male & 161 | Gajdos (1984) |
| Montreal | 1985 | 42 Female | Staub (1986) |
| Rotterdam | 1987 | 165 Male & 201 Male | Claessens et al. (1991a) |
| | | 201 Female | Claessens et al. (1991b) |
| | | 201 Female | Claessens et al. (1990) |
| | | | |
| **European Champs** | | | |
| Amsterdam | 1967 | 38 Female | Pool et al. (1969) |
| | | | |
| Jr European | | | |
| Lyon | 1981 | 34 Male & 53 Female | L'Eglise et al. (1982) |
| Rimini | 1984 | 34 Male & 53 Female | Calderone et al. (1986) |
| Karlsruhe | 1986 | 68 Male & 86 Female | Brüggemann & Böhmer (1986) |
| | | | |
| **Other International** | | | |
| Santiago | 1977 | 33 Male & 24 Female | Lopez et al. (1979) |
| Cottbus (Friendship | 1986 | 67 Male & 69 Female | Schmidt (1987) |

Table 5.2. A summary of the content of anthropometric investigations of female gymnasts

| Study | Sample | Height | Weight | Sitting height | Skeletal lengths | Skeletal widths | Epiphyseal widths | Armspan |
|---|---|---|---|---|---|---|---|---|
| Salmela (1979) | 7 | **** | **** | **** | **** | **** | **** | **** |
| Leglise et al. (1982) | 53 | **** | **** | **** | | **** | | |
| Beunen et al. (1981) | 23 | **** | **** | **** | **** | **** | **** | |
| Moffat et al. (1984) | | **** | **** | | | **** | **** | |
| Peltenberg et al. (1984) | 298 | **** | **** | | | | | |
| Verycrussen et al. (1984) | 20 | **** | **** | | **** | **** | **** | |
| Brüggeman & Böhmer (1986) | 86 | **** | **** | | | **** | | **** |
| Calderone et al. (1986) | 52 | **** | **** | **** | | | | **** |
| Eiben et al. (1986) | 132 | **** | **** | **** | **** | **** | **** | |
| Carter & Brailler (1988) | 7 | **** | **** | | | **** | **** | |
| Theintz et al. (1989) | 34 | **** | **** | **** | | | | |
| Claessens et al. (1991) | 366 | **** | **** | **** | **** | **** | **** | |
| Hadjiev (1992) | | **** | **** | | | | | |

There is also evidence to suggest that there are systematic variations in body proportions between international populations (Malina & Bouchard, 1991). The determination of an appropriate reference population or standard with which to compare the profiles of international competitors is likely to prove problematic. Eveleth & Tanner (1990) highlighted the inadequacy of using British standards to judge the growth of Asian children, given that both the size and tempo of growth are different between the populations. Such regional variations in size and growth ensure that the task of interpreting the data from World and Olympic studies to produce a profile of the 'elite international' gymnast is fraught with difficulties.

In the most comprehensive study of world class gymnasts, Claessens et al. (1991a) measured the anthropometric characteristics of those gymnasts competing at the 1987 World championships in Rotterdam. The majority of subjects were of European ancestry and thus reference data of Flemish girls (Simons et al., 1990) were used in statistical comparisons. However, a closer examination of the study revealed that 16% of the gymnasts were of Asian ancestry and as such the validity of applying European reference data may be questioned. Due to the relatively small number of investigations detailing the anthropometric characteristics of elite female gymnasts, the possibility of combining samples is attractive. However, in addition to the limitations posed by sampling variations across studies, the pooling of data is restricted due to the inter-study variations in equipment and measurement techniques, the accuracy and precision of measurements and the variations in the performance level that existed between samples.

To date, only two studies have investigated the longitudinal development of the anthropometric characteristics of elite female gymnasts (Salmela, 1979; Baxter-Jones, 1994b). The study by Salmela (1979) investigated the changes that occurred in anthropometric variables of seven elite gymnasts between two measurement sessions, 475 days apart. The Training of Young Athletes Study (TOYA) was a more comprehensive mixed longitudinal study designed to investigate the effects of intensive training in a sample of 453 young British athletes. The following section will summarise the anthropometric profile of the elite female gymnast and consider how each component of the profile develops through childhood and into adolescence.

*Profile of the elite female gymnast*

Height and weight

Female gymnasts have consistently been reported to be smaller and lighter than the reference population and samples of athletes from various sports. Medved (1966) reported female gymnasts to be the smallest of all Olympic competitors. Carter (1984) confirmed these findings for gymnasts competing at the 1968 and 1976 Olympic Games. However, the study of Medved is of particular significance as it predates the transformation in the nature of women's artistic gymnastics which is commonly associated with the performance of Olga Korbut in the 1972 Olympic Games. In relation to specific comparisons with athletes from different sports, Novak, Woodward, Bestit & Mellerowicz (1977) found that Olympic female gymnasts were smaller and lighter than both swimmers and middle distance runners. In addition, Carter (1982) reported that Olympic gymnasts were smaller in stature and body weight than rowers, canoeists, swimmers and track and field athletes. In a review of previous research, Claessens et al. (1991a) identified secular trends in the anthropometric profile of the elite female. Most notably, the mean height and weight of the elite female gymnast decreased between the 1964 Tokyo Olympic Games and the 1987 Rotterdam World Championships. This trend was accentuated in the period between the Olympics Games of 1976 and the 1983 World Championships. Moreover, the profile of the female gymnast has been reported to have changed to a greater extent than that of the male gymnast over last three decades (Claessens et al., 1991a).

Stature and body weight are the most common indices of growth; these parameters have been reported in the majority of studies. The mean values for the height and weight of elite female gymnasts competing at major international events are presented in Table 5.3. Hadjiev (1992) reported the anthropometric characteristics of those gymnasts competing at the Barcelona Olympic Games. Heights and weights of the competitors were lower than the statistical average provided by the UNESCO for different regions, nations and continents. Studies have consistently shown that elite gymnasts are below the 50th percentile of reference populations for weight and height (Eiben et al., 1986; Bernadot & Czerwinski 1991). In addition, cross-sectional data suggests that older gymnasts are proportionally shorter and lighter than their younger peers (Bernadot & Czerwinski 1991).

Table 5.3. Height and weight of elite female gymnasts competing at major international events

| Competition | Date | Authors | Sample | Age (y) | Height (cm) | Weight (kg) |
|---|---|---|---|---|---|---|
| Olympic Games | 1964 | Hirata (1966, 1979b) | 102 | 22.7 | 157.0 | 52.0 |
| European Championships | 1967 | Poll et al. (1969) | 38 | 20.5 | 158.4 | 52.6 |
| Olympic Games | 1968 | DeGary et al. (1974) | 21 | 17.8 | 156.9 | 49.8 |
| Olympic Games | 1972 | Hirata (1979) | 133 | 19.0 | 159.0 | 49.5 |
| World Championships | 1974 | Zaharieva et al. (1979) | 106 | 18.5 | 158.6 | 50.7 |
| Olympic Games | 1976 | Hirata (1979) | 93 | 18.1 | 159.0 | 48.0 |
| World Championships | 1983 | Gajdos (1984) | 161 | 16.8 | 154.4 | 44.0 |
| Olympic Games | 1984 | Staub (1986) | 75 | 17.2 | 154.1 | - |
| World Championships | 1985 | Staub (1986) | 42 | 16.7 | 155.2 | - |
| World Championships | 1987 | Claessens et al. (1991) | 165 | 16.5 | 154.3 | 45.6 |

This observation was further supported by the results of the Toya study (Baxter-Jones et al., 1994) which reported that in comparison to a reference sample, female gymnasts only began to demonstrate shorter stature between 13-16 years of age and lower body weight between 12-18 years of age. However, at all ages, female gymnasts were shorter and lighter than athletes participating in tennis and swimming.

Claessens et al. (1991a) reported gymnasts to be 'remarkably smaller' than reference data for weight and height, with weight between the 6th and 15th percentiles of reference data and height between the 1st and 13th percentiles. No individual gymnasts were reported to have a weight or stature exceeding the 79th and 75th percentiles respectively. Similarly, Calderone et al. (1986) found those gymnast competing in the 1984 Junior European Championships had stature and weight below the 50th percentile of the value for North American reference data. Several studies of elite gymnasts reporting values for the body mass index (BMI) indicated that weight was low in relationship to stature (Schmidt, 1987). It has been proposed such a relationship between weight and stature would provide the gymnast with a direct biomechanical advantage during tumbling and acrobatic movements (Salmela, 1979).

The development of stature and body weight during growth and maturation has been reported to follow a four phase pattern (Malina & Bouchard, 1991). An inspection of distance curves reveals that height and weight increase rapidly in infancy before exhibiting a steady increase during childhood. A second rapid increase is observed during adolescence which is associated with the adolescent growth spurt. Subsequently, weight and height continue to increase slowly with the increase in stature terminating once adult height is reached (Malina & Bouchard, 1991). An examination of the corresponding velocity curve for stature reveals a constant deceleration in height velocity through infancy and childhood which reaches a nadir just before the onset of the adolescent growth spurt (Malina & Bouchard, 1991; Roemmich & Rogol, 1995). Some, but not all, children may demonstrate an small increase in velocity between 6.0 - 8.5 years of age, which is commonly referred to as the mid-childhood spurt (Tanner, 1989; Malina & Bouchard, 1991; Bogin, 1998). In British girls the adolescent growth spurt begins at about 10.5 years of age with peak height velocity (PHV) reached at approximately 12 years of age (Tanner, 1989; Baxter-Jones, 1994b). The adolescent spurt has been reported to reach an instantaneous peak of 9 cm per year (Tanner, 1989). Various

estimates report that on average adult stature is attained at 15.5 - 16 years of age (Tanner, 1989; Eveleth & Tanner, 1990; Malina & Bouchard, 1991; Baxter-Jones, 1994b).

With respect to the growth of body weight, a sharp decrease occurs in early childhood followed by a constant acceleration of approximately 3 kg per year throughout the rest of the childhood years (Roemmich & Rogol, 1995). During puberty, the peak growth in body weight (peak mass velocity or PMV) generally occurs after the peak height velocity (Mirwald & Bailey, 1986 op cit. Shephard, 1991; Malina & Bouchard, 1991) and may approach 8.5 kg per year (Roemmich & Rogol, 1995). The reported timings of these events varies across studies. For example, in the Harpenden study, the mean PHV in English girls occurred at 12.1 years and the mean PMV occurred at 12.9 years (Malina & Bouchard, 1991). However, considerable inter-subject differences were reported in the timing of these two events with between 0.3-0.9 years separating PHV and PMV. However, after PHV the gain in body weight decelerates rapidly (Roemmich & Rogol, 1995).

Sitting height

A number of studies have investigated the relationship between sitting height and subischial leg length (stature minus sitting height) (Eveleth & Tanner, 1990) in samples of elite gymnasts. For those gymnasts competing in the Rotterdam World Championships, the ratio of sitting height to stature appeared to be consistent within the range of 52.5% - 53.1% across all age groups. The results indicated that for this sample of elite gymnasts sitting height was slightly greater than leg length which was not dissimilar to the proportionality observed in the control population (Claessens et al., 1991a). The youngest (11 years) and oldest (15 years) gymnasts competing in the 1984 Junior European Championships demonstrated similar sitting height to stature ratios (53.05 ± 0.25% and 52.91 ± 0.97% respectively). However, proportionality was slightly different in those gymnasts aged 12-14 years who demonstrated sitting height to stature ratios in the range 50.53%-50.96%. This may be interpreted as evidence of the adolescent spurt in leg length which occurs in advance of the spurt in trunk length. In a further investigation, the sitting height of junior elite gymnasts was greater than that of control subjects although, the differences in proportionality did not reach statistical significance (Broekhoff, Nagdir & Pieter, 1986). The disparities reported across studies in the proportionality of sitting

height to leg length may be interpreted in part as a consequence of differences in relative maturity and in particular variations in the timing of peak growth velocities between samples of gymnasts and control subjects. Studies of growth and development have reported that the lower extremities grow rapidly during the early phase of the adolescent growth spurt while the adolescent spurt in sitting height or trunk length occurs somewhat later. In relation to the peak height velocity (PHV), development follows a sequential pattern in which the peak velocity for leg length occurs before PHV while the peak velocity for sitting height occurs after PHV (Malina & Bouchard, 1991; Simons et al., 1990). Although the adolescent spurt in leg length occurs relatively early, the growth in leg length ceases early in relation to the growth in sitting height. As a result of the extended period of growth in trunk length, a greater proportion of the adolescent increase in standing height comes from the spurt in sitting height in comparison to the spurt in leg length (Malina & Bouchard, 1991).

Skeletal widths

Relative to their stature and pelvic width, female gymnasts have relatively broad shoulders (Beunen et al., 1981). The absolute values for biacromial and biiliac widths for elite female gymnasts lie between the 18th-25th and 6th-11th percentiles of reference data respectively (Claessens et al., 1991a). Thus, whilst the absolute dimensions of these anthropometric dimensions are smaller in the elite gymnasts than in the reference population, elite gymnasts have relatively broad shoulders and narrow hips. This aspect of the profile was confirmed in samples of gymnasts of mixed ability (Vercruyssen, 1984; Broekhoff et al., 1986).

With respect to the pattern of growth, hip and shoulder widths increase at a similar rate during childhood. Therefore, the ratio of the biacromial to biiliac widths remains constant or slightly increases between approximately 6-11 years of age (Simons et al., 1990; Malina & Bouchard, 1991). Subsequently, girls experience growth spurts in these skeletal widths. The spurt in hip width is particularly marked as a result of hormonal factors and specifically, the response of cartiliginous cells in the hip to oestrogen (Tanner, 1989). The spurt in hip width begins earlier and is more marked than the spurt in shoulder width, and as a result females experience a broadening of the hips in relation to the shoulders

which is characteristic of female adolescence (Simons et al., 1990; Malina & Bouchard, 1991).

Widths of epiphyses

Data regarding the widths of the epiphyses are sparse. Claessens et al. (1991a) found humerus and femur widths to be close to reference values. The lack of any significant differences between gymnasts and controls for these measurements was purported to indicate average levels of bone development in the extremities. Broekhoff et al. (1986) in a study of younger gymnasts found similar humerus and significantly smaller femur widths when gymnast were compared with age-matched controls. However, when these values were expressed in relation to a phantom stature, the gymnasts appeared to possess proportionally greater humerus widths and femur widths which were almost identical to controls (Broekhoff et al., 1986). Few studies describe the longitudinal development of the epiphyses in female children and adolescents. However, the study of Flemish Girls revealed a linear increase in the width of the humerus and femur during childhood, followed by a small spurt before levelling off (Simons et al., 1990).

Skeletal lengths

Little data have been presented concerning the lengths of the upper and lower extremities in elite female gymnasts. In the most comprehensive investigation, Claessens et al. (1991a) found no differences between gymnasts and controls in the length of upper and lower extremities in proportion to stature. Forearm lengths were approximately 14% of stature with leg length corresponding to 47% of stature. With respect to the sequential development of skeletal lengths, the lower extremity is the first to experience peak growth velocity followed by the trunk and upper extremity (Malina & Bouchard, 1991). Extremity development generally occurs in a distal to proximal direction with the more distal segments experiencing their peak velocities prior to the proximal segments (Malina & Bouchard, 1991; Blanksby et al., 1994; Norgan, 1998a). A related anthropometric variable, armspan, has not been extensively measured in studies of elite female gymnasts (Table 5.2). The studies of Calderone et al. (1986) and Brüggemann & Böhmer (1986) reported that for samples of international junior gymnasts the difference between armspan and height was always positive. The study of Verycrussen (1984) found a similar

relationship between armspan and height for collegiate gymnasts. However, the relatively greater armspan of gymnasts in relation to stature may be the result of the greater biacromial diameter.

Summary of the characteristics of the elite female gymnast

Numerous studies have indicated that the elite female gymnast has a specific anthropometric profile that is distinct from the reference population and indeed from athletes of different sports (Calderone et al., 1986; Claessens et al., 1991a). The important features of such a profile are those characteristics which distinguish the elite female gymnast from a reference individual. In summary, it appears that the elite gymnast is well-proportioned, but small and thin. Whilst they have smaller absolute biacromial and biiliac diameters than control subjects, gymnasts are relatively broad shouldered in relation to their stature and pelvic width. The limited data relating to the lengths of limbs indicates that proportions of upper and lower extremity lengths do not differ from the control population, however, armspan appears to be consistently greater than stature for gymnasts of all performance levels which may be the result of the proportionally greater biacromial diameter observed in female gymnasts.

Therefore, it appears that there is a specific profile of the 'elite' female gymnast and that this profile appears to be consistent across samples of gymnasts. Salmela (1979) suggested that there may be variations in this anthropometric profile between gymnasts of varying levels of proficiency. This suggestion was confirmed by Hadjiev (1992) who reported that the mean body weight of Olympic gymnasts was lower for those gymnasts competing in the highest level of competition, the apparatus finals, than for gymnasts competing in all other levels. While clear differences exist in absolute anthropometric measurements of gymnasts of varying proficiency levels, the relative skeletal proportions appear to be consistent across samples, irrespective of the age, level of achievement, and maturity of the gymnasts (Carter, Sleet & Martin, 1971).

*Stability of anthropometric characteristics*

Twin researchers comparing monozygotic (MZ) and dizygotic (DZ) twins have consistently reported high heritabilities for height and weight (Bouchard et al., 1990a).

However, the genetic control of adult stature is reported to be greater than genetic control of body weight (Malina & Bouchard, 1991). The re-analysis of data from 19 twin pairs originally studied by Bouchard & Lortie (1984) resulted in a mean heritability estimate of 0.85 ± 0.07 for stature (Bouchard et al., 1997). This estimate is in broad agreement with estimates provided by Bouchard, Brunelle & Godbout (1973) based upon the work of Schreider, (1969) which reported the heritability of stature to be 0.79 and 0.92 in males and females respectively. Twin studies reporting the pattern of intra-pair correlations for stature during childhood have provided further support for the important role of genetic factors in the control of anthropometric parameters (Bouchard et al., 1997; Eveleth & Tanner, 1990). For example, in the large sample of 952 twin pairs included in the Louisville Twin Study, within pair correlations for both stature and weight decreased in DZ twin pairs after birth while the resemblance of MZ twins increased over time (Wilson, 1986).

A number of large scale surveys have applied various models of path analysis to investigate the transmission of anthropometric parameters across a variety of relatives linked by descent or adoption. In general, the estimates of the genetic contribution to the phenotypic variance in stature were lower than previous estimates derived from twin data. Using data generated in the Canada Fitness Survey, Pérusse et al. (1988) employed the TAU model of path analysis to investigate familial correlations and partition total phenotypic variance into estimates of transmissible and environmental components. Estimates of transmissible variance of 0.28 and 0.27 were reported for stature and weight respectively. However, the low estimate of transmissible variance in stature must be viewed with caution given the poor model fit reported for this parameter. Other investigations have applied the TAU model to twin and family data and produced transmissibility estimates of 0.65-0.70 which are in line with the results of previous research (Byard, Sharma, Russell & Rao, 1984; Byard, Poosha & Satyanarayana, 1985; Devor, McGue, Crawford & Lin, 1986). These estimates received support from a large scale study of the Canadian population which reported a total transmissibility of 0.60 of the adjusted phenotypic variance in stature with a corresponding heritability estimate of 0.40 (Bouchard, 1991). As expected, transmissibility estimates for body weight derived from studies of twins and relatives using the TAU model of path analysis were lower than for stature (0.4-0.5) (Byard et al., 1984; Byard et al., 1985; Devor et al., 1986; Malina & Bouchard, 1991).

Autocorrelations have been reported between adult stature and the height of individuals at various times during childhood. The correlations were reported to be low during infancy (0.2-0.3), but to rise to approximately 0.8 by three years of age and remain at or around this level throughout childhood (Malina & Bouchard, 1991; Malina, 1990). These correlations provide additional support for the twin and family studies which indicate that stature is largely influenced by genotype and may be considered sufficiently stable to merit consideration as a talent characteristic (Borms, 1998). The magnitude of the adolescent growth spurt was reported to have only a minor influence upon the variability of adult stature as indicated by the high correlation between adult stature and stature attained prior to the onset of the adolescent growth spurt (Bouchard et al., 1997; Malina & Bouchard, 1991; Tanner, 1989). However, autocorrelations with adult stature have been reported to decrease during adolescence as a function of inter-individual variation in the timing of the adolescent growth spurt (Bouchard et al., 1997; Malina, 1990; Malina & Bouchard, 1991). A similar pattern of correlations has been observed between adult body weight and the weight of individuals at various times during childhood. However, the strength of the correlation (0.60-0.80) was lower than for stature (Tanner & Whitehouse, 1982, op cit. Malina, 1990).

The majority of practical research relating to the stability of anthropometric characteristics within samples of elite female gymnasts has focused upon the indices of height and weight. Only a limited number of studies have provided support for the influence of environmental factors on such parameters. Eiben et al. (1986) in a study of elite Hungarian gymnasts reported that stature, for the majority of gymnasts, was below the 25th percentile for age. However, parental heights were not appreciably different from the Hungarian reference population, thus Eiben et al. (1986) suggested that the observed small stature in elite female gymnasts was the result of retardation due to environmental rather than genetic factors. Bernadot & Czerwinski (1991) suggested that a combination of factors best explained the extremely low statures observed in female gymnasts with respect to the reference population. The observations of low stature and body weight were suggested to be the result of nutritional deficits and sport specific selection. The analysis of dietary intake of elite gymnasts by Bernadot & Czerwinski (1991) confirmed that nutrient intake was less than optimal which could be a contributing factor in low growth indexes. However, the majority of evidence supports the role of genetics in

determining stature (Peltenburg et al., 1984; Theintz et al., 1989; Beunen, Malina, Renson, Simons, Ostyn & Lefevre, 1992; Malina, 1994a).

Peltenburg et al. (1984) concluded the small height of female gymnasts is largely due to their genetic make-up and is not affected by physical training. Further support for role of genetics was gained from a retrospective analysis of the growth records of Dutch adolescent athletes. Peltenburg et al. (1984) confirmed that gymnasts differed in stature and weight from groups of swimmers and controls from 3 years of age. In addition, the mid-parental heights for the parents of swimmers were greater than those of the parents of gymnasts. Peltenburg et al. (1984) concluded that the differences in body height between groups of swimmers and gymnasts appeared to be largely based on the genetic growth regulation. No evidence was found to indicate that physical activity from an early age directly influences growth until puberty. Theintz et al. (1989) studied 34 young female gymnasts and demonstrated that while the projected adult heights for the gymnasts was significantly lower than for swimmers and controls they were adequate given the target height range calculated from parental data. The results of this study indicated that the growth of female gymnasts follows particular familial patterns, which may be utilised in the identification of talent.

The heritability of both skeletal length and breadth measurements is high (Bouchard et al., 1973), particularly in the case of the linear measurements (Bouchard et al., 1997). Bouchard et al. (1997) derived heritability coefficients of skeletal lengths and breadths using data from previously published twin studies. Estimates cited for the linear measurements approximated those reported for stature, ranging from 0.62 ± 0.01 for upper arm length to 0.94 ± 0.04 for total arm length. Genetic pleotropism, which implies that several traits are dependent upon a single gene or a set of genes, has been suggested as an explanation for the high heritability estimates reported across skeletal lengths (Bouchard, Demirjian & Malina, 1980; Bouchard et al., 1997). The heritability estimates for biacromial and biiliac widths also indicated a large genetic effect although somewhat smaller and more variable than the linear dimensions (0.64 ± 0.22 and 0.60 ± 0.13 respectively). Although less data were available, the heritability estimates of epiphyseal widths were similar to skeletal breadths (0.60 ± 0.18).

Data from the Quebec Family Study (Bouchard, 1991 op cit. Bouchard et al., 1997), including the pattern of correlations between biological siblings and between natural/adoptive parents and their offspring, provided further evidence in support of the role of the genotype in explaining the phenotypic variance in skeletal lengths and breadths. Indirect support for the influence of the genotype may be derived from the apparent difficulty associated with modifying the effect of body segment proportionality through training (Ackland & Bloomfield, 1996). With reference to the elite gymnasts, Rich, Fulton, Ashton, Bass, Brinkert, Brown & Villani (1991) suggested that it was difficult to conceive that environmental factors and specifically the training effect were responsible for the characteristic profile of male gymnasts in terms of biacromial and biliiac widths citing genetic predetermination as the more likely explanation. The sitting height to stature ratio has frequently been cited as an expression of proportionality. There has been little research to investigate the stability of body segment proportionality. However, unpublished data from the Quebec family study revealed that correlations for the sitting height to stature ratio of children and their biological parents were approximately five times greater than correlations derived from households in which children and parents did not share genes by descent (Bouchard, unpublished data op cit. Bouchard et al., 1997).

Using longitudinal data derived from the Western Australia Growth and Development Study (Blanksby et al., 1994), the stability of body proportions during the adolescent period was investigated by Ackland & Bloomfield (1996). For each of 15 proportionality characteristics, 125 subjects were classified as high, middle or low according to their score at pubescent stage one (Tanner, 1962). A two factor ANOVA with repeated measures was applied to determine the extent to which the differences in proportionality between the high and low groups were maintained as maturation proceeded. For a number of variables relating to skeletal breadths, upper limb and trunk lengths the differences between high and low tertiles remained stable across pubescent stages 1 through 5. In contrast, for a number of lower limb variables the group differences present in stage one were not maintained to stage 5. The authors suggested that this observation may be due to the greater susceptibility of the lower limb to environmental influences as a result of the later closure of the epiphyses in comparison to the long bones of the upper limb. Therefore, the utility of lower limb dimensions and ratios associated with these dimensions may be of little utility in the identification of talented children prior to end of

pubescent stage 5. These observations may assist in interpreting the disparities reported in previous research concerning the lack of a clearly defined proportionality profile in terms of the sitting height/leg length ratio in elite female gymnasts.

### 5.2.2 BODY COMPOSITION

For the majority of sporting pursuits, high levels of body fat are associated with reductions in performance standards (Norton, Craig, Withers & Whittingham, 1994). A notable exception is long distance swimming in channel or ocean conditions in which buoyancy and insulation enhanced by high levels of body fat may be advantageous. By contrast, sports which require body weight to be supported and propelled demand a high strength to weight ratio and correspondingly low levels of body fat. Such a body composition favours a high level of power production per unit body weight and is most advantageous to the young female gymnast (Withers, Whittingham, Norton, LaForgia, Ellis & Crockett, 1987). In women's artistic gymnastics a lean physique is demanded for both aesthetic and mechanical reasons. The sport is judged subjectively and elite level performances are associated with an image of body leanness. The mechanical benefits of leanness are based upon Newton's Second Law which states that force is the product of mass and acceleration. In accordance with this law, any increase in fat mass that occurs without a subsequent increase in the ability of the muscles to exert force will decrease the potential for acceleration. In addition, fat mass is inert and does not contribute to the body's work capacity, thus in physiological terms, increased energy production is required to produce and sustain movement of a greater mass (Norton et al., 1994). Finally, high levels of body fat are associated with a reduction in the time to onset of fatigue, which is in turn associated with deterioration in skill performance (Withers et al., 1987).

*Methodological considerations*

Methods applied to the estimation of body composition are classified as direct, indirect or double indirect depending on the degree to which the measured variable is removed from the estimated parameter of body composition. In terms of direct methods, cadaver dissection can be considered the only truly valid method of determining body composition. Indirect methodologies involve the calculation of a parameter of body

composition according to its constant theoretical relationship with another variable and include densitometry and bioelectrical impedance analysis. For example, in densitometry, percentage body fat can be estimated given the theoretical relationship between percentage body fat and whole body density. However, densitometry requires a considerable time commitment from the subject and entails the use of sophisticated laboratory equipment. Therefore, it is not suitable for the routine assessment of body composition in field conditions. Finally, anthropometric regression equations are examples of a double indirect method, since these regression equations themselves predict a variable which is in turn related to percentage body fat. The most frequently applied regression equations require the assessment of subcutaneous adipose tissue via a series of skinfold measurements. A skinfold is a double fold of skin which contains water, connective tissue, blood vessels, nerves and theoretically all the underlying subcutaneous fat (Shephard, 1991). The prediction of body fatness from skinfold measurements is based on the rationale that it is possible to measure the subcutaneous fat layer via skinfold thickness and that the amount of subcutaneous fat in turn correlates well with total body fat, as assessed from densitometry (Westrate & Deurenberg, 1989).

There are two main assumptions that enable the prediction of body fatness from skinfold measurements. The first concerns the relationship between the quantities of subcutaneous and total body fat. Any predictive equation inherently assumes that the relationship between internal and subcutaneous fat stores is constant for all individuals (Davies, 1994). Clarys, Drinkwater, Martin & Marfell-Jones (1987) questioned this assumption, suggesting that while skinfold readings are highly correlated with the amount of subcutaneous fat they are unrelated to the amount of deep body fat. However, this study was limited as a result of the nature of the subject pool and in particular the advanced age of the subjects. However, individual differences in the distribution of fat between subcutaneous and internal fat stores have been cited to be in part responsible for the low validity of skinfold equations (Davies, 1994). However, in support of the assumption, the correlation between skinfold thickness and body fatness has been estimated to be moderately high with 50-80% of the variance in the criterion measure of fatness being explained by the variation in skinfold thicknesses (Lohman, 1982). Inter-individual variation in the proportion of fat located subcutaneously has been proposed as reason for the lack of validity of skinfold equations (Davies, Jones & Norgan., 1986) with differences observed in the relationship between internal and subcutaneous fat stores

occurring as a result of age, sex and ethnicity (Slaughter, Lohman, Boileau, Loan, Horswill & Wilmore, 1984, Durnin & Wormersley, 1974). In addition, the level of fatness has been suggested as a cause of systematic variation which may be of concern in the assessment of elite athletes who have been shown to have extremely low amounts of subcutaneous fat (Despres, Bouchard, Tremblay, Savard & Marcott, 1985).

The second assumption suggests that selected skinfolds are representative of total body subcutaneous fat (Roche, 1987). The regional distribution of subcutaneous fat is influenced by age, sex and also by environmental factors such as the dietary status and habitual physical activity levels of the individual (Ballor, 1996). However, the distribution of subcutaneous fat within a given individual appears to be relatively stable over several years (Garn, Sullivan & Hawthorne, 1988). Additional assumptions underlying the prediction of body fatness from skinfold readings relate to the constant compressibility of skinfold, the constant fat fractionation of adipose tissue and the consistency of the contribution of the skin to the thickness of the fold (Ross & Marfell-Jones, 1991). Lohman (1981) quantified the sources of errors associated with skinfold measurements. A 2.5% error was apportioned to inter-individual differences in the ratio of subcutaneous to total body fat with a further 1.8% resulting from inter-individual differences in the distribution of subcutaneous fat. Finally 0.5% error resulted from problems associated with the repeatability of the measurement process (technical error of measurement). Thus, given the independence of these sources of variance, the total error in the prediction of body fat from skinfold measurements was estimated to be 3.3%, which rates favourably with errors for the 'criterion' method of densitometry (Shephard, 1991).

Since Brozek & Keys (1951) first published equations relating regional skinfold measurements to percentage body fat, numerous anthropometric prediction equations have been employed in the determination of body composition (Parizkova, 1961; Durnin & Rahaman, 1967). Most skinfold equations have been applied to estimate body density. For example, Durnin & Womersley (1974) published an extensive data set relating skinfold measurements to body density for samples of various ages and gender to account for variations that occur in the relationship between body density and skinfold thickness with age and sex (Durnin & Womersley, 1974; Jackson & Pollock, 1978; Lohman, 1981). The advantages of applying skinfold equations to estimate body fatness of large

samples in field conditions have been emphasised (Roche & Guo, 1993). However, the majority of equations are population specific (Davies 1982) and are rarely of general validity (Jackson & Pollock 1978: Norgan & Ferro-Luzzi 1985). The validity of prediction equations depends upon the use of equipment and the replication of technique consistent with the methodology of the original study in which the equation was developed. Generalised equations have been proposed and successfully cross-validated for use in the general population (Jackson & Pollock, 1985; Jackson & Pollock, 1978; Jackson, Pollock & Ward, 1980).

*Application of skinfold equations to children*

The use of skinfold equations in the assessment of body fat in children is inherently appealing given their non-invasive nature, but it is also problematic due to differences in the chemical composition of fat free mass in children and adults and the changes that occur in this chemical composition during maturation (Deurenberg, Pieters & Hautvast, 1990; Lohman et al., 1984a; Boileau, Lohman, Slaughter, Ball, Going & Hendrix, 1984; Lohman, 1986; Forbes, 1987; Westrate & Deurenberg, 1989). Overwhelming evidence from the literature suggests that children are not chemically mature. Specifically, the body water content of the fat free mass of pre-pubescent children is reported to be greater than in young adults (Boileau et al., 1984; Shephard, 1991). Moreover, as a result of the incomplete calcification of bone, the bone mineral content is reported to be lower in children (Lohman et al., 1984a,b). The chemical immaturity of children results in a lower density of fat free mass, which is substantially less that 1.100 g/cm$^3$ assumed in the adult two component model. Thus, application of adult regression equations result in a systematic overestimation of the density of the fat free mass of children (Lohman 1986; Slaughter et al., 1984). The extent of the overestimation of body density in children has been estimated at an average of 0.023 g/ml in 8-12 year old males and 0.010 g/ml in 8-12 year old females (Lohman et al., 1984a) In addition, conventional approaches to convert body density to percentage body fat overestimate body fatness in the pre-pubescent child. The use of conversion constants derived from adult samples may result in an overestimation of total body fatness by 3-6% with a corresponding underestimate of fat free body mass (Lohman et al., 1984a). The composition and density of fat free mass change with maturation. These changes are the result of bone mineralisation and muscle formation and increases in protein deposition from birth through to adulthood (Westrate

& Deurenberg, 1989). Thus, body density increases as the child grows and matures. The difference in body density is larger between pre-pubescent children and adults than between adolescents and adults (Westrate & Deurenberg, 1989) and the inaccuracy associated with the application of adult equations to estimate body composition in children and youth decreases as children approach maturity.

*The development of body composition equations for children*

Skinfold equations to predict body composition in children have been developed (Parizkova, 1961; Brook, 1971; Parzikova, 1977; Durnin & Womersley, 1974). However, the majority of such equations were developed in accordance with the reference method of densitometry and with the subsequent application of the adult two component model. The error of densitometry as a criterion method combined with the chemical immaturity of children ensures the validity of such equations is questionable (Shephard, 1991). Equations have been constructed based on published data of the changes in density of fat free mass with age in children and the subsequent estimation of percentage body fat from body density by the use of age and sex dependent equations (Westrate & Deurenberg, 1989). In addition, population specific regression equations have been developed for children based upon multi-component age and sex specific models, taking into account the changes that occur in the density of the fat free mass as children mature. (Slaughter, Lohman, Boileau, Hostwill, Stillman, Loan & Bemben, 1988; Guo, Roche & Houtkeeper, 1989). With the exception of the comparison of the Slaughter equations with Lohman's Siri age adjusted body density equation (Janz et al., 1993), there have been few attempts to cross-validate the equations of relating skinfolds to body density in children. Hence, there is little information available regarding their general applicability.

*The application of regression equations to an athletic sample*

The application of suitable equations to predict body fat is particularly important in athletes given the concern for the achievement of an optimum ratio of fat to fat free mass and the connotations associated with the overprediction of body fatness. Roche & Guo (1993) highlighted that whilst the nature of the independent variables in the prediction equations are likely to remain unchanged, the associated coefficients are likely to differ as

a result of a higher density in the fat free mass of athletes. There is evidence to suggest that bone mineral density is higher in athletes than sedentary individuals (Jones & Norgan, 1994). Bone mineral has a high density in relation to the other components of the fat free mass and has been estimated at 3.000g/cm3 (Mendez, Keys, Anderson & Grande, 1960). Therefore, the density of the fat free mass can be influenced markedly by changes in bone mineral content (Lohman et al., 1984a,b). It is most likely that increases in the density of fat free mass in athletic samples results from higher proportions of bone mineral. One notable exception is the amenorrhoeic female athlete with low skeletal mass (Roche & Guo, 1993; Drinkwater et al., 1984; Lindberg, Fears & Hunt, 1984). The greater density of fat free mass reported in most athletic samples is purported to explain the extremely low and sometimes negative estimates in percentage body fat from densitometry for some athletes using conventional methods of estimation (Jones & Norgan, 1994). It has been estimated that athletes may have an 18% higher bone mineral density in their fat free mass than the population upon which the most popular equation to convert body density to percentage boy fat (Siri, 1961) was derived. This results in a potential magnitude of error of approximately 15% body fat (Jones & Norgan, 1994). Preliminary results of a study of bone mineral density in gymnasts and swimmers suggest that increases in bone mineral density resulting from athletic pursuits may not be uniform across sports. Gymnasts were reported to have a significantly greater bone density than swimmers matched for gender, maturation and body weight (Grimston & Hanley, 1992). These results suggest that the type of loading may be an important factor affecting bone mineral density. Impact loading, which occurs in gymnastics and other sports which demand the body weight to be supported and repeatedly propelled, may result in greater increases in bone mineral density than in sports involving active loading such as swimming.

Numerous regression equations have been proposed to determine the percentage body fat of athletes from anthropometric variables (Forsyth & Sinning, 1973; Sinning, 1974; Pollock, Gehman, Jackson, Ayres, Ward & Linnerup, 1977). With respect to elite level athletes, Carter (1986) developed regression equations based on the data of Yuhasz (1977) for use in the Montreal Olympic Games Anthropological Project (1976). Several equations relating skinfold thicknesses to percentage body fat have been derived specifically for female athletes of various sports (Sinning, 1978; Meleski, Shoup & Malina, 1982; Mayhew, Clark, McKeown & Montaldi, 1985). However, the generalised

regression equations of Jackson & Pollock (1978) and Jackson et al. (1980) are suggested to be the most appropriate for the determination of body density in athletes (Porta, De Suzo, Tejedo & Prat, 1995; Thorland, Johnston, Tharp, Housh & Cisar, 1984; Webster & Barr, 1993).

*Application of regression equations to predict body fat in young female gymnasts*

Thus far, the review has highlighted that due to differences in the chemical composition of the fat free mass, adult skinfold equations have a tendency to overestimate body fatness in children and underestimate percentage body fat in athletes. Therefore, it is not clear which set of equations, relating skinfold thicknesses to percentage body fat, are the most appropriate to apply in a sample of athletic children. Webster & Barr (1993) compared a series of regression equations used in prediction of body composition in adolescent skaters and gymnasts. The range of equations included specific equations adjusted to estimate body composition in children using BIA (Deurenberg et al., 1990) and skinfold thicknesses (Jackson et al., 1980; Lohman, 1986). Prediction of the percentage body fat in gymnasts using the BIA equation was 100% higher than the value estimated using the age adjusted skinfold equation. This result was particularly interesting given the tendency for adult skinfold equations to overpredict body fatness and BIA equations to underpredict body fatness in reference children. The differences in the body fat predictions between the age adjusted equations were attributed to the effects of physical activity on the chemical maturity of the female adolescent athlete. However, as yet these effects have not been clearly established. The differences may in part be the result of the significantly higher bone densities which have been recorded in gymnasts (Grimston & Hanley 1992). From the results of this study it is not possible to estimate the most appropriate level of adjustment for chemical immaturity that is required to produce accurate assessments of body composition.

Without specific data relating to the effects of physical activity in the chemical composition of the fat free mass, it is not possible to gauge whether the age adjusted constants in the estimation of percentage body fat using skinfolds over-compensated for the chemical immaturity of the young athletes and thereby underestimated their percentage body fat. This uncertainty led Webster & Barr (1993) to recommend the use of the Jackson & Pollock (1980) quadratic equations for skinfolds with Lohman's age

specific constants (1986). The rationale for this recommendation being that while the use of such constants may result in the underprediction of body fat, this is safer than to overestimate body fat and risk the athletes restricting their caloric intake in pursuit of 'unrealistic' body fat values. It is also appropriate to highlight that the use of the age specific constants as suggested by Lohman (1986) may not be appropriate for a group of young female gymnasts. Samples of female gymnasts have consistently been reported to experience later sexual and skeletal maturity (Calderone et al., 1986; Malina, 1994b). As a result, age and sex specific constants may have limited validity in the determination of body composition in this population. The application of constants adjusted for variations in the rate of maturation (Lohman, 1986) would seem more appropriate to a population of young female gymnasts.

Moreno, Escudero & Gimeno (1993) compared body fat values obtained from different anthropometric prediction equations in a sample of 67 elite gymnasts. Significant differences were found between the predictions from all equations ($p<0.05$). Similarly, Claessens et al. (1991b) compared various skinfold prediction equations in the estimation of body composition parameters in those female gymnasts competing at the 1987 World Championships in Rotterdam. Body density was converted to percentage fat using the Siri formula with age and gender associated corrections (Lohman, 1986). There were significant differences between all body composition variables between the equations. The mean percentage body fat varied from 7.1% to 14.1% and mean fat weight from 3.4 to 6.6 kg for the Thorland et al. (1984) and Slaughter et al. (1988) equations respectively. Hence, in a specific population of highly talented female gymnasts, use of different prediction equations resulted in significantly different estimates of percentage body fat. Anthropometric regression equations used to estimate body composition have been developed for a population of collegiate female gymnasts using the technique of step-wise linear regression (Sinning, 1978). However, the application of such equations to a population of pre-pubescent female gymnasts is unlikely to be valid given the variation in age between the samples. Despite the limitations associated with regression equations a number of studies have converted raw skinfold data collected from young female gymnasts to percentage body fat using the equations proposed by Parizkova, 1961 (Brüggeman & Böhmer, 1986; Schmidt, 1987), Sinning, 1978 (Vercruyssen et al., 1984) and Durnin & Rahaman, 1967 (Beunen et al., 1981).

The methodology chosen to be incorporated into the research design must be in line with the ethical requirements for the determination of body composition in children of a young age. In addition, the technique must be acceptable to the study population and it must be applicable and socially acceptable in a mass screening situation. Thus, many of the contemporary indirect techniques are inappropriate. Regression equations developed to estimate body composition are an attractive method given the non-invasive nature of skinfold measurements. However, there is no conclusive evidence to suggest that any of the published prediction equations are appropriate to accurately determine percentage body fat in a sample of pre-pubescent female gymnasts. Moreover, given the potential problems associated with overpredicting fatness in young females, the measurement of absolute skinfold thicknesses appears to be the most appropriate technique for the assessment of body composition in young female gymnasts. This is in line with recommendations published by Claessens et al. (1991b) and Ross & Marfell-Jones, (1991).

*Body composition in female athletes*

Low body fat has consistently been associated with high level athletic performance. However, the age at which differences in body composition between various athletic groups and control subjects become apparent has not been conclusively determined. The study by Blanksby et al. (1994) showed that measures of body composition were unable to discriminate between groups of pre-adolescent female swimmers, tennis players and control subjects. These results suggested that such measures may be of limited prognostic utility prior to the onset of puberty. Data collected in association with the University of Western Australia Growth and Development Study (Blanksby et al., 1994) challenged previous research findings that female athletes have less relative fatness, particularly during the adolescent years (Malina & Bouchard, 1991). The study also demonstrated differences across sports in the age at which body composition measures began to differentiate between female athletes and controls (Blanskby et al., 1994). In tennis, body composition measures differentiated between samples of players of various ability and control subjects in a predictable manner from 11 years of age whereas in swimming the sum of skinfolds was unable to differentiate between simmers and controls until after pubescent stage 5 (Blanksby et al., 1994). However, in contrast, the results of the TOYA study (Baxter-Jones, 1994b) reported that significant differences in skinfold thicknesses

between various athletic groups were apparent by 10 years of age and interestingly in this study swimmers demonstrated significantly lower skinfold thicknesses than tennis players and age-matched controls. It was possible to differentiate female gymnasts from all other groups of athletes and control subjects according to their lower body fat between the ages of 12 and 16 years (Baxter-Jones, 1994b).

*Subcutaneous adipose tissue in the young female gymnast*

A number of investigations have reported absolute skinfold data in female gymnasts (Table 5.4).

Table 5.4. Means (standard deviations) of absolute skinfold data in female gymnasts

| Study | age (yrs) | competitive level | biceps ($mm^2$) | triceps ($mm^2$) | subscap ($mm^2$) | supra-iliac ($mm^2$) |
|---|---|---|---|---|---|---|
| Salmela (1979) | 13.9 | elite national | | 7.5 (0.8) | 5.7 (1.1) | 3.9 (0.8) |
| Moffatt et al. (1984) | 15.2 | high school | | 10.9 (0.9) | 7.3 (0.5) | 8.1 (0.9) |
| Vercruyssen (1984) | 20.3 | collegiate | 3.9 (2.7) | 8.4 (3.2) | 7.8 (3.1) | 9.2 (6.1) |
| Carter & Brallier (1988) | 10.3 | club | | 8.4 (2.5) | 5.5 (0.9) | |
| Claessens et al. (1991a) | 16.5 | international | 3.9 (1.3) | 7.4 (2.4) | 6.6 (1.6) | 4.7 (1.7) |

These studies revealed that young female gymnasts have a lower amount of subcutaneous fat in comparison with selected reference populations (Moffatt, Surina, Golden & Ayres, 1984; Verycrussen, 1984; Carter & Brallier, 1988; Claessens et al., 1991a; Baxter-Jones, 1994b). Although the magnitude of the difference between gymnasts and controls varied across studies partly in accordance with the ages and/or performance standards of the gymnasts under investigation, it is clear that gymnasts possess very low levels of subcutaneous fat. In the most comprehensive cross-sectional study of elite gymnasts to date, the sum of five skinfolds of those gymnasts competing in the 1987 World Championships was at the 48$^{th}$ percentile in comparison to a reference population of Flemish girls. Particularly low skinfolds were recorded in these gymnasts at the triceps site (Claessens et al., 1991a). In a small sample Carter & Brallier (1988) confirmed low skinfold values with triceps and subscapular skinfolds of 9-11 year old female gymnasts

at the 20th and 35th percentiles respectively in comparison with a reference sample of American children.

*Development of subcutaneous adipose tissue in the growing child*

In female subjects subcutaneous fat increases rapidly during infancy with a peak in several skinfold measurements observed at around 9-12 months of age (Tanner, 1989; Norgan, 1998b). A decrease in body fat and skinfold measurements is reported after this age which has been associated with the increased mobility of the infant (Shephard, 1991). The value of skinfold measurements continues to decrease during childhood until a low point is reached between 6-8 years of age (Parizkova, 1977 op cit. Shephard, 1991; Malina & Bouchard, 1991). Finally, girls experience a second rapid increase associated with puberty which results in a linear increase in subcutaneous fat through adolescence (Malina & Bouchard, 1991). The pattern of development of subcutaneous adipose tissues has been referred to as the adiposity rebound (Norgan, 1998b). Of particular interest is the observation that children who experience the rebound at an earlier age tend to have higher levels of body fat at the end of growth (Norgan, 1998b).

Two investigations have adopted a cross-sectional approach to investigate age changes in the skinfold measurements of elite gymnasts (Eiben et al., 1986; Claessens et al., 1991a). The data from Eiben et al. (1986) is plotted in Figure 5.1 with filled circles representing the mean skinfolds of a sample of elite Hungarian gymnasts and the open circles denoting the mean skinfold measurements of a reference sample of Hungarian children. The graphs indicate that although female gymnasts have thinner skinfolds the pattern of development appears to be similar to that of control subjects with all skinfolds increasing during the adolescent years.

Only two studies have investigated the longitudinal development of skinfold data in the female gymnast (Salmela, 1979; Baxter-Jones, 1994b). The study by Salmela (1979) was limited by the small sample of gymnasts involved and inclusion of only two observations at mean ages 13.9 and 15.3 years. Of the four skinfolds measured (triceps, subscapular, iliac and calf) only the triceps skinfolds significantly decreased over the measurement interval. However, this result must be viewed with caution given the author's use of multiple t-tests at the 5% significance level. The mixed longitudinal design adopted in

the TOYA study revealed that skinfold thicknesses increased linearly over time in gymnasts 9-15 years of age. However, in the older gymnasts aged 15-19 years, the rate of accumulation of subcutaneous adipose tissue appeared to increase.

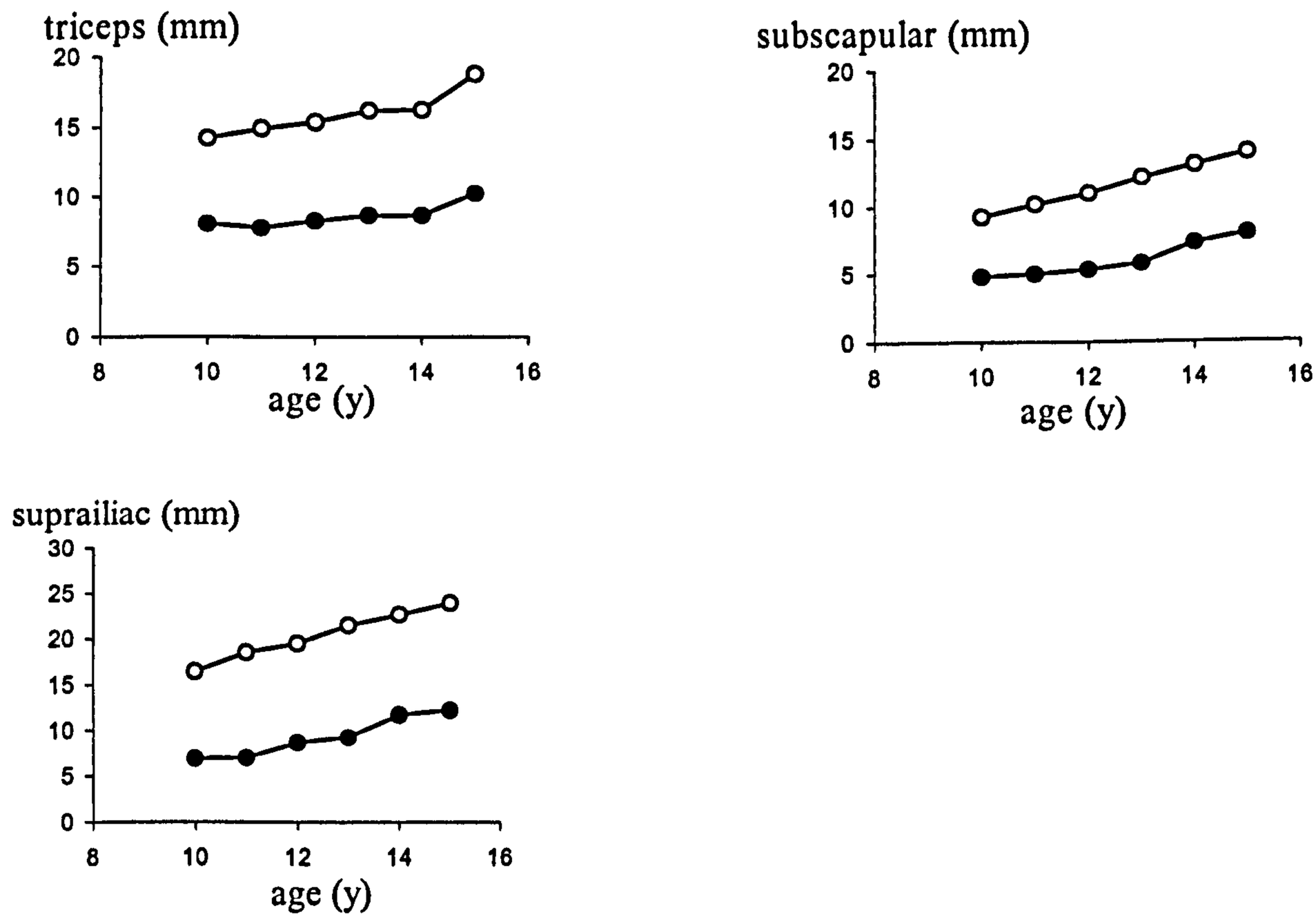



Figure 5.1. Cross-sectional skinfold data for Hungarian elite gymnasts (filled circles) and controls (open circles).

*Stability of subcutaneous adipose tissue*

The majority of research investigating the stability of skinfold thicknesses has taken the form of large scale studies of family members related by descent or adoption. In one such study, Pérusse et al. (1988) applied the TAU model of path analysis to data derived from a stratified sample of the Canadian population and found a total transmission effect of 0.35 for the sum of five skinfolds. This estimate was in close agreement with other studies using similar statistical modelling techniques (Byard et al., 1984, 1985; Devor et al., 1986). These estimates were also in line with results from a series of studies based upon a sample of 409 families of French-Canadian descent as summarised by Bouchard (1988). The studies revealed a total transmission effect of 0.37 for the sum of six skinfolds. However, the majority of this variance was attributed to cultural factors with an estimated

genetic effect of only 0.02. The limited role reported for biological inheritance in the transmission of skinfold thickness was in line with a previous study by Bouchard et al. (1985) who reported a total transmissibile effect of 0.40 for the sum of six skinfolds with genetic factors responsible for only 0.05 of the transmissible variance. In contrast to the majority of research employing path analytical techniques, the study by Maes et al. (1993, 1996) reported heritability estimates of approximately 0.86 for the sum of six skinfolds in female subjects. However, it is likely that these inflated estimates may be the result of a number of factors relating to the study design including the twin sample, the limited age range of the twins and the particular path model used in the analysis (Maes et al., 1996).

The pattern of inter-individual correlations for the sum of six skinfolds has also confirmed that absolute skinfold thickness are not associated with a large genetic affect. Specifically, correlations were higher for foster-midparent/adopted child (0.36) than for mid-parent/natural child (0.31) (Bouchard, 1985; Bouchard, 1985 op cit. Bouchard, 1988). In conclusion, the weight of evidence derived from studies employing correlation and/or path analytical techniques suggests that genetic factors have a limited effect upon the amount of subcutaneous fat (Shephard, 1991). In contrast to the limited contribution of genetic factors in the phenotypic variance of skinfold thicknesses, genetic affects were shown to be responsible for approximately 25% of the phenotypic variance in percentage body fat (Bouchard & Pérusse, 1996). It may therefore be concluded that genetic factors have the greatest influence upon deep/internal fat stores.

A review of several tracking studies investigating the longitudinal stability of skinfold measurements revealed little consistency in the maintenance of relative rank in very young children (less than 6 years of age) but that stability increased with age in the pre-pubertal years (Roche, Siervogel, Chumlea, Reed, Valadian, Eichorn & McCammon, 1982). The autocorrelations for skinfold thicknesses between childhood and adult values, though significant, have been described as low to moderate (Garn, 1985 op cit. Johnston, 1988). There is some disagreement regarding the stability of skinfold thicknesses during adolescence. Marshall, Sarkin, Sallis & McKenzie (1998) used quarterly measurements to track the sum of two extremity skinfold measurements in 9 year old children over a three year period. The application of Spearman's rank order correlation coefficients revealed that the tracking and stability of skinfolds was high (0.71-0.75) over this period. The results of this study were in line with a number of previous investigations (Clarke,

Schrott, Leaverton, Connor & Lauer, 1978; Webber et al., 1983 op cit. Marshall, 1998) which supported the maintenance of relative ranks as children enter into adolescence. It may be further suggested that skinfold measurements are likely to be particularly stable in a sample of female gymnasts who are exposed to consistent environmental conditions associated with the training demands of the sport. However, support for the stability of skinfold measurements during puberty has not been unequivocal. For example, the review of longitudinal data by Roche et al. (1982) op cit. Malina (1990) suggested that the stability of subcutaneous adipose tissue declined during puberty.

The presence of a genotype-environment interaction has been investigated in small samples of MZ twins using positive and negative energy balance protocols (Bouchard, Tremblay, Després, Nadeau, Lupien, Thériault, Dussault, Moorjani, Pineault & Fournier, 1990; Bouchard, Tremblay, Després, Poehlman, Thériault, Nadeau, Lupien & Moorjani, 1988; Poehlman, Déspres, Marcotte, Tremblay, Thériault & Bouchard, 1986; Poehlman, Tremblay, Dépres, Fontaine, Pérusse, Thériault & Bouchard, 1986 op cit. Bouchard et al., 1997). This component of the general model proposed by Bouchard & Malina (1983a) refers to the extent to which the sensitivity of an individual to environmental influences is genotype dependent (Bouchard, 1986). There were considerable inter-individual differences in the response to both short and long-term over-feeding protocols lasting 22 and 100 days respectively. However, members of twin pairs demonstrated significantly similar changes in the amount and distribution of accumulated body fatness (Bouchard et al., 1990; Bouchard et al., 1988b, Poehlman et al., 1986b). Interestingly, the role of the genotype had a significant influence in the response to only long-term negative energy balance protocols during which an energy deficit of 1000 calories was induced via an exercise regime and maintained for a duration of 93 days (Poelhlman, Tremblay, Marcotte, Pérusse, Thériault & Bouchard, 1987). In summary, approximately 40% of the phenotypic variance in total skinfold thicknesses may be explained by transmissible factors. However, this transmissibility is largely the result of cultural factors with only a minor genetic affect. In contrast, genetic factors appear to play a much greater role in the pattern or distribution of subcutaneous adipose tissue. The influence of genotype also appears to have an important influence in determining the sensitivity or responsiveness of individuals exposed to long-term positive or negative energy balance conditions.

### 5.2.3 INERTIA PARAMETERS

Moment of inertia provides a mechanical description of the distribution of body mass with respect to a particular axis; it provides an indication of the resistance to the rotational motion and more specifically angular acceleration of the body. The determination of personalised segment inertia parameters has been identified as a priority for future research in sports biomechanics (Yeadon & Challis, 1994). However, the motivation behind the determination of personalised inertia data has most frequently served methodological purposes, for example, to enable more accurate parameters to be derived for use in simulation models. The investigation of personalised inertia parameters to investigate their development during growth and the potential relationship to sporting performance has been limited. While the utility of these parameters in the simulation and analysis of athletic movement is undisputed their value in the context of talent identification has yet to be determined.

It is the relationship between moment of inertia, angular velocity and angular momentum that is of particular interest in the identification of gymnastic talent. According to the principle of Conservation of Angular Momentum (Newton's First Law of motion), angular momentum is conserved during flight. Therefore, if two gymnasts rotating in free flight have the same angular momentum, the one with the smaller moment of inertia will rotate more quickly. Thus, in gymnastics, a sport involving complex rotational skills, segmental and whole body moments of inertia have potential prognostic value in the context of talent identification and development. It is important to consider the gymnast's moment of inertia about the three principal axes through the mass centre, as this is the point about which angular momentum is conserved during flight.

Absolute values of moment of inertia during flight must be considered in relation to the angular momentum a gymnast can generate at take-off or release from apparatus. At any given value of angular momentum, the amount of rotation that can be achieved in a given period of time is inversely proportional to the moment of inertia (Jensen, 1981). Hence, a change in moment of inertia during flight will result in a proportional and opposite change in angular velocity. With the aid of computer simulation, it is possible to estimate the percentage change in angular velocity a gymnast is likely to experience as a result of a

change in body configuration during flight, thus providing an indication of the potential control a gymnast can exert over rotation.

*Techniques of investigation*

Various methods have been applied to determine inertia parameters. These can be classified according to conceptual or methodological criteria. Both experimental and theoretical methods have been employed to determine segmental inertia parameters, however, there has been very little research to determine the segmental inertia parameters of children (Jensen, 1978). Traditional experimental methods involved direct measurement of inertia parameters using dissected cadavers. In an early study, Dempster (1955) estimated segment mass centre and moments of inertia in 8 male subjects using balance plate and compound pendulum techniques respectively. However, the study was limited in that it only considered parameters about the transverse axis (Forwood, Neal & Wilson, 1985). Clauser, McConville & Young (1969) applied a step-wise regression to select the best predictor equations for segment mass and location of mass centre from a total of 73 measured anthropometric variables. Whilst this study provided a valuable insight into the parameters studied, its major limitation was the failure to measure segmental moments of inertia. Finally, in one of the most comprehensive cadaver studies, Chandler, Clauser, McConville, Reynolds & Young (1975) determined segmental moments of inertia of six embalmed cadavers and using simple linear regression equations derived equations to predict principal moments of inertia from body mass and segment volume. However, in general the cadaver studies were limited by the characteristics of the sample from which the cadavers were drawn. The cadavers were derived from an elderly male caucasian population, and as such are not representative of other sample groups, particularly of pre-pubescent athletic females who possess different segmental proportions which are subject to change during growth and maturation (Jensen, 1981). Secondly, the nature of dissection ensures that sample sizes are restricted. This problem was exacerbated as a result of the variations in measurement procedures and inconsistent sectioning of segments between studies which limited the possibility of combining samples or comparing results across studies. Direct experimental techniques have been applied to determine body segment parameters of living subjects in situ. These include the quick release method (Bouisset & Pertuzon, 1968). Pendulum and pendulum torsion techniques and various oscillation techniques have been applied to determine

moments of inertia (Hatze, 1975; Peyton, 1986). However, such methods do not permit access to the complete range of axes and body segments, most commonly failing to determine the inertia of the thorax or torso segment.

Inertia parameters have also been determined from anthropometric measurements by applying the technique of regression analysis and appropriate scaling techniques (Hinrichs, 1985; Forwood et al., 1985). Yeadon & Morlock (1989) generated linear and non-linear equations for estimating segmental inertia parameters from anthropometric measurements. Cross-validation using the colateral limb indicated that the non-linear equations, based upon theoretical considerations, were most appropriate for use with subjects whose anthropometric characteristics were outside the range of the sample. The majority of attempts to generate regression equations were based on the extrapolation of cadaver data which, given the limitations of these data, result in questionable applicability particularly to a sample of young athletic females.

Other techniques applied to the determination of body segment parameters included the Gamma Mass Scanning technique. This involved the passage of gamma radiation from a cobalt-60 source through an object and was first applied to inanimate objects by Casper, Jacobs, Kenny & McMaster (1971) and subsequently applied to living tissue by (Brooks & Jacobs, 1975). The technique enables an estimation of segment mass to be calculated from the transmission of photons through the segment. The technique was applied to human subjects by Zatsiorsky & Seluyanov (1983). Recent proposals have included sophisticated non-invasive methods for the estimation of segmental inertia parameters most notably Magnetic Resonance Imaging, MRI, (Martin, Mungoile, marzke & Longhill, 1989) and Computerised Axial Tomography, CAT, (Huang & Wu, 1976), with applications to the determination of inertia parameters in children (Hu Degui et al., 1994).

Finally, mathematical models which represent the body as a series of geometric solids have been proposed which have enabled personalised inertia data to be derived by mathematical procedures (Whitsett, 1963; Hanavan, 1964; Jensen, 1976; Hatze, 1980; Yeadon, 1990). Such models employ specific assumptions regarding the structure and operation of the human body. Application of such models in computer simulation permit the determination of segmental and whole body inertia parameters in various body configurations. The models involve the determination of segmental volumes from

anthropometric measurements which are either obtained by direct measurement or from the digitatization of photographic images. Using the calculated volumes and previously reported densities the mass and moments of inertia of the various body segments can be determined. Due to the use of previously published density values, the majority of mathematical models are partly reliant upon cadaver data, although to a much lesser extent than regression or scaling techniques.

The photogrammetric model of Jensen (1976) has been applied most frequently in the study of the inertia parameters of children (Jensen, 1981; Jensen, 1986; Jensen, 1987; Jensen, 1989; Jensen & Nassas, 1988a). Based on the elliptical zone approach pioneered by Weinbach (1938), Jensen represented the body in terms of 16 segments and numerous transverse elliptical zones 2 cm wide. Geometrical calculations enabled the volume of each zone to be determined which were in turn summated to represent the segmental volume. Using reported average segmental densities (Dempster, 1955; Clauser et al., 1969), the body segment parameters were estimated. Hatze (1980) developed a complex mathematical model of 17 segments to closely represent the body's geometry. The model accounted for changes in shape and tissue density of the segments and was considered valid for children. However, the model required 242 anthropometric measurements on each subject which in the context of the limited time available with the elite performer is a serious limitation. The model was reported using three adults and a 12 year old boy. The model of Yeadon (1990) represented the body as an 11 segment rigid body model consisting of 40 separate solids. When applied to three adult subjects the model predicted total body mass to within 2.3%.

Mathematical models are limited by the governing assumptions regarding the structure and function of the human body. The geometrical representation of the human body does not adequately map the fluctuations in the shape of body segments, thus there are limitations in the accuracy with which segment volumes can be estimated. However, the geometrical representation of the human body adopted by Yeadon (1990) permitted fluctuations in the shape of body segments to be modelled more closely than was possible using the ellipse based model proposed by Jensen (1976). The use of geometric solids and in particular the use of the stadium solid to model the trunk segment ensured that the Yeadon model provided a close representation to physique which may be considered a particularly important advantage for investigations seeking to assess the changes

associated with growth and development in an athletic sample. In addition, the majority of mathematical models employ the assumption of uniform density, failing to account for variations in density within the segment. The exception to this generalization is the model of Hatze (1980) which incorporated the density profiles reported by Dempster (1955). In an attempt to evaluate the extent of the limitation of the uniform density assumption, Ackland, Henson & Bailey (1988) analysed profiles of the leg segment derived using computerised tomography. Variations in cross-sectional density values throughout the length of the segment indicated the limitations of the assumption of uniform density. However, the errors as a result of this assumption were shown to be minor in comparison to the errors resulting from inaccurate estimations of segment volumes. Wei & Jensen (1995) compared the application of density profiles obtained from study of Asian females with average densities obtained from cadaver studies. Using the mathematical model of Jensen (1976), the density profiles produced larger estimated segment mass and principal moments of inertia, and whilst the lack of any direct evaluation of the accuracy of the mathematical model prevented any firm conclusions regarding the benefit of using density profiles, their use in future studies was recommended. Rodrigue & Gagnon (1983) recommended the use of three regionalised density values in the determination of moment of inertia of the forearm segment. The uniform density assumption may be most limiting in longitudinal studies which extend the assumption to infer that segment density values remain constant during growth and maturation (Ackland, Blanksby & Bloomfield, 1994a). Body composition studies have confirmed that the growth and maturation of children is associated with changes in segmental density profiles (Ackland et al., 1994a). In addition to maturational factors, density values may be influenced by level and nature of physical activity.

*Moment of inertia in the young female gymnast*

The cross-sectional study conducted at the 1986 Junior European Championships appears to be the only investigation which has considered the moment of inertia characteristics of young female gymnasts (Brüggemann & Böhmer, 1986). The whole body moment of inertia about the longitudinal axis was estimated in the anatomical standing position in a sample of 86 competitors using the following equation:

$$0.043 * \text{body mass} * \text{body height}^2$$

From the results reported it is likely that the moment of inertia terms are about the transverse axis as opposed to the longitudinal axis, however it was suggested that this was probably the result of an error in translation (Kerwin, 1986). In addition, no details are provided concerning the source of the regression coefficient used to determine the moment of inertia values. In particular, it is unclear whether the sample from which this coefficient was derived may be considered appropriate in terms of age, gender and physical activity status. As a result, the validity of the estimates cannot be determined and therefore comparisons with studies reporting inertia data for children and adolescents may be of limited value.

*Development of moment of inertia within the growing child*

The Laurentian Study of Biomechanical development by Jensen & colleagues provided the most comprehensive investigation into the longitudinal development of the body segment parameters (BSPs) of children. By adopting a mixed longitudinal design, changes in BSPs and whole body moments of inertia for male children over a 16 year period of development were studied (Jensen & Nassas, 1988a). Changes in the mass and volume of segments as a result of the growth process were shown to be segment specific and consistent with the principles of cephalocaudal and distal to proximal development (Jensen, 1987, Tanner, 1962, 1989; Norgan, 1998a). The changes in the mass and volumes of segments were similar across individuals prior to the age of 10 years, with inter-individual variations in the growth of segmental masses and volumes becoming more apparent in older children.

Large inter-individual differences were revealed in absolute moments of inertia at given chronological ages (Jensen, 1986). Jensen (1981) studied the effect of a 12 month growth period and observed that the magnitude of changes in moment of inertia were greater than suggested by traditional indices of growth. The regression analyses (Jensen, 1986) revealed that changes in moment of inertia, although best represented by changes in $MH^2$, were still under-estimated by this parameter, thus highlighting the potential contribution of moment of inertia over and above standard anthropometric dimensions (Jensen, 1986). However, the 36 observations used in the regression model were derived from the repeated measurements of 12 individuals. The validity of using repeated measures data in regression analyses was questioned in relation to the assumption of statistical

independence underlying this technique (Ackland et al., 1994a). Jensen (1981) observed large individual differences in the magnitude of the change of moment of inertia during the 12 month growth period and in the principal axis which experienced the greatest degree of change. The greatest and most variable change in moment of inertia was demonstrated by the oldest childen (12-13), the most stable increase in moment of inertia was observed in the 9-10 year olds, with the younger children aged 6-7 years revealing intermediate variability.

Jensen (1986) examined the growth of childrens, moment of inertia in two body configurations specific to gymnastics (tucked position and back handspring). When plotted graphically, the change in moment of inertia for the back handspring position between 10-15 years of age was described as a *'positively accelerating curve'*, with the rate of increase in moment of inertia for subjects over 10 years of age approximately 3.5 times greater than for their younger peers. Expression of moment of inertia values in terms of decrease in rotation experienced during a free flight situation highlighted the potential constraints upon a subjects ability to rotate. The implications for the development of angular and vertical impulses at take-off are clear if a child is to maintain or enhance the performance of rotational skills through adolescence.

Jensen & Nassas (1988a) confirmed a cephalocaudal development for moment of inertia in line with that demonstrated previously for segment lengths (Tanner, 1962), segment volume (Jensen & Nassas, 1988b) and segment mass (Jensen, 1986). The magnitude of the change in moment of inertia of body segments was greater than that recorded for other BSPs (mass, length or volume), thus emphasising the potential importance of moment of inertia as a talent characteristic and highlighting the need to monitor changes in these parameters in relation to the gymnast's capacity to generate angular momentum. While the Laurentian study revealed interesting information regarding the longitudinal development of BSPs within children it was limited to male subjects. While anthropometric investigations suggest that rate of development is similar prior to 10 years of age variations in the temporal occurrence of peak height and peak mass velocity and changes associated with puberty ensure limited applicability to young female gymnasts. In addition, the heterogeneity of the Laurentian sample in terms of morphological and maturational characteristics has also been questioned (Ackland et al., 1994a).

Yokoi, Shibukawa, Ae, Ishijima & Hashihara (1985) applied the elliptical zone method to the study of 255 Japanese children, 3-15 years old. The children were subsequently classified into 18 groups according to their age, sex and body type characteristics. Yokoi, Shibukawa & Ae (1986) highlighted differential development patterns between male and female Japanese children. However, comparative studies suggest that children of Asian ancestry have an anthropometric profile that is different from the profile of children of European origin (Claessens et al., 1991a). Hence, the applications of the findings of this study to a sample of European junior gymnasts are limited. The magnitude of changes in the inertia parameters that occur during growth and maturation (Jensen 1981; Jensen & Nassas 1988a) demand the derivation of the personalised inertial parameters of pre-pubertal athletes. In spite of the limitations of the mathematical models, their use is required to enable subject specific inertia parameters to enhance the understanding of motor skill development within childhood and in the biomechanical analysis and simulation of movement.

*Relationship between moment of inertia and muscular strength in the growing athlete*

A sequential pattern has been demonstrated regarding the peak rate of growth of body mass (PMV), peak height velocity (PHV) and the rate of development of muscular strength (Tanner, 1962). Considerable variation in the temporal delays between these events has been recorded in the literature. Group means of boys involved in the University of Western Australia Growth and Development study reported by Ackland, Blanksby & Bloomfield (1994b) confirmed that for a sample of male children peak growth in muscular strength occurred after both PHV and PMV. The extent of the lag in strength development appeared to be specific to the joint action, with a 6.1 and 7.8 month delay for knee extension and thigh flexion strength respectively. Since changes in moment of inertia exceed traditional indices of growth, delays in strength development have been predicted to result in a deterioration of motor performance (Jensen, 1978). While no data are available specific to the athletic female subjects this sequential pattern of development may underlie problems in acquisition and maintenance of technical skill in the adolescent female gymnast. These physical limitations in combination with the psychological stress associated with adolescence may contribute to the high incidence of withdrawal from sport at this age. Analysis of subject specific developments are required as case studies reveal variation in the sequence and timing of these events Ackland et al.

(1994b). Longitudinal monitoring of growth and changes in moment of inertia together with the motor capacity of the individual may enable training to be systematically structured on an individual basis to prevent potential problems during the pubertal years.

### 5.2.4 ISOMETRIC STRENGTH

Strength has been defined as:

> "the maximal force or torque that a muscle or group of muscles can exert on the associated skeletal structure at a specific speed of movement"
>
> (Lakomy, 1994)

Since the time taken to develop maximum force can be as much as one second (Komi, 1979, 1984), an additional qualification frequently applied to the definition of strength states that the duration of the contraction is unrestricted (Atha, 1981; Enoka, 1994). The assessment of muscular strength has been suggested to play an important role in the identification of sporting talent (Sale, 1991). Previous research has indicated that strength, and in particular a high level of strength relative to body weight, is an important attribute of elite gymnasts (Regnier & Salmela, 1987; Sol, 1987; Maffulli, King & Helms, 1994; Salmela, 1979). In addition to the production of high levels of force, the rapid generation of sub maximal force has been associated with successful sporting performance (Fisher & Borms, 1990).

Women's Artistic Gymnastics, like the majority of sporting pursuits, is a complex activity requiring both static and dynamic strength. While several modes of testing are available to reflect the demands of sporting performances, including isometric, isokinetic, isotonic and isoinertial modes, no mode of testing has been given unequivocal support (Abernethy, Wilson & Logan, 1995). Isometric strength involves the development of force against an unyielding resistance which lies in series with a force transducer (Wilson & Murphy, 1996). While the definition of isometric strength implies no change in muscle length a slight shortening has been reported to occur as a result of the stretching of the series elastic components (Maughan, 1986). However, there is general agreement that during an isometric muscle action there should be no change in the joint angle (Abernethy et al., 1995; Wilson & Murphy, 1996).

Closely akin to the choice of assessment mode is the debate as to whether strength exists as a general quality or whether it is specific to the mode of testing and the contraction type employed. Generality would imply strong relationships between the various measures of muscle function independent of contraction mode or velocity (Hortobagyi, Katch & LaChance, 1989), hence, individuals would be expected to rank similarly across all testing modes. A correlation coefficient of 0.71 has been suggested to statistically validate the concept of generality which would indicate 50% common variance between tests (Clarke & Clarke, 1970). Support for the generality hypothesis is equivocal, with some studies providing support (Hortobagyi et al., 1989; Mueller & Buehrle, 1987; LaChance, Hortobagyi, Katch & Janney, 1987) and others rejecting the concept of generality (Pryor, Wilson & Murphy, 1994; Baker, Wilson & Carlyon, 1994; Young & Bilby, 1993; Hortobagyi, LaChance & Katch, 1987). However, given that Hortobagyi et al. (1989), one of the studies expressing support for the generality hypothesis failed, to include an isometric assessment within their protocol, claims of generality must be viewed with caution. The concept of generality has not been investigated in children (Froberg & Lammert, 1996).

For the assessment of muscular strength to have a valid role in the identification and development of gymnastic talent, certain criteria as outlined by Wilson & Murphy (1996) must be satisfied. In particular, the parameters used to express strength must relate closely to gymnastic performance and to the underlying structure of muscle within the pre-pubescent child. Moreover, in the specific context of talent identification, parameters of strength are required to differentiate between potentially good and poor performers in both heterogeneous and more homogeneous subject pools. Finally, given the longitudinal nature of the study, the ability of assessments of muscular strength to monitor and possibly predict training induced changes is of paramount importance.

*The validity of isometric strength assessment*

Relationship to performance

The nature of the relationship between isometric strength and high level performance within various sports has been extensively reported. A good relationship between maximal isometric strength and performance has been reported in sports such as rowing

(Secher, 1975 op cit. Wilson & Murphy, 1996), sprinting (Mero, Luhtanen & Viitasalo, 1981 op cit. Wilson & Murphy, 1996) and water polo (Bloomfield, Blanksby & Ackland, 1990b op cit. Wilson & Murphy, 1996), with the strength of the relationship increasing as the assessment was made specific to sporting performance. By contrast, other studies have reported a poor relationship to dynamic performance in sprint swimming (Strass, 1991 op cit. Wilson & Murphy, 1996), running speed (Mero et al., 1981) and women's volleyball (Fry, Kraemer & Weseman, 1991 op cit. Wilson & Murphy, 1996). Additionally, low relationships have been observed between maximal isometric force and various dynamic activities including tests of jumping performance (Viitasalo, Häkkinen & Komi., 1981; Jaric, Ristanovic & Corcos, 1989). A stronger relationship has been reported between isometric rate of force development (IRFD) and jump performance (Viitasalo, Häkkinen & Komi, 1981; Viitasalo & Aura, 1984; Häkkinen, Komi & Kauhanen, 1986), which is not unexpected given the impulsive nature of jumping activities. However, empirical support for the correlation between IRFD and jumping performance has been inconsistent (Komi, Karlsson, Tesch, Suominen & Heikkinen, 1982; Young & Bilby, 1993). Indeed Wilson & Murphy (1995a,b) described the relationship between maximal IRFD and jump performance as moderate, with the majority of correlations reported to be in the range 0.3-0.6. (Wilson & Murphy, 1996).

Ability to differentiate between levels of performer

A number of studies have demonstrated that female athletes are significantly stronger than non-athletic controls. However, there is little evidence to support differences in strength between athletes from different sports. For example, in the training of young athletes study (TOYA) isometric strength in the upper and lower extremities was determined in a sample of 453 elite young athletes (9-18 years of age) (Maffulli et al., 1994). The female athletes exerted a greater amount of isometric strength than control school children at all ages (Maffulli et al., 1994). Specifically, the average maximum strength of female athletes was 22% and 18% greater than control subjects in the left knee extensor and the left elbow flexors respectively. However, no significant differences were reported between gymnasts, swimmers and tennis players. Blanksby et al. (1994) compared the isometric arm extension, thigh flexion, leg extension and grip strength of pre-pubescent swimmers, tennis players and controls (7-12 years of age). The level of strength was found to be similar across sports with the only significant difference detected being a

greater isometric leg extension strength in swimmers. However, it was demonstrated that during the pubertal years and more specifically from pubescent stage 4 onwards, the swimmers demonstrated superior strength scores. The inability to determine differences in strength between athletes competing in a variety of sports may reflect the adoption of generic strength assessments which lack specificity to the demands of any particular sport.

A number of studies have revealed that strength is greater in high level gymnasts in comparison to lower level participants (Nelson, Johnson & Smith, 1983; Lindner & Caine, 1992). With respect to female gymnasts, the study by Nelson et al. (1983) showed that both absolute and relative strength as measured by an overhead pull test was greater in competitive gymnasts than recreational gymnasts and PE students, with relative strength more important than absolute strength in determining group membership. In contrast, Rich et al. (1991) found that young male gymnasts possessed similar absolute strength at the knee and elbow to control subjects and that the groups were only different when strength was expressed in relation to body weight. Wilson & Murphy (1996) reported that maximum isometric strength effectively discriminated between athletes of different levels of ability in 50% of the studies they reviewed. In terms of particular sports, isometric parameters were able to differentiate between different levels of performer in sprinting (Mero et al., 1981) and rowing (Secher, 1975). By contrast isometric parameters were found to be unable to differentiate between performers of various levels in shot-put (Murphy, Wilson & Pryor, 1994), peak power output during 6 seconds of stationary cycling (Wilson & Murphy, 1995b), alpine ski-jumping (Abe, Kawakami, Ikegawa, Kanehisa & Fukunaga, 1992) and women's volleyball (Fry et al., 1991).

The heterogeneity of subject pool is proposed to be an important factor to consider in determining whether a particular mode of testing is able to differentiate between performers of various levels of ability. For example, Viitasalo & Komi (1978) reported that the rate of force development produced during maximal isometric bilateral leg extension was able to differentiate between male ski-jumpers and controls. By contrast, isometric parameters were unable to differentiate female national level alpine skiers from those who were college trained (Abe et al., 1992). Despite gender differences in the nature of the sample and differences in the nature of the sport, the degree of homogeneity of the sample is likely to be an important consideration when interpreting the results of

these two studies. Given the heterogeneous nature of athletes in the initial stages of the talent identification process, isometric parameters, in particular IRFD, are likely to play an important role in differentiating between the various levels of talent.

Ability to monitor changes induced by training

In general, parameters of isometric strength have proved insensitive to the changes induced by sports training. Several studies have reported that changes detected in sporting performance failed to relate to changes in the various parameters of isometric strength and speed-strength (Jaric et al., 1989; Wilson, Newton, Murphy & Humphries, 1993; Baker et al., 1994; Young & Bilby, 1993). Considering the inverse of this relationship Komi et al. (1982) demonstrated that while isometric strength of the leg extensor muscles increased after strength training, no improvement in vertical jump performance were sustained. Abernethy et al. (1995) outlined the importance of examining the correlations between the changes in the various modes as a consequence of training. The authors observed that while correlations between modes may be high in pre- and post training conditions, correlations between the changes in parameters of isometric strength and performance after training may be much lower. These observations have been supported empirically by several studies (Baker et al., 1994; Jaric et al., 1989). Therefore, the weight of evidence suggests that training induced changes are mode specific and may vary as a function of the specific pattern and velocity of movement (Abernethy et al., 1995). Given the evidence inferring mode specificity, it may be most appropriate to modify training programmes according to the results of performance rather than tests of muscular function. While this suggestion may be acceptable for sports such as cycling or sprinting which are based upon objectively defined performance criteria, its relevance to gymnastics, a complex and subjectively evaluated sport, may be of limited value.

Structural, mechanical and neural differences between isometric and dynamic exercise modes have been cited to explain the relatively poor relationship between parameters of isometric strength, dynamic performance and training (Pryor et al., 1994; Baker et al., 1994; Wilson & Murphy, 1996; Nakazawa, Kawakami, Fukunaga, Yano & Miyashita, 1993; Ter Haar Romeny , Dernier & Gielen, 1982, 1984). The specificity of the strength assessment to the performance of interest has been proposed as a major factor

contributing to the low relationship between isometric strength and sporting performance (Baker et al., 1994). Studies in which isomeric tests were specific to the performance of interest have limited the influence of structural factors in sports such as cycling (Wilson & Murphy, 1995b). However, the nature of the isometric mode implies testing at a single joint angle, thus limiting specificity to a single point in the movement range (Wilson & Murphy, 1995a). Therefore, even though the joint angle may be carefully selected, there is a lack of evidence to suggest that a single point in the movement range may be considered representative of the entire movement (Murphy, Wilson, Pryor & Newton, 1995).

There are two main mechanical factors proposed to contribute to the differences reported between assessments of isometric and dynamic strength. Firstly, isometric muscle action does not involve the stretch shortening cycle (SSC) which is characteristic of the many sporting movements. While the precise mechanisms responsible for potentiation are the subject of some debate it is accepted that a more forceful concentric contraction can be produced immediately after a rapid pre-stretch of that muscle (Lees & Fahami, 1994). Individual differences in the ability to utilise the SSC may contribute to greater success of dynamic strength testing in differentiating between athletes of various performance levels (Wilson, Elliot & Wood, 1992). The second mechanical factor relates to the high correlation between parameters of isometric force and the stiffness of the muscle tendon unit (MTU) (Wilson, Murphy & Pryor, 1994). If the MTU is 'stiff' the conditions for the development of force are more favourable as force length and force velocity relationships are closer to optimal values. In contrast to dynamic muscular contractions, the shortening of the contractile component in an isometric action occurs as a direct result of the extension of the MTU and therefore the influence of MTU stiffness is likely to be greater in isometric muscle actions.

A major difference between isometric and dynamic strength testing modes relates to the pattern of neural recruitment. The recruitment of motor units has been reported to be specific to the nature of the tasks (Ter Haar Romeny et al., 1984). More specifically, neural recruitment patterns have been reported to vary as a function of mode, with differences in EMG responses detected between isometric and dynamic contractions at the same joint angle (Nakazawa et al., 1993; Tax, Dernier & Erkelens, 1990). This may be partly attributed to the deviations from established patterns of recruitment reported to

occur in certain testing modes. For example, the size principle proposed by Henneman, Somjen & Carpenter (1965) is thought to hold for isometric muscular contractions (Komi, 1979) in which the small, slower conducting motor units are the first to be recruited (Baltzopolous, 1996). In contrast, the pattern of neural recruitment during isotonic muscle action has been reported to deviate from this established principle with both types of fibres being recruited simultaneously in dynamic activities (Knuttgen et al., 1976 op cit. Komi, 1979).

*Methodological considerations*

Subject positioning

To enhance internal validity, the position of the subject during isometric strength testing should be standardised and remain consistent across subjects and between measurement sessions. Subject positioning has been reported to be a critical factor influencing force output in relation to the length of the muscle and its lever arm (Gravel, Richards & Filion, 1990; Amundsen, 1990; Baltzopolous, 1996). Abernethy et al. (1995) attempted to quantify the potential influence of subject positioning on the maximal force produced during elbow flexion. The authors reported that flexion of the elbow in a standing position, encouraged the extensors of the lower extremity to produce a momentary eccentric contraction that could increase peak force output by 50% (Abernethy et al., 1995). However, by assuming a seated position during the test the influence of such substitution could be reduced.

Joint angle

Examination of strength curves highlighted that the production of isometric force is a function of joint angle (Gravel et al., 1990; Sale, 1991; Murphy et al., 1995; Rowland, 1996; Wilson & Murphy, 1996). Sale (1991) suggested that the most appropriate joint angle corresponded to the peak of the strength curve for the muscle. In this way the variability associated with small errors in the determination of joint angle could be reduced. However, the validity of isometric strength testing is also dependent upon joint angle and the joint angle corresponding to the peak of the strength curve may not be the optimal angle in terms of specificity to gymnastic performance. To illustrate this point,

Murphy et al. (1995) showed that when elbow angle was reduced from 120 to 90° MIF and RFD decreased but the relationship between the isometric bench press test and dynamic performance increased by 100%. These results led Murphy et al. (1995) to recommend that the most appropriate joint angle corresponds to the joint angle at which peak force is developed in the performance of interest. However, in women's artistic gymnastics, the identification of a single joint angle at which maximum force production occurs is difficult and varies between elements.

The influence of joint angle is suggested to occur as a result of differences in the mechanical properties of muscle (the length tension relationship) and the differential recruitment of motor units (Murphy et al., 1995). The preferential recruitment of certain motor units has been demonstrated to occur at certain positions or angles in dynamic movements (Ter Haar Romeny et al., 1982). Nakazawa et al. (1993) demonstrated that the relative activation levels of the elbow flexor muscles (biceps brachii & brachioradialis) varied as a function of elbow angle. The variation in the level of activation received by a particular muscle was proposed to optimise the mechanical advantage, such that greater activation levels were present in those muscles possessing the greatest mechanical advantage (Zuylen, Velzen & Dernier, 1988).

Stabilisation

Amundsen (1990) outlined several reasons for stabilising the subject. Firstly, stabilisation was reported to isolate the working muscle groups to prevent substitution, thus avoiding the potential conversion from isometric action to a momentary eccentric contraction. A further contribution of stabilisation towards internal validity concerns the increased security of the subject who as a result is more likely to produce a maximal isometric contraction. Finally, the stabilisation of the body part proximal to the centre of rotation was suggested to facilitate maintenance of the desired joint angle throughout the test. The presence of single or multiple sharp peaks in the force trace of a maximal contraction indicate that substitution is likely to have occurred and that the method of stabilisation should be reconsidered.

Level of pre-tension

The level of pre-tension in a muscle prior to contraction has been suggested to influence certain parameters of the isometric force-time curve. The influence of pre-tension on the production of maximal force was reported to be negligible (Asai & Akoi, 1996; Viitasalo, 1982). The major effect of pre-tension is in relation to maximum rate of force development (MRFD) (Wilson & Murphy, 1996). An inverse relationship has been demonstrated between MRFD and muscular pre-tension, with a decrease in the MRFD reported to occur as the level of pre-tension was increased (Viitasalo, 1982). The magnitude of the effect became greater as the level of pre-tension increased. For example, the MRFD at a pre-tension level of 20% MIF was 65% of that when pre-tension was reduced to zero. This decreased to 21.8% MRFD as pre-tension was increased to 70% MIF (Viitasalo, 1982). The decrease in MRFD with increased levels of pre-tension has been associated with the recruitment of fast-twitch motor units to maintain pre-tension, the same motor-units considered to be responsible for the rapid development of muscular force (Viitasalo, 1982). While Asai & Akoi (1996) confirmed the inverse relationship between MRFD and pre-tension levels in adult subjects, the children involved in their study failed to demonstrate any effect of pre-tension on the development of MRFD. While the reasons for this age-related variation remain unclear, the trend was thought to be in part the consequence of maturational differences in the order of muscle fibre recruitment (Asai & Aoki, 1996). Given the weight of evidence, it has been recommended that isometric tests be conducted with minimum levels of pre-tension (Pryor et al., 1994).

Instruction

Various instructional sets have been employed in the assessment of isometric strength, requiring subjects to apply force either "*as hard and as fast as possible*" (Murphy et al., 1995; Sleivert, Bakus & Wenger, 1995) or "*as fast as possible*" (Pryor et al., 1994; Bell & Jacobs, 1986; Jaric et al., 1989; Wilson & Murphy, 1995a). The form and consistency of the instructional set has been reported to influence parameters of the force-time curve and their reliability (Abernethy et al., 1995). Bemben, Clasey & Massey (1990) investigated the influence of the instructional set given to 30 subjects performing an isometric handgrip test. Subjects were required to produce force; 1. in a slow

concentrated maximal effort; 2. as hard and as fast as possible; or 3. as fast as possible without concern for peak force. The Maximal RFD was attained in condition 3 with MIF produced in condition 2. While the goals of the study necessarily dictate the nature of the instructional set, condition 2, "as hard and as fast as possible", appeared to be the most appropriate 'all purpose' set. During this condition MIF was produced and the rate of force development reached 94% of that produced in condition 3 and is hence the set of instructions most frequently adopted in the literature (Going, Massey, Hoshizaki, 1987).

*Parameters of the isometric force-time curve*

Force-time curves reflecting force development during a maximal isometric contraction are characteristically sigmoid in shape (Komi, 1979; Komi, 1984). To demonstrate validity in the context of talent identification, the parameters of the isometric force-time curve are required to relate closely to future performance whilst remaining independent of each other. In this way each parameter is able to provide information about a unique aspect of muscle function. The parameters of the isometric force-time curve have been reported to satisfy the condition of independence. Specifically, the various parameters of maximal isometric force are reported to be highly correlated with each other but relatively independent of rate or time parameters (Viitasalo et al., 1981; Going et al., 1987; Jaric et al., 1989). Teeple & Massey (1976) reported zero order correlation coefficients between MIF and MRFD to be 0.70 indicating a common or shared variance of 49%. The authors concluded from this result that RFD was 'somewhat independent' of maximum force.

Maximal isometric force

Maximal isometric force (MIF) best describes the strength of the muscle and is closely related to both muscle size and activation level (Amundsen, 1990; Sale, 1992; Moritani & Devries, 1979 op cit. Sleivert et al., 1995). In terms of structure, muscle cross sectional area is proposed to be one of the major factors influencing the development of maximal isometric force (Ikai & Kukunaga, 1968; Komi, 1979, 1984).

The influence of muscle fibre type on maximal isometric force is the subject of debate with some tentative support for a positive relationship between MIF and the percentage of fast-twitch fibres in both isolated fibres (Sleivert et al., 1995; Tesch & Karlsson, 1978 op

cit. Viitasalo et al., 1981) and at the level of whole muscle (Burke & Edgerton, 1975; Thorstensson 1976; Tesch & Karlsson, 1979 op cit. Komi, 1984). However, support for the relationship has not been unequivocal (Viitasalo et al., 1981; Komi, 1984; Maughan, 1986). It may be concluded that absolute strength may be most closely associated with the size of individual muscle fibres irrespective of their type (Komi, 1979, 1984). In addition to structural and neurological antecedents maximal isometric force is largely contingent upon the motivation of the subject.

The valid assessment of the function of individual muscles may not be possible 'in situ'. Therefore, joint torque which refers to the function of the group of muscles which surround a joint (Baltzopolous, 1996) is considered a more appropriate means of expressing muscular force production. Joint torque or joint moment is the angular equivalent of force and is given by the product of force and the perpendicular distance between the point of force application and the centre of rotation, most frequently the biomechanical joint centre. The preferred term of reference is that of '*resultant joint moment*', which accepts the contribution of antagonistic muscle action to the joint moment (Hay, 1992). Whilst the evaluation of torque production is an essential aspect of muscular function assessment, problems are commonly associated with the accurate and precise identification of the joint centre (Maughan, 1986).

Rate of force development

Rate of force or torque development (RFD) has traditionally been used to infer high velocity strength (Viitasalo & Komi, 1981). The rationale for this parameter is based upon the requirement for rapid force production given the characteristically short contract times of many sporting activities (Abernethy et al., 1995). The rate at which force can be developed in an isometric contraction, isometric rate of force development (IRFD), has been cited as an estimate of power. However, this parameter has attracted criticism due to the absence of limb displacement in isometric actions which necessitates that no work or power can be produced (Abernethy et al., 1995). Despite such theoretical limitations IRFD has continued to be a popular index of 'pseudo-power'.

Numerous algorithms and functions have been applied to calculate isometric RFD (Baker et al., 1994; Teeple & Massey, 1976; Jaric et al., 1989). The time epoch over which

RFD is determined has ranged from intervals of 5 ms (Asai & Akoi, 1996) through to 60 ms (Christ, Slaughter & Stillman, 1994 op cit. Wilson & Murphy, 1996) with the relationship between RFD and performance enhanced as the time interval was reduced (Abernethy et al., 1995). It has been reported that changes in the time interval had a relatively minor effect upon the reliability of the RFD (Murphy & Wilson in their current research), although the exact nature of such changes has not been conclusively determined. While the legitimacy of RFD in differentiating between athletes and non-athletic controls has been demonstrated (Komi, 1984), it will be appropriate to establish the validity of the parameter for each sport in which it is to be applied.

The rate of force development has been hypothesised to be a function of both the number and activation of motor units (Viitasalo, Komi & Hakkinen., 1981). Additionally, a relationship has been established between RFD and muscle fibre type distribution (Viitasalo & Komi, 1978; Viitasalo, 1980, Wilson & Murphy, 1996). For example, studies have demonstrated that subjects with a large percentage of fast-twitch fibres in the vastus lateralis muscle were able to develop force and reach certain levels of MIF in a bilateral leg extension test more rapidly than subjects with predominantly slow-twitch fibres (Viitasalo & Komi, 1978). In addition, Viitasalo & Komi, (1978) reported that the relationship between fibre-type and RFD, expressed as the time to reach certain percentages of MIF, was load dependent with the strongest relationship occurring when RFD was maximal at approximately 40% MIF. A study by Viitasalo & Komi (1978) highlighted that although ski-jumpers and controls were able to produce the same level of maximal isometric force the ski-jumpers were able to develop force more quickly than control subjects. Since there were no differences between the groups in terms of muscle fibre composition, the difference in the shape of the isometric force-time curves was attributed to the effects of training.

*Development and trainability of strength in the pre-pubescent child*

Adults and adolescents have consistently demonstrated greater absolute and relative strength than younger children (Sunnegårdh, Bratteby, Nordesjö & Nordgren, 1988). However, numerous studies have indicated that when data were normalised according to body mass or other anthropometric indices, age-wise differences were reduced or disappeared (Ikai & Fukunaga, 1968; Davies, White & Young, 1983; Davies, 1985;

Seger & Thorstensson, 1994). While research regarding the longitudinal development and trainability of muscular strength in children is limited (Sunnegårdh et al., 1988; Blimkie & Bar-Or, 1996), it has been reported that maximum force production increased with chronological age (Teeple & Massey, 1976; Sunnegårdh et al., 1988; Kanehisa, Ikegawa, Tsunoda & Fukunaga, 1994; Parker, Round, Sacco & Jones, 1990). In girls, the increase in muscular strength is generally linear from early childhood through to approximately 15 years of age with no clear evidence of an adolescent spurt (Froberg & Lammert, 1996). The development of isometric strength is less clear during the pubertal period in females, with some studies reporting a continuation of the linear rise while other report a plateau with no substantial improvements occurring during the adolescent period (Rowland, 1996). It was also observed that 8-10 year old children required longer periods of time to reach selected levels of maximal isometric force during contractions of the forearm flexors and extensors (Going et al., 1987). The characteristically sigmoid-shaped force-time curve of adult subjects was 'platykurtic' within this pre-adolescent sample. Isometric rate of force development is reported to increase consistently as a function of age (Teeple & Massey, 1976; Going et al., 1987; Asai & Akoi, 1996).

Muscular strength is determined by a number of factors including muscle size or cross-sectional area, neural activation, specific tension, and the ability of the individual to produce coordinated movement (Sale, 1989). Differences in strength parameters between adults and children may be attributed to one or a combination of these factors. It is well established that muscle mass increases with age. A 3.5 fold increase in muscle mass has been reported to occur in females between the ages of 5 and 17.5 years of age (Malina, 1969 op cit. Blimkie, 1989). However, a thorough review of research revealed that muscle size and muscular strength were moderately and positively correlated, the age associated variation in strength between childhood and adulthood could not be explained solely in terms of changes in muscle mass (Blimkie, 1989). It has also been suggested that changes in mechanical advantage may also contribute to the age related variation in parameters of muscular strength. For example, Blimkie (1989) reported a positive association between stature, estimated moment arm and specific tension for the elbow flexors and knee extensors in males aged 9-18 years of age.

The age associated variation in maximal strength may in part be attributed to the extent to which individuals are able to maximally activate their muscles during a voluntary

isometric contraction (Blimkie, 1989; 1992; 1993). This was supported by the results of a cross-sectional study by Davies (1985) in which the ratio of peak twitch tension to maximal voluntary strength decreased with increasing chronological age in male subjects between 11 to 21 years, indicating that the age associated increases in voluntary strength may be attributed to changes in the activation of muscles (Davies, 1985). However, more recent studies using the interpolated twitch technique have reported relatively minor age related differences indicating that children could activate their muscles as fully as adults (Sale, 1989, Belanger & McComas, 1989). Belanger & McComas suggested a critical age before which motor unit activation cannot be achieved and suggested that this age may be specific to each muscle group. This observation was confirmed in a study by Blimkie (1989) which demonstrated that while there was no difference in the degree of motor unit activation in the elbow flexors between 10 and 16 year old males (89.4% v 89.9%), there was a substantial difference in the knee extensors (77% v 95.3%).

The influence of age on factors intrinsic to the muscle is equivocal. Several studies have indicated that twitch torque was greater in older children and adults than younger children, indicating greater specific tension in the muscle (Davies, 1985; Belanger & McComas, 1989). A number of studies have reported no significant change in contraction time with age (Belanger & McComas, 1971; Davies, 1985). For example, in male subjects 3-22 years of age, the twitch contraction times of the extensor hallucis brevis muscle of youngest children were already within the adult range (Belanger & McComas, 1971). Given only minimal changes across a number of muscle groups from mid-childhood to adulthood, contraction time was not suggested to be a primary determinant of age associated variation in strength in males (Blimkie, 1989). In contrast, while studies of female subjects are limited, an age related increase in contraction time has been demonstrated for the triceps surae (Blimkie, 1989).

A number of early studies reported that resistance training was not an effective means of enhancing muscular strength in pre-pubertal children. However, such findings were suggested to be the result of inappropriate loading strategies, inadequate training volumes and/or insufficient study duration (Blimkie, 1993; Blimkie, 1992). In contrast, the majority of recent studies which have employed progressive resistance loading reported that training can effectively increase strength in preadolescents (Sale, 1989; Blimkie, 1992; 1993; Rowland, 1996). For example, in a group of pre-pubertal males, 20 weeks of

progressive isotonic loading in the elbow flexor and knee extensor muscle groups resulted in significant increases in 1RM bench press (35%), 1RM double leg press (22%), maximum voluntary isometric elbow flexion (37%) and knee extension (25%) (Ramsay, Blimkie, Smith, Garner, McDougall & Sale, 1990). The achievement of significant training induced effects is influenced by the frequency and duration of training but it is largely dependent upon the volume and intensity of the programme (Blimkie, 1993; Blimkie, 1992). There is consensus in the literature that pre-adolescent children experience lower increases in absolute muscular strength in response to a training stimulus. However, with respect to relative strength gains, pre-adolescent children are equally if not more trainable than adults (Sale, 1989; Blimkie , 1992, 1993 Blimkie & Bar-Or, 1996; Rowland, 1996).

In adults, the initial adaptations to strength training are primarily neural (Häkkinen & Komi, 1983 op cit. Komi, 1984). After a period of several weeks, muscular hypertrophy commences, becoming the dominant mechanism of adaptation in the later stages of training (Häkkinen, Pakarinen, Alen, Kauhanen & Komi, 1988; Sale, 1989). In contrast, the mechanisms responsible for training induced increases in muscular strength in pre and early pubertal children have not been clearly established (Blimkie, 1992). The majority of studies have demonstrated that resistance training has little effect on muscle size in children (Blimkie, 1992) as assessed by both indirect anthropometric measurements and more direct techniques including roentgenography (Vrijens, 1978) and computerised axial tomography (Ramsay et al., 1990). For example, the study by Ramsay et al. (1990) reported no significant increases in elbow flexor or quadriceps muscle cross-sectional area in response to 20 weeks of weight training, despite substantial increases in muscular strength. This was a particularly significant result given that the duration of the study was considered sufficient to permit muscular hypertrophy. However, increases in muscle cross sectional area in response to resistance training have been detected in two recent studies (Mersch & Stoboy, 1989; Fukunaga, Funato & Ikegawa, 1992). Mersch & Stoboy (1989) reported an increase in the cross-sectional area of the quadriceps muscle (4-9%) in two pre-pubertal boys after 10 weeks maximal knee extension training. Although the increase in muscle size was significant, it was small in comparison with the 38% increase reported in isometric muscular strength. Therefore, while muscular hypertrophy may take place as result of training in pre-pubertal children, the effect of any

changes in muscle mass are likely to be small compared with training induced gains in muscular strength.

In early studies, neural adaptations were proposed as a way of explaining the training induced strength gains which occurred in the absence of significant muscular hypertrophy (Weltman, Janny, Rians, Strand & Berg, 1986; Hassan, 1991 op cit. Blimkie & Bar-Or, 1996). More recently, the twitch interpolation technique has been applied to directly estimate the contribution of motor unit activation to training induced changes in muscular strength in pre-pubertal boys. Ramsay et al. (1990) reported that after 10 weeks of resistance training, motor unit activation in the elbow flexors had increased by 9% which was considerably lower than the increase in maximal isometric strength (22%) and the improvement in dynamic strength as assessed by the 1RM double arm curl (40%). Moreover, after an additional 10 weeks of training, motor unit activation increased by only 3% (Blimkie et al., 1989). The importance of early neural adaptations was confirmed by Ozmun, Mikesy & Surburg (1994) who reported a 16.8% increase in the EMG activity in pre-pubertal after 8 weeks of strength training. Therefore, it appears that changes in the muscular strength of pre-adolescent children may in part be attributed to increased neural activation particularly, in the early stages of training (Blimkie, 1992, 1993).

Changes in intrinsic muscle function have also been associated with resistance strength training in pre-adolescents. An increase in absolute twitch torque was observed in the elbow flexors and knee extensors of 13 pre-pubertal boys exposed to a 20 week programme of progressive resistance strength training (Ramsay et al., 1990). However, it remains unclear whether such intramuscular adaptations are due to an increase in the amount of contractile force or the result of a prolonged active state (Sale, 1989; Blimkie, 1992). Finally, changes in the gross motor skill coordination may also contribute to the changes associated with resistance training, particularly during complex movements (Blimkie, 1992; Blimkie, 1993; Blimkie & Bar-Or, 1996).

*Stability of isometric force parameters*

Traditional heritability estimates derived using twin and sibling data have indicated that the contribution of biological inheritance to the phenotypic variance in muscular strength

is moderately high (Sklad, 1973; Kovar, 1974; Malina & Mueller, 1981). The heritability estimates for relative and summary strength were generally similar to those reported for the absolute strength of individual muscle groups (Kovar, 1981 op cit. Malina, 1986b; Carron & Bailey, 1974 op cit. Malina, 1990). However, reported heritability estimates varied between studies as a function of testing mode, muscle group tested and the heritability calculation employed (Malina, 1986b; Malina, 1990; Bouchard et al., 1997). Sklad (1973) op cit. Malina (1986b) reported heritability estimates for Polish twins aged 8-15 years in a range of strength tests. For the majority of strength tests, heritability estimates were slightly lower for females, with estimates in the range of 0.61-0.82 and 0.44-0.73 for male and females respectively. Kovar (1974) studied a slightly older group of Czechoslovakian twins aged 11-25 years of age and reported moderate heritability for four static strength measures, with heritability estimates in the range 0.45-0.75.

Malina & Mueller (1981) derived heritability estimates for 4 static upper body strength tests from sibling correlations among a mixed race sample of siblings 6-12 years of age. Corrections were made to adjust for body weight differences and test reliability. However, the raw heritability estimates (0.44 and 0.58) indicated that the contribution of the genotype to phenotypic variance was moderate. Szopa (1982, 1983) also derived heritability estimates of absolute and relative upper body strength from sibling data in a large sample of Polish subjects aged 3-42 years. The heritability estimates were low to moderate (0.00-0.50) and were particularly low in the case of grip strength in female children and adolescents (0.00-0.23). There appeared to be a general tendency for heritability estimates to be higher in male subjects and for the contribution of the genotype to increase with age, however, the significance of these observed trends was not tested statistically.

In a more recent investigation, Maes et al. (1996) applied the technique of path analysis to estimate the heritability of absolute static strength in male twins and their parents using an arm pull assessment. Initially heritability was estimated at 0.72 using data from 10 year old twin pairs. When parental data were included in the analysis the contribution of the genotype to phenotypic variance increased slightly to 0.74. In both cases, the most parsimonious model included the additive genetic effect and specific environment. Inclusion of a common environmental component did not significantly improve the fit of

the model in either data set. Heritability estimates derived from large scale family studies employing path analytical techniques were low to moderate, much lower than those using data derived from twins (Bouchard et al., 1997). For example, in a large scale study of 375 French-Canadian families Pérusse et al. (1987) applied the BETA model to estimate the heritability in a maximal isometric contraction of the quadriceps group. The transmissibility of relative quadriceps strength was 0.63, however, only 0.30 of phenotypic variance was explained by a genetic effect. Using data derived from a National Survey of the Canadian population, Pérusse et al. (1988) estimated the transmissibility of relative grip strength to be 0.37. Use of the TAU precluded the relative contributions of genetic and cultural factors to the phenotypic variance from being evaluated.

In conclusion, estimates of heritability derived from twin and sibling data suggest a moderate to high genetic contribution to the phenotypic variance in muscular strength. However, the validity of such estimates must be questioned in the light of the low to moderate heritabilities reported in the large scale family studies which employed path analysis to study a variety of relatives linked by descent or adoption. It has been observed that the heritability estimates reported in twin studies are more in line with the transmissibility estimates of family studies (Bouchard et al., 1997). In a review of previous research, Malina (1990) hypothesised that the greater stability observed in lower extremity strength measurements may be the result of the weight bearing function of the lower extremities. The results of the family studies discussed above support these observations with transmissibility estimates indicating a greater contribution of genetic factors to relative quadriceps strength (0.63) than relative grip strength (Pérusse et al., 1987; Pérusse et al., 1988). Finally, the review of previous research indicates that heritability estimates are generally lower in female subjects (Bouchard et al., 1997). However, the extent to which the influence of gender would affect heritability estimates derived from a sample of athletic females has not been investigated.

Two studies have investigated the role of genetic factors in strength training. In the first study 5 pairs of MZ twins completed a 10 week isokinetic resistance training programme of knee flexion/extension (Thibault, Simoneau & Côté, 1986). A two-way ANVOVA revealed that despite a wide range of training responses (24% ± 12%) there was no evidence that changes in peak torque production in response to strength training were

genotype dependent. In a more recent investigation Thomis, Beunen, Maes, Blimkie, Leemputte, Claessens, Marchal, Willems & Vlietnick (1998) studied the responses of 41 twin pairs to a 10 week programme of high resistance strength training. Results of the two-way ANOVA revealed that genetic factors significantly influenced the training response in both one repetition maximum performance (1RM) and maximum isometric force (MIF) at 110° of flexion. Bivariate modelling confirmed these findings with the most parsimonious model for both 1RM and MIF measures including a genotype-environment interaction component. Consistent with the results of Thibault et al. (1986) there was little support for a significant genotype-environment interaction in the response of concentric and eccentric moments to resistance training.

Given that the current research is exploratory in nature and one of the major aims of the study is to maximise internal validity, the isometric mode of assessment appears to be an appropriate choice for the assessment of muscular strength. Isometric testing is the mode in which effective stabilisation and isolation of a specific muscle group can most easily be attained. In addition, fatigue is less of a concern in the isometric as opposed to the isotonic mode (Amundsen, 1990) and given that a large number of tests are contained within the test battery, the minimisation of systematic fatigue is an important concern. The close relationship demonstrated between indices strength of various muscle groups in adults (Glenmark, Hedberg, Kaijser & Jansson, 1994) and the significant correlation between isometric strength scores in various muscle groups in children and adolescents (Berger, 1982, op cit. Rowland, 1996) suggest that the most appropriate strategy in the current investigation would be to assess isometric muscular strength in a limited number of joint actions. However, the potential prognostic value of dynamic muscular actions is acknowledged and in particular the importance influence of the stretch-shortening cycle. Therefore, lower extremity muscle power will be estimated using vertical and horizontal jumping actions.

### 5.2.5 JUMPING AND INSTANTANEOUS POWER PRODUCTION

In women's artistic gymnastics only a limited number of skills are performed in isolation, beginning from a stationary position. The structure of the current F.I.G. Code of Points rewards gymnasts for performing difficult skills in combination; direct connections in acrobatic and gymnastic sequences receive bonus. Therefore, the time to produce force is

rarely unrestricted and the majority of contemporary elite gymnastics routines are characterised by short contact times with limited joint (hip and knee) flexion. Reported contact times highlight the importance of power production and moreover the force-velocity characteristics of muscle. Takei (1990) reported that upper and lower body force production times in gymnastic activities were as low as 137 and 245 ms respectively. Brüggemann (1983) reported further reduced contact times during take-off for single and double backward somersaults of 131 and 123 ms respectively. However, gymnastic skills performed by the world's most elite gymnasts are much more complex which may suggest even further reductions in apparatus contact times. More recently, contact times for elite female gymnasts performing double backward somersaults in the straight position at the 1996 Atlanta Olympics were reported to be 112 ± 5ms (Webb, 1997). The ability to produce force during short contact times has also been incorporated into talent identification programs. Rozin (1979) reported that contact times of between 80-100 ms during simple jumping tests were used as a criterion for selection in the former USSR.

The requirement for force to be produced quickly highlights the importance of short-term power production where power is defined as the rate of transfer of energy and as such can be measured in terms of the rate of energy production or dissipation (Lakomy, 1988). Lakomy (1987) outlined the practical difficulties limiting the direct measurement of power given the definition of power in terms of energy production, transfer and dissipation. However, several standardised protocols are available to estimate short-term power output which include cycle ergometry (Bar-Or, 1978), ergometers based upon a non-motorised treadmill (Lakomy, 1985) and the vertical jump (Davies & Rennie, 1968). As a result of the duration of the vertical jump, this assessment is reported to be the only test available to specifically assess those alactic processes which involve only the phosphocreatine stores (Sébert, Barthélémy, Dietman, Douguet & Boulay, 1990).

*Vertical jumping*

In field conditions, vertical jump performance is most frequently assessed using a jump and reach test. However, since jump performance is limited by the subject's ability to co-ordinate the reach with the apex of the jump, the adoption of the point mass approach is advocated. The height the mass centre attains during a vertical jump performance is a function of both the position and vertical velocity of the mass centre at the point of take-

off. However, the majority of early studies focused upon the latter as the criterion representing vertical jump performance (Kerwin, 1997). Given the parabolic flight path of the mass centre during the flight phase of the jump it is possible to estimate jump height from flight time according to the equations of uniformly accelerated motion.

Mats connected to a digital timing device provided a simple field protocol which utilised this relationship to estimate jump height (Bosco, 1980 op cit. Viitasalo, 1988). However, time of flight has most frequently been derived using a force plate (Asmussen & Bonde-Petersen, 1974; Komi & Bosco, 1978a,b) which provides information regarding the timing and magnitude of horizontal and vertical components of ground reaction force. However, this estimation is not without error due to restrictive theoretical assumptions which require that the positions of the mass centre at take-off and landing are identical and also the minimal effect of air resistance is neglected. The degree to which the latter assumption is likely to influence peak jump height has been shown to be a function of the jump style, with the relative contributions of vertical velocity at take-off and stretch height to the peak, or jump height, varying according to the style of jump (Kerwin, 1997). Additional methodological concerns which limited early investigations of jump height relate to the rate at which the force data was sampled and the method used to record and display the force-time curve (Kerwin, 1997). Given the limitations of jump height calculated from flight time, numerical integration may be a more sound method to use in the estimation of peak jump height. Peak jump height, which combines stretch height and jump height from flight time, is considered to be the most appropriate criterion in the assessment of vertical jump performance.

The measurement of maximal leg power in the vertical jump was first demonstrated by D.A Sargent in 1921 (Sargent, 1989). The protocol has since been adopted in numerous biomechanical investigations (L.W. Sargent, 1924; Davies & Rennie 1968). By adopting a point mass approach, power at each time interval can be estimated as the product of instantaneous vertical force and vertical velocity (Davies & Rennie, 1968 op cit. Davies et al., 1984). However, the use of vertical jump to estimate power has not been without criticism. Adamson & Whitney (1971) suggested that for impulsive actions such as the vertical jump, power production and dissipation could not be regarded as instantaneous. Hence, the product of instantaneous force and velocity was not considered to be an appropriate measure of muscular capacity. Since it is the case in all mechanical systems

that maximum force always precedes maximum velocity which in turn precedes maximum displacement, Adamson & Whitney (1971) recommended that impulse be the parameter of choice in the assessment of vertical jump performance. However, whilst such criticism is acknowledged, the use of vertical jump protocols as measures of 'pseudo power' (Lakomy, 1988) continue to be widely accepted within the field of biomechanical research (Dowling & Vamos, 1993).

*Relationship to sporting performance*

Vertical jumping ability has been associated with high level performance in a number of sports (Matsudo, 1987 op cit. Matsudo, 1996). However, the prognostic value of vertical jumping as an indicator of talent in the initial stages of development has been questioned. Blanksby et al. (1994) found no significant differences between pre-adolescent swimmers, tennis players and control subjects for the two indices used to define squat jump performance (height jumped and leg power). However, significant differences in vertical jumping ability were reported across groups of adolescent female tennis players, with high performers producing greater jump heights than less skilled tennis players and age-matched non-competitors. These results suggested that while vertical jump may be an important talent characteristic, it only became a valuable indicator in the latter stages of the identification process.

It may be hypothesised that vertical jumping would be most likely to differentiate between performers in sports such as gymnastics which involve impulsive activities. Empirical evidence from the literature supports this statement with indices of vertical jump performance previously reported to differentiate between gymnast and control subjects (Beunen et al., 1981; Rich et al., 1991) and between gymnasts of varying levels of ability (Lindner & Caine, 1992). The extent to which parameters of jump performance were able to differentiate between elite female gymnasts and control subjects was highlighted by Beunen et al. (1981). When data from 23 National level gymnasts were transformed using the z distribution 78% of gymnasts produced performances that were equal to or greater than one standard deviation above the population mean. However, there has been less support for the prognostic value of jump parameters with vertical jump achievement unable to explain a significant proportion of the variance in future gymnastic performances (Sol, 1987).

There are several variations in jump style which may be employed to evaluate jumping ability in the young female gymnast most notably static jump (SJ), counter movement jump (CMJ) and drop jump from a specified height. With respect to drop jumping, Bobbert et al. (1986) classified drop jump techniques into two distinct styles, counter drop jumps (CDJ) and bounce drop jumps (BDJ). It was suggested that whilst individuals adopted a particular style, both styles could be employed by each individual after demonstration (Bobbert et al., 1986). In order to determine which jump style(s) may have prognostic value in the identification of gymnastic talent it is necessary to consider the extent to which each style replicates the dynamic take-off activities which characterise contemporary Women's Artistic Gymnastics and the factors which contribute to performance in the various styles. Moreover, it is also pertinent to consider inter subject differences in the ability to perform the various jump styles and the mechanisms responsible for these differences.

*The stretch shortening cycle*

One of the major mechanical differences between jump styles concerns the extent to which each style incorporates the stretch shortening cycle. The stretch-shortening cycle (SSC) is the term applied to a sequence of muscle actions in which a concentric contraction immediately follows a rapid pre-stretch of that muscle (Lees & Fahami, 1994). It has been demonstrated 'insitu' that when the rate of pre-stretch is rapid, the muscle is able to generate a more forceful concentric contraction (Cavagna, Dusman & Margaria, 1968). The force produced in the concentric contraction is reported to be in excess of that from rest or from a prior isometric contraction (Komi, 1979). The enhancement of muscular force production following the stretch-shortening cycle has been demonstrated experimentally in a number of jump styles, although the precise mechanism(s) responsible for the potentiation effect remains unclear. The subsequent section will consider evidence from a number of empirical and theoretical studies which have investigated inter-individual differences in performance across jump styles.

Early investigations consistently demonstrated that jump height following a counter movement was superior to that attained in a static jump (Asmussen & Bonde-Petersen, 1974; Komi & Bosco, 1978a; Bosco & Komi, 1980). However, Kerwin (1997) questioned the validity of these results citing limitations associated with the estimation of

jump height from flight time information obtained using transient recorder outputs (Asmussen & Bonde-Petersen, 1974; Komi & Bosco, 1978a,b). Moreover, the analysis of group data may mask variations at the level of the individual. Indeed, a closer inspection of Asmussen & Bonde-Petersen's 1974 data revealed that for 7 out of 19 subjects (37%) jump height was greater in the SJ. Support for the enhancement of jump height after a counter movement was questioned elsewhere. Lees & Fahmi (1994) investigated differences in jump height between CMJ and SJ determined using the method of numerical integration. Data collected over three testing sessions revealed that SJ resulted in a superior jump height than CMJ ($p<0.05$). While the subjects were 30 male sports participants the discrepancy with previous findings was interpreted by the authors to be the result of skill or ability differences in their subject pool in comparison to subjects of previous studies. However, excluding this study, the majority of contemporary experimental and theoretical research continues to support suggestions that a preliminary counter movement enhances jump performance (Bobbert, Gerritsen, Litjens & Soest 1996; Kerwin, 1997; Anderson & Pandy., 1993; Voight, Simonsen, Dyhre-Poulson & Klausen, 1995).

An alternative to experimental research is to adopt a theoretical approach. This may take the form of inverse or forward dynamics modelling. Theoretical models are based on mathematical formulations of Newtonian systems (Yeadon & Challis, 1994). Forward dynamics, which is often called simulation, has been applied in the study of human jumping. The common form of input to simulation models comprises the forces acting on the system with the output being the subsequent motion. The model is usually a simplification of the living system into its most fundamental components which facilitates an understanding of the underlying mechanics of the activity in question. The main advantage of simulation modelling lies in the control the researcher has over the theoretical experiment. Two research groups which have employed simulation in the study of human jumping are the working group in Amsterdam (Bobbert et al, 1986; Bobbert & Ingen Schenau, 1988; Bobbert & Soest, 1994; Bobbert et al., 1996) and the North American research group (Pandy, Zajac, Sim & Levine, 1990; Pandy & Zajac, 1991; Anderson & Pandy, 1993). The models developed by both research groups comprised four rigid segments representing the feet, lower legs, upper legs and the head, arms and trunk. Hill-type muscle models were used to represent the extensor muscles of the lower extremity. These muscle models could be driven using stimulation patterns

derived experimentally or theoretically. The jumping models were used to gain an understanding of the differences in performance across various jump styles, including the mechanisms responsible for potentiation following the stretch shortening cycle.

Early empirical investigations attributed the potentiation of jump height associated with a preparatory counter movement to the storage and reutilization of elastic energy (Asmussen & Bonde-Petersen, 1974; Komi & Bosco, 1978a). The pre-stretch of active muscles was suggested to absorb and store elastic strain energy in the series elastic components which could be re-utilised during the concentric phase of the jump to enhance maximum work production (Komi, 1979; Bobbert et al., 1996; Ingen Schenau, Bobbert & Haan, 1997). The greater amount of energy stored during a CMJ was a proposed to be a function of the higher level of active force rather than the greater amount of negative work performed in the CMJ (Cavagna, 1977; Lees & Fahmi, 1994; Bobbert et al., 1996; Ingen Schenau et al., 1997). While there is general agreement that elastic energy may be stored and reused in the CMJ, the extent to which this mechanism is responsible for the potentiation of work in the subsequent concentric phase has been questioned (Cavagna , 1977; Bobbert et al., 1996; Ingen Schenau et al., 1997). For example, Bobbert et al. (1996) assessed the contribution of stored elastic energy in counter movement and squat jumps using a two segment simulation model with a single torque generator representing extension at the hip. When the speed of the simulation was doubled the magnitude of joint moments increased which resulted in an increase in the difference in the amount of elastic energy stored between squat and counter movement conditions but a decrease in the amount of work produced.

The contribution of stored elastic energy has also been questioned in the light of changes in the contractile conditions which are associated with the pre-stretch of active muscle. In addition to facilitating the storage of elastic energy, a prior eccentric muscle action increases the length of the series elastic elements at the expense of restricting the shortening distance of the contractile elements (Ingen Schenau et al., 1997). As a result of these length changes the contractile conditions become less favourable (Avis, Toussaint, Huijing & Ingen Schenau, 1986; Voight et al., 1995; Bobbert et al., 1996) which potentially negates any benefits derived from the storage of elastic energy (Avis et al., 1986). Using the previously described simulation model, Anderson & Pandy (1993) demonstrated that although approximately equal amounts of energy were stored in squat

and counter movement jumps, differences occurred in mechanisms through which energy was stored. In the squat jump, a large amount of work was performed by the contractile elements to stretch the series elastic components. In contrast, storage of elastic strain energy in the counter movement was derived from the conversion of gravitational potential energy during the eccentric phase of the movement. Empirical studies support the suggestion that the contribution to positive work in leg extensor muscles is similar with and without a preceding counter movement. For example, Avis et al. (1986) reported while there were large differences in the level of initial forces between squat and counter movement conditions, only a 4% difference in positive work was observed. Therefore, while early modelling attempts were not in agreement regarding the importance of elastic energy in jumping performance (Bobbert et al., 1986; Pandy, 1990), recent theoretical convergence suggests that the role of stored elastic energy may be to enhance the efficiency, rather than the effectiveness, of jumping performance (Pandy, 1990; Anderson & Pandy, 1993; Voight et al., 1995; Bobbert et al., 1996).

The level of force achieved at the start of the push off phase is proposed to be the most critical factor in explaining the performance differences observed between jump styles (Lees & Fahmi, 1994; Bobbert et al., 1996). A preparatory counter movement allows the muscles a greater time to build up a high level of active state and hence force prior to the commencement of the concentric phase of muscle action (Ingen Schenau, 1984; Shorten, 1987; Chapman & Sanderson, 1990). Therefore, greater joint moments are produced at the commencement of the push-off phase which result in a greater amount of work produced over the concentric phase of the jump (Bobbert et al., 1996). The extent to which this mechanism may contribute to enhanced work has been questioned by Sanders & Wilson (1992) who suggested that the effect on performance may be minimal due to the limited range of displacement during the early phase of the jump. Bobbert et al. (1996) re-addressed the question using a simulation model in which the EMG activity of the phase preceding the start of the push-off phase of a CMJ was replaced with that derived experimentally during a SJ. Results indicated that while moments at hip, knee and ankle were much lower at the start of the push off phase ($p<0.05$), the effects on joint work were less dramatic. As a consequence of the proximal to distal sequencing of muscle activation in the vertical jump (Ingen Schenau, 1989), the greatest decrease in work was experienced by the hip extensors. Therefore, performance enhancement produced by the counter movement was suggested to be due to a higher level of active

state and hence force primarily in the hip extensor muscle group prior to shortening (Bobbert et al., 1996 op cit. Ingen Schenau et al., 1997). It may be anticipated that a greater movement amplitude in the squat jump would compensate for lower initial force production during the first phase of the SJ as hypothesised by Sanders & Wilson (1992). However, studies have failed to find experimental support for this hypothesis (Sanders & Wilson, 1992; Bobbert et al., 1996).

It has also been proposed that the counter movement may induce spinal and/or long latency stretch reflexes which may act to increase muscle stimulation and hence result in a higher active phase during the concentric phase of the CMJ (Dietz, Schmidtbleicher & Noth, 1979; Bobbert et al., 1986; Shorten, 1987; Komi, 1992). However, support for the reflex potentiation of activation has been equivocal (Chapman & Sanderson, 1990) with a number of investigations failing to find any significant differences in EMG activity between concentric and counter movement conditions (Svantesson & Grimby, 1995; Bobbert et al., 1996).

The contribution of potentiation, the final mechanism proposed to contribute to the enhancement of jump in the CMJ, remains to be quantified. The concept of potentiation which suggests that a modification takes place in the properties of the contractile machinery as a result of pre-stretch (Bobbert et al., 1996), has been demonstrated in experiments using isolated muscle (Cavagna et al., 1968). Shorten (1987) highlighted that elastic recoil in the musculo-tendon complex enhances the contraction velocity which may precipitate a shift of the force-velocity curve to the right permitting a more favourable part of the force-velocity relationship to be utilised. However, the speed and extent of pre-stretch conditions combined with the time interval between the eccentric pre-stretch and peak power output during the subsequent concentric contraction are likely to limit the magnitude of potentiation effects following a counter movement (Cavagna, 1977; Shorten, 1987). Finally, differences in control or co-ordination between jumps styles are also considered unlikely to be responsible for performance differences, as toe-off positions were found to be equivalent at the point of take-off for both CMJ and SJ (Bobbert et al., 1996). Since empirical data is limited, the influence of coordination remains to be quantified.

In line with the principle of the stretch-shortening cycle, when a vertical jump is preceded by a drop from a specified height an enhancement of jump height over and above that possible from static and/or counter movement may be expected. However, empirical research has failed to provide unanimous support for the attainment of a superior jump height in the bounce drop jump (Bobbert et al., 1987a; Bedi, Creswell, Engel & Nichol, 1987). Several early investigations using the velocity of the mass centre at take-off to estimate jump height reported superior jump heights in drop compared to counter movement jumps, particularly when drop heights and hence stretch loads were high (Asmussen & Bonde-Petersen, 1974; Komi & Bosco, 1978a). In contrast, Cavagna, Komarek & Citterio (1971) found no significant differences between CMJ and DJ heights.

Kerwin (1997) examined jump height attained following drop and countermovements using jump height derived from take-off velocity and found superior performances in counter movement jumps. However, when peak jump height (stretch height plus jump height) was measured, performances were found to be equivalent following counter movement and rebound phases of the 'Marey' style jump. However, the take-off velocity of the mass centre provided a greater contribution to peak jump height following the counter movement and stretch height was proportionately greater following the rebound phase.

Bedi et al. (1987) in comparing counter movement and drop jumps from various heights found that attainment of jump height following a counter movement was significantly greater than all drop jump heights. The magnitude of the difference in jump heights between counter movement and drop jump conditions was such that superior peak jump heights (PJH) would be expected when stretch height was included (Kerwin, 1997). Moreover, where performance enhancements have been demonstrated, the identification of a universally accepted optimum drop height has proved elusive. Asmussen & Bonde-Petersen (1974) compared jump performances across increasing drop heights (0.233, 0.404, 0.690). Results revealed that the optimal performance occurred at a drop height of 0.404 m. The subsequent failure to increase performance at the maximum drop height was attributed to inhibition by the subjects in response to the increase in forces sustained during the impact phase of the jump. Komi & Bosco (1978a) identified an increase in performance in terms of positive energy following a drop jump in comparison to the static jump. The optimum drop height was higher than recorded by Asmussen & Bonde

Petersen (1974), with different optimums being recorded for male and female subjects (0.62 m and 0.50 m respectively).

Lees & Fahmi (1994) considered a large range of drop heights and identified an optimum drop height of 0.12m, considerably lower than recorded in previous studies. While increased forces necessary to enable the storage of elastic energy were recorded up to a drop height of 0.36m, failure to enhance jump performance up to this point was attributed to insufficient co-ordination. Lees & Fahmi suggested that the ability to tolerate drop height varied considerably between subjects. More recent research has failed to identify an optimum drop height. Bobbert, Huijing & Ingen Schenau (1987b) investigated performance over three drop jump heights 0.2m, 0.4m and 0.6m respectively. No significant differences were found in performances across the drop heights, but peak forces increased as drop height increased. Similarly, Kerwin & Challis (1985) found little evidence of an optimum drop height in drop jumps ranging 0.15-0.90 m. However, fitting a quintic spline indicated an optimum drop height at 0.40 m.

Several reasons have been cited to explain the discrepancies in the results. Bedi et al. (1987) suggested that sampling influences and particularly heterogeneity in the characteristics of subjects to be in part responsible for contradictory findings. In addition, the choice of the statistical tests used to detect mean differences, specifically, the use of multiple t-tests were suggested to have increased the possibility that significant differences occurred by chance (type I errors). Bedi et al. (1987) reanalysed the data for male subjects (Asmussen & Bonde-Petersen, 1974) using a more powerful repeated measures ANOVA and were unable to detect differences in jump height at $p<0.001$ level of significance. Additionally, Kerwin & Challis (1985) questioned the numerical values cited for optimum drop height in previous investigations. The authors estimated the actual drop height from landing impulse and found the range of calculated drop heights to be much smaller than the drop heights used in their study. Differences between calculated and nominal drop heights were positively skewed, with the greatest variation occurring at the highest drop heights.

*Individual differences in the ability to utilise the stretch shortening cycle*

In order for the ability to utilise the SSC to be considered a potentially important talent characteristic, inter-individual differences in the ability to utilise this mechanism must exist and be easily identified within a screening situation. Previous studies have identified a gender difference in the ability of individuals to utilise the SSC in both dynamic jumping activities (Komi & Bosco, 1978a) and isokinetic assessments (Svantesson & Grimby, 1995). In these studies, female subjects demonstrated a greater improvement in performance than male subjects when the concentric contraction was preceded by an eccentric muscle action. The observed gender difference was attributed to the ability of female subjects to utilise a greater proportion of the stored elastic energy (Komi & Bosco, 1978a; Svantesson & Grimby, 1995).

However, an alternative interpretation which focuses on inter-individual differences in muscle fibre composition is more in line with current understanding that the time available to develop active force is the most critical determinant of SSC potentiation (Lees & Fahmi, 1994; Bobbert et al., 1996; Ingen Schenau et al., 1997). As a result of variations in the cross-bridge cycling rates, subjects with a large proportion of fast twitch (Type II) fibres respond favourably well to high velocity pre-stretch and a small amplitude of movement whereas subjects with predominantly slow twitch (Type I) fibres require longer pre-stretch times and a greater amplitude of pre-stretch (Bosco, Tihanyi, Komi, Fekete & Apore, 1982). Therefore, assuming that male subjects possess a greater percentage of Type II fibres in the leg extensor muscles, the levels of force developed in CMJ and SJ would be expected to be more similar in male subjects than in female subjects whose muscle fibre-types would be more suited towards more sustained force development during the CMJ. However, Kerwin (1997) reported the increase in performance between SJ and CMJ to be superior for male subjects, with percentage improvements of 25% and 11% recorded for male and female subjects respectively. It is anticipated that differences in the subject pool may be in part responsible for the discrepancies between studies.

Inter-individual differences in the ability to utilise the SSC have been identified between athletes competing in a number of different sports. The magnitude of the potentiation effect, defined as the difference between counter movement and squat jump height, was

compared for athletes competing in various sports (Bosco & Komi, 1982). The smallest potentiation effect was recorded for middle distance runners (5cm difference) with ski-jumpers recording the greatest difference (8-11cm). However, the group differences reported in these early investigations must be viewed with some caution given that the errors associated with the experimental determination of jump height may be greater than the magnitude of the potentiation effect.

Inter-individual differences have also been identified in the ability to tolerate and utilise stretch loads (Shorten, 1987) with different optimum drop heights being recorded for male and female subjects (0.62 m and 0.50 m respectively) (Komi & Bosco, 1978a). It has been proposed that the inability of subjects to utilise stretch loads associated with large drop heights may be the result of neural inhibition, which functions to protect the muscular system during maximal eccentric contractions. Evidence to support the concept of neural inhibition was demonstrated by Westing, Seger, Karlson & Ekblom (1988) who noted that in contrast to the results of isolated muscle experiments, peak eccentric torque created by the quadriceps during maximal knee flexion on an isokinetic dynamometer did not significantly change with increasing velocity. Moreover, it has been suggested that neural inhibition may be influenced by training status (Westing et al., 1988) which may help to explain the superior eccentric performance recorded for elite ski-jumpers in comparison with a lower ability trained group (Abe et al., 1992). Evidence in support of training effects upon the neural inhibitory mechanism has been highlighted in the field of human jumping. Komi (1984) observed that the optimum drop height varied as a function of athletic activity with female gymnasts demonstrating superior jump heights in comparison to control subjects over a range of drop heights (Figure 5.2). The greatest differences between gymnasts and controls were recorded in the highest pre-stretch conditions indicating that gymnasts have a greater tolerance to stretch loads than physical education students over a range of drop heights between 20 cm and 70 cm (Komi, 1984).

The extent to which the ability to tolerate/utilise the SSC may be considered a prognostic indicator of talent has not been conclusively determined. However, a number of investigations have suggested that the ability may develop with specific training regimes. For example, Abe et al. (1992) attributed the unique ability of the eccentric mode of testing to differentiate between elite and college trained alpine skiiers to training

adaptations in the lower extremity associated with the stretch shortening cycle (Abe et al., 1992).

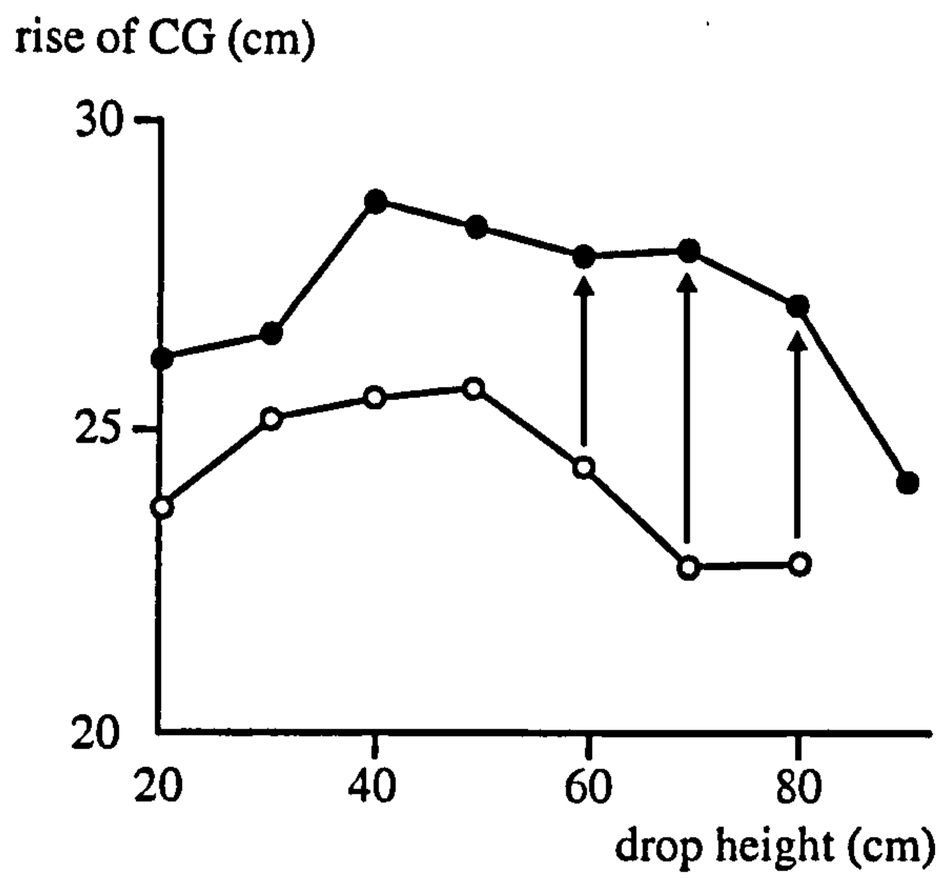



Figure 5.2. Comparison of drop jump performance in female gymnasts and control subjects (adapted from Komi, 1984).

Furthermore, an 18 month period of specialised elasticity training resulted in an increase in the optimum dropping height among Finnish volleyball players (Komi et al., unpublished results op cit. Komi, 1979).

*Factors influencing vertical jump performance*

To attain maximum height in vertical jumps both the nature and control of the musculo-skeletal system are of paramount importance. It has been suggested that the nature of the musculo-skeletal system may determine the *'potential'* maximum jump height while the control of this system is responsible for determining the *'actual'* jump height (Bobbert & de Bruin, 1998). Anatomical characteristics relating to the mass distribution and moment arms of muscles are important factors contributing to jump performance (Bobbert & Soest, 1994). In addition, skeletal muscle architecture in terms of fibre length and the angle of pennation of muscle fibres plays a critical role in the determination of the contractile properties of skeletal muscle (Roy & Edgerton, 1992). These characteristics are considered to be particularly important given their invariance and lack of responsiveness in relation to training effects (Bobbert & Soest, 1994). Biochemical (enzyme activities and substrate concentrations in muscle), physiological characteristics

(muscle strength and muscle fibre composition) and coordination are also proposed to contribute to jumping performance.

Muscle fibre composition

Studies have revealed that those subjects who possess a high percentage of fast twitch fibres are able to produce superior performances in both counter movement and squat jumps (Bosco & Komi, 1979; Viitasalo, Hakkinen & Komi, 1981). In addition, significant correlations have been reported between the percentage of fast twitch fibres and jump parameters including average force, r = 0.52, net impulse, r = 0.45 and mechanical power, r = 0.52 (Komi, 1979). Figure 5.3 provides an illustration of the relationship between muscle fibre-composition and the production of ground reaction forces in the squat jump.

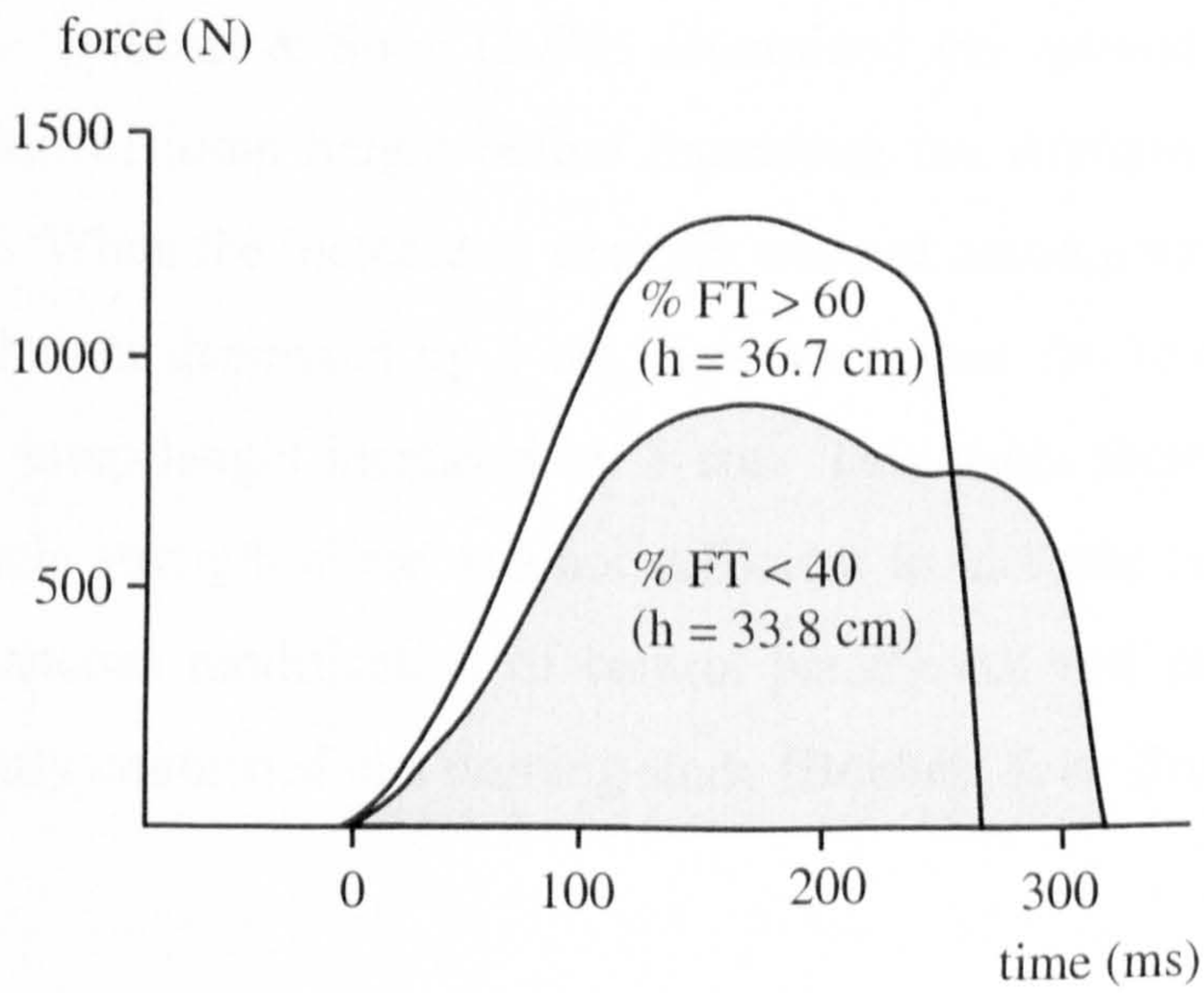



Figure 5.3. The relationship between muscle fibre composition (vastus lateralis) and contact time in vertical jump (adapted from Bosco & Komi, 1979).

The force trace of 'fast-twitch' subjects was characterised by high forces and a short contact time with the inverse pattern of ground reaction forces demonstrated by 'slow-twitch' subjects (Bosco & Komi, 1979; Komi, 1984). However, while the relationship between muscle fibre composition and jumping performance has received considerable empirical support, the validity of these studies must be questioned in the light of limitations associated with the experimental determination of jump height and the estimation of muscle fibre composition from biopsy samples of human skeletal muscle.

Strength

Evidence from empirical studies concerning the relationship between maximal isometric force, rate of force development and vertical jump performance have been inconclusive. Previous studies have demonstrated a correlation between the production of force at high velocities and vertical jump performance. This may be particularly relevant to drop jumping, as the counter movement lessens the effect of RFD by allowing additional time to reach maximum force (Chapman & Sanderson, 1990). However, the relationship between isometric strength parameters and jumping performance is limited as a result of the inability of isometric parameters to account for the 'dynamic' nature of jumping.

The relationship between jump performance and strength parameters has also been highlighted by theoretical investigations. Using a forward dynamic simulation model Pandy (1990) concluded that jump height was most sensitive to increases in the strength to weight ratio. Bobbert & Soest (1994) determined the optimal stimulation pattern for the maximisation of jump height before increasing the strength of muscles within the model by 20%. When the increase in strength was not accompanied by a modification in control, jump height decreased by 2 cm, however, upon the re-optimisation of control parameters the jump height increased by 8 cm. This study therefore demonstrated that increasing muscle strength alone was not sufficient to increase vertical jump height and that the simultaneous modification of control parameters was essential. These results were subsequently confirmed in a training study (Bobbert & de Bruin, 1998).

Co-ordination and control

Analyses of squat and counter movement jumps have consistently demonstrated a proximal-to-distal sequencing of muscle activation. During both styles of jumping, the hip extensors are the first to be activated, followed by the knee extensors and finally the ankle plantar flexors (Bobbert & Ingen Schenau, 1988; Pandy & Zajac, 1991; Anderson & Pandy, 1993; Soest et al., 1993; Bobbert & Soest, 1994). These results have been attained using both experimental (Bobbert & Ingen Schenau, 1988; Anderson & Pandy, 1993) and theoretical approaches (Pandy & Zajac, 1991; Anderson & Pandy, 1993; Soest et al., 1993; Bobbert & Soest, 1994). Bobbert & Ingen Schenau (1988) suggested that the successful performance of a vertical jump was dependent upon the maximisation

of energy at the point of take-off. This concept takes into account both the vertical velocity and the height of the mass centre as the subject leaves the ground. If the only requirement was to maximise the vertical velocity of the mass centre then the differences in the vertical velocities of the segment end points should peak simultaneously. However, in order to maximise effective energy a proximal-to-distal sequencing is most appropriate. This sequence permits each muscle to shorten over its complete range before take-off thus allowing the muscles to maximise the energy they release before the subject looses contact with the ground.

*Development of jump parameters within the growing child*

The majority of previous research investigating the development of jumping ability in children has focused upon male subjects. A number of studies reported that vertical jumping performance in males develops in an essentially linear manner through childhood and adolescence (Branta et al., 1984; Malina & Bouchard, 1991; Blanksby, Bloomfield, Ackland, Elliot & Morton, 1994), moreover, an examination of cross sectional data has revealed no evidence of a marked adolescent spurt in performance (Malina & Bouchard, 1991) An examination of the rate of development of jump performance in relation to key maturational events revealed that in both Belgian and Australian boys the peak gains in vertical jump height occurred occur after PHV (Beunen, Malina, Hof, Simons, Ostyn, Renson & Gerven, 1988; Blanksby et al., 1994). Several investigations have reported a temporary decrease in the rate of development of vertical jump performance in male adolescents (Espenschade, 1940, 1960; Blanksby et al. (1994), in the study of Australian children this occurred approximately 6-12 months after the attainment of PHV (Blanksby et al., 1994). When data were expressed in terms of mean velocity (Blanksby et al., 1994) and median velocity (Beunen et al., 1988), the rate of change in vertical jump height remained positive during the adolescent growth spurt, providing no indication of a temporary period of adolescent awkwardness (Malina & Bouchard, 1991).

Using a mixed longitudinal design, Blanksby et al. (1994) investigated children's growth, the development of muscular strength, inertia parameters and performance in the squat jump. A total of 55 boys were monitored over a five year period with assessments conducted at 6 monthly intervals. The data were subsequently splined to permit growth and velocity estimates to be derived at monthly intervals. When data were aligned with

respect to the peak height velocity of each individual subject a considerable amount of inter-subject variability was detected in the maturational rate. Given the extent of this variability it was anticipated that measures of central tendency, as cited in the previous paragraph, may mask individual developmental differences and therefore a case study approach was considered to be the most appropriate method of analysis. The case study approach revealed that for a number of individuals a temporary decrease in squat jump performance was observed when the development in muscular strength lagged behind the growth in inertia parameters, resulting in a temporary 'mismatch'. However, jumping performance was subsequently restored as muscular strength increased. The sample in the study of Blanksby et al. (1994) included both swimmers and tennis players who it may be assumed were engaged in regular strength training programmes. It may therefore be hypothesised that a greater decrement in jump performance may be anticipated in a group of non-athletic subjects.

There is less information available regarding the development of vertical jump performance in girls, however, a linear trend has been reported up to the age of 12 years (Haubenstricker & Seefeld, 1986). There has been no clear consensus regarding the development of jump performance into adolescence (Figure 5.4).

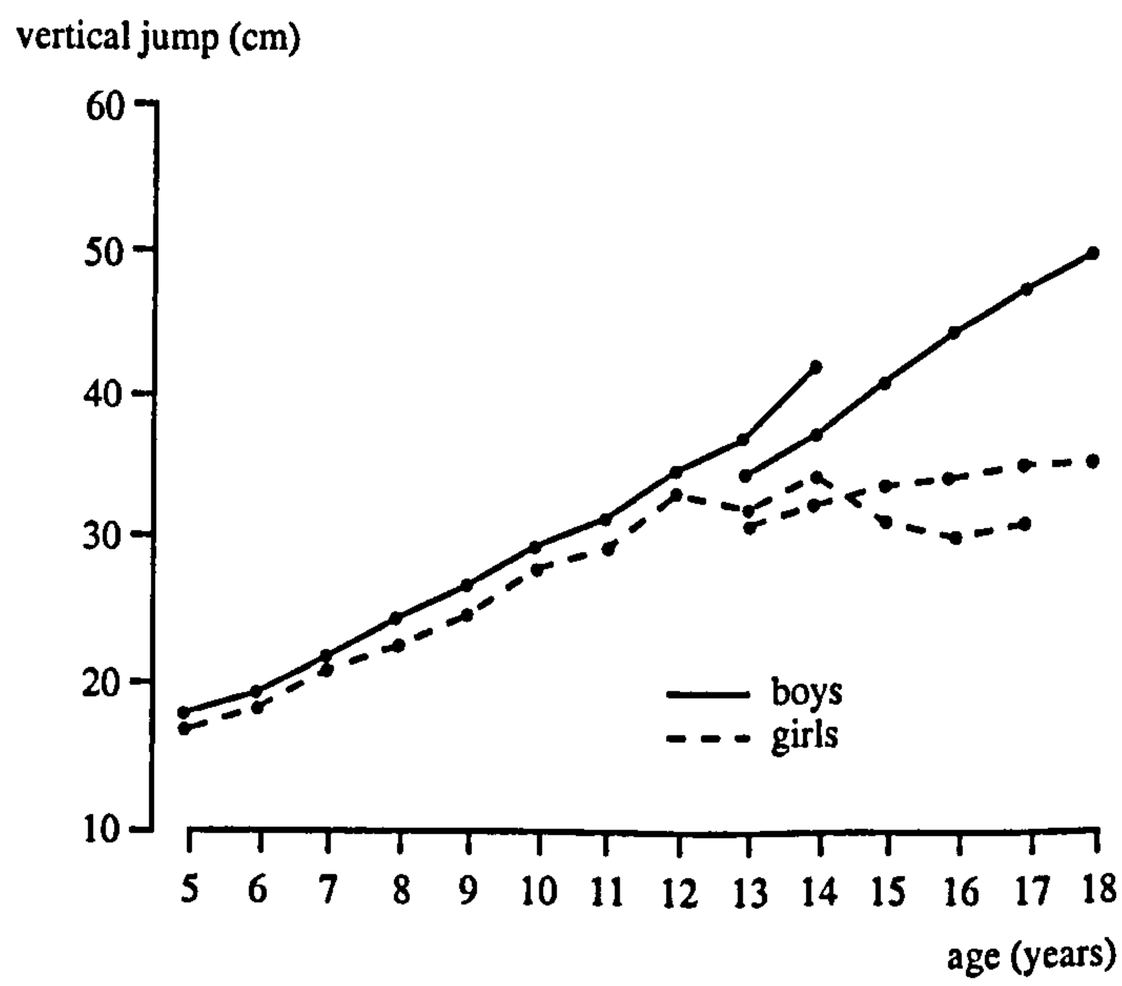



Figure 5.4. The mean performance of girls in vertical jump between 5 and 18 years of age (adapted from Malina & Bouchard, 1991, pp. 194).

In a study of American girls performance reached a plateau between 12-14 years of age before subsequently declining (Haubenstricker & Seefeld, 1986). In contrast, the

performance of Belgian girls was reported to improve slightly between the ages of 13-18 years. There is no evidence of an adolescent spurt for female subjects with only small changes in vertical jump performance observed around menarche (Espenschade, 1940).

Bosco & Komi (1980) investigated the influence of ageing upon the development of jumping ability in male and female subjects. The study was limited in terms of the cross-sectional design and the use of relatively wide age bands which covered different age groups in male and female subjects. However, the study represents one of the first attempts to consider the development of jumping within the growing child and the age-related variation in the nature of development across jump styles. In female subjects, maximum jump height in both squat and counter movement jumps was attained in the age group (9-12 years) with a lower jump height being recorded for older females (19-26 years). The decrease in performance observed in the young adults was attributed to the increase in adiposity associated with female pubertal development. However, it is interesting to note that in contrast to jump height, peak performance in a number of jump parameters (average force, jump height, net impulse and average power output) was recorded in the young adults (20-30 years of age). No explanation was proposed to explain this apparent discrepancy. By numerically integrating the force-time curves Ferretti, Narici, Binzoni, Gariod, Le Bas, Reutenauer & Cerretelli (1989) estimated peak instantaneous power output during jumps in children and adults. In line with the findings of Bosco & Komi (1980) the peak instantaneous power in children was only 65% of that of recorded in adult subjects. The observed differences in peak power production between children and adults could not be explained solely in terms of changes in muscle cross-sectional area but were suggested to be the result of hormonal events associated with puberty and the incomplete activation of motor units as reported by Belanger & McComas, (1989) (Ferretti et al., 1989).

The study by Bosco & Komi (1980) also reported an ageing effect in the ability to utilise the high stretch loads associated with drop jumping. The 9-12 year old females produced lower jump heights than the young adult subjects which was explained in terms of the inability of the young girls to utilise the increased stretch loads. This was suggested to be either the result of an immature central nervous system or the effect of an inhibitory mechanism which may function to protect the immature skeleton (Bosco & Komi, 1980). However, the validity of the observed age effect must be questioned given the small

differences in jump height between adults and children and given that different drop heights were used for children and adults.

Two studies have reported developmental differences in the ability to utilise the SSC (Bosco & Komi, 1980; Moritani, Oddsson, Thorstensson & Åstrand; 1989). In contrast to adult subjects, children produced only small differences in jump height between static and counter movement conditions (Bosco & Komi, 1980) which was interpreted to indicate that the potentiation of performance associated with pre-stretch was sensitive to ageing. In a subsequent study, Moritani et al. (1989) reported that the height of the centre of mass achieved in maximal height hopping (10-15s) in pre-pubertal boys (14.0 ± 1.2cm) was much lower than in adult males (28.6 ± 2.3cm). The most marked difference was that the pre-pubertal boys demonstrated lower potentiation of the medial gastrocnemius muscle in the eccentric phase of the activity. In the original paper this was suggested to influence the ability of pre-pubertal boys to utilise stored elastic energy, however, in the light of the current consensus regarding the SSC (Ingen Schenau et al., 1997) these findings may alternatively be interpreted in terms of the lower level of active force produced by pre-pubertal boys at the onset of the concentric phase.

Approaches investigating the presence of invariant temporal or spatial relationships in vertical jumping activities have considered the influence of both maturational factors within the growing child and changing task constraints. Developmental research has been largely cross-sectional in nature and has considered the variations in jumping performance from its entry into the movement repertoire at approximately 2-3 years of age until a mature jumping action becomes established when children are approximately 9 years of age (Clark, Phillips & Petersen, 1989). Invariance in the timing of peak extension velocities of lower extremity segments has been demonstrated in skilled adult subjects and children of increasing chronological age (Bobbert & Ingen Schenau, 1988; Jensen & Phillips, 1991; Clark et al., 1989; Hudson, 1986). Invariance has also been demonstrated across changing task conditions and between subjects of varying skill level (Clark et al., 1989). Temporal invariance in the timing of peak extension velocities was reported to be a common propulsive strategy. The proximal to distal sequencing of peak extension velocities, identified across jump styles in children as young as 3 years of age, enables an active state to be maintained throughout the range of shortening thus maximising the release of effective energy at the point of take-off (Bobbert & Ingen Schenau, 1988). The

extent to which temporal invariance occurs in more demanding jump styles, such as the bounce drop jump, remains to be clarified.

The timing of joint reversal delays was also suggested to display invariance. While stability was confirmed across age and task conditions (Jensen, Phillips & Clarke, 1994), variance was observed as a function of sporting proficiency (Jensen & Phillips, 1991). Critical of Petersen's (1984) use of group comparisons Jensen & Phillips suggested common rather than universal temporal patterns had been identified. Inspection of the coordination patterns of six adult male subjects confirmed differences in both sequence and timing of joint reversals. Jensen & Phillips (1991) suggested that consistent sequencing and timing in novice subjects may be replaced by increased variability as skill level increases with the ultimate result being the flexibility to adapt to changing task demands in the proficient subject. The proposed development of patterns of joint reversal is analogous to the stage-like development of postural stability within the growing child described in chapter 6. The apparent stability in the timing of joint reversals across age, while less clearly interpretable, may be a function of methodological and statistical design. Statistical analysis of group means rather than analysis at the level of the individual may have masked inter-subject variability. The cross-sectional nature of the studies and the relatively large increments in chronological age between measurements may further compound the problem. While coordinative structures have been identified in vertical jump performance certain modifications seem possible as a function of training or experience. However, research confirms that control parameters provide the greatest potential for performance enhancement. Control variables associated with body positioning, joint configuration and the magnitude of various kinematic variables have consistently demonstrated inter-subject variability. Modifications to such 'control' variables are proposed to enable skilled performers to adapt the jumping action to changing task demands (Clarke et al., 1989).

*Parameters of the vertical jump*

Several empirical studies have investigated the relationship between selected kinetic variables and vertical jump performance. However, the majority of investigations illustrate correlational rather than causal relationships. Adamson & Whitney (1971) advocated that vertical impulse is related to performance and that the pattern of impulse

generation best represents muscular activity. The authors suggested that generation of positive impulse must be maximised via an increase in the peak force, an increase in the duration of positive impulse or an increased gradient of the positive impulse. Hunebelle & Damoiseau (1973) found empirical support for the important role of the slope of positive impulse, maximal instantaneous force (expressed in percent of body weight) and the time duration of impulse. Poor jumpers displayed a triangular impulse characterised by a slow and low increase in slope and long duration. The more successful jumpers produced a rapid increase of the curve. Impulse duration was found to be more variable, but was generally shorter, in the more proficient jumpers (large slope, short duration). A flat triangular impulse was proposed to indicate of a poor jumper, the pattern of which was unlikely to be modified as a result of training.

Sewall & Lander (1992) identified 14 key times from force-time, velocity-time, displacement-time and power-time curves and used them to calculate 56 variables which were assumed to be related to vertical jump performance. The subsequent factor analysis yielded 4 factors, three of which related to impulse and one to power (impulse during the weighted part of the jump, impulse during the unweighted portion of the jump, relative time spent in weighted versus unweighted and maximum instantaneous power produced during the jumps). Despite theoretical limitations regarding the calculation of peak positive power, this factor has emerged as a consistently significant predictor of jump height (Dowling & Vamos, 1993; Harman, Rostenstein, Frykman & Rostenstein, 1990; Perrine, Gregor, Munroe & Edgerton, 1978). Normalisation relative to body weight increased the strength of the correlation between jump height and peak power. Dowling & Vamos (1993) demonstrated that maximum positive power was an excellent single predictor of vertical jump height ($r = 0.928$). The RMS error of the regression equation (+/- 2.9 cm) indicated that strength, specifically produced at high velocities, was a requirement for excellent performance. A high maximum force was found to be necessary but not sufficient for good performance, thus raising the suggestion that the pattern of force application and specifically the generation of forces late in movement was of paramount importance. The attainment of maximum force as the joints approach full extension late in the movement to contribute to high velocity at take-off is consistent with the principle of late development (Hochmuth & Marhold, 1977). However, such a pattern of force application requires greater muscle power (Dowling, 1992) which may be attainable as a result of the unique action of biarticular muscles in the transportation of

power/energy (Bobbert & Ingen Schenau 1988). The attainment of high power output, due to large forces late in the push off phase of the jump when velocity has been suggested to be responsible for differences in jump height between static and counter-movement jumps.

*Stability of vertical jump performance*

Only a limited number of investigations have considered the stability of activities requiring a high degree of explosive strength such as vertical jump and standing broad jump performances (Bouchard et al., 1997). It has been widely acknowledged that pooling, or direct comparison of heritability estimates across studies, is difficult as a result of differences in the statistical estimation of heritability and the variations in the measurement protocol. However, despite these limitations, published results have consistently indicated that vertical jump performance has a large genetic component. This was confirmed in a recent review of research which highlighted that heritability estimates derived from early twin studies were within the range 0.82-0.93 (Maes et al., 1996). The majority of early twin studies were conducted in Eastern Europe and produced estimates in or around the range cited in the review of research cited above. For example, Sklad (1973) studied vertical jump performance in a sample of Polish twins aged 8-15 and derived heritability estimates of 0.75 and 0.63 for male and female twins respectively.

In more recent investigations conducted by the research group based in Leuven, path analytical techniques using the technique of maximum likelihood estimation have been applied to a combination of twin and family data (Maes et al., 1993, 1996). In the earlier investigation of 10 year old twin pairs, vertical jump performance was one of only two parameters in which the intra-pair correlations for the MZ twins were significantly higher than those of the DZ twins, with heritability for the mixed sex sample was estimated at approximately 0.63 (Maes et al., 1993). In the latter, twin data were initially considered in isolation (Maes et al., 1996). In this case, gender heterogeneity was observed in the genetic contribution to phenotypic variance with heritability estimates of 0.47 and 0.78 reported for male and female subjects respectively. While the estimate for male twins was lower than reported in previous investigations the estimated heritability for the female twin pairs was not dissimilar to the more traditionally derived estimates. It is of interest to note that when parental data were included in the analysis, gender

heterogeneity was no longer present and heritability was estimated at 0.65. For both sets of data, the most parsimonious model incorporated both additive genetic effects and specific environmental parameters.

In line with expectations, heritability estimates derived from family data are lower than those generated from samples of twins. A review of relevant investigations revealed that heritability estimates fall within the range 0.22-0.68 (Maes et al., 1996). In a study of families living in an Urban district of Poland significant parent-sibling correlations (0.17-0.54) were reported (Szopa, 1982, 1983 op cit. Bouchard et al., 1997). Heritability estimates derived from this data set using sibling correlations were 0.44 and 0.33 for male and female children and 0.68 and 0.47 for male and female adolescents indicating that the genetic contribution to phenotypic variance is likely to increase with age. It is also of interest to note that in contrast to the gender heterogeneity effect evident in the studies of twins, heritability estimates were greater in male children and adolescents than age matched samples of female siblings (Szopa, 1982, 1983 op cit. Malina, 1986b). In summary, the majority of evidence suggests that vertical jump performance is largely dependent upon the genotype. Although evidence has been cited indicating gender heterogeneity the precise nature of the relationship between heritability and gender is yet to be determined.

### 5.2.6 LOCAL MUSCULAR ENDURANCE

Energy for physical activity is derived from anaerobic and aerobic systems via three metabolic pathways; alactic, lactacid and oxidative (Cahill, Misner & Boileau, 1997). It was previously contended that mobilisation of these pathways occurred sequentially, however, more recent studies have consistently confirmed that as exercise is commenced the pathways produce energy simultaneously (Spriet, 1995). The relative contribution of each pathway varies according to the intensity and duration of the activity (Spriet, 1995). Figure 5.5 shows the contribution of each metabolic pathway during the first 180s of maximal exercise in adult subjects

The anaerobic energy system comprises alactic and lactacid pathways, which produce energy rapidly and therefore provide the majority of energy in sports requiring high intensity or supra-maximal exercise of a limited duration. According to the classification

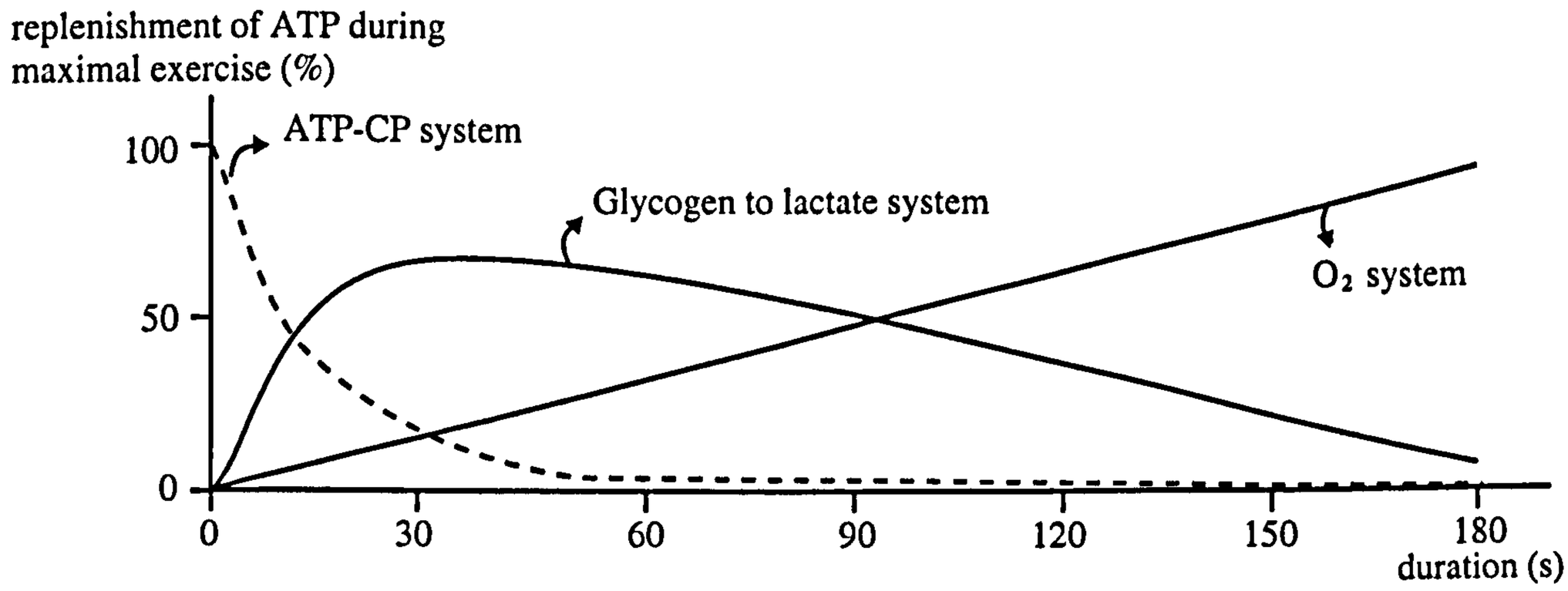



Figure 5.5 Contribution of each metabolic pathway during the first 180s of maximal exercise in adult subjects (adapted from Bouchard et al., 1990 op cit. McDougall, Wenger & Green, 1991).

proposed by Malina & Bouchard (1991), short-term anaerobic performance refers to maximal effort lasting ≤ 10 s. Approximately 90% of ATP produced during this time is derived via anaerobic pathways using a combination of ATP immediately available within the muscle, the degradation of creatine phosphate and anaerobic glycolysis (Malina & Bouchard, 1991). Intermediate-term anaerobic performances are defined as high intensity activities lasting 20-50 s (Malina & Bouchard, 1991).

The major source of energy for these activities is the anaerobic energy system, with approximately 80% of the energy requirements during the first 30 s of exercise being provided by alactic and lactacid pathways (Spriet, 1995). Finally, long-term anaerobic performance refers to high intensity exercise lasting 60-90 s (Malina & Bouchard, 1991). The aerobic energy system provides the majority of energy in these activities, anaerobic pathways have been estimated to provide only 45-50% of the energy requirements (Malina & Bouchard, 1991). Boulay, Lortie, Simoneau, Hamel, Lebland & Bouchard (1985) investigated the interrelationships between short, intermediate and long-term tests of anaerobic performances. Correlation coefficients between tests of 0.96 (10 and 30 s), 0.90 (30 and 90 s) and 0.77 (10 and 90 s) indicated that each test provides some unique information about the delivery of anaerobic energy (Malina & Bouchard, 1991). Therefore, in sports such as gymnastics, which rely heavily upon the anaerobic energy system, multiple assessments encompassing short, intermediate and long term anaerobic performance may be required in batteries designed to identify sporting talent.

Gymnastic routines have been described as intermittently maximal performances with bursts of high intensity activity interspersed with periods of relative rest (Montpetit, 1987). In addition, several of the apparatus within artistic gymnastics have specific requirements for the temporal duration of routines which favour the supply of energy via anaerobic pathways. Research previously conducted at Loughborough University reported the mean duration of routines performed by female gymnasts in the 1993 World Championships to be 0.03±0.15, 0.34 ±0.15, 1.26±0.07 and 1.24±0.05 mins for vault (excluding run-up), bars, beam and floor respectively. Therefore, it may be concluded that given the nature and timing of routines the majority of energy required in artistic gymnastics is derived from anaerobic sources (Beaudin, 1978; Montpetit, 1976). Support for this statement can be derived from Montpetit (1976) op cit. Montpetit (1987) who estimated that the contributions of anaerobic and aerobic sources of energy in the four pieces of apparatus unique to men's artistic gymnastics (pommel horse, rings, parallel bars and high bar) were approximately 80% and 20% respectively. Although there have been no direct estimates of the relative contributions of aerobic and anaerobic energy sources in Women's Artistic Gymnastics, it may be hypothesised that both anaerobic power and local muscular endurance are important characteristics in the elite female gymnast which may have potential utility in the prediction of future gymnastic performance.

A variety of testing protocols have been devised to measure anaerobic performance which differ according to the mode, duration and muscle group tested (Cahill et al., 1997). Anaerobic performance is assumed to be a local characteristic since the training adaptations which take place occur in the absence of significant systemic adaptation (Bar-Or, 1987; Cahill et al., 1997). Therefore a number of gymnastic specific assessments have been devised to evaluate short, intermediate and long-term anaerobic performances which are all potentially important indicators of gymnastic performance. Tests employed to assess short term anaerobic performance most frequently include power tests such as standing broad and vertical jump which have been discussed previously and tests of 'speed-strength' which require gymnasts to perform the maximum number of conditioning elements in a short period of time (for example, the number of leg lifts in 10 s). Intermediate and long-term anaerobic performances are commonly assessed in terms of local muscular endurance which is defined as the ability of an individual to sustain a high level of mechanical power output over a given period of time (Blimkie &

Bar-Or, 1996). In contemporary Women's Artistic Gymnastics, sports specific muscular contractions which depend upon anaerobic pathways are defined and the ability of gymnasts to consistently reproduce these contractions over 30 and/or 60 s have been assessed (Montpetit, 1987).

A number of studies have confirmed the importance of anaerobic power and local muscular endurance in the elite female gymnast. The majority of these studies have employed functional assessments of local muscular endurance which are assumed to reflect anaerobic fitness. For example, in a cross-sectional study of national level gymnasts in Belgium, Beunen et al. (1981) reported that 22 out of 23 (96%) national level gymnasts scored in excess of 1 standard deviation above a reference population of school children in terms of the number of leg lifts completed. In contrast, the performances of only 13 out of 23 (57%) national gymnasts were superior to reference controls in the bent arm hang. The relatively superior performance of the gymnastic group in leg lifts compared to the flexed arm hang indicates that elite female gymnasts have superior muscular endurance but highlights the locality of the training effect. Lindner & Caine (1992) recorded the number of leg lefts completed by young female gymnasts classified as high or low competitive level across three age groups (9, 11 and 13 year olds respectively). Although the study was limited by the use of multiple t-tests, results revealed differences in muscular endurance between high and low level competitive gymnasts in each age group which were significant at the 1% level ($P<0.01$). Finally, Moffatt et al. (1984) compared the anaerobic power and capacity between adolescent gymnasts and controls using a mechanically braked cycle ergometer. Both groups performed maximal effort cycling for 40 s against a constant resistance. Both the anaerobic power reported over a 4 s interval and the anaerobic capacity of gymnasts was significantly greater than control subjects.

*Development of anaerobic performance within the growing child*

Research has consistently demonstrated that indices of anaerobic performance including absolute and relative anaerobic power output are lower in children than adults (Di Prampero & Ceretelli, 1969; Bar-Or, 1983; Borms, 1986; Inbar & Bar-Or, 1986; Blimkie, Roache, Hay & Bar-Or, 1988; Sargeant, 1989; Malina & Bouchard, 1991; Saavedra, Lagassé, Bouchard & Simoneau, 1991; Bar-Or, 1983 op cit. Rowland, 1996;

Roemmich & Rogol, 1995; Inbar, 1996). However, the majority of studies which have investigated the development of anaerobic power within the growing child have been cross-sectional in nature and can therefore at best indicate probable developmental trends.

Most investigations have focused upon the development of indices of anaerobic performance in male subjects. In boys, anaerobic power and local muscular endurance have been reported to increase throughout the entire period of growth and development until 18 years of age (Inbar, 1996). Only a limited number of studies have investigated the development of anaerobic performance in females. In a widely cited cross-sectional study, Saavedra et al. (1991) recorded anaerobic power and local muscular endurance in a sample of 84 girls aged 9-19 years using a repetitive unilateral knee flexion and extension protocol. The results of this study, shown in Figure 5.6, indicated that both absolute and relative anaerobic power output (10 s) and local muscular endurance (30 s and 90 s) increased from 9-15 years of age with no further increases. The '*plateauing*' of indices of anaerobic performance in late female adolescence has been confirmed in a number of investigations. For example, an unpublished cross-sectional study of 220 girls confirmed that short-term anaerobic performance, assessed using maximal effort cycle ergometry, increased only until puberty (Bouchard & Simoneau, unpublished op cit. Malina & Bouchard, 1991).

A similar pattern of development has been observed for upper extremity anaerobic performance in female subjects (Inbar, 1985; Blimkie et al., 1988). Using the arm cranking protocol of the WAnT, Inbar (1985) observed that mean and peak anaerobic power, whether expressed in absolute or relative terms, increased in girls from 9-13 years of age. Using a similar protocol, Blimikie et al. (1988) demonstrated that mean and peak anaerobic power did not increase significantly in adolescent females aged 14-19 years. Moreover, no significant increases were observed even after corrections were made for lean body mass in the upper arm. The pattern of development of anaerobic power and local muscular endurance appears to be similar in the arms and legs which suggests that although anaerobic performance is a local characteristic it develops across various muscle groups in a parallel fashion (Inbar, 1996).

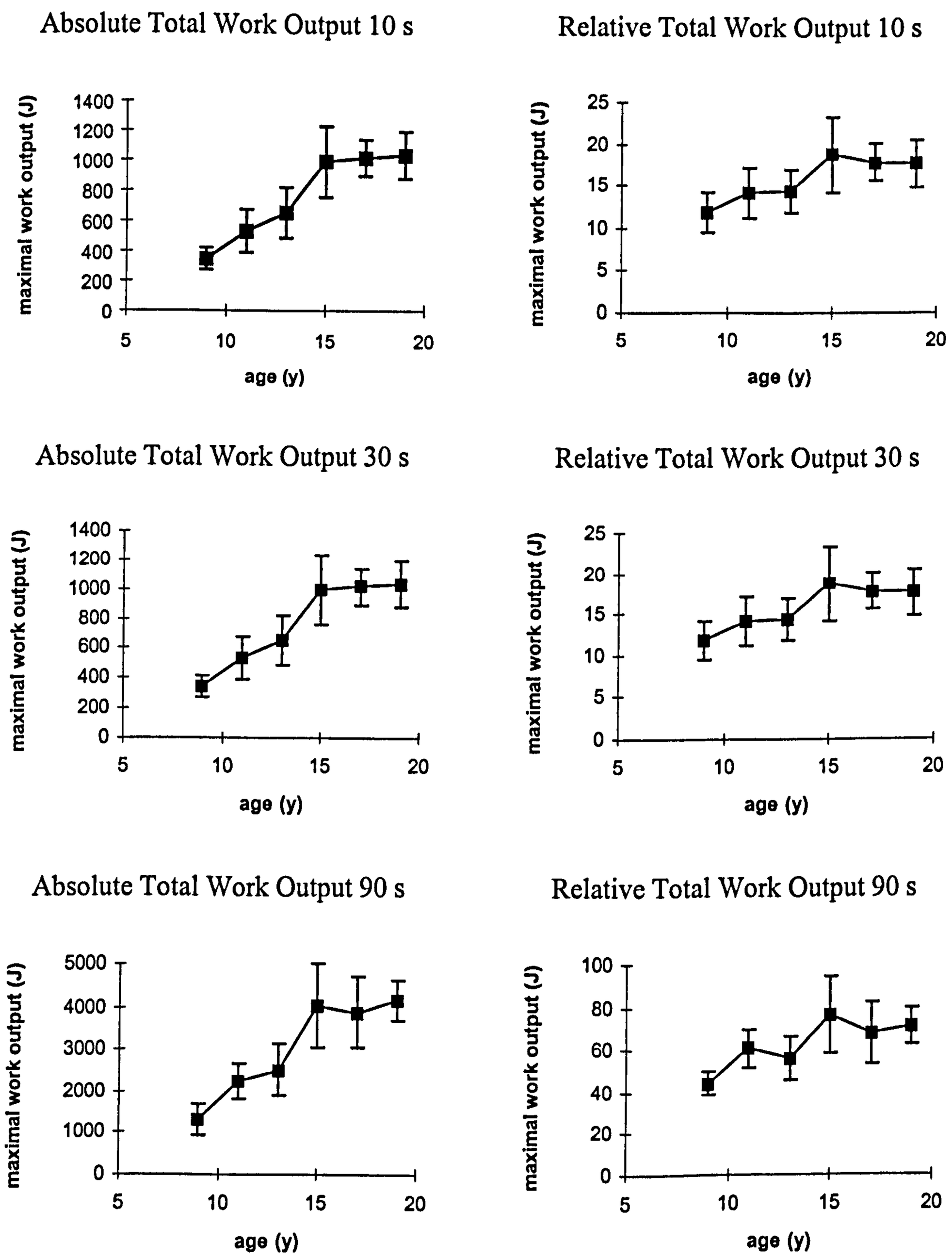



Figure 5.6. The development of absolute and relative anaerobic performance in female subjects (graphs drawn from data presented by Saavedra et al., 1991).

In summary, studies have consistently reported that in female subjects anaerobic power increases in a non-linear fashion throughout childhood and adolescence before reaching a plateau at approximately 15 years of age (Inbar, 1985; Blimkie et al., 1988; Saavedra et

al., 1991; Roemmich & Rogol, 1995; Cahill et al., 1997). The reasons for this plateauing effect have not been conclusively determined. However, it may be hypothesised that the increased adiposity associated with female adolescence and/or changes which occur in the lifestyle and in particular the physical activity habits of adolescent females may contribute to this developmental trend.

In the Leuven Study of growth and fitness in Flemish girls, muscular endurance in the trunk and upper body was assessed in a cross-sectional sample of 9,698 girls aged 6-19 years (Simons et al., 1990). Two different tests were used to assess muscular endurance in the trunk depending upon the age of the children. In girls aged 6-9 years, muscular endurance was assessed according to the maximum number of situps completed in 30 s, whereas in 9-18 year olds, the assessment consisted of the number of supine leg lifts completed in 20 s. Muscular endurance in the upper body was defined as the length of time a bent arm hang could be maintained with the chin over the bar. In contrast to the majority of previous research, both measures of muscular endurance continued to show significant increases in performance throughout late adolescence with improvements recorded until 17 years of age for leg lifts and 18 years of age in the bent arm hang. The authors suggested that these results and in particular the evidence of a delayed plateauing of local muscular endurance were indicative of changes in the lifestyle of adolescent females. Only a limited number of investigations have included indices of biological maturity status and therefore the extent to which the development of anaerobic performance is influenced by biological maturation has not been conclusively determined. It is therefore unclear whether the plateauing of anaerobic performance indicators which occurs at approximately 15 years of age in most samples of females would occur significantly later in elite gymnasts whose frequently experience delayed biological maturity.

*Development and trainability of anaerobic performance*

It is clear from cross-sectional studies that there is a consistent pattern of improvement in short, medium and long-term anaerobic performance with age, whether these indices are expressed in absolute or relative terms (Rowland, 1996). However, the difference between adults and children is most striking for indices of absolute anaerobic performance (Bar-Or, 1985; Blimkie et al., 1988; Saavedra et al., 1991). In comparison to absolute

indices relative anaerobic power and endurance are closer to adult values throughout growth and maturation (Inbar, 1996; Saavedra et al., 1991). Therefore, the development of muscle mass is clearly an important factor contributing to the increases in absolute anaerobic power and local muscular endurance that occur with age (Malina & Bouchard, 1991). However, since relative anaerobic power also increases with age, the increase in muscle mass cannot fully explain the development of anaerobic performance (Saavedra et al., 1991; Roemmich & Rogol, 1995).

Several hypotheses have been proposed to explain the differences in anaerobic performances between children and adults. However, the extent to which each factor contributes to the observed differences has not been conclusively determined. Morphological factors may be in part responsible for increases in anaerobic performance observed during childhood and adolescence. The development of anaerobic power has been linked to changes in the architecture of skeletal muscle which include an increased myofibrillar density and a more favourable angle of pennation (Sargeant & Dolan, 1986; Sale, 1989; Sargeant, 1989; Malina & Bouchard, 1991; Saavedra et al., 1991; Roemmich & Rogol, 1995; Rowland, 1996). In addition, changes in the activation and recruitment of muscle fibres and the transmission of muscular forces have also been postulated as contributory factors (Sargeant, 1989; Saavdera et al., 1991; Roemmich & Rogol, 1995; Rowland, 1996).

A considerable amount of research has suggested that the anaerobic energy system is not fully mature in young children (Cahill et al., 1997). It is generally accepted that the anaerobic energy system and in particular the glycolytic pathway continues to develop throughout growth and does not reach maturity until after the adolescent growth spurt (Malina & Bouchard, 1991; Saavedra et al., 1991; Inbar, 1996; Rowland, 1996; Cahill et al., 1997). These suggestions were primarily based upon age related changes in post exercise concentrations of muscle and blood lactate and the concentration and activity of rate limiting glycolytic enzymes (Sargeant, 1989).

Post exercise blood and muscle lactate concentrations are indicative of the capability of the glycolytic pathway to produce ATP (Rowland, 1996). A number of studies have reported that blood lactate concentrations in response to both maximal and submaximal exercise intensities were lower in children and adolescents compared to adults (Åstrand,

1952; Eriksson, 1972 op cit. Sargeant, 1989; Bar-Or, 1983; Sargeant, 1989; Malina & Bouchard, 1991; Rowland, 1996). This is consistent with the observation that children do not generate or sustain the levels of acidosis which have been reported in adults (Matejkova, Koprivova & Placheta, 1980; Bar-Or, 1985; Malina & Bouchard, 1991; Rowland, 1996). Moreover, in comparison with adults the concentration and activity of the rate limiting glycolytic enzyme phosphofructokinase (PFK) have been reported to be significantly lower in children and adolescents (Eriksson, 1972 op cit. Sargeant, 1989; Malina & Bouchard, 1991; Eriksson, Gollnick & Saltin, 1973; Eriksson, 1980 op cit. Inbar, 1996; Rowland, 1996). Support for developmental trends in the markers of anaerobic glycolysis has not been unequivocal. Of particular significance is the study by Cumming, Hastman, McCort & McCullough (1980) which reported that lactate concentrations were identical in young girls and adult females aged 4-5 and 16-20 years respectively (Cumming et al., 1980). However, the majority of research suggests a consistent pattern of development in the responses of glycolytic markers indicating that children are less dependent upon anaerobic glycolysis for the production of energy during submaximal and maximal exercise (Malina & Bouchard, 1991; Inbar, 1996; Cahill et al., 1997).

As a result of the immaturity of the anaerobic energy system the relative contribution of aerobic and anaerobic energy systems differs between children and adults (Vrijens, 1982 op cit. Borms, 1986; Bale, 1992). Specifically, in exercise of limited duration, children derive a greater percentage of their energy requirements from aerobic sources in comparison to adults (Macek & Vara, 1977 op cit. Bale, 1992). It was previously estimated that in adult subjects the ratio of energy derived from anaerobic to aerobic energy systems during the first 30 s of maximal exercise is approximately 80:20 in comparison with a ratio of 60:40 reported in children (Borms, 1986). The ratio of anaerobic to aerobic power production has been reported to increase progressively throughout childhood before plateauing in adolescence (Rowland, 1996). This is considered to reflect the both the increased capability of the anaerobic energy system and the maintenance/decrease in maximal aerobic power which occurs with growth in male and female children respectively.

A limited number of studies have reported that the anaerobic performance of children may be improved as a result of training (Cahill et al., 1997). Anecdotal evidence of a training

effect has been derived from studies comparing the anaerobic performances of athletes and untrained controls. For example, the peak and mean power outputs of adolescent female track and field athletes were 21% and 28% greater than a group of untrained controls (Weijang & Juxiang, 1988 op cit. Blimkie & Bar-Or, 1996). However, since athletes are frequently selected to participate in sport, through natural or systematic means, the influence of training cannot be distinguished from the effects of biological inheritance. Several investigations which have employed an intervention protocol have confirmed that anaerobic performances can be improved with training in children and adolescents. Clarke & Vaccaro (1979) reported that in response to a 7 month intensive swimming programme local muscular endurance in the arm and shoulder musculature improved by over 100% in 9-11 year old swimmers, but not in control subjects. Grodjinovsky, Inbar, Dotan & Bar-Or (1980) op cit. Rowland (1996) reported the influence of 6 weeks of cycling/sprint training in 11-13 year old boys. Mean power output assessed using the WAnT increased by a small but significant amount in the trained groups (approximately 3.5%) but not in control subjects. The improvement in peak power appeared to be mode specific with training improvements recorded in the cycling but not the sprint trained group.

The nature of the response to anaerobic training in children and adolescents has not been conclusively determined. Studies have consistently reported significant increases in the activity of glycolytic enzymes in response to high intensity anaerobic training (Eriksson, Gollnick & Saltin, 1973; Rowland, 1996). The extent to which lactate concentrations are modified as a result of training is less clear. However, in a recent review of research, Rowland (1996) highlighted that peak lactate responses have consistently been reported to be insensitive to training stimuli. This conclusion was in contrast to the results of an early investigation by Eriksson & Saltin (1973) who reported an increase in the concentration of muscle lactate following a four month training programme. However, the validity of this observation must be questioned in the light of the decrease noted in blood lactate and the poor relationship observed between muscle lactate and the rate of glycogen depletion. In addition, as a result of the absence of control subjects, it is not possible to separate the effects of training from the influence of growth and maturation.

*Stability of anaerobic performance*

The majority of studies which have investigated the stability of anaerobic performances have focused upon field tests of local muscular endurance. Using a traditional twin design, Kovar (1974) estimated the heritability of two field measures of dynamic muscular endurance in a sample of 30 Czechoslovakian twin pairs aged 11-25 years (Kovar, 1974 op cit. Malina, 1986b). The genetic contribution to the phenotypic variance was low to moderate with heritability estimates of 0.22 and 0.45 recorded for push-ups and sit-ups respectively. The limited influence of genetic factors upon performance in field tests of muscular endurance was confirmed in a large scale study of 375 French-Canadian families (Pérusse et al., 1987). The pattern of inter-class correlations between pairs of relatives by descent and adoption highlighted the important contribution of environmental factors to the phenotypic expression of abdominal muscular endurance. Specifically, the correlations between spouses (0.30) and between foster-parents and their adopted children (0.15) were both significant at the 1% level which provided support for the important role of lifestyle in determining muscular endurance. In the same study, Pérusse et al. (1987) applied the BETA path model and reported a total transmissibility of 0.55 for abdominal muscular endurance. However, genetic factors were only responsible for 0.21 of the phenotypic variance. In a subsequent investigation based upon the Canada Fitness Survey, the TAU model of path analysis was applied to determine the transmissibility of two measures of muscular endurance (Pérusse et al., 1988). The transmissibility estimates for the maximum number of sit-ups in 60 s and push-ups without a time restriction were 0.37 and 0.44 respectively. However, the transmissibility estimate reported for the push-up data must be viewed with caution as a result the poor model fit.

Several studies have investigated the stability of parameters of muscular endurance over time. Marshall et al. (1998) used quarterly measurements to track the development of local muscular endurance in 9 year old children over a three year period. Local muscular endurance in the upper extremity was assessed in terms of the number of pull-ups to exhaustion and in the abdominal muscle group, according to the number of sit-ups completed in 60 s. Stability was estimated using rank order autocorrelations and found to be moderate-high. As expected, the strength of the correlations decreased as the time interval between the measurements increased. The autocorrelations for sit-ups ranged

from 0.58 for a measurement interval of 8 months to 0.47 for an interval of 32 months. The tracking of the pull-ups was slightly higher with all rank order correlations in the range 0.58-0.67. However, the validity of the stability estimates reported for the pull-up test was questioned given the observation that a large percentage of female children were unable to complete a single repetition at the initial assessment and in any subsequent measurement session. Given the poor performance of many girls, a less strenous measure of upper extremity muscular endurance may have been more appropriate to ensure a positive score at the commencement of the study and hence increase the validity of tracking estimates.

Only a limited number of studies have investigated the contribution of the genotype to the phenotypic variance in laboratory based measures of anaerobic performance. The pattern of correlation observed between different types of relatives by descent has indicated significant familial resemblance in laboratory measures of short-term anaerobic performance (Simoneau, Lorti, Leblanc & Bouchard., 1986). Simoneau et al. (1986a) reported the inter-class correlations between various pairs of relatives for normalised total work output during 10 s maximal cycling. The coefficients were greatest in MZ twins (0.80) and lowest in adopted siblings (-0.01) with similar coefficients reported for DZ twins (0.58) and biological siblings (0.46). In addition, Simoneau et al. (1986a) reported heritability estimates for total work output of between 0.44-0.92 using a variety of methods. In a mixed longitudinal study, Falk & Bar-Or (1993) op cit Rowland (1996) tracked the development of peak and mean anaerobic power in 10-14 year old boys over an 18 month period. Rank order correlations indicated a high level of stability for absolute peak (0.92) and mean (0.97) power output. However, when normalised for body mass the stability of these indices declined considerably with autocorrelations for relative peak power and relative mean power of 0.56 and 0.85 respectively. As far as can be ascertained, the study by Falk & Bar-Or (1993) is the only investigation of the longitudinal stability of laboratory based measures of local muscular endurance. Therefore, at present it is not possible to conclusively determine the relative stability of laboratory and field based assessments of intermediate and long-term anaerobic performances.

Simoneau, Lortie, Boulay, Marcotte, Thibault & Bouchard (1986) investigated the role of the genotype in determining the response to high intensity anaerobic training. After

establishing considerable heterogeneity in the responses of sedentary subjects Simoneau et al (1986b) subjected 14 pairs of MZ twins to a 15 week training programme of high intensity intermittent exercise. The response of long term anaerobic performance (power output in 90 seconds) was found to be largely genetically determined, with approximately 70% of the variability in the training effect attributed to genetic factors (Simoneau et al., 1986b op cit. Bouchard, 1992). In contrast, the responsiveness of short term anaerobic performance (power output in 10 seconds) appeared to be only minimally affected by genotype.

### 5.2.7 FLEXIBILITY

Derived from the Latin flectere or flexibilis 'to bend', flexibility has been defined as the range of motion at a single joint or at a series of joints (Hubley-Kozey, 1991). As a result of the unique structural features of each articulation, range of motion is specific to each joint and each particular joint action (Corbin & Noble, 1980; Alter, 1996; Bouchard et al., 1997). Flexibility comprises static and dynamic sub-components where static flexibility represents range of motion with no emphasis upon speed of movement. In contrast, dynamic flexibility is the ability to perform a movement at normal or rapid speed (Corbin & Noble, 1980), which may be of greatest value in the assessment of sporting talent. Other authors have distinguished between active and passive ranges of movement (Greene & Heckman, AAOS, 1994; Hamil & Knutzen, 1995; Borms & Van Roy, 1996). In the assessment of active range of movement, the limb is moved without the assistance of an external force inferring strength in the agonist muscle. By contrast, passive flexibility involves no active muscular contraction, with the range of motion being determined by other factors including the extensibility of the antagonist muscle. Large differences have been reported in the active and passive range of motion at a joint (Bird & Barton, 1993). and whilst passive flexibility may be easier to measure in a controlled setting, active flexibility has been shown to be more closely correlated to sporting achievement (Iashvili, 1982).

*Relationship to performance*

The requirements for joint range of motion are specific to both the sport (Corbin & Noble, 1980; Maffulli et al., 1994) and the particular event or discipline in which an athlete

participates (Iashvili, 1982; Gleim & McHugh, 1997). In the TOYA study, flexibility was assessed linearly in three sites in 453 young athletes competing at the elite level in gymnastics, swimming, tennis and football. With respect to the glenohumeral joint, the older female gymnasts were less flexible than both swimmers and tennis players. In contrast, gymnasts were more flexible than athletes from other sports in terms of flexibility in both the hamstrings/lumbar spine and the hip adductor muscle group. Considering age related changes, the range of motion in the glenohumeral joint of female gymnasts increased from 8-14 years of age before decreasing significantly. In contrast, both trunk and hip flexibility increased with age from 8-18 years of age. It is apparent that within this particular sample of elite female gymnasts, the combined influence of growth and gymnastic training varied between joints which may reflect the sport's demands for both range of motion and articular stability. A positive relationship has been proposed between sporting proficiency and flexibility (Alter, 1996). A previous study of male athletes competing in four different sports revealed that proficient athletes demonstrate greater active and passive flexibility than less skilled competitors (Iashvili, 1982). Moreover, the correlation between athletic proficiency and mobility was greater for active (0.81) than passive (0.69) flexibility. Nelson et al. (1983) reported a significantly greater degree of hip flexion for competitive gymnasts in comparison with recreational gymnasts and physical education students.

In comparison to control subjects, competitive female gymnasts aged 5-17 years demonstrated significantly greater flexibility in the following regions: shoulder flexion (by 11.9°), lumbar flexion (by 4.7%), shoulder horizontal abduction (by 4.4°), hip extension (by 4.3°) and toe touching abilities (by 20.8 cm) (Kirby, Simms, Symington & Garner, 1981). A good range of motion is necessary to enable gymnasts to achieve the body configurations required to perform complex elements and to enhance the aesthetic appeal of gymnastic performances (Corbin, 1984). Specific deductions are outlined in the F.I.G. Code of Points for lack of flexibility, for example, up to 0.15 may be deducted for insufficient hip joint range in split movements.

Elite female gymnasts require an extensive range of motion in the hip and shoulder joints (Kirby et al., 1981; Nelson et al., 1983; Régnier & Salmela, 1987; Sol, 1987). However, interestingly lumbar flexibility was not considered to be important providing that gymnasts possessed adequate flexibility in the hip and shoulder regions (Sol, 1987).

The latter observation was supported by Kirby et al. (1981). It has also been observed that gymnasts demonstrate reduced flexibility in the wrists which are regularly used to support the body weight (Corbin & Noble, 1980). Haywood (1980) observed a decrease in the extent of ankle joint flexibility in both pre and post menarcheal girls over a period of one year. While the reduction in ankle joint range of motion was interpreted to be the negative consequence of a deficient training programme, the reasons behind the limited flexibility observed in the weight bearing joints has not been conclusively determined.

While flexibility is an important attribute of many elite athletes, the importance of flexibility as a prognostic indicator of talent in the young athlete remains unclear. It has traditionally been assumed that flexibility assessment may be of particular importance in the early stages of talent identification and development, with a reduction in their prognostic value once high levels of flexibility have been attained (Corbin, 1984). However, results of the mixed longitudinal investigation conducted by Blanksby et al. (1994) reported that flexibility failed to discriminate between high level swimmers and non-competitors in adolescence. This is particularly interesting since there were considerable differences observed in these characteristics between post adolescent female swimmers competing at a high level and control subjects. The authors concluded that since measures of joint mobility failed to differentiate between competitors and controls until pubescent stage five (Tanner, 1962) such assessments did not merit inclusion in swimming talent identification programmes. However, it is possible that the absence of a relationship between swimming performance and flexibility may be the result of the compensation phenomenon and that the true prognostic value of flexibility parameters may only be determined by considering the ability of such parameters to predict future, rather than current, competitive performances. In a prospective study which investigated the relationship between initial talent characteristics and 'future' gymnastic performance, Sol (1987) determined the flexibility of the hips, as shown by right splits, was a good predictor of subsequent competitive performance (6 months later) and was one of two factors responsible for explaining 57% of the variance in competitive results. The importance of hip flexibility in explaining competitive performance was confirmed by Régnier & Salmela (1987) for male gymnasts. Regression analyses revealed that hip flexibility was one of only three variables which were among the best five predictor variables of gymnastics performance in 50% of the age groups studied.

In addition to investigating the existence of a potentially positive relationship between range of motion and athletic performance it is also pertinent to consider whether a relationship exists between flexibility and the predisposition to sustain musculoskeletal problems. Recent investigations have failed to provide conclusive support for the relationship between a lack of flexibility and the prevalence of musculoskeletal injuries (Maffulli et al., 1994; Gleim & McHugh, 1997). However, lack of flexibility in certain muscle groups has been associated with specific musculoskeletal symptoms. For example tightness in the hamstrings has been associated with both low back pain (Blanke, 1994) and patellofemoral pain in adolescents (Smith, Stroud & McQueen, 1991). Regarding the aetiology of injuries it is proposed that individuals with limited flexibility have a higher susceptibility to muscle strains than joint sprains as a result of the support provided by the connective tissue surrounding the joint (Blanke, 1994). There has been more consistent support regarding the relationship between imbalances in flexibility and injuries. Specific athletic pursuits have been associated with particular imbalances, for example, elite classical ballet dancers have consistently been reported to demonstrate greater hip external rotation and reduced hip internal rotation relative to untrained controls (Reid, Burnham, Saboe & Kushner, 1987 op cit. Burton, 1991; Khan, Roberts, Nattrass, Bennell, Mayes, Way, Brown, McMeeken, & Wark, 1997). In addition, the imbalance between musculoskeletal strength and flexibility associated with spurts in growth during childhood and adolescence is considered to be an important factor in the development of overuse injuries in the skeletally immature athlete (Gill & Micheli, 1996). The level of risk may be particularly high in those sports such as gymnastics in which the upper extremity is exposed to repetitive microtrauma.

*Development of flexibility in the growing child*

There is a lack of agreement with regard to age related changes in flexibility, and in particular concerning the nature of the changes which occur during childhood and adolescence (Alter, 1996). With respect to untrained individuals it is generally agreed that small children are quite flexible and that flexibility tends to decrease throughout the school years until puberty (Corbin, 1984). The decrease in flexibility observed during the school years has been interpreted as a consequence of the prepubertal growth spurt (Birrer & Levine, 1987). Flexibility subsequently increases throughout adolescence before plateauing and subsequently decreasing (Alter, 1996). Alter (1996) highlighted the

existence of critical periods in the development of flexibility during which improvements may occur at a greater rate. In an extensive investigation Sermeev (1966) op cit. Alter (1996) confirmed that the development of flexibility in the hip joint did not proceed uniformly with increasing age but rather the greatest improvements occurred between 7-11 years of age, with the maximum range of motion being attained by 15 years of age and declining thereafter. The decrease in flexibility associated with periods of rapid growth has been attributed to increases in muscle length lagging behind bone growth (Smith et al., 1991). This temporal disparity may result in a tightening of the muscle-tendon complex and other soft tissue structures which surround the joint. Flexibility training is recommended during such periods to ensure that the range of motion may be maintained (Leard, 1984 op cit. Alter, 1996; Durandt & Salmela, 1994). Additional factors which may contribute to the age related differences in flexibility include changes in the physical and biochemical nature of collagen (Alter, 1996) and specifically increases in both the diameter of collagen fibres and the crystalline nature of collagen fibrils (Alter, 1996). It has also been reported that the number of cross links or cross bridges may increase as a result of the ageing process which may also contribute to the decrease in the elasticity of adult tissue (Russell, 1987b; Alter, 1996).

*Techniques of investigation*

Flexibility may be estimated using indirect linear or direct angular methods. Traditional studies frequently relied upon indirect techniques which involved the distance between two anthropometric landmarks or between a selected body part and an externally standardised object to be estimated (Rooks & Micheli, 1988). Examples of indirect flexibility assessments include the Apley "scratch" test, an assessment of flexibility in the glenohumeral joint (Rooks & Micheli, 1988; Maffulli et al., 1994) and the popular sit and reach test which determines flexibility in the hips and hamstrings (Wells & Dillon, 1952; Borms & Van Roy, 1996; Rooks & Micheli, 1988). Such indirect measurements have been criticised for their lack of specificity and the extent to which they are influenced by inter-subject variations in body proportionality (Broer & Galles, 1958 op cit. Gleim & McHugh, 1997). In contrast, proportionality differences have a negligible impact upon flexibility estimates obtained using direct angular techniques (Corbin, 1984; Borms & Van Roy, 1996). The major limitation associated with standard goniometric assessment concerns the difficulty in locating and positioning the fulcrum of the goniometer over the

centre of rotation of the joint. This is particularly difficult to achieve in the hip and shoulder joints as a result of the extensive soft tissue surrounding these articulations (Greene & Heckman, AAOS, 1994). Difficulties may also be experienced in aligning the arms of the goniometer along the bony axes of the distal and proximal limbs simultaneously. The VUB-goniometer (Vrije Universiteit Brussel) (Van Roy et al., 1985 op cit. Borms & Van Roy, 1996) was designed to permit the scale, the fulcrum and the moving arm to slide along the stationary arm of the goniometer. This allows the arms to be aligned with the long axes of the segments, thus eliminating the need to align the goniometer with the centre of rotation of the joint. Pendulum goniometers also do not require axis alignment and include the commonly used Leighton flexometer (Leighton, 1966). Fluid-filled goniometers, alternatively referred to as hydrometers or inclinometers are also popular instruments in the measurement of flexibility (Borms & Van Roy, 1996). One of the main advantages of inclimoneters is that they are not subject to errors in estimating the location of joint centres or anatomical landmarks. They are relatively inexpensive and are quick and easy to apply, hence they are well suited to large scale clinical investigations. However, the placement of inclinometers may be influenced by variations in the soft tissue surrounding the segment. In addition, difficulties have been associated with the precise determination of the fluid level in the MIE inclinometer and in taking the measurement given the proximity of the scale graduations (Mellin, Olenius & Setälä, 1994). Finally, electrical goniometers which incorporate flexible strain gauges may be attached across a particular joint or body segment avoiding joint centre alignment problems (Burton, 1991). While the sophistication and accuracy of these instruments is acknowledged they are of limited use in large scale clinical investigations.

Temperature is an important factor which influences the extent to which a tissue may be stretched (Sapega, Quedenfeld, Moyer & Butler, 1981; Rooks & Micheli, 1988; Alter, 1996). Temperature influences the mechanical behaviour of connective tissue which becomes more extensible as temperature increases (Sapega et al., 1981). Specifically, a thermal transition takes place which causes the collagen fibres to relax (Sapega et al., 1981 op cit. Alter, 1996) which results in a reduction in the force required to produce a given deformation (Lehmann, Masock, Warren & Hoblanski, 1970 op cit. Stanish & McVicar, 1993). An increase in temperature may also increase the sensitivity of the GTO which contributes to muscular relaxation (Stanish & McVicar, 1993). While the use of a standardised warm-up is frequently adopted to increase the validity of flexibility

assessments certain authors have opted to assess flexibility from a cold start (Kirby et al., 1981). However, the validity of such studies must be questioned given the weight of evidence indicating that repeated testing is associated with an increased range of motion (Atha & Wheatley, 1976; Dijsktra, Bont & Weele, 1994). For example, it was demonstrated that sit and reach performance was on average 4.5 cm greater on the tenth trial compared with the first trial, with the largest increases in performance being recorded for the early trials (Atha & Wheatley,1976). In addition to the enhancement of test validity and reliability, warm up is also reported to reduce the risk of injuries such as muscular sprains (Sapega et al., 1981; Smith, 1994; (Garrett, 1990 & Stanish & Hubley-Kozey, 1984 op cit. Enoka, 1994)).

*Stability of flexibility parameters*

Three main factors limit range of motion; the shape of the bony articulating surfaces, the connective tissues structures present in the joint capsule and ligaments, both of which are largely genetically determined, and the neuromuscular tone which is sensitive to the training stimulus (Bird & Barton, 1993). Only a limited number of studies have attempted to quantify the contribution of genetic factors to determining range of motion at a particular joint (Maes et al., 1996). The majority of studies have focused upon the estimation of trunk flexibility in male subjects through the application of the popular sit and reach test (Marshall et al., 1998). However, since the stability of flexibility measures is reported to be gender specific, the potential contribution of previous research to the estimation of the stability of flexibility measurements in a sample of young female gymnasts must be viewed with caution. The majority of twin studies have reported the heritability of flexibility parameters to be high (Kovar, 1974, 1981 op cit. Bouchard et al., 1997). Using traditional analytical methods, the heritability of lower back flexibility was estimated to be 0.69 in male twins aged 11-15 years (Kovar, 1974 op cit. Bouchard et al., 1997). In a mixed gender sample aged 12-17 years of age, the heritability of trunk, hip and shoulder flexibility were reported to be 0.84, 0.70 and 0.91 respectively (Kovar, 1981 op cit. Bouchard et al., 1997).

Support for a high degree of genetic control was also derived from the study of Maes et al. (1993) which used structural equation modelling to analyse the data from 91 twins measured at 10 years of age. In a simple genotype-environment model (HE) 81.8%

variance in sit and reach performance was explained by genetic factors compared with 56.6% in a second more complex (HCE) model in which the environmental variability was partitioned into common and specific components. In a subsequent study, Maes et al. (1996) extended the investigation to include 105 twin pairs and their parents. The most parsimonious model for flexibility in female twins included a common environmental factor. In this model, genetic factors accounted for 50%, shared environmental factors accounted for 38% and specific environmental factors accounted for 8% of the phenotypic variance respectively. It is of interest that in this investigation, flexibility in female subjects was one of the few fitness parameters in which the common environment was significant.

In general, studies of family members have reported more conservative estimates for genetic contributions to flexibility. Studies which have adopted the TAU model of phenotypic variance (in which genetic and cultural factors are combined into a single transmissibility component) revealed that the transmissibility of trunk flexibility was high with respect to other physical fitness components, 0.66 (Devor & Crawford, 1984 op cit. Bouchard et al., 1997) and 0.48 (Pérusse et al., 1988) respectively. Tracking studies have confirmed the stability of sit and reach flexibility. In girls, the inter-age correlation for the sit and reach test was reported to be 0.26 between the ages of 5-10 years and 0.52 between the ages of 8-14 years (Branta et al., 1984). In a mixed gender study which included 201 girls (9.48 ± 0.41) tracking coefficients were calculated biannually for three years. Coefficients for the sit and reach assessment were high, remaining around 0.70 at all points in time indicating that flexibility levels were likely to be maintained into adolescence (Marshall et al., 1988).

*Joint laxity*

Various terms have been applied to define extensive joint mobility, which include hypermobility and hyperlaxity. However, the term joint laxity as advocated by Dubs & Gschwend (1988) is preferred which does not infer a distinction between the normal and pathological range of motion at a joint. Joint laxity is most frequently measured using the clinical assessment of five joint movements as outlined by Carter & Wilkinson (1964) and subsequently modified by Beighton, Solomon & Soskolne (1973) to produce a nine point scale/index to define hypermobility, where hypermobility at the elbow and knee joints

was defined according to a minimum of 10° hyperextension at the joint. In the general population, the prevalence of joint laxity is estimated to be between 4-7% (Sutro, 1947; Carter & Wilkinson, 1964; Alter, 1996). The majority of studies have confirmed that joint laxity is most prevalent in young children (Wynne-Davis, 1970; Gedalia, Person, Brewer & Giannini, 1985; Cheng, Chan & Hui, 1991) and decreases during childhood. With respect to total joint laxity, approximately 50% of Edinburgh children were classified as lax at 3 years of age compared to 5% at 6 years and less than 1% at 12 years of age (Wynne-Davis, 1970).

There appears to be a lack of agreement in the literature regarding the prevalence of joint laxity among athletes (Klemp et al., 1985; Decoster, Vailas, Lindsay & Williams, 1997). However, those gymnasts in the British National Squad did not demonstrate greater joint laxity when measured from a cold start (Bird, Walker & Newton, 1988 op cit. Bird & Barton, 1993). Support for this statement can be derived from the study of Kirby et al. (1981) which found no significant differences between gymnasts and control subjects with respect to both elbow and knee extension (Kirby et al., 1981). In terms of clinical measurement, the evaluation of hyperextension at the knee and elbow joints may be considered most relevant in Women's Artistic Gymnastics. With respect to the consequences of excessive flexibility, joint laxity has been associated with the following chronic conditions; premature degenerative disease (Bird, Tribe & Bacon, 1978; Bird & Barton, 1993), premature osteoarthritis (Beighton, Grahame & Bird, 1989), condromalacia patellae (Alrawi & Nesson, 1997) and juvenile episodic arthritis (Gedalia et al., 1985). The relationship between joint laxity and the frequency of acute injuries remains the subject of debate (Huston & Woitys, 1996). The increased susceptibility of hypermobile individuals to sustain joint sprains is hypothesised to be a consequence of the failure of connective tissue to sustain joint stability (Blanke, 1993; Alter, 1996). However, in a retrospective study Steele & White (1986) found no relationship between extreme flexibility or hypermobility and injury in female gymnasts.

## 5.3 METHODS

### Anthropometry

Anthropometric measurements were collected according to the protocol prescribed by the International Society for the Advancement of Kinanthropometry (ISAK) (op cit. Bloomfield, Ackland & Elliot, 1994b). However, all measurements were taken on the left side of the body with the exception of subject 21 who, in March 1997, had a plaster cast on her left arm. In this isolated case, upper extremity measurements were recorded from the right side of the body. Height data were recorded using a Harpenden portable stadiometer (model 603, Holtain Ltd) and lengths and widths were obtained using a Harpenden anthropometer (model 601, Holtain Ltd). All linear measures being recorded to the nearest 0.001m. Body mass values were recorded to the nearest 0.1 kg using a calibrated digital scale (Seca Alpha 770). Subjects were barefooted and dressed in sleeveless leotards.

Standing height (stature) was recorded with the subject standing erect with heels and buttocks touching the upright section of the portable stadiometer. The subject's head was aligned in the Frankfort plane and the distance between the base of the portable stadiometer and the vertex of the head was recorded. The Frankfort plane is defined by a horizontal line between the inferior margin of the eye socket (orbitale, O) and the notch above the flap of the ear, the upper margin of the zygotic bone (tragion, T) (Figure 5.7).

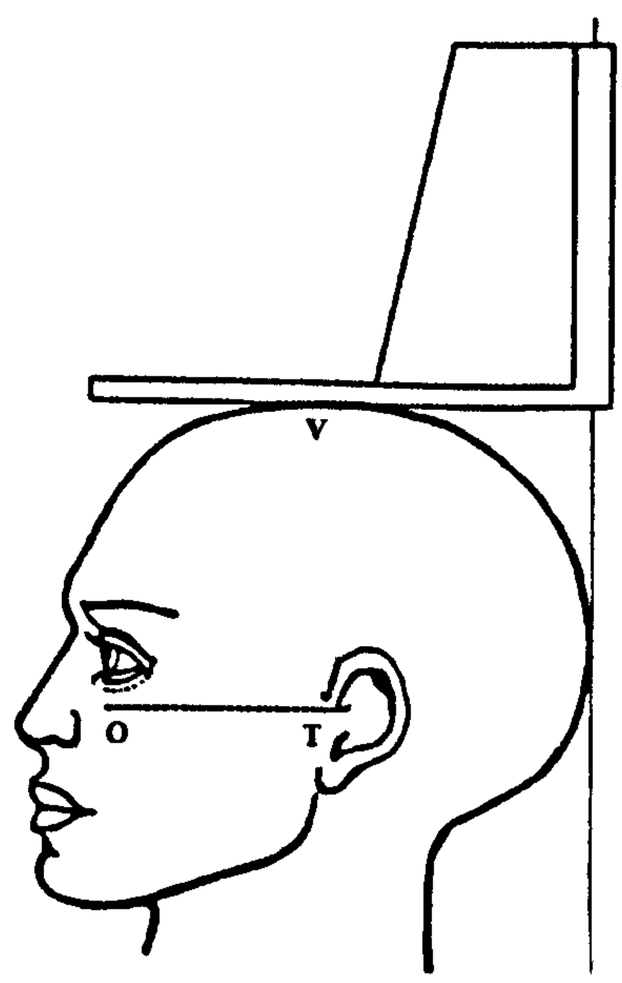



Figure 5.7. The Frankfort Plane (adapted from MacDougall, Wenger & Green, 1991).

Sitting heights were recorded with subjects seated on a horizontal platform placed over the base of the portable stadiometer, with buttocks and shoulders touching the upright section. The subject's head was again aligned in the Frankfort plane (Figure 5.7).

The predicted adult height for each subject was determined according to the non-invasive method proposed by Tanner (1989) where 13 cm represents the average difference in stature between the sexes:

$$\text{Final Height} = \frac{\text{maternal height} + (\text{paternal height} - 13\text{cm})}{2} \quad \text{Rogol (1996)}$$

Armspan was recorded with the subject in a standing position, facing the wall, with the arms extended laterally. The extreme distance between the tips of the two longest fingers (normally the middle fingers or dactylions) was recorded.

The lengths of the upper and lower extremities were measured according to the landmarks and procedures outlined by the International Society for the Advancement of Kinanthropometry (ISAK) (op cit. Bloomfield et al., 1994b). All landmarks were identified by palpation and marked using a fine non-permanent marker. The skin was released and the mark re-checked to avoid measurement error due to the movement of the skin. The following lengths were determined:

| | |
|---|---|
| Upper arm | acromial-radiale length |
| Lower arm: | radiale-styloin length |
| Hand: | midstylon-dactylion length |
| Upper leg: | trochanterion-tibiale lateral length |
| Lower leg: | tibiale mediale-sphyrion length |
| Foot: | acropodian-pternion length |

Biacromial width was measured whilst the subject was erect, with shoulders relaxed and arms by the sides. The most lateral aspects of the acromion processes were located by palpation and the distance between them recorded, from the rear of the subject, with the anthropometer inclined at an angle of 45°. Biiliac width was recorded with the subject in the same posture. The most lateral aspects of the iliocristale were located by palpation.

From the front of the subject, the anthropometer was inclined at 45° and the distance between the most lateral points on the superior border of the iliac crest was recorded.

Epiphyseal widths were measured using a calibrated Bicondylar Vernier (model 604, Holtain Ltd). Firm pressure was applied to compress the soft tissue during the skeletal width measurements.

Biepicondylar humerus width was measured with the subject standing with the left arm raised to the horizontal with the elbow flexed to an angle of 90°. The callipers were inclined at an angle of 45° and the maximum distance between the lateral and medial epicondyles of the humerus was recorded.

Biepicondylar wrist breadth, the distance between the radius and ulna styloid processes, was recorded whilst the subject flexed the left hand to an angle of approximately 90°.

Biepicondylar femur width was recorded with the subject in a seated position with the legs flexed to 90° at the knee. The maximum distance between the lateral and medial epicondyles of the femur was recorded.

Bimalleolar ankle breadth was recorded with the subject standing with feet approximately 6 cm apart. From the rear of the subject, the maximum distance between the medial and lateral malleolus was recorded. Care was taken to ensure that the measurement was taken in the horizontal plane and that the weight of the subject remained evenly distributed.

**Body composition**

Skinfolds were measured using a Harpenden Skinfold Callipers (HSCBI). The callipers were rectangular ended and had been calibrated through the application of known weights, confirming them to be within the required 10% of the manufacturer's specified constant pressure of 9.8 g/mm$^2$.

All skinfolds were measured on the left side of the body according to the procedures outlined by Lohman, Roche & Martorell (1988). Each measurement site was located and

marked. The thumb and index finger of the left hand were placed a distance of 8 cm apart on a line perpendicular to the long axis of the skinfold. The folds were lifted 1 cm proximal to the measurement site to permit a parallel fold. The skinfold was lifted by drawing the fingers together. The reading was collected, to the nearest 0.1 cm, three seconds after the release of the fold. To ease subject anxiety, a calliper measurement was demonstrated on the hand of the gymnast prior to the commencement of the protocol. A description of the location of each measurement site is given below:

Triceps - The arm was flexed to 90° to enable the mid-point between the lateral projection of the acromion and the inferior margin of the olecranon process to be marked. The subject then lowered the arm into a relaxed position at her side with the palm directed anteriorly. From the rear of the subject, a skinfold was raised on the midline of the posterior aspect of the arm, 1 cm above the marked site and a vertical fold recorded at the level of the marked site.

Biceps - The subject faced the measurer in a standing position with the arm relaxed at the side and the hand supinated. A skinfold was raised on the anterior aspect of the arm, 1 cm superior to the site marked for the triceps skinfold. A vertical fold was taken at the level of the marked site over the belly of the biceps muscle.

Subscapular - The subject maintained a relaxed standing position with the arms held loosely by the sides. A skinfold was taken 1cm below the inferior angle of the scapula on a diagonal line approximately 45° to the horizontal plane.

Suprailiac - The subject maintained a relaxed standing position with the arms held in slightly abducted position. The suprailiac skinfold was raised slightly posterior to the midaxillary line. An oblique fold was measured on the midaxillary line directly above the iliac crest.

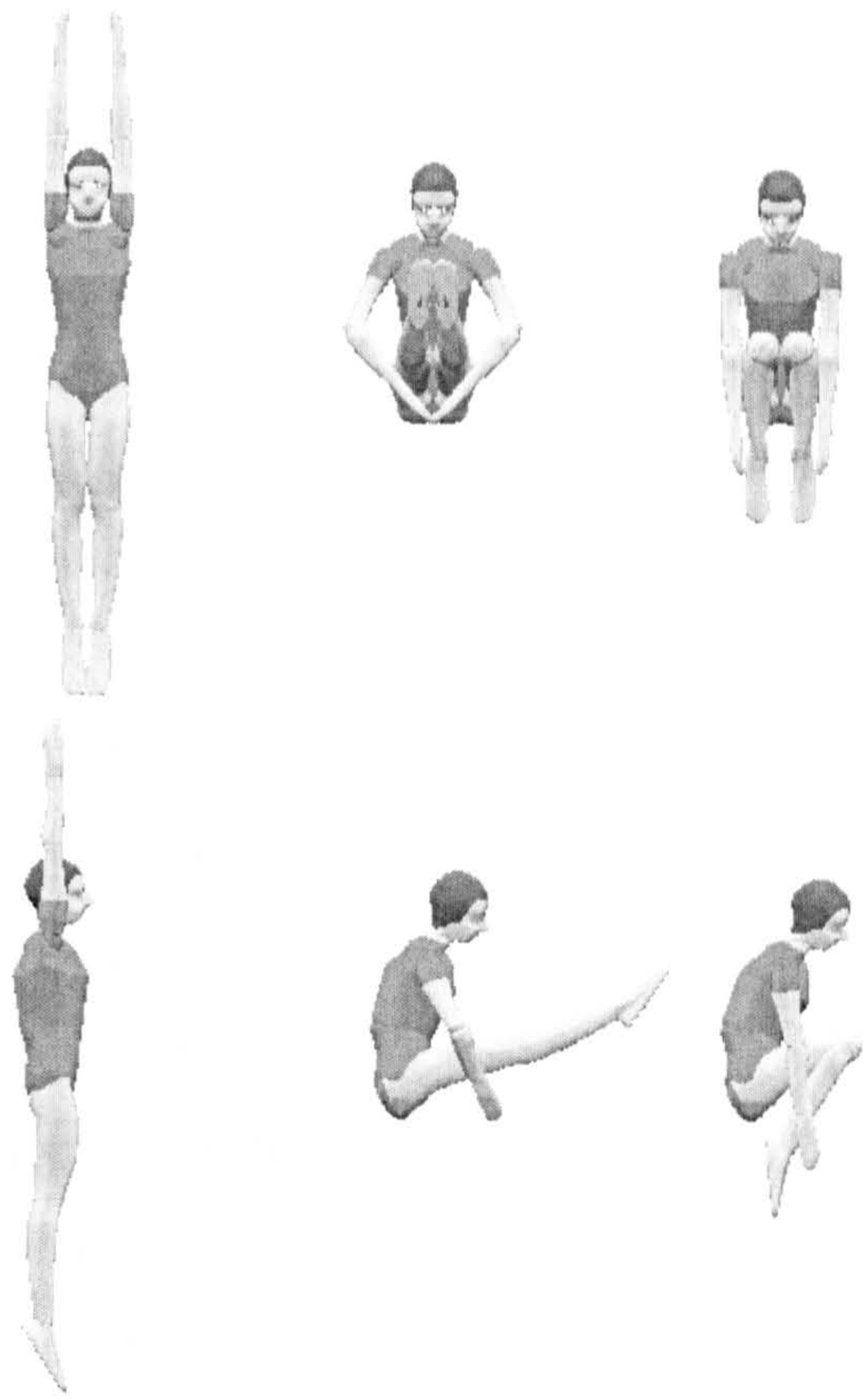
**Moment of inertia**

In the inertia model of Yeadon (1990), a series of 95 anthropometric measurements were required to determine the volumes of the 40 solids which represent the 11 segments in the

model. Specifically, the measurements comprised 34 lengths, 41 perimeters, 17 widths and 3 depths taken at specified levels on the body and are shown in Figure 5.8.

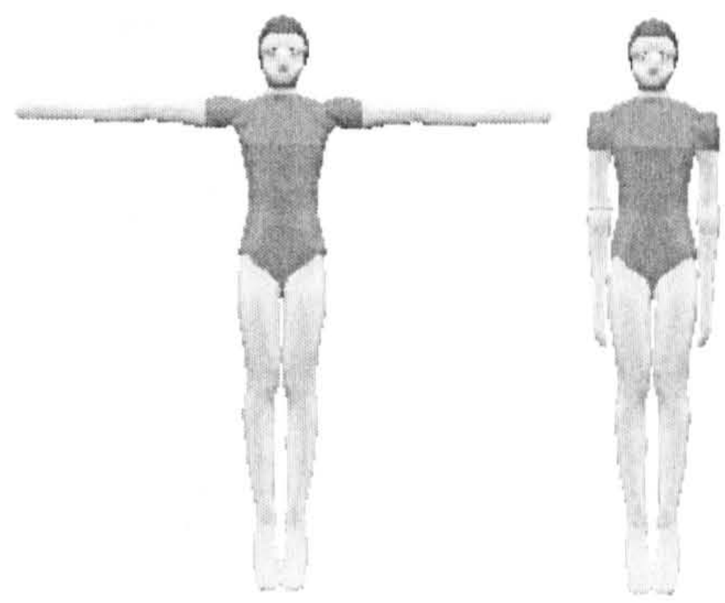
Figure 5.8. The inertia model of Yeadon (1990).

The nature of gymnastic training indicates that limb development is likely to be symmetrical in young female gymnasts. The validity of this assumption was confirmed using a random sample of five gymnasts. Measurements were therefore taken on the torso, the head and the limbs on the left side of the body only. A completed proforma outlining the reduced set of 58 anthropometric measurements collected in the present study is provided in Appendix 5.1. The inertia model of Yeadon (1990) used the subject specific anthropometric data and density values obtained from Dempster (1955) to calculate segmental inertia parameters (mass, mass centre location and the principal moments of inertia) for each of the 11 segments defined in the model. The whole body moments of inertia about the mass centre for the three principal axes of rotation were determined using the computer simulation program 'sim93' (Yeadon, Atha & Hales, 1990). In addition to the anatomical standing position, four additional body configurations were simulated to represent the standard configurations used by the gymnast whilst rotating about the transverse (somersault) axis and the longitudinal (twist) axis. The joint angles used to define the body configurations are presented in Figures 5.9 and 5.10 together with a pictorial representation of each configuration.



(a) layout (b) pike (c) tuck

Figure 5.9. Body configurations used to estimate moment of inertia about the transverse axis.



(d) wide arm (e) straight

Figure 5.10. Body configurations used to estimate moment of inertia about the longitudinal axis.

**Isometric strength**

*Collection of force data*

The vertical and horizontal components of ground reaction force produced during isometric strength and vertical jumping activities were recorded using a force platform with dimensions 600 mm x 400 mm (Kistler 9281-B12). The force platform was located within a raised runway (17 m x 1.2 m) such that the surface of the platform was flush with the runway. Force ranges were set to 5 kN full scale deflection (FSD) vertical and 2 kN FSD horizontal. The analogue force signal was amplified and passed through an anti-aliasing filter with a frequency of 256 Hz. The force data were converted into a binary signal via a 12 bit laboratory interface analogue to digital converter (CED 1401 ADC) at a sampling rate of 250 Hz. The sampling rate was considered appropriate given the resolution of the force platform (Kerwin, 1997) and the estimated frequency of athletic movement (Kerwin & Chapman, 1988). In addition, 250 Hz was demonstrated to be an appropriate sampling frequency for the process of numerical integration, with an error of approximately 1% reported in the estimation of impulse at this frequency (Kerwin, 1997). The data were recorded on floppy disc and stored as binary files using an Acorn A5000 RISC personal computer. The arrangement of the computerised data capture system used to collect force data is shown in Figure 5.11.

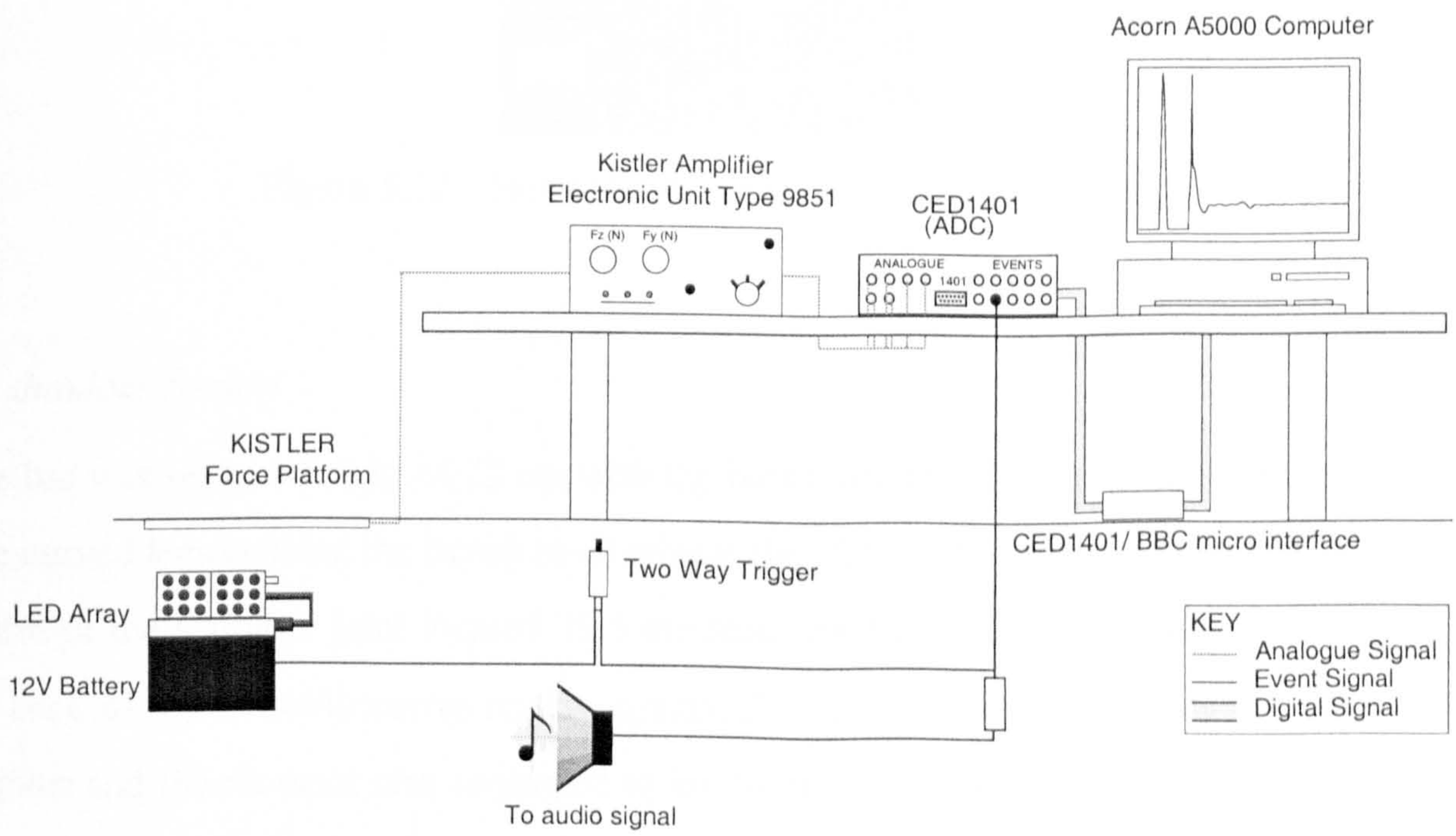



Figure 5.11. Data capture system used to collect force data.

A steel isometric strength testing rig was constructed and mounted over the Kistler force platform. A sliding stainless steel bar 34 mm in diameter could be fixed between the uprights at any height on the rig. A padded bench was positioned at specific distances from the rig to enable the gymnast to attain the specified body configuration for each of three isometric strength measurements (Figure 5.12). For each joint action, the bench was placed in an identical position for all subjects and the gymnast's body was aligned with specific reference points to ensure that the moment arm was approximately the same for all subjects. As a result of this design, force values could be estimated directly from the torque values recorded by the platform. Isometric strength was assessed for three joint actions considered to be representative of those required in contemporary Women's Artistic Gymnastics. The joint actions used to assess isometric strength are presented in Figure 5.13.

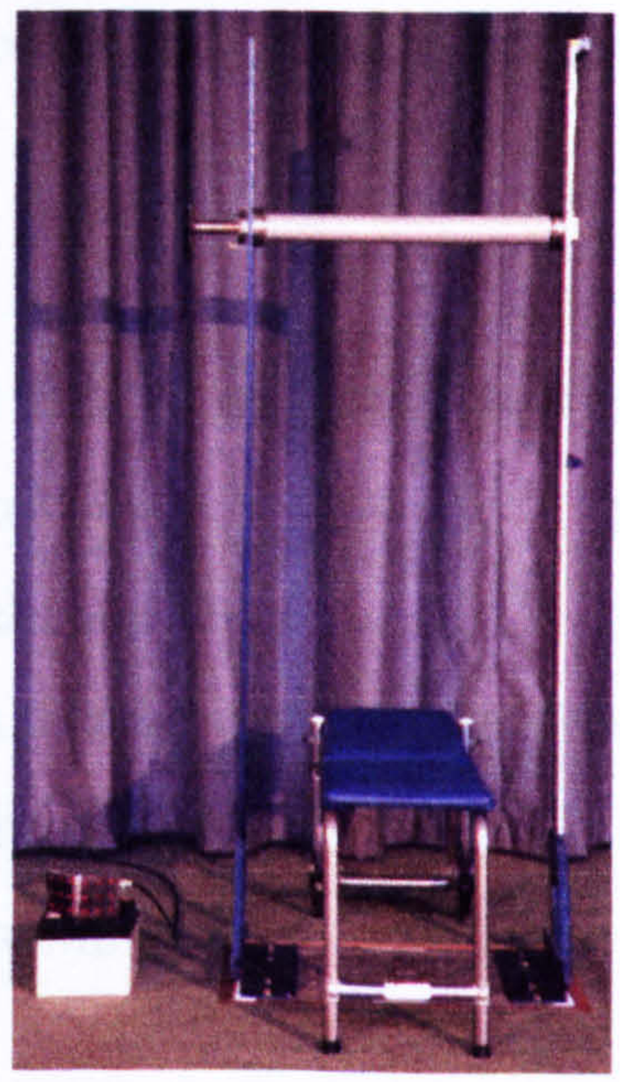


Figure 5.12. Isometric strength testing rig and bench.

*(a) shoulder flexion*

The bar was set to a height of 72 cm with the bench placed adjacent to the force platform. The curved legs enabled the bench to overhang the plate. The gymnast lay supine with the centre of the shoulder joint located 29.5 cm from the bar. The arms were extended with the back of the wrists/forearms resting against the bar. The shoulder angle was set at 45° degrees and the moment arm estimated to be 40 cm. The bar was covered with 9 mm of foam padding to enhance the comfort of the gymnast and encourage a maximal effort. The gymnast was required to maintain a 90° angle at the hips and the knees to prevent the lower limbs from contributing to the joint action. To prevent an initial torque overshoot

and therefore encourage a pure isometric contraction, the subjects were stabilised manually by an experimenter. Stabilisation was achieved by placing heel of hands under the clavicle and towards the sternum. The gymnast was asked to maintain a 'flat back' with the pelvis fixed throughout the duration of the test.

*(b) hip extension*

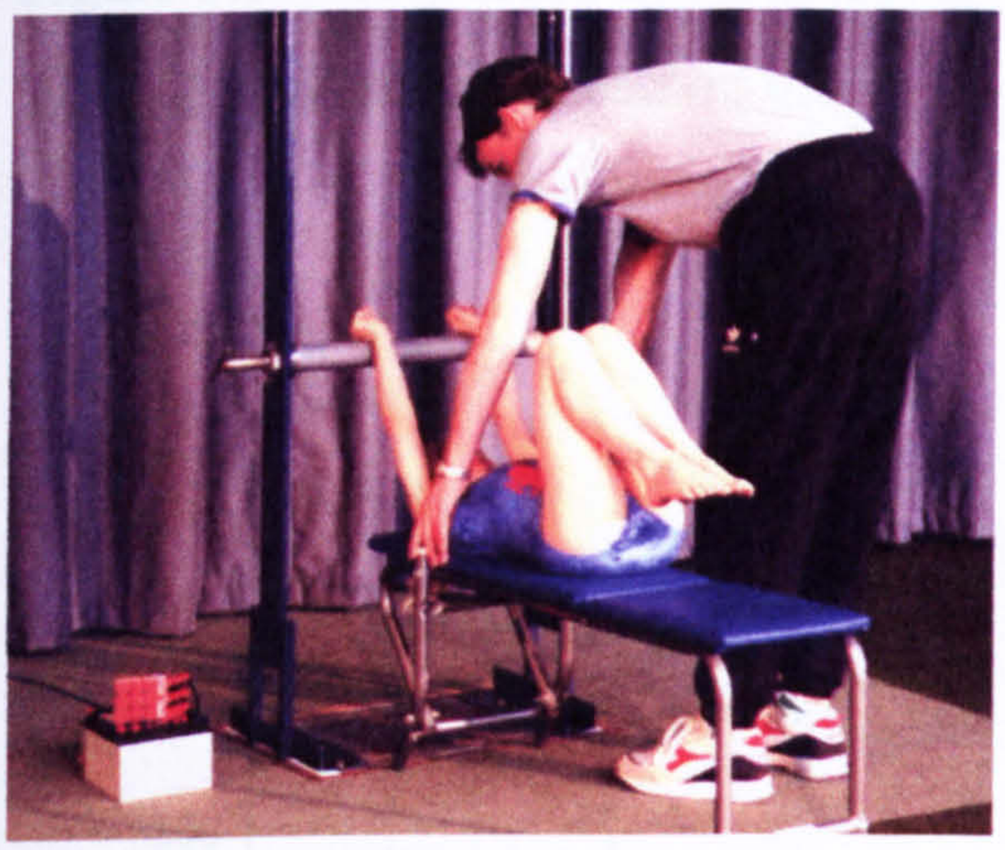
The height of the bar was set to 36 cm and the bench was placed a distance of 18.5 cm from the edge of the force plate. The gymnast lay prone, with the centre of the hip joint located at the corner of the bench to permit hip flexion. The back of the gymnasts thighs rested against the underside of the bar with the knees kept straight. The hip angle was set at 160° and the moment arm estimated to be 23.5 cm. The gymnasts grasped the underside of the bench at a specific point for support. The gymnast was stabilised manually by placing the heel of the hands across the upper back.

*(c) shoulder girdle elevation*

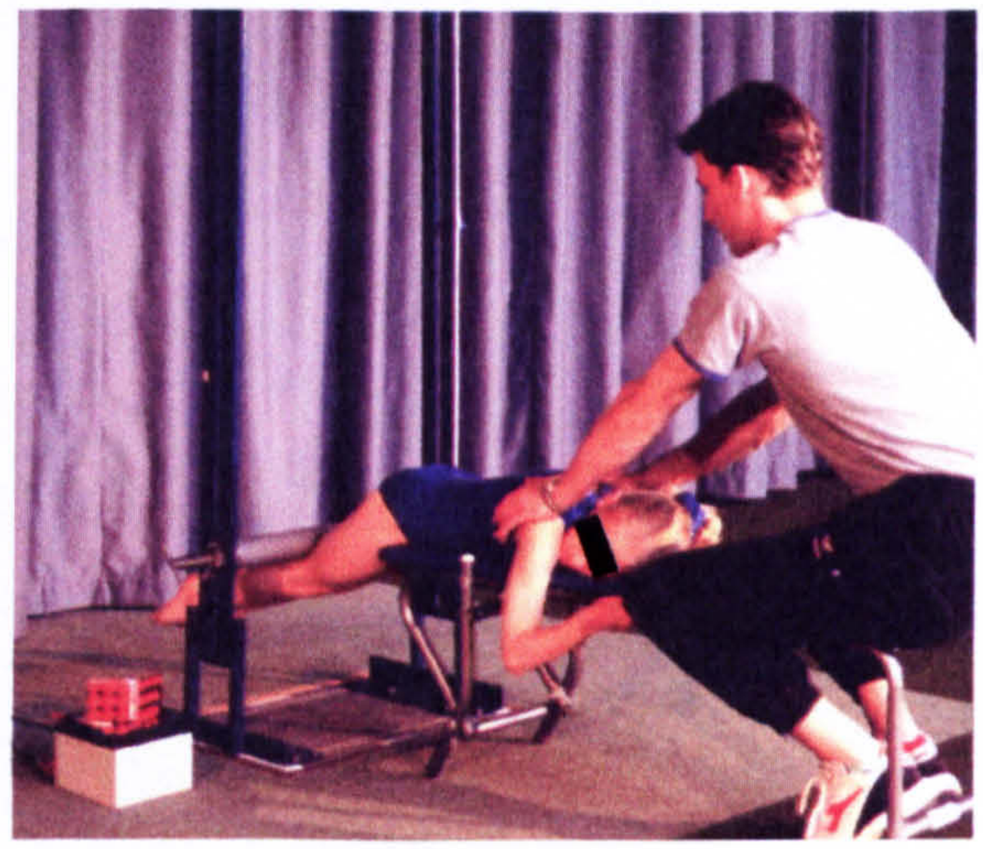
The gymnast sat on the bench directly under the bar with knees extended along the bench and the back upright. The arms were extended above the head, shoulder width apart. The gymnast was asked to depress the shoulder girdle maximally whilst maintaining the upright position. The bar was then adjusted to rest gently upon the heel of the gymnast's hands. Throughout the test the gymnast was required to maintain an erect posture with careful attention to ensure no arching of the lower back.

For each joint action the gymnast initially held the limbs against the bar with minimal pre-tension in accordance with the recommendations of Wilson & Murphy (1996). A minimal level was advocated since high levels of pre-tension have been associated with reductions in the magnitude of the isometric rate of force development and to a lesser extent maximum isometric force (Viitasalo, 1982). The gymnast was required to perform the required muscular action as "hard and as fast as possible" upon hearing an audio signal, then momentarily relax before repeating the contraction. The action was initially demonstrated by the experimenter, with each gymnast given time to familiarise by performing the joint action submaximally. Gymnasts were pre-warned of the trial 1-5 seconds prior to the audio signal which was considered an appropriate foreperiod for the estimation of a reaction time parameter (Magill, 1989).

Verbal encouragement was given throughout the tests. A single acceptable trial was collected for each gymnast.



(a) shoulder joint flexion



(b) hip extension

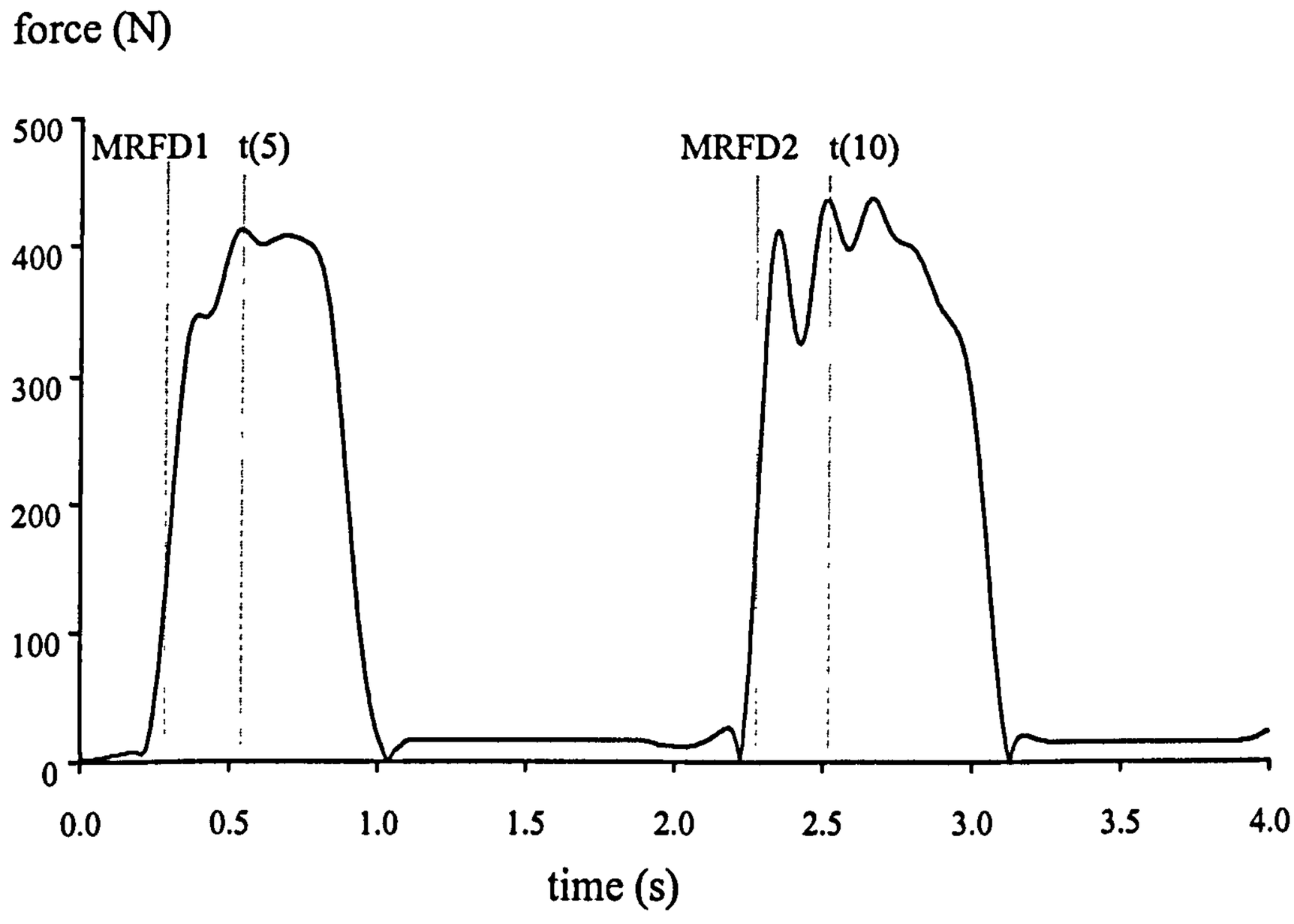
(c) shoulder girdle elevation

Figure 5.13. Joint actions and approximate angles used to assess isometric strength: shoulder joint flexion, (b) hip extension, (c) shoulder girdle elevation.

*Analysis of force data*

The analysis program 'Isocalc' (Kerwin, 1997, unpublished) was used to determine the potentially prognostic parameters associated with isometric force production. Vertical and horizontal components of ground reaction force were recorded and smoothed using a second order Butterworth Filter with a cut-off frequency of 5Hz. The resultant force was calculated using the smoothed data, with both raw and smoothed data plotted to provide a

visual representation of the force-time curve. A number of key times were identified, examples of which are indicated on a typical hip extension (HXT) force-time curve in Figure 5.14. Key times t(1)-t(5) correspond to the first muscle action and key times t(6)-t(10) correspond to the second muscle action:




| | | | |
|---|---|---|---|
| t(1) | 0% peak force action 1 | t(6) | 0% peak force action 2 |
| t(2) | 10% peak force action 1 | t(7) | 10% peak force action 2 |
| t(3) | 50% peak force action 1 | t(8) | 50% peak force action 2 |
| t(4) | 90% peak force action 1 | t(9) | 90% peak force action 2 |
| t(5) | 100% peak force action 1 | t(10) | 100% peak force action 2 |
| MRFD1 maximal rate action 1 | | MRFD2 maximal rate action 2 | |

Figure 5.14. A typical force-time curve for isometric hip extension (HXT).

Maximal isometric force for the first muscle action (MIF1) was determined as the maximum force occurring over the first 500 readings. The maximum gradient or maximum rate of force development for this muscle action (MRFD1) occurring above a threshold of 10% MIF1 was identified using a 9 point moving average method. An initial estimate of t(1), which may be defined as the reaction time or the point at which the force curve begins to rise, was obtained by the reverse extrapolation of MRFD. A more precise estimate of t(1) was derived by working backwards from the point of intersection one

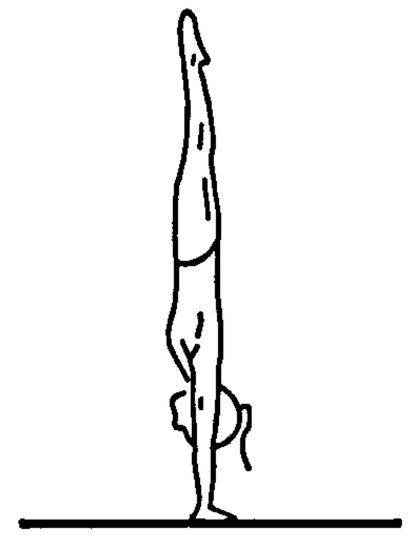
reading at a time until the resultant force corrected for the force offset dropped below a threshold set at 1% of the force range or the resultant force was less than or equal to the force offset. In each case the force offset associated with the first muscle action was defined as the average force over the first 10 readings. The program subsequently calculated 10%, 50% and 90% of MIF1 and the times associated with these percentage values. Finally, the average rate of force development (AFRD) was calculated over the range 10-90% MIF. The process was then repeated for the second muscle action where MIF2 was determined between t(6) and the final reading (1000). The maximum slope associated with the second peak (MRFD2) was located in the portion of the force-time curve between 100 readings after MRFD1 and the 1000$^{th}$ reading. The force offset associated with the second muscle action was defined as the average force occurring 90-100 readings prior to key time t(6).

**Local muscular endurance**

The battery of tests used to determine functional strength and local muscular endurance were a modified version of the tests produced by the current Performance Director for Women's Artistic Gymnastics within Great Britain (Stan, 1994). These assessments which have previously been applied to test National Squad gymnasts are outlined together with guidelines for administration in Figures 5.15-5.16. The tests were performed in the gymnast's clubs or at National Squad training sessions at the National Sports Centre. It was anticipated that certain pieces of equipment required to complete the battery would not be available in all clubs, therefore modifications were made to ensure that only standard equipment was required and the test protocol could be consistently administered in all participating clubs. The functional tests were devised to assess the muscular speed, and local muscular endurance characteristics of the gymnasts. In the majority of tests, the gymnasts were instructed to complete as many repetitions of a particular conditioning element as quickly as possible during a 60 s period. The number of repetitions completed in 10 s, 30 s and 60 s were recorded for each exercise. The number of repetitions performed during the first 10 s of the test provided an indication of the gymnast's speed-strength. Local muscular endurance was assessed after 30 and 60 s respectively. Only those repetitions executed according to the range specified in the protocol were accepted and the test was ceased upon continued deviation from this range.

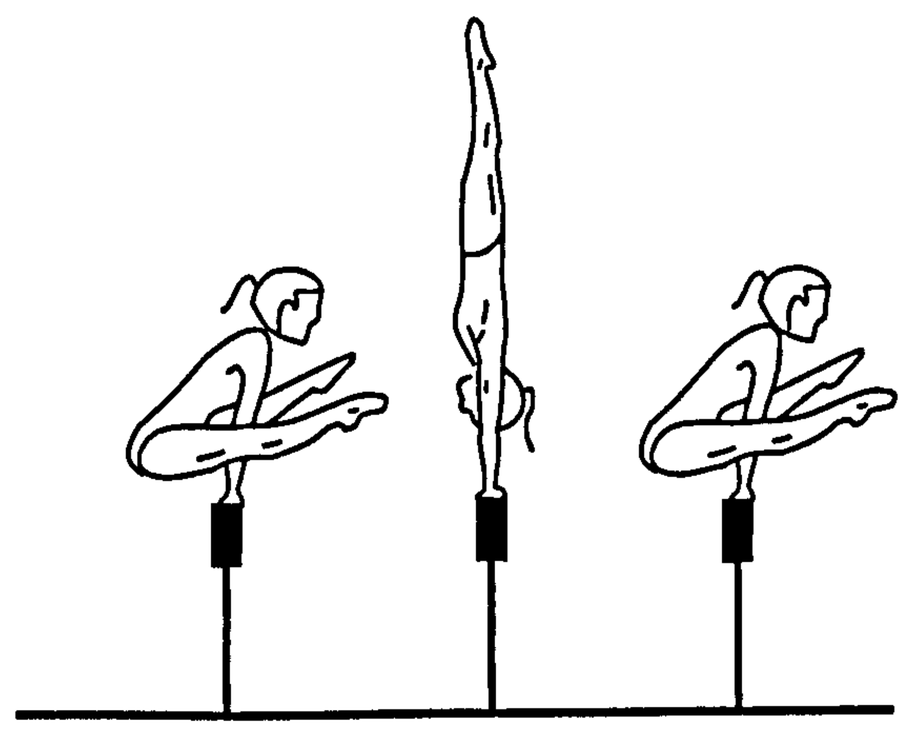
(i) handstand hold

Gymnasts were instructed to hold a still handstand for as long as possible. Three attempts were permitted with the longest trial counting. Timing was taken to the nearest second and commenced as the gymnast's support leg left the floor.



(ii) straddle lever

Gymnasts were required to complete as many continuous straddle lever press to handstands as possible from a side position on the beam. One point was awarded when the gymnast pressed to handstand and returned to straddle lever. If the gymnast failed to return to straddle lever a half point was awarded. Gymnasts were provided with the option of three attempts.



(iii) leg lifts

From a still hang gymnasts were required to complete as many leg lifts as quickly as possible in 60 seconds. Readings were taken after 10, 30 and 60 seconds. The gymnast was stabilised behind the shoulders to maintain an open shoulder angle. Repetitions were only counted if the legs were straight and the feet touched the bar.

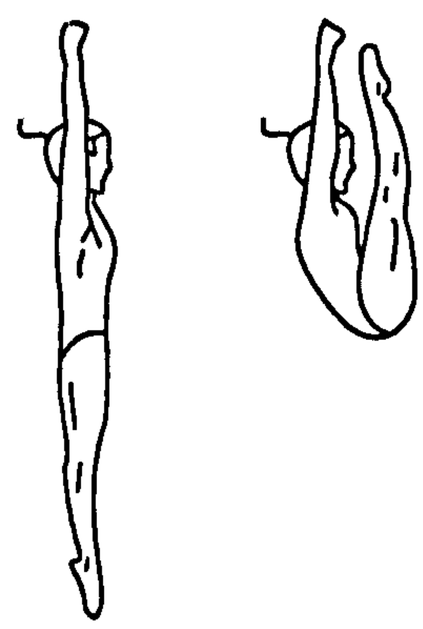
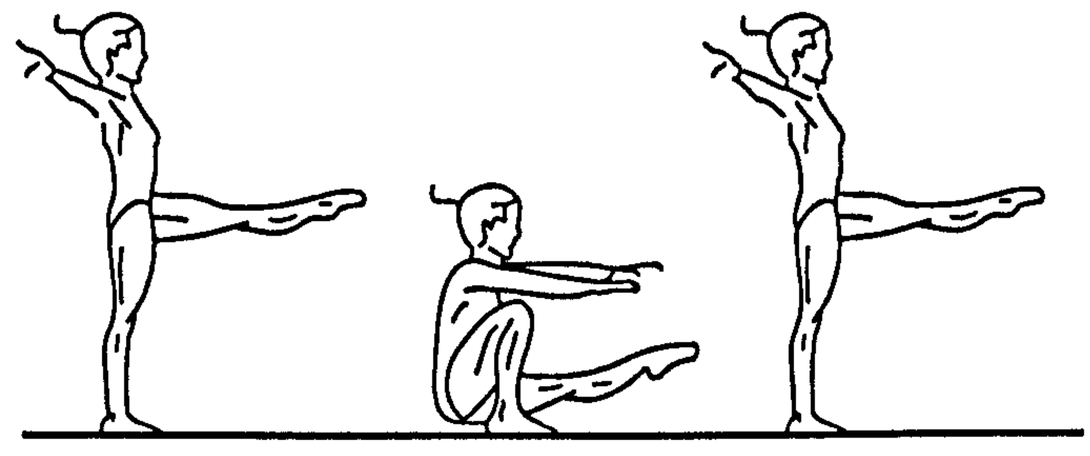


Figure 5.15. The battery of tests adopted to assess local muscular endurance.

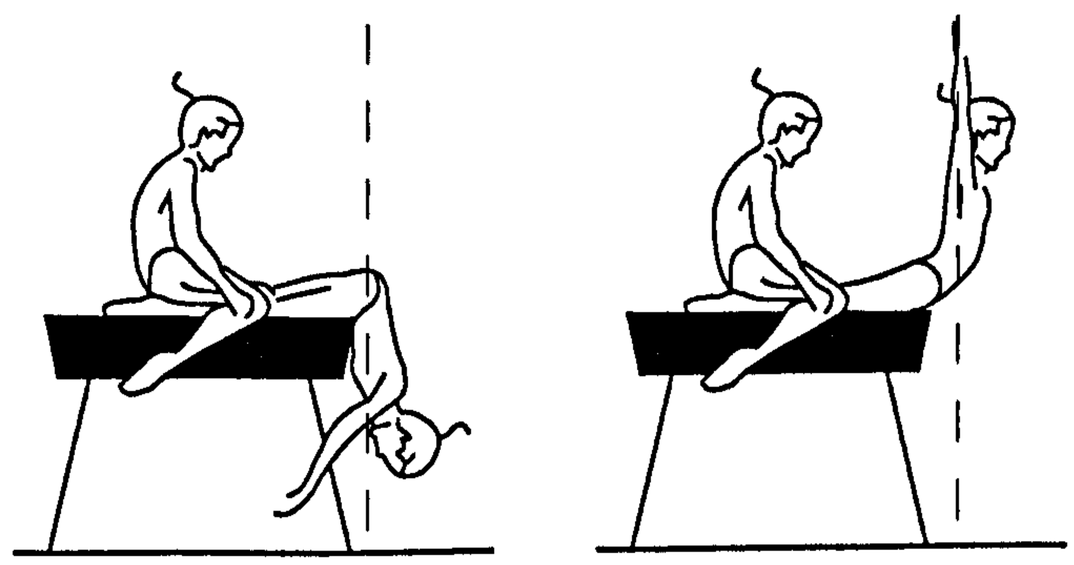
(iv) leg dips

While standing on a beam gymnasts were instructed to complete as many one leg squats as possible in 60 seconds. Readings were taken after, 10, 30 and 60 seconds. The support leg was required to flex at the knee by at least 90° for a repetition to count. At no point was the free leg permitted to contact the beam. Gymnasts completed the exercise on both legs with a short rest interval between trials.



(v) back-ups

From the starting position indicated in the diagram, the gymnast was required to complete as many back-ups as possible in 60 seconds. Readings were taken after 10, 30 and 60 seconds. The gymnast was required to lift the torso to the vertical with the arms extended by the side of the head.



(vi) leg-ups

From the starting position indicated in the diagram, the gymnast was required to complete as many leg-ups as possible in 60 seconds. Readings were taken after 10, 30 and 60 seconds. The gymnast was required to lift the legs to the vertical position with legs together and straight. The gymnasts were instructed to maintain a fixed body line to avoid excessive extension of the lumbar spine.

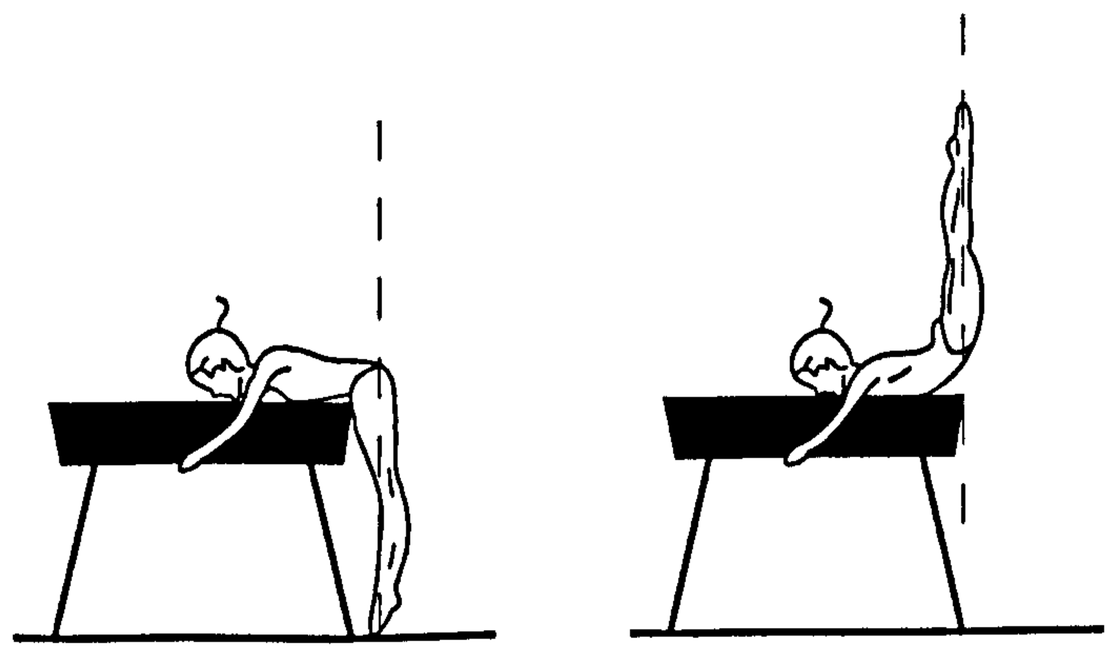


Figure 5.16. The battery of tests adopted to assess local muscular endurance (continued).

### Standing broad jump

Gymnasts completed three maximal standing broad jumps on judo matting as shown in the sequence of images presented in Figure 5.17. The back of the heels were placed on a horizontal line marked with tape on the mat. Gymnasts were instructed to jump forwards as far as possible without falling or staggering on landing. The position of the heel closest to take-off was marked and the distance of the jump recorded. Each gymnast completed three accepted trials with the longest jump selected as the score.

### Counter movement and drop jumps

The vertical component of ground reaction force was recorded as gymnasts performed counter movement and bounce drop jumps on the force platform using the data recording equipment described in Figure 5.11. Analysis programs were written to determine a number of potentially prognostic parameters from the kinetic data (Kerwin, 1997, unpublished). The programs were evaluated by comparing the calculated vertical displacement of the mass centre at key times during the jump with an estimation of the vertical location of the mass centre derived from video data.

*Collection of video data*

In order to evaluate the analysis programs, kinematic data were recorded using a video camera (Panasonic CCD F15 framing rate 50 fields per second, shutter speed 1/250 second) and SVHS video recorder (Panasonic AG 7350), connected to a time code generator (IMP Electronics V9000). The recording system was located above the force plate at an angle of approximately 45 degrees to the plane of motion. The approximate distance from the centre of the lens to the centre of the force plate was 13.5 m. The force plate was illuminated using 2.5KW arri lights. The equipment used to collect the kinematic data is shown in Figure 5.18. The force and video data were synchronised using a Light Emitting Diode (LED) array placed in the field of view. The trial was initiated by a manual trigger which marked the onset of force data collection, activated the LED array and gave an audio signal to the gymnast. The LED/trigger system allowed the kinetic and kinematic data to be synchronised to the nearest video field. A calibration frame was placed in the field of view and recorded prior to each data collection session (Figure 5.18).

Figure 5.17. Standing broad jump.

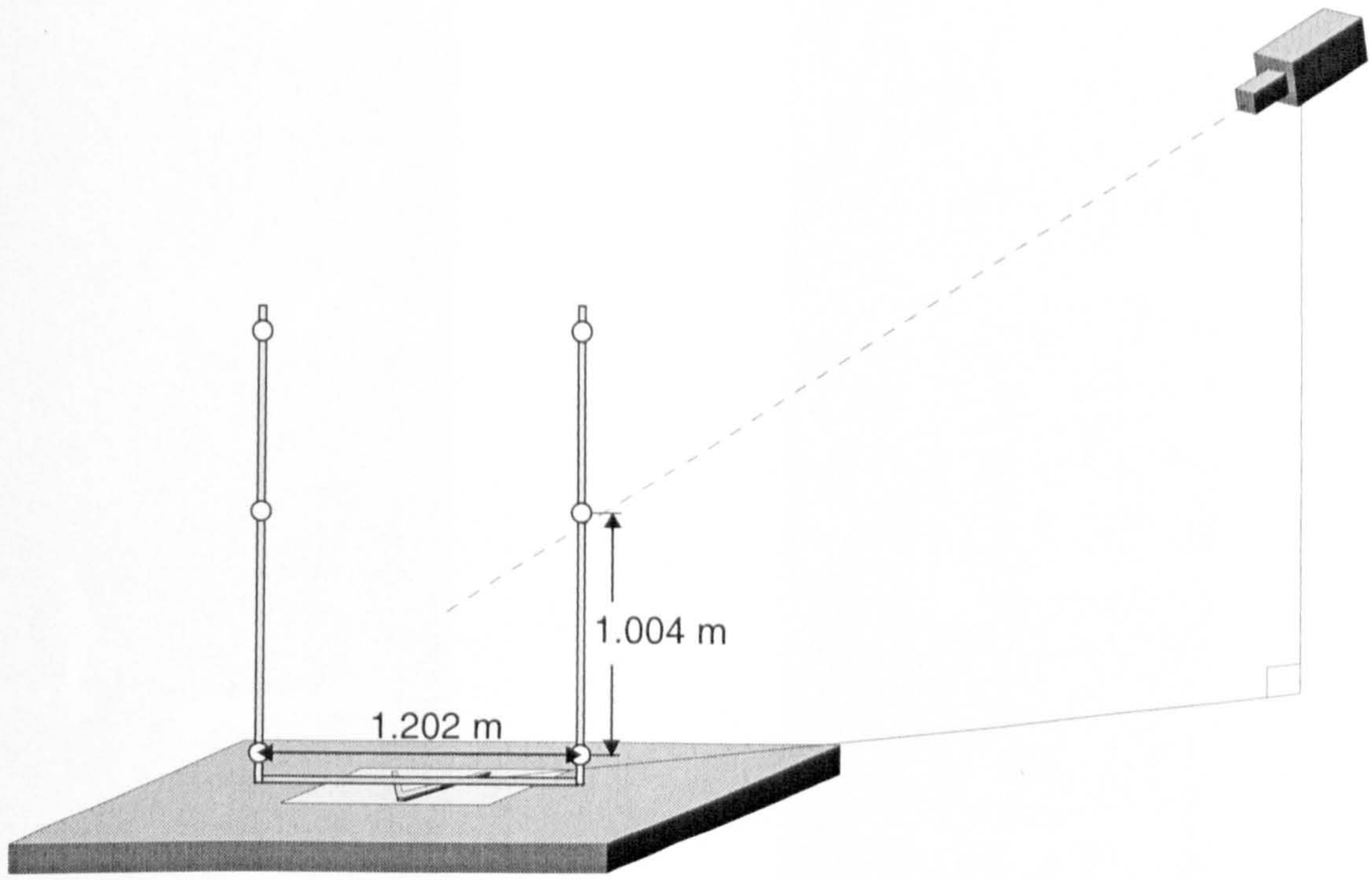



Figure 5.18. The data capture system used to collect video data for drop and counter movement jumps.

*Procedure*

*Counter movement jump*

From an initial standing position, a counter movement involving flexion of the trunk and lower extremities preceded a maximal vertical jump. The arms were held loosely by the sides at the beginning of the jump. Gymnasts were allowed to swing their arms during the jump (Figure 5.19).

*Bounce drop jump*

The bounce drop jump was performed from a wooden box 0.15 m in height placed adjacent to the force platform. After dropping from the platform the subjects were required to rebound as high as possible, land on the force platform and return to a still standing position. The hands remained on the hips for duration of the jump since constraining the arm movement had previously been reported to facilitate the consistency of the rebound action. (Bobbert et al, 1986) (Figure 5.20).

Figure 5.19. Counter movement jump.

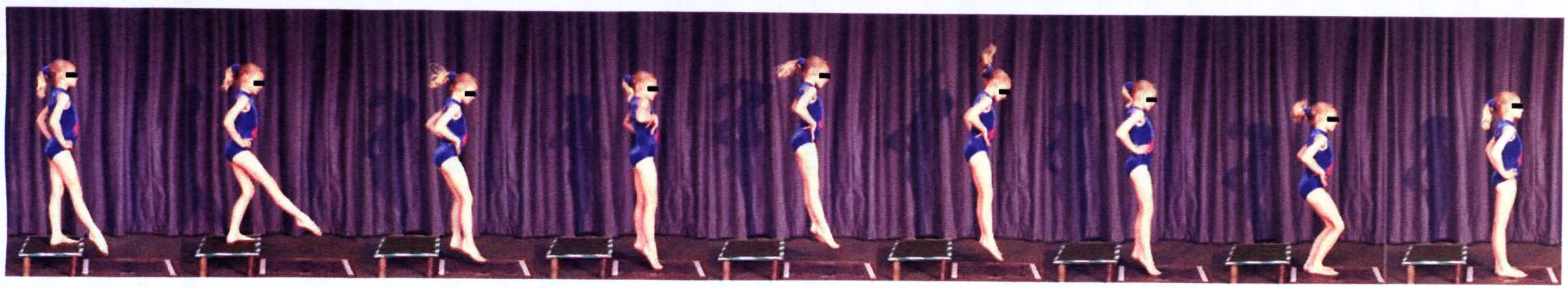


Figure 5.20. Bounce drop jump.

Gymnasts were asked to perform three maximal counter movement and bounce drop jumps with correct style and return to a stationary standing position on the force platform. A maximum of six jumps per subject was required to achieve this task. Each jump style was demonstrated by the experimenter with gymnasts given the opportunity to practice the style of the jump sub-maximally. The order in which gymnasts performed the jump styles was randomised. However, given the young age of the subjects, inter-style randomisation was considered inappropriate. To enable a longitudinal evaluation, the order in which the jump style was presented at the initial testing session was repeated at all subsequent testing dates. Trials were repeated if any evidence of counter movement was detected during the bounce drop jump or if the subject failed to return to a still landing position. A rest period of 30 s was provided between jumps to minimise fatigue. All subjects performed the jumps barefoot and in a sleeveless leotard to facilitate joint centre location during the subsequent digitisation process.

*Analysis of force data*

The analysis programs 'Dropjump' and 'Counterjump' (Kerwin, 1997, unpublished) were written in BBC Basic to identify important parameters of the bounce and counter movement jumps respectively. The programs initially identified a number of key times which are indicated on the force-time curves in Figures 5.21 and 5.22.

| Bounce Drop Jump | | Counter Movement Jump | |
|---|---|---|---|
| t(1) | Landing time 1 | t(0) | Start of trace [f(start)] |
| t(2) | Peak force prior to take-off | t(1) | Point weight line is crossed |
| t(3) | Take-off | t(2) | Peak force prior to take-off |
| t(4) | Landing time 2 | t(3) | Take-off |
| t(5) | End of trace [f(end)] | t(4) | Landing time |
| | | t(5) | End of trace [f(end)] |

*Bounce drop jump*

For the bounce drop jump (Figure 5.21), key time t(5) was defined as the end of the force-time analysis, when the gymnast had returned to a stationary standing position and the vertical force was equivalent to body weight. Initially, t(5) was set to the final reading (1023), however, the final part of the trace was often inconsistent as the subjects either did not return to quiet standing, or stepped off the plate before the completion of the trial. Therefore, each force trace was plotted to allow the user to manually select the end point

of the trace using a cursor. In trials where the gymnast failed to attain a quiet standing position t(5) was located at the first reading after landing where vertical force corresponded to body weight.

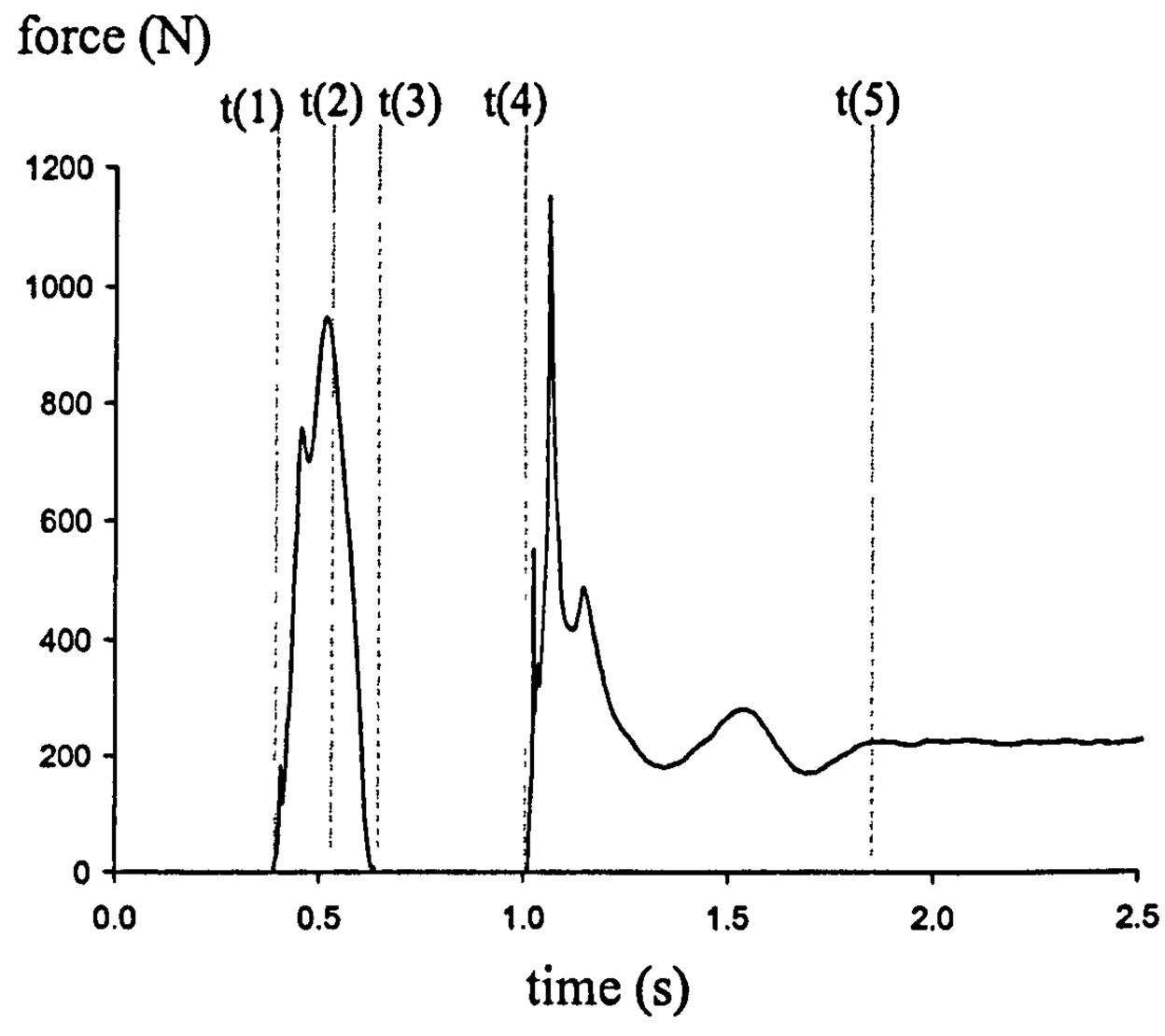



Figure 5.21. Key times in the 'bounce drop jump' force time trace. Where: t(1) = 1st impact, t(2) = peak force before take-off, t(3) = take-off time, t(4) = 2nd impact (landing), t(5) = chosen end point.

A number of parameters were estimated using the technique of numerical integration via the trapezium rule. Reverse integration was initiated from the selected end point of the trial t(5) and continued to the first impact t(1). For each trial an offset value was calculated to correct the vertical force data for systematic error in the data capture system (zero offset) and error associated with the process of numerical integration (integration offset). Zero offset was calculated as the average of the initial 90 data capture readings during which the plate was unloaded. The integration offset was determined through a comparison of velocity at t(3) determined from flight time and from reverse integration according to the following equation:

$$\text{Integration Offset} = \frac{\left(V_{int} - V_{flight}\right)}{t(5) - t(3)} * \text{mass}$$

where:

$V_{int}$ velocity at t(3) determined from reverse integration

$V_{flight}$ velocity at t(3) determined from flight time

After an adjustment for the total offset (integration offset - zero offset), the reverse integration was repeated to identify the bottom of the squat (bi%). The push-off phase was defined as the time interval between the bottom of the squat and take-off. Impulse, average force, peak and average power were calculated during this phase of the jump. Power was calculated by multiplying instantaneous force and velocity. Flight time was defined as the time interval between the first zero force reading t(3) and the first non-zero force reading t(4), however, as a result of noise in the ADC unit a threshold of 25 N was set. The calculation of jump height from flight time information required two assumptions. Firstly, it was assumed that the vertical location of the mass centre was the same at take-off and landing and secondly, that the motion of the mass centre during free flight was symmetrical. Therefore, using the equations of motion under constant acceleration, take-off velocity and jump height were estimated from the time of flight. Stretch height was defined as the height of the mass centre at take-off above the height of the mass centre in the standing position and was determined using double integration. However, some gymnasts landed the jump in a semi-squat position, therefore the location of the mass centre at f(end) was calculated and stretch height corrected accordingly. Peak jump height was defined as the difference between the height of the mass centre at standing and at the apex of the jump and was calculated as the sum of stretch height and jump height.

Previous investigations have revealed that the actual or calculated drop height drop may differ from the nominated drop height (Kerwin & Challis, 1985; Kerwin, 1997). The actual drop height of the mass centre was determined from the landing velocity using the equations of motion under constant acceleration. The landing velocity was calculated from the take-off and landing impulses produced during the contact phase of the bounce drop jump.

$$\text{Net Impulse} = \int_{t(1)}^{t(3)} \left(Fz - \text{weight} - \text{total offset}\right) dt$$

$$\text{Landing Impulse} = \text{Net Impulse} - (\text{Take-off Impulse})$$

$$\text{Take-off Impulse} = \text{mass} * v_{time}$$

$$\text{Landing Velocity} = \frac{\text{Landing Impulse}}{\text{mass}}$$

$$\text{Drop Height} = \frac{(\text{Landing Velocity})^2}{2g}$$

Finally, landing and take-off impulses were compared and expressed as a ratio.

*Counter movement jump*

Similar parameters were determined for the counter movement jump using forwards integration (Figure 5.22).

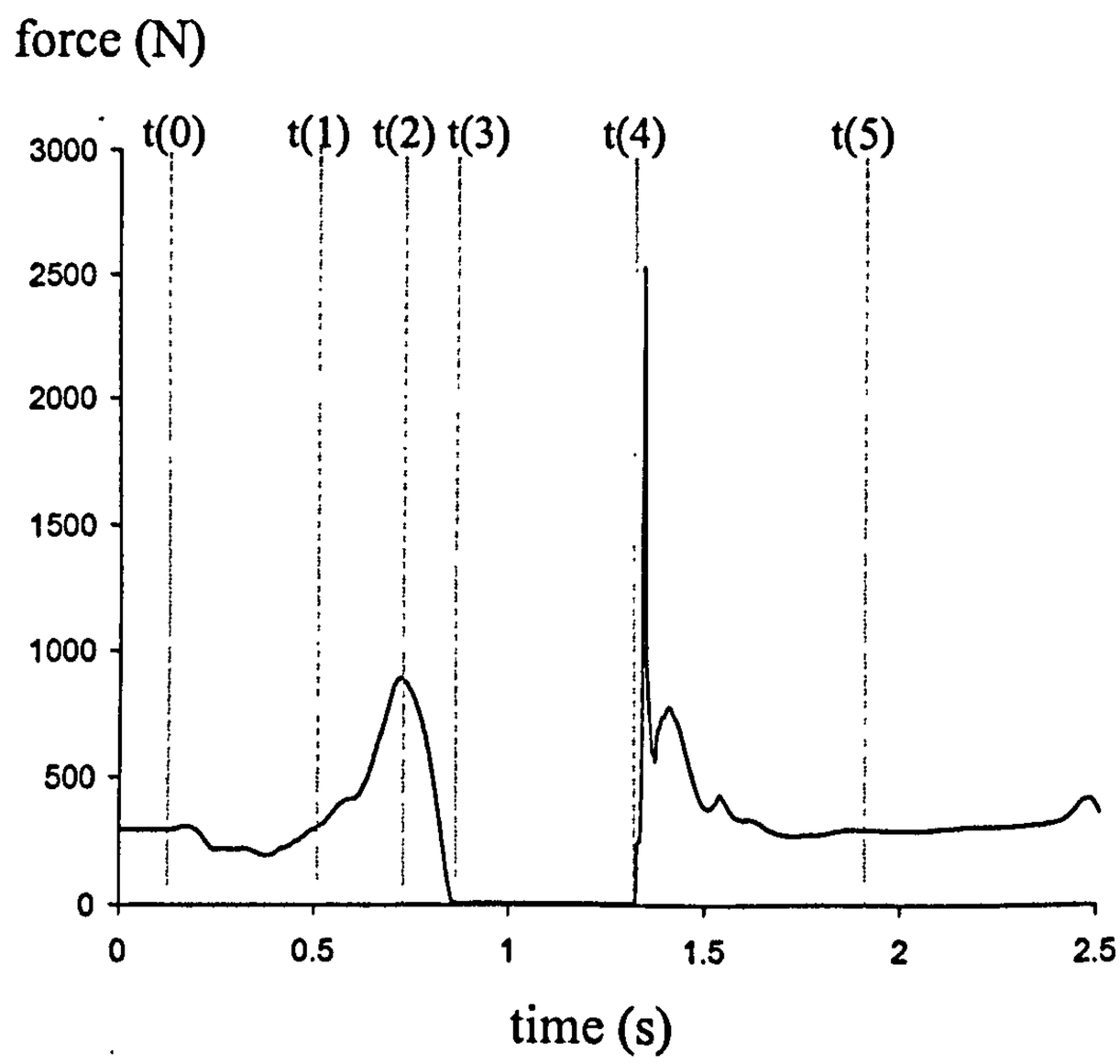



Figure 5.22. Key times in the 'counter movement jump' force time trace. Where: t(1) = 1st impact, t(2) = peak force before take-off, t(3) = take-off time, t(4) = 2nd impact (landing) t(5) = chosen end point.

The user was required to manually select start and end points for the analysis of the counter movement trace according to the criteria outlined in for the bounce drop jump. It was assumed that the gymnast was in an identical stationary position at the start and end of the trace and therefore the net take-off impulse from t(0) to t(3) was equal to the net landing impulse from t(4) to t(5). The difference between the take-off and landing impulses was defined as the offset value. In addition, the positive and negative impulses produced prior to take-off were expressed as a ratio. For both jump styles, the best trial

for each subject was chosen according to the criterion of peak jump height. Where peak jump height did not differentiate between trials, normalised peak power output was used as the criterion for trial selection.

*Analysis of video data*

The video data were digitised using the Target high resolution system. Ten video fields of the calibration frame were digitised prior to the movement data. The DLT parameters were determined from the average digitised coordinates of the calibration frame and their known locations using the 2-D DLT method (Kerwin, 1997, unpublished). In each movement field, a total of 17 reference points on the body were digitised. These comprised the toe, heel, ankle, knee, hip, shoulder, elbow and wrist on both sides of the body and the centre of the head. The movement data were converted into S.I. units using 2-D DLT (Kerwin, 1997, unpublished).

*Calculation of mass centre location*

The program '2D DLTCM' (Kerwin, 1997, unpublished) was used to calculate the vertical location of the mass centre for each video field. The mass centre of each of the 12 segments was determined using the segment mass and length ratios generated from the inertia program (Yeadon, 1990) and the spatial co-ordinates derived from the 2-D DLT program (Kerwin, 1997, unpublished). The vertical location of the whole body mass centre of the gymnast was calculated by taking moments about the horizontal axis and dividing by the sum of the segment masses. A sample calculation is provided in Appendix 5.2.

$$z = \frac{\sum_{i=1}^{12}(m_i z_i)}{\sum_{i=1}^{12}(m_i)}$$

Where:

| | |
|---|---|
| $z$ | vertical location of whole body mass centre |
| $m_i$ | mass of the segment |
| $z_i$ | vertical location of the segment mass centre |

To evaluate the 'Dropjump' and 'Counterjump' analysis programs peak jump height was determined from video analysis and compared with the program output. The location of the mass centre was determined in five video fields around the apex of the jump. A parabola was fitted to the data points and differentiated to obtain an estimate of peak jump height. For a sample of five jumps the RMS differences between peak jump height estimated from force data and video data were 0.012 and 0.016 m for counter movement and bounce drop jumps respectively.

**Flexibility**

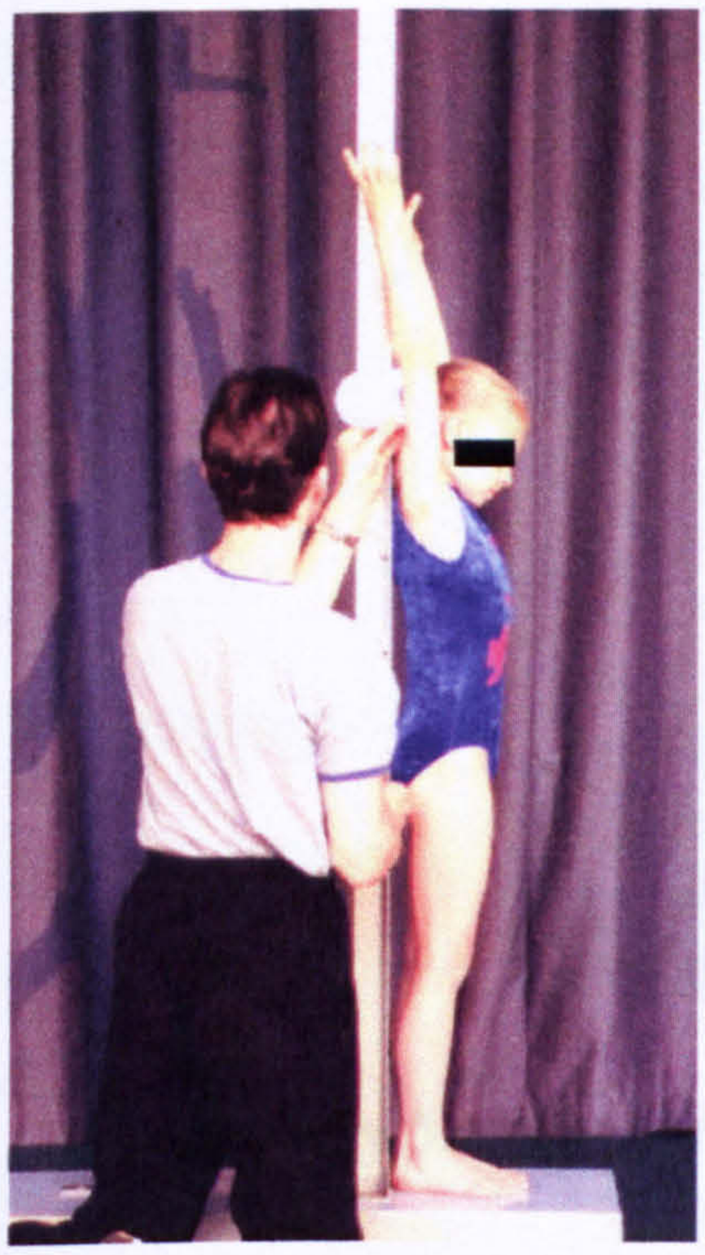
Prior to the flexibility measurements the gymnasts completed a five minute standardised warm-up (see Appendix 5.3). The temperature in the laboratory was recorded during each measurement session.

*Clinical flexibility*

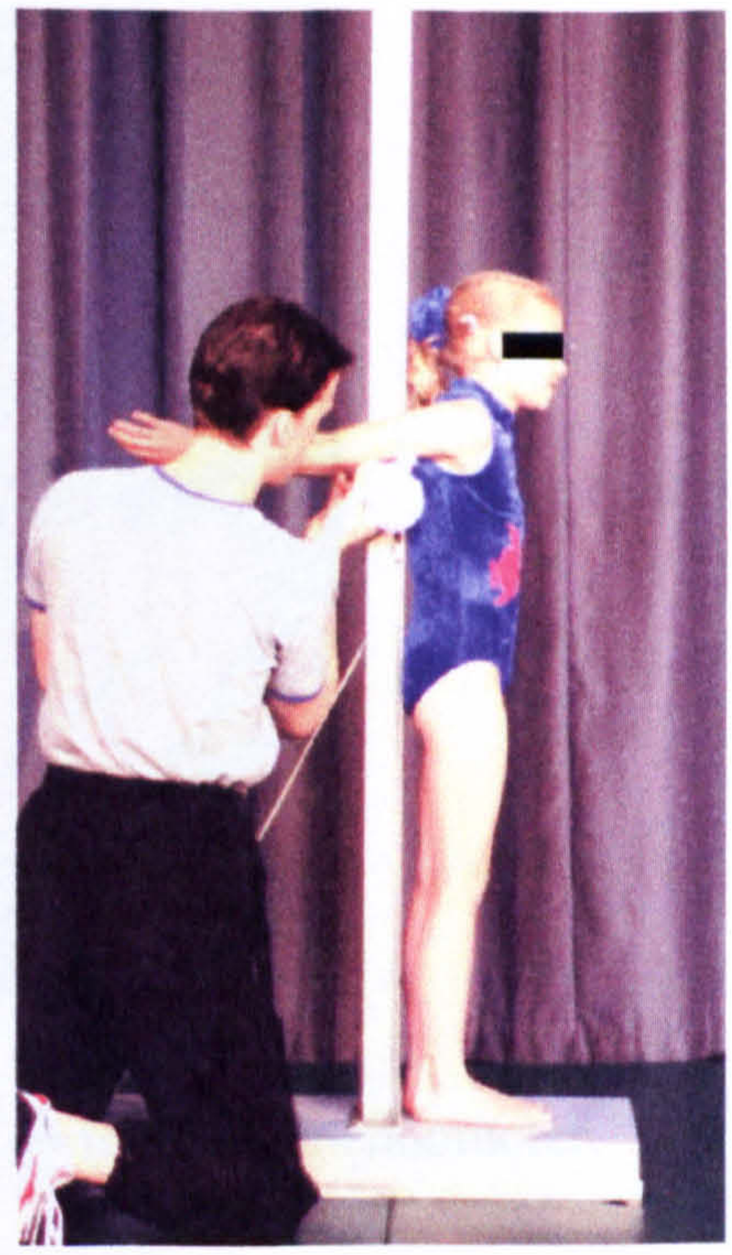
An inclinometer (MIE Medical Research Limited 8401841) was used to estimate the range of motion for the following joint actions: shoulder joint flexion and extension, internal and external rotation of the shoulder girdle, elbow hyper-extension, wrist flexion and extension, hip flexion and extension, hip external rotation, hip abduction and knee hyper-extension. Details regarding the positioning of the subject and placement of the inclinometer are provided in Figures 5.23-5.32.

Shoulder flexion/extension

The gymnast was positioned with heels, buttocks and shoulders touching the upright section of the portable stadiometer. The inclinometer was placed on the anterior aspect of the upper arm and zeroed with the arm hanging vertically (neutral position). During both flexion and extension the arms were elevated maximally while remaining shoulder width apart. Care was taken to ensure that the heels, buttocks and shoulders remained in contact with the stadiometer throughout the measurement.



(a) shoulder flexion

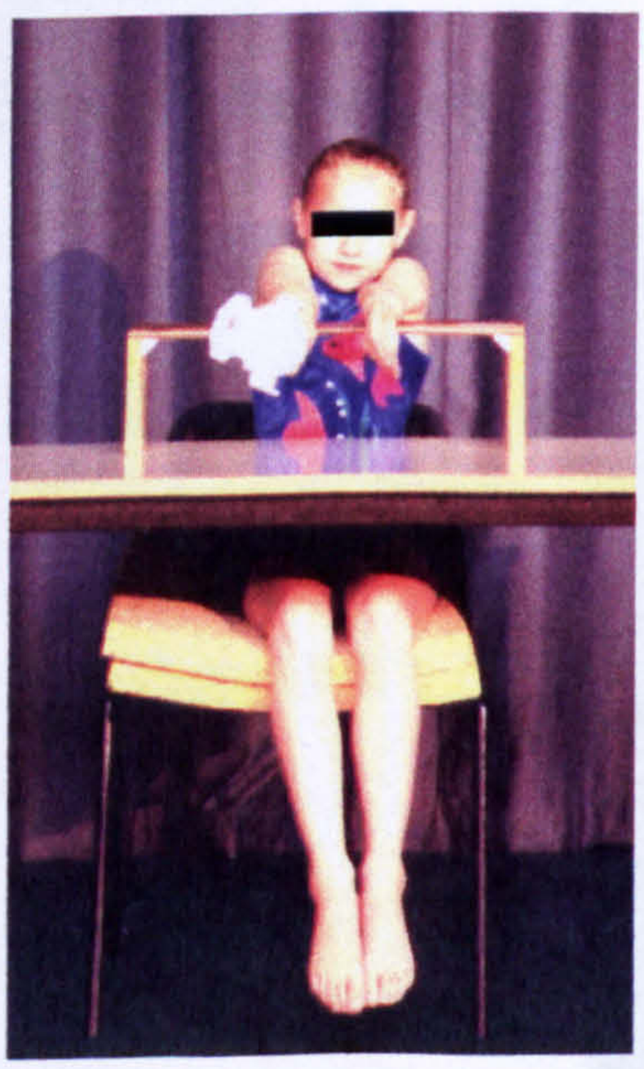


(b) shoulder extension

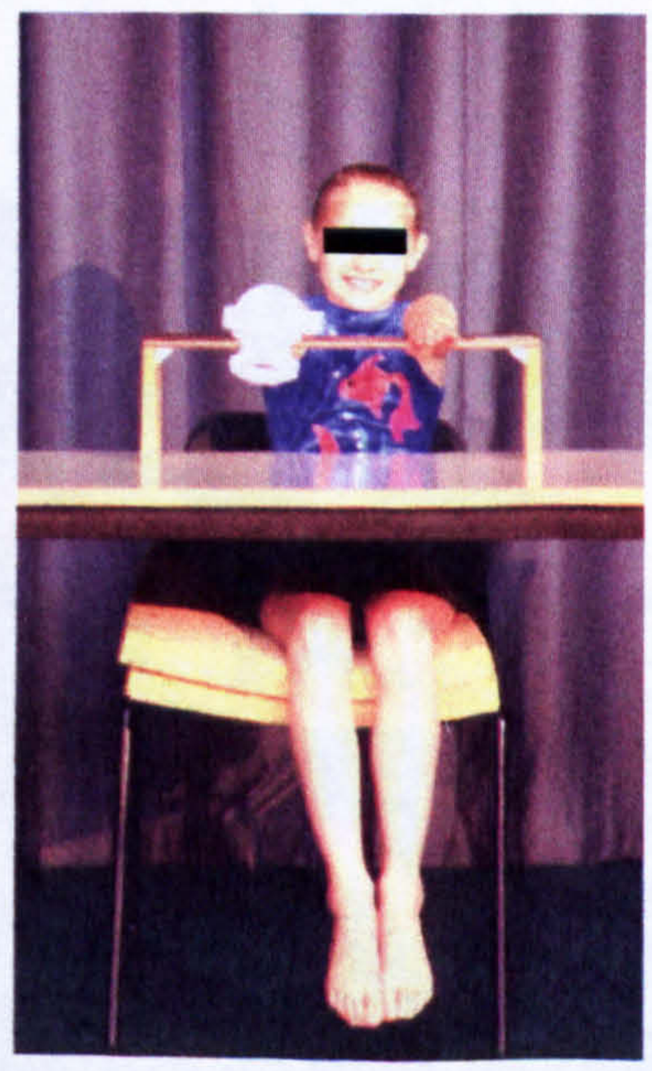
Figure 5.23. Clinical measurement of (a) shoulder flexion and (b) shoulder extension.

Shoulder internal/external rotation

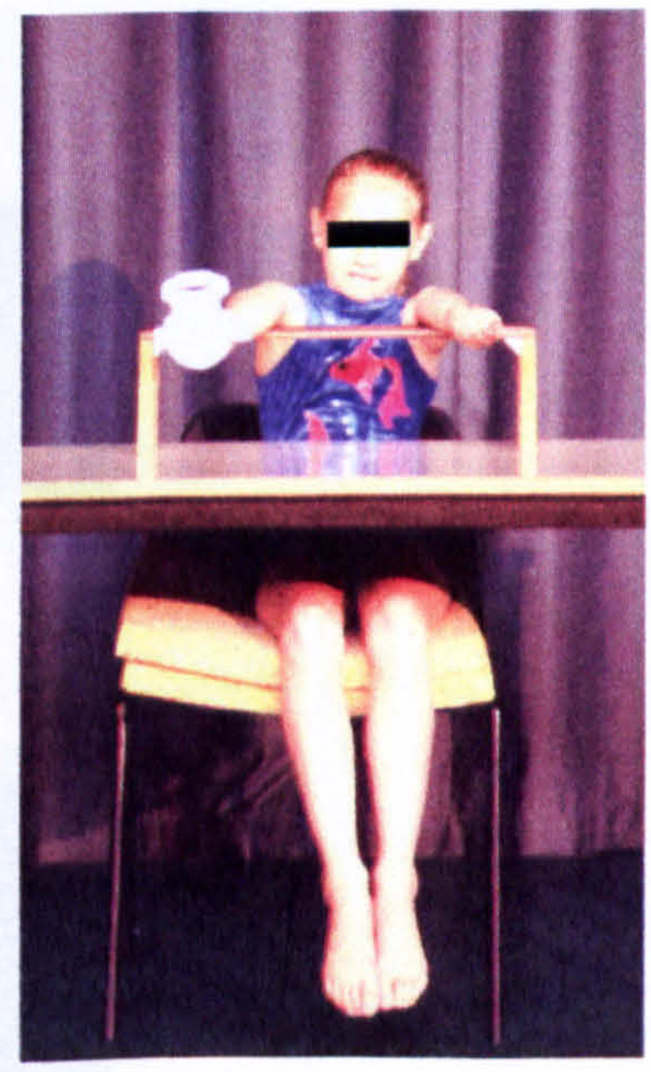
The gymnast was seated and their height adjusted using foam layers so that the shoulder was level with the lower arms, which were resting on a wooden support.



(c) shoulder internal rotation



'neutral' position



(d) shoulder external rotation

Figure 5.24. Clinical measurement of (c) shoulder internal rotation and (d) shoulder external rotation.

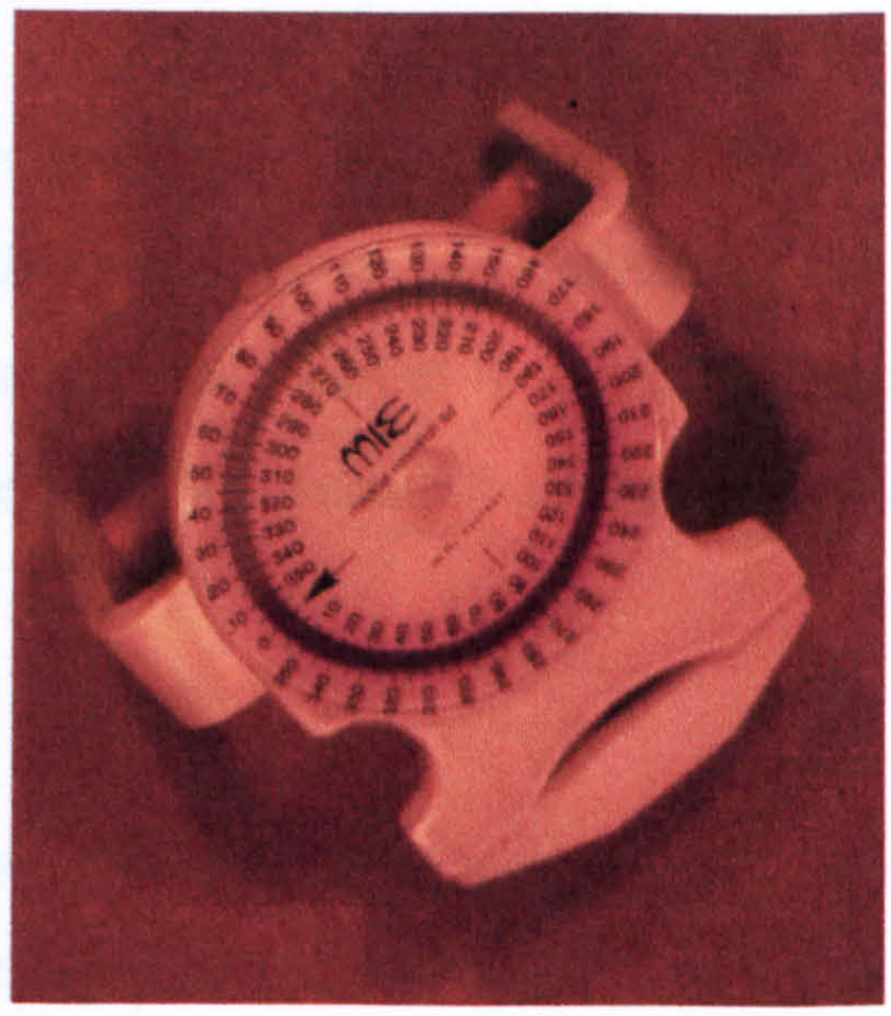
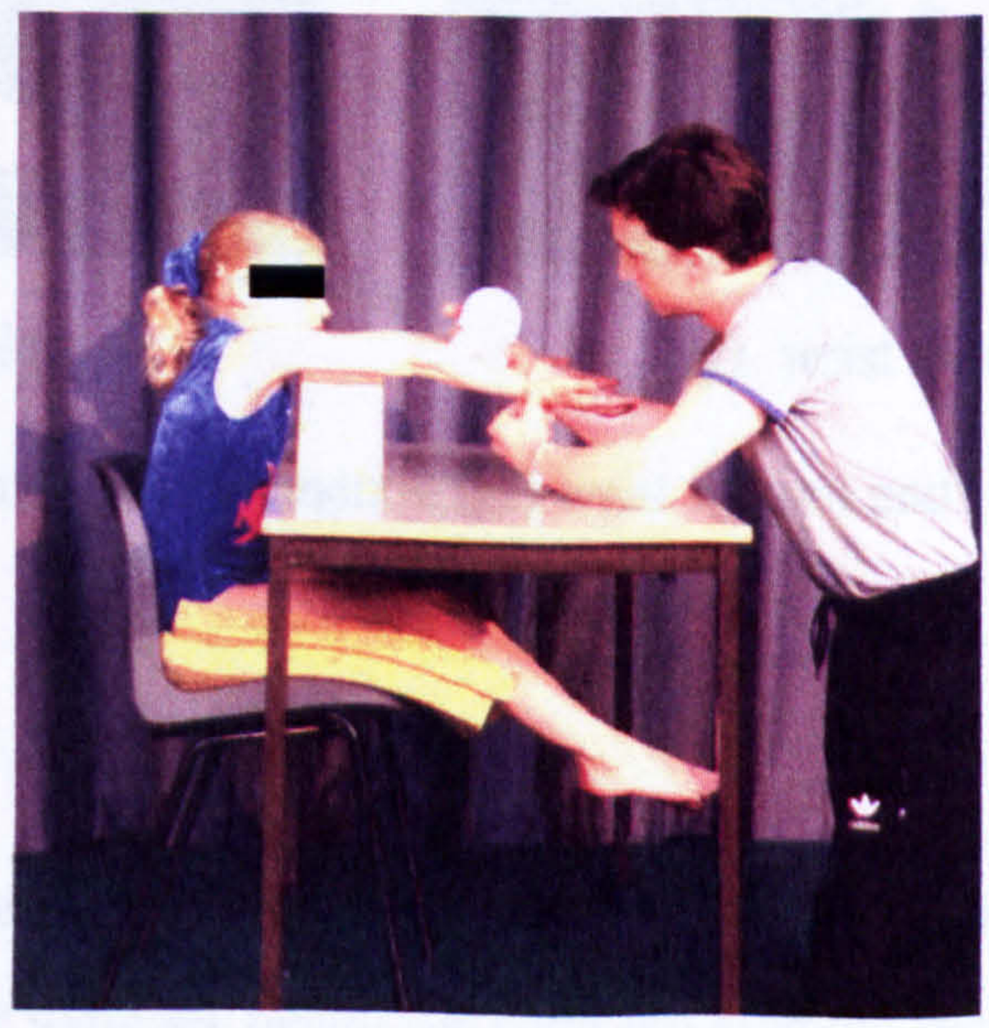



Figure 5.25. Modifications made to the MIE inclinometer.

An inclinometer was fitted with a handle (Figure 5.25) which the gymnast grasped with the right hand. After the inclinometer was zeroed in the neutral position the gymnast was instructed to internally rotate the arms, a reading was taken at the point of maximum rotation. The arms were returned to the neutral position after which the gymnast was instructed to externally rotate the arms, once again a reading was taken at the point of maximum rotation. In both instances care was taken to ensure that left and right arms were rotated equally and that the wrists were aligned with the lower arm.

Elbow hyper-extension



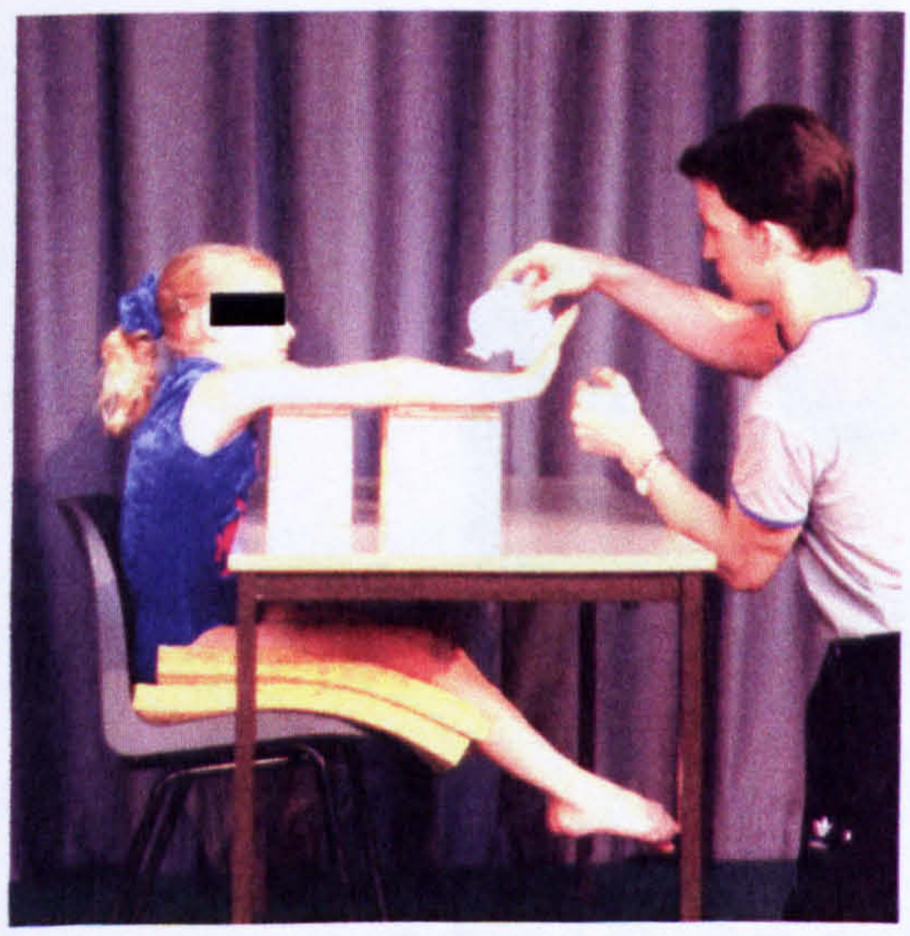
(e) elbow hyper-extension

Figure 5.26. Clinical measurement of (e) elbow hyper-extension.

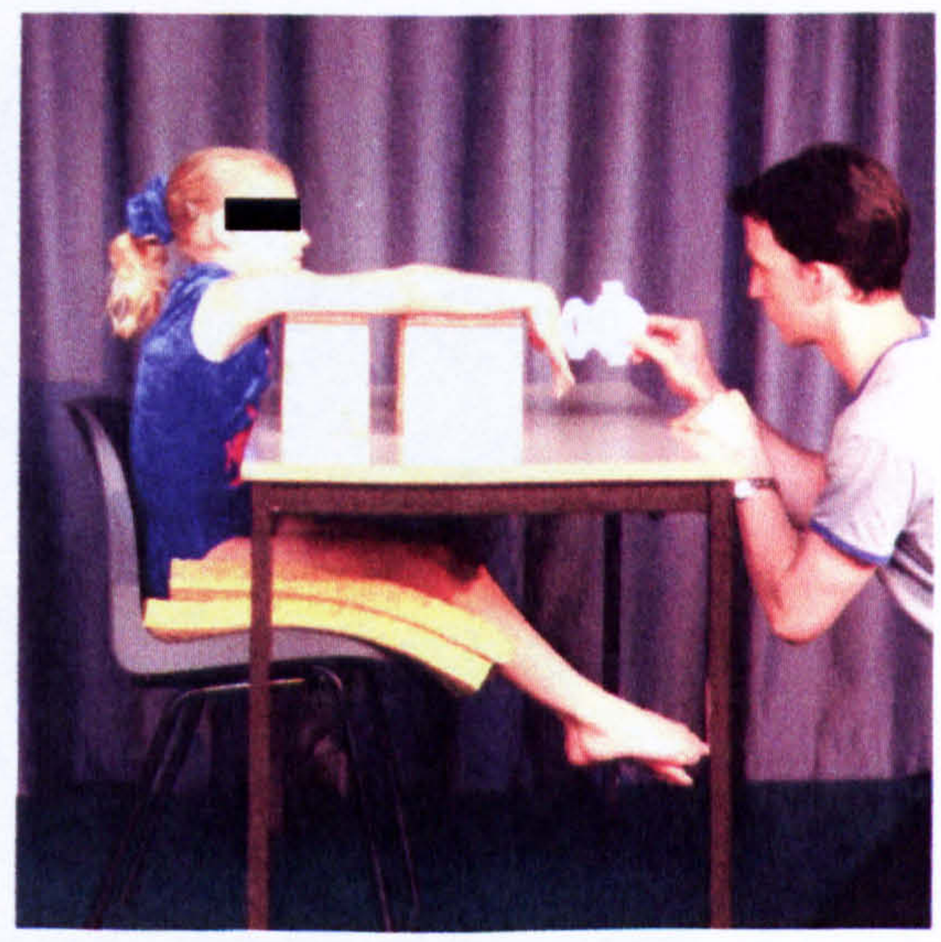
The gymnasts was seated as previously but with the upper arms resting on the wooden support in a supinated position. The inclinometer was placed on the forearm and set to zero with the elbow straight (zero degrees of extension). The gymnast was instructed to extend the elbow and a reading was taken at the point of maximum extension. Care was taken to ensure that the upper body remained fixed throughout the measurement.

Wrist flexion/extension

The gymnast was seated as previously with a second wooden support placed under the forearms. An inclinometer was modified so that its base would fit on the back of a child's hand and still allow maximum flexion (Figure 5.25). The modified inclinometer was placed on the back of the right hand and set to zero with the hand in line with the arm. Both wrists were flexed then extended with readings being taken at the maximum points. Again, care was taken to ensure the upper body and upper extremities remained fixed throughout the measurement.



(f) wrist flexion



(g) wrist extension

Figure 5.27. Clinical measurement of (f) wrist flexion and (g) wrist extension.

Hip flexion

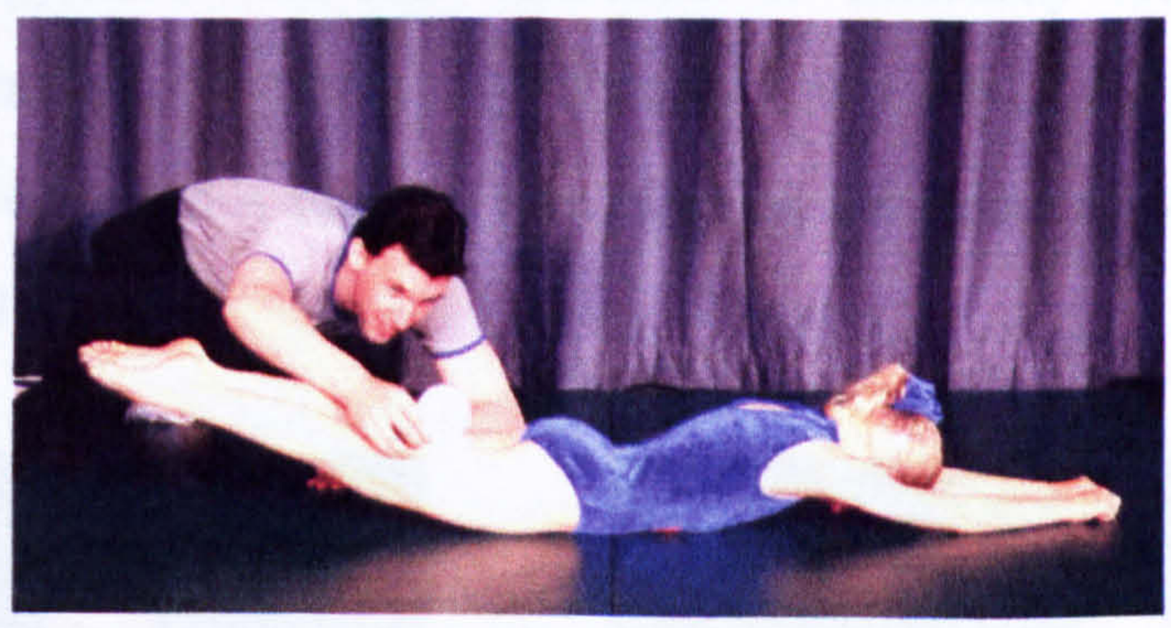
With the gymnast supine the inclinometer was placed on the anterior aspect of the right shin and set to zero. The gymnast flexed the right hip keeping the knees extended and the hips square and in contact with the floor. A reading was taken at the point of maximum hip flexion (Figure 5.28).

(h) hip flexion

Figure 5.28. Clinical measurement of (h) hip flexion.

Hip extension

With the gymnast prone, the inclinometer was placed on the posterior aspect of the right thigh and set to zero. The gymnast extended both hips whilst keeping the knees extended (Figure 5.29). A reading was taken at the point of maximum hip extension.

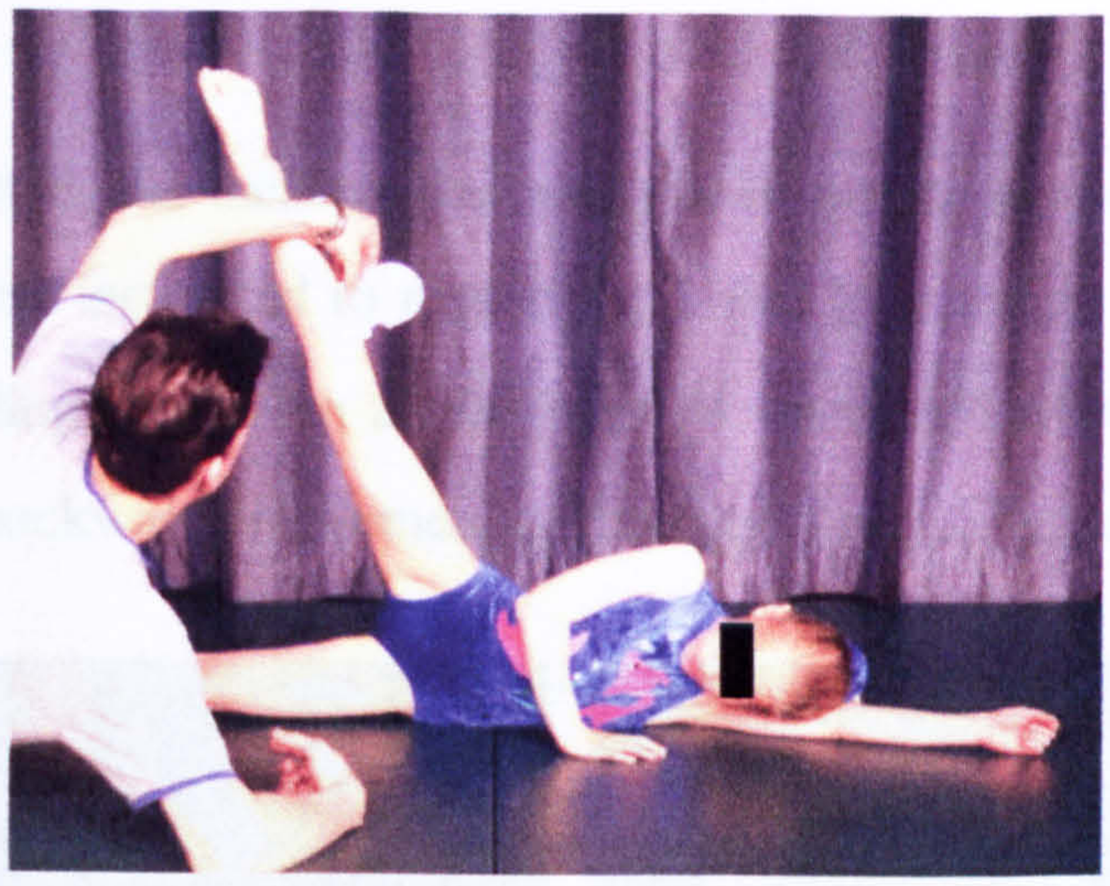


(i) hip extension

Figure 5.29. Clinical measurement of (i) hip extension.

Hip abduction

With the gymnast resting on the left side of the body, the right leg was raised until parallel with the floor. At this point the inclinometer was placed on the lateral side of the lower leg and set to zero. The gymnast was instructed to abduct the right leg whilst keeping the knee pointing forwards and maintaining a straight body. A reading was taken at the point of maximum abduction (Figure 5.30).

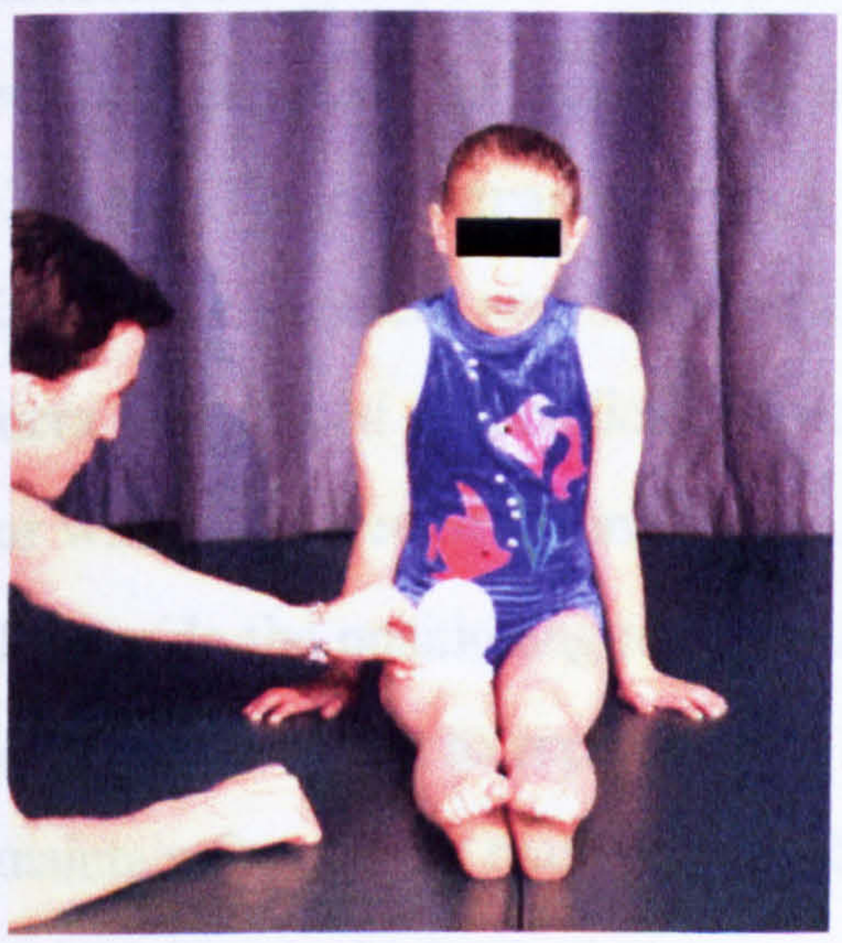


(j) hip abduction

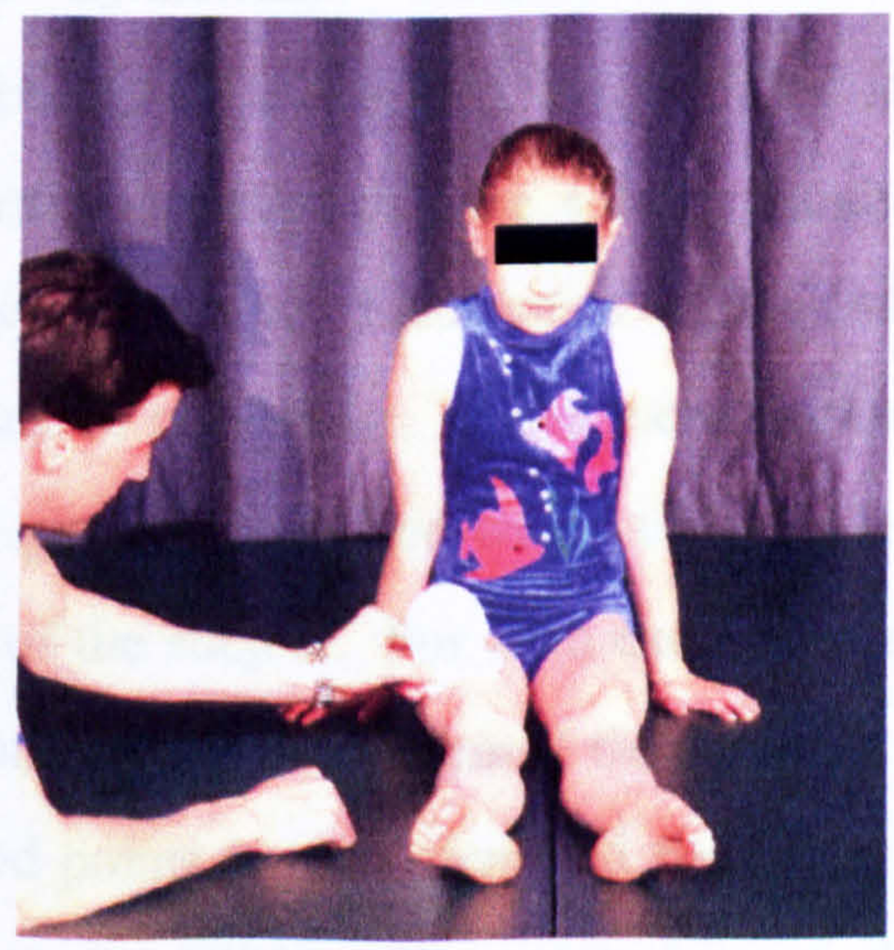
Figure 5.30. Clinical measurement of (j) hip abduction.

Hip external rotation

The gymnast adopted a seated position with knees and heels together. The inclinometer was placed on the anterior thigh just above the knee and set to zero with the soft tissue compressed. The gymnast was then instructed to externally rotate both hips whilst maintaining full extension of the knee. With the compression of the soft tissue maintained throughout the measurement a reading was taken at the point of maximum hip external rotation (Figure 5.31).



hip external rotation 'neutral'



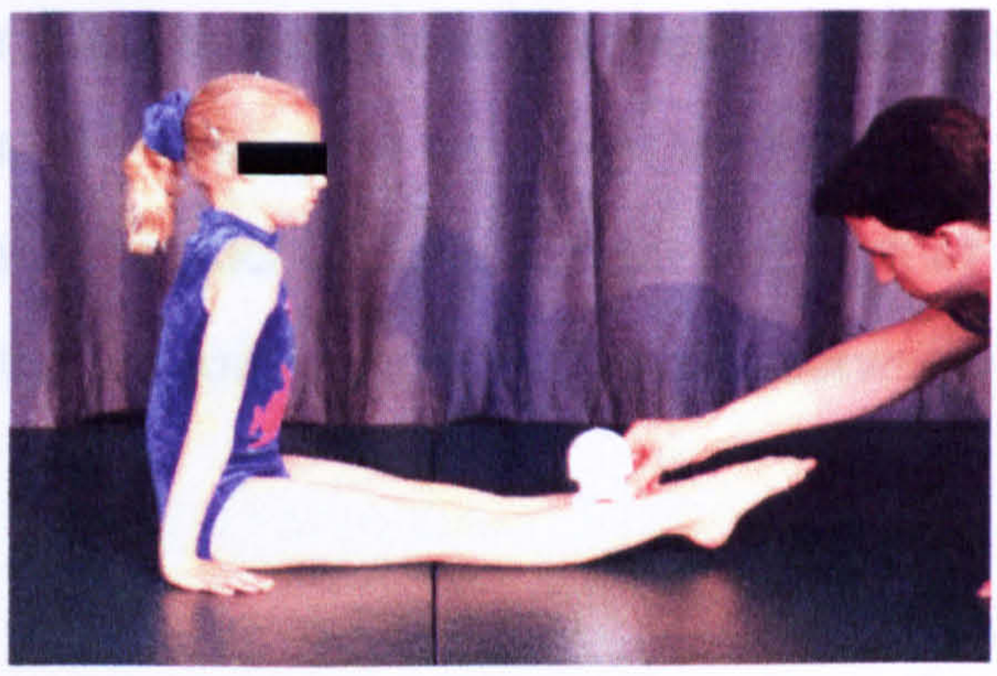
(k) hip external rotation

Figure 5.31. Clinical measurement of (k) hip external rotation.

Knee hyper-extension

With the gymnast seated, the inclinometer was placed on the lower right shin and set to zero. The gymnast was instructed to extend the knees by pressing the back of the knees into the mat. A reading was taken at the point of maximum extension with care being taken to prevent any backwards movement of the upper body (Figure 5.32).

knee hyper-extension 'neutral'



(l) knee hyper-extension

Figure 5.32. Clinical measurement of (l) knee hyper-extension.

*Functional flexibility*

Range of movement was also estimated using a battery of static and dynamic flexibility measurements specific to Women's Artistic Gymnastics. Details of the measurement procedure including the positioning and alignment of the subject are provided in Figures 5.33-5.46. The performance of each gymnast was recorded using a Sony Handycam Hi8 (CCD-VX1E) camera and subsequently time coded (IMP Electronics V9000 IMP). The camera was placed perpendicular to the plane of movement. Lines were marked on the floor within the area of testing to ensure the gymnast remained within the plane of motion and to guide the positioning and orientation of the subject. For each exercise, three video fields were identified to represent the maximum range of movement the gymnast was able to maintain for at least two seconds. Selected points in each identified field were digitised using the Target high resolution system (Kerwin, 1995). The points in each field were digitised twice and averaged. A record of the points digitised for each exercise is provided in the set-up files contained in Appendix 5.4. The digitised data were transformed into real coordinates using 2-D DLT. An analysis program was written to determine joint angles using trigonometry. An example of the process through which the digitised data were

used to derive joint angles is presented in Figure 5.47. An example showing the calculated angles for each exercise together with the video data for each of the flexibility measurements are provided in Figures 5.48-5.67.

Shoulder flexion

The gymnast grasped a wooden pole with the index fingers placed biacromial width apart and was instructed to flex the shoulders maximally. The arms were kept straight with the chest held in. Points were digitised at the elbow, shoulder and on the front and back of the leotard to determine the average location of the hip joint centre. The angle between the torso and the upper arm was determined.

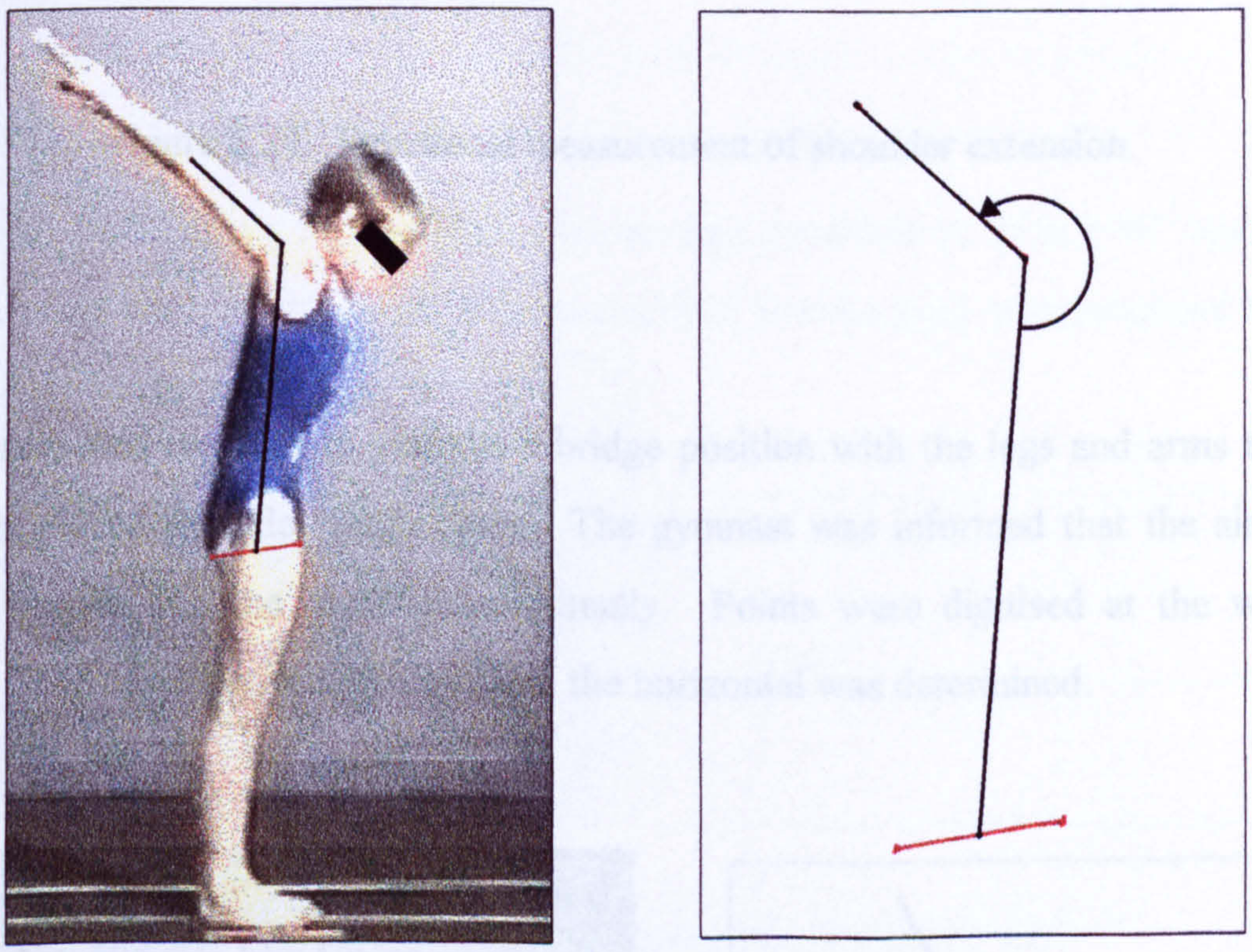


Figure 5.33. Functional measurement of shoulder flexion.

Shoulder extension

Holding the pole as in the exercise above, the gymnast was required to extend the shoulders maximally. Care was taken to avoid excessive forwards lean. The angle between the torso and the upper arm was determined.

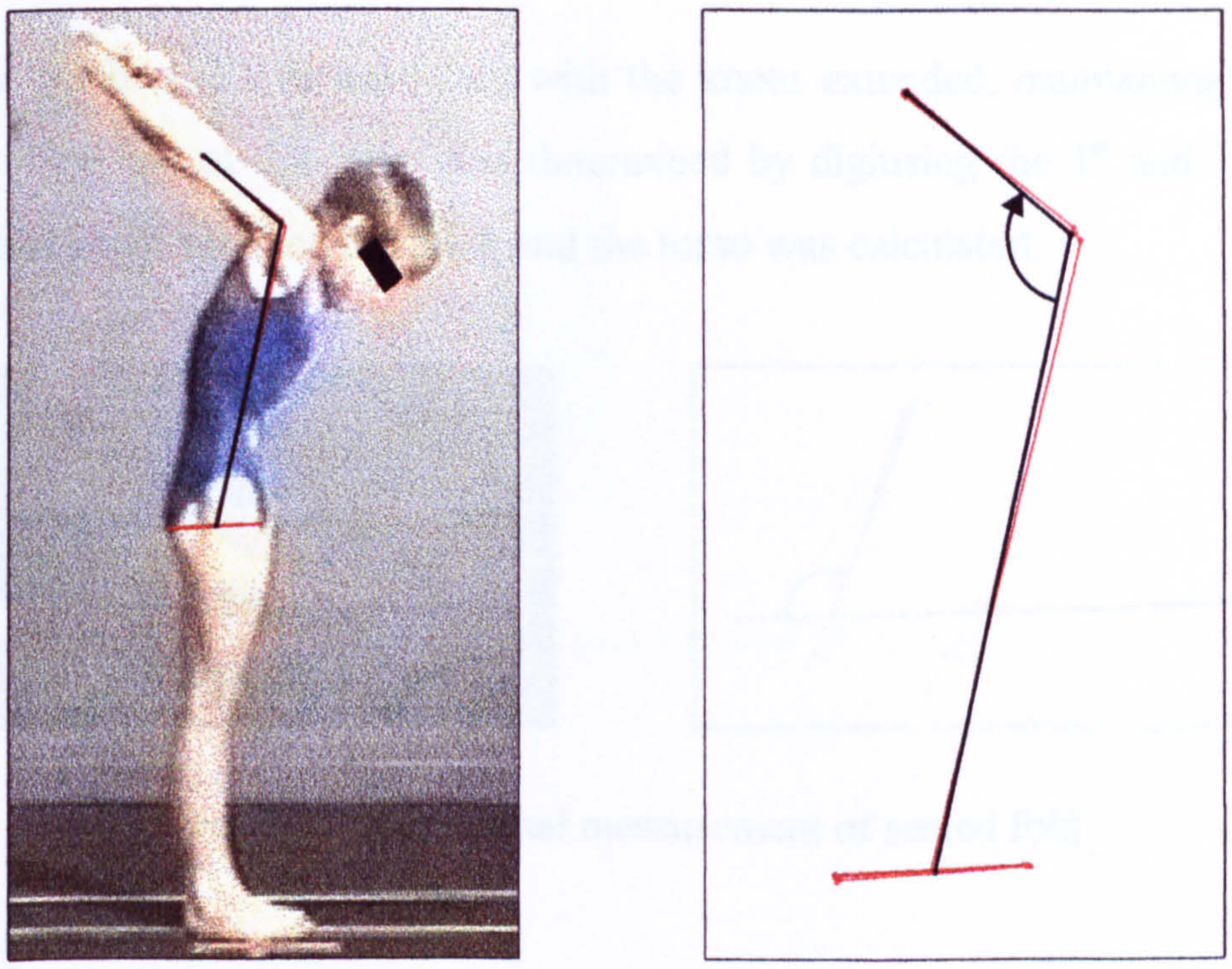


Figure 5.34. Functional measurement of shoulder extension.

Bridge

The gymnast was required to perform a bridge position with the legs and arms extended and hands placed shoulder width apart. The gymnast was informed that the aim of the exercise was to flex the shoulders maximally. Points were digitised at the wrist and shoulder. The angle between the arm and the horizontal was determined.

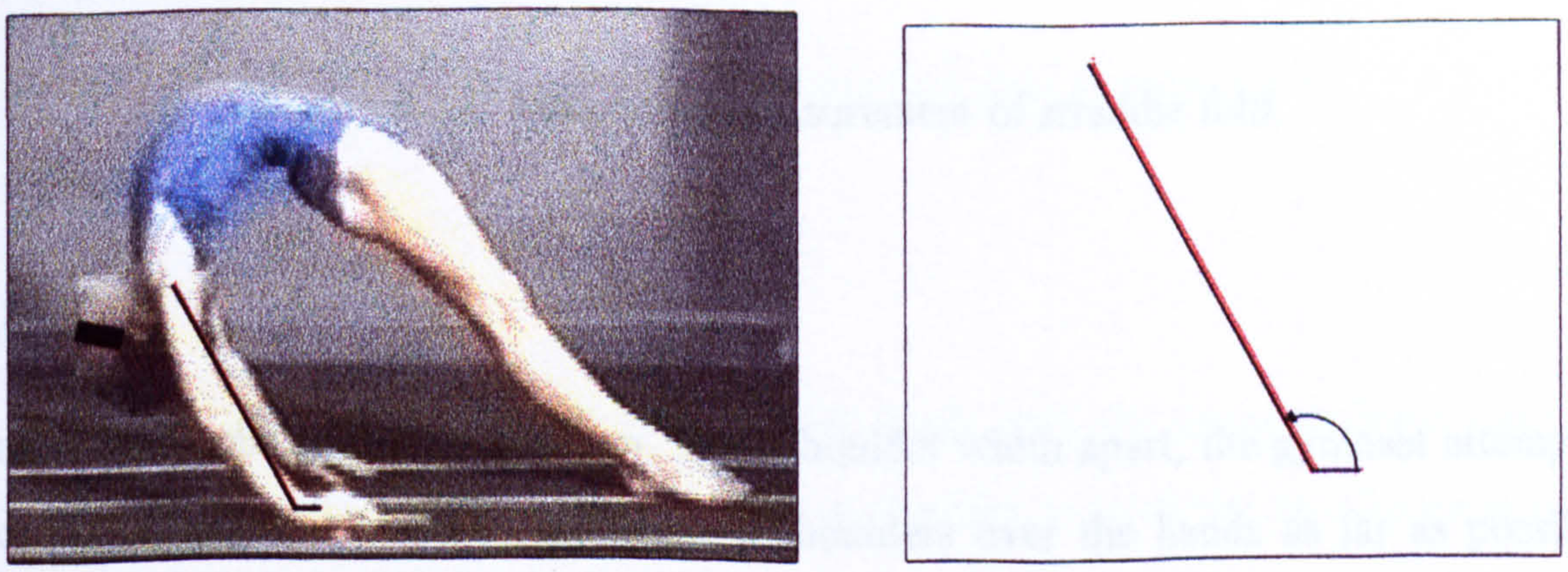


Figure 5.35. Functional measurement of bridge.

Seated fold

The gymnast performed a forward fold with the knees extended, maintaining a flat back throughout. The line of the torso was determined by digitising the 1st and 12th thoracic vertebrae. The angle between the thigh and the torso was calculated.

Figure 5.36. Functional measurement of seated fold.

Straddle fold

The gymnast performed a forward fold with the legs straddled to form a 90° angle. The line of the torso was determined as in the seated fold and the angle was measured between the torso and the horizontal.

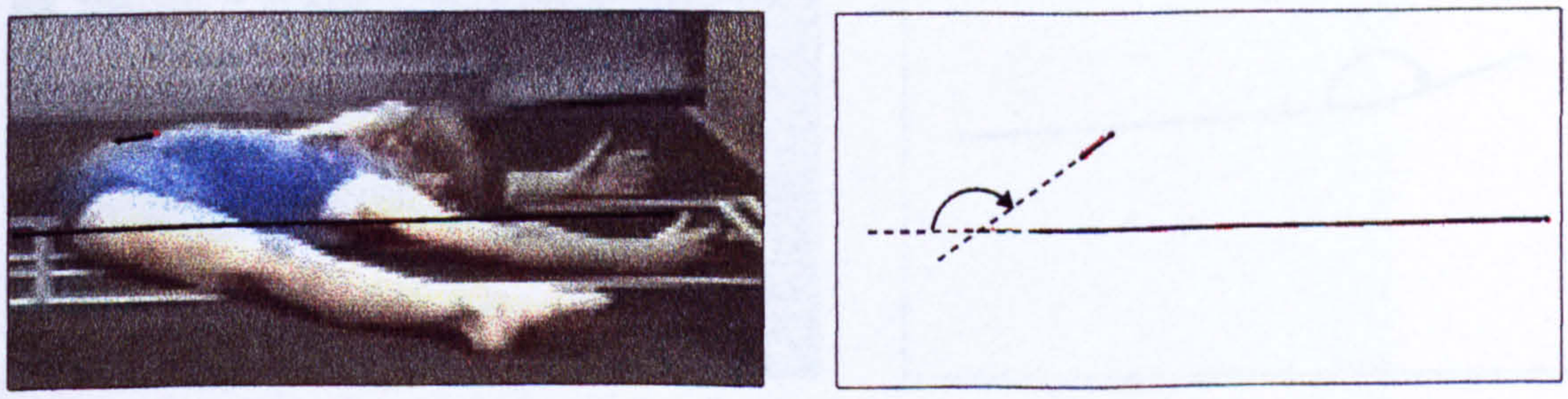


Figure 5.37. Functional measurement of straddle fold.

Wrist flexion

With the hands placed flat on the floor, arms shoulder width apart, the gymnast attempted to flex the wrists maximally by moving the shoulders over the hands as far as possible. The gymnasts were instructed to keep the hands flat on the floor and the arms extended throughout the exercise. Points were digitised at the elbow, wrist and middle finger (dactylion). The angle between the hand and lower arm was calculated.

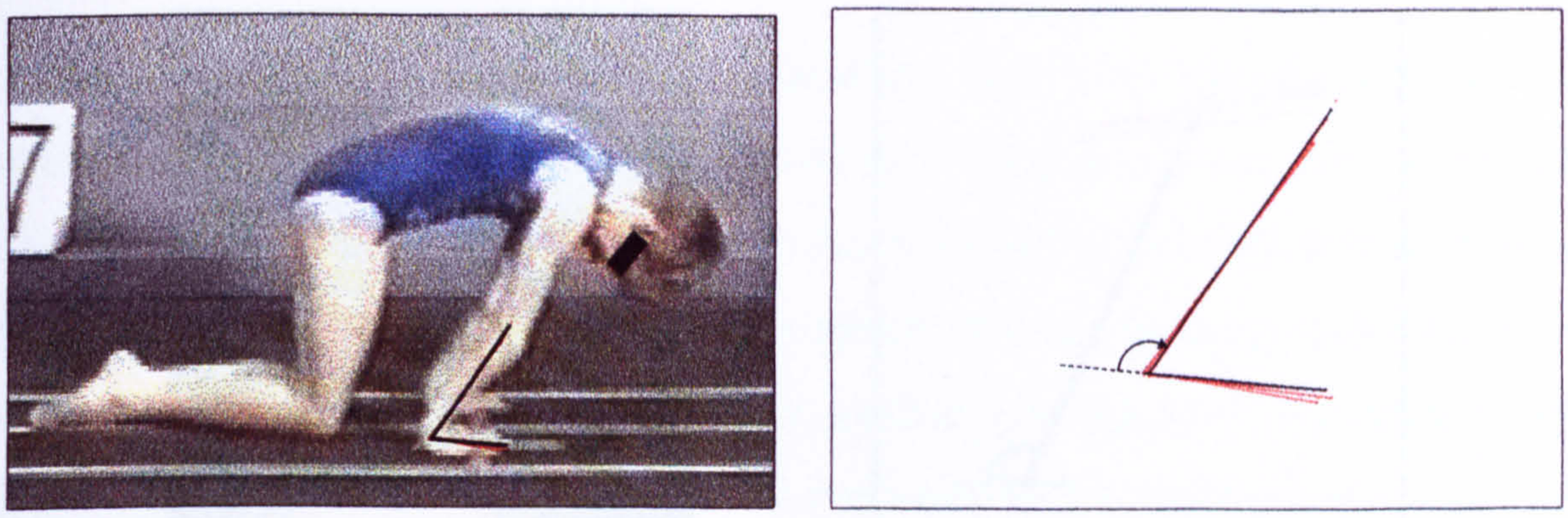


Figure 5.38. Functional measurement of wrist flexion.

Ankle plantar flexion

Sitting in an extended position, the gymnast was instructed to maximally plantar flex the feet. Points were digitised on the knee, lateral maleolus and first metatarsal. The angle of plantar flexion was determined as above.

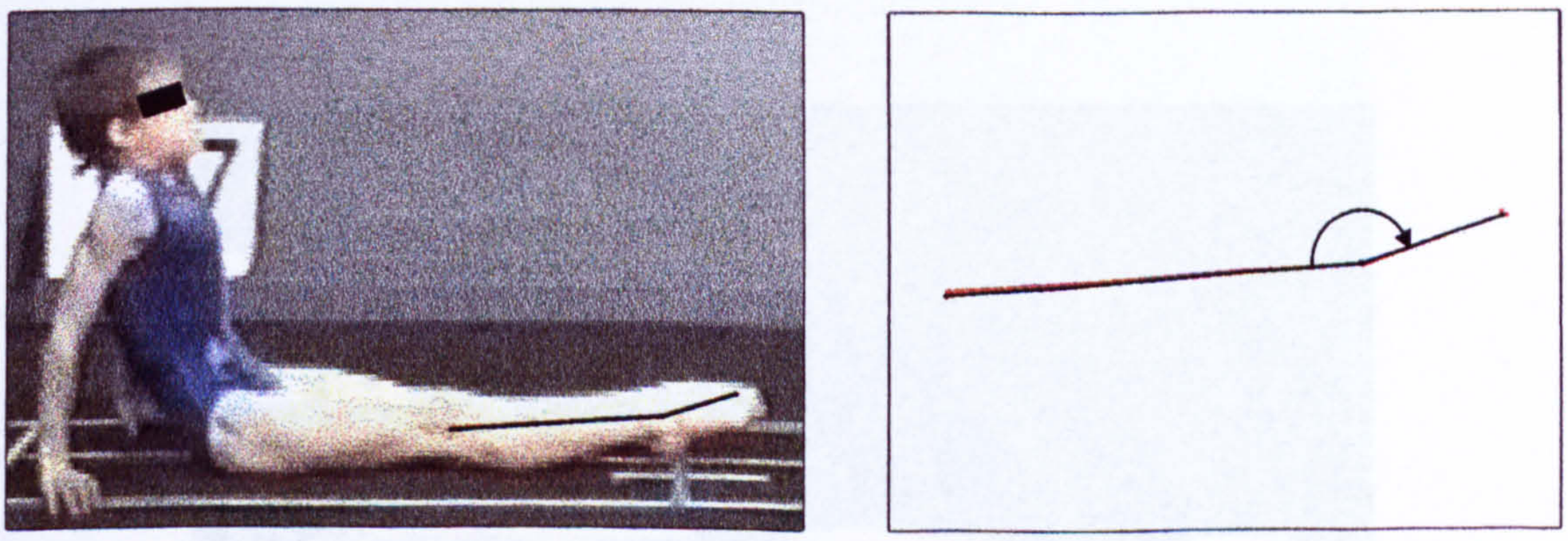


Figure 5.39. Functional measurement of ankle plantar flexion.

'D' angle

In a kneeling position the gymnast grasped both heels with the knees pressed together. While keeping hold of the heels the gymnast was required to push the hips forward as far as possible. Points were digitised at the knee and on the front and back of the leotard to determine the average location of the hip joint centre. The angle between the horizontal and the line joining the knee to the hip joint centre was determined.

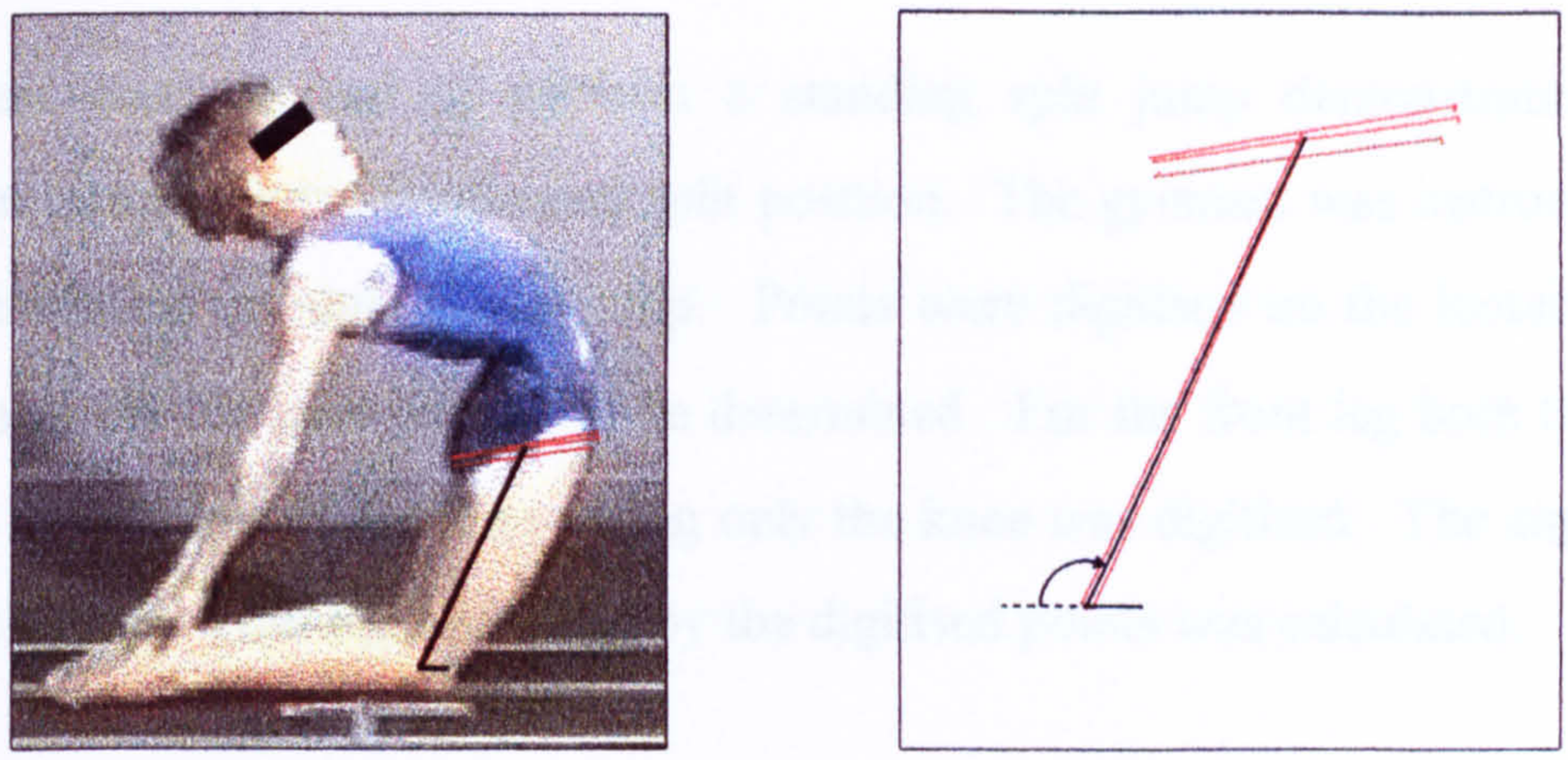
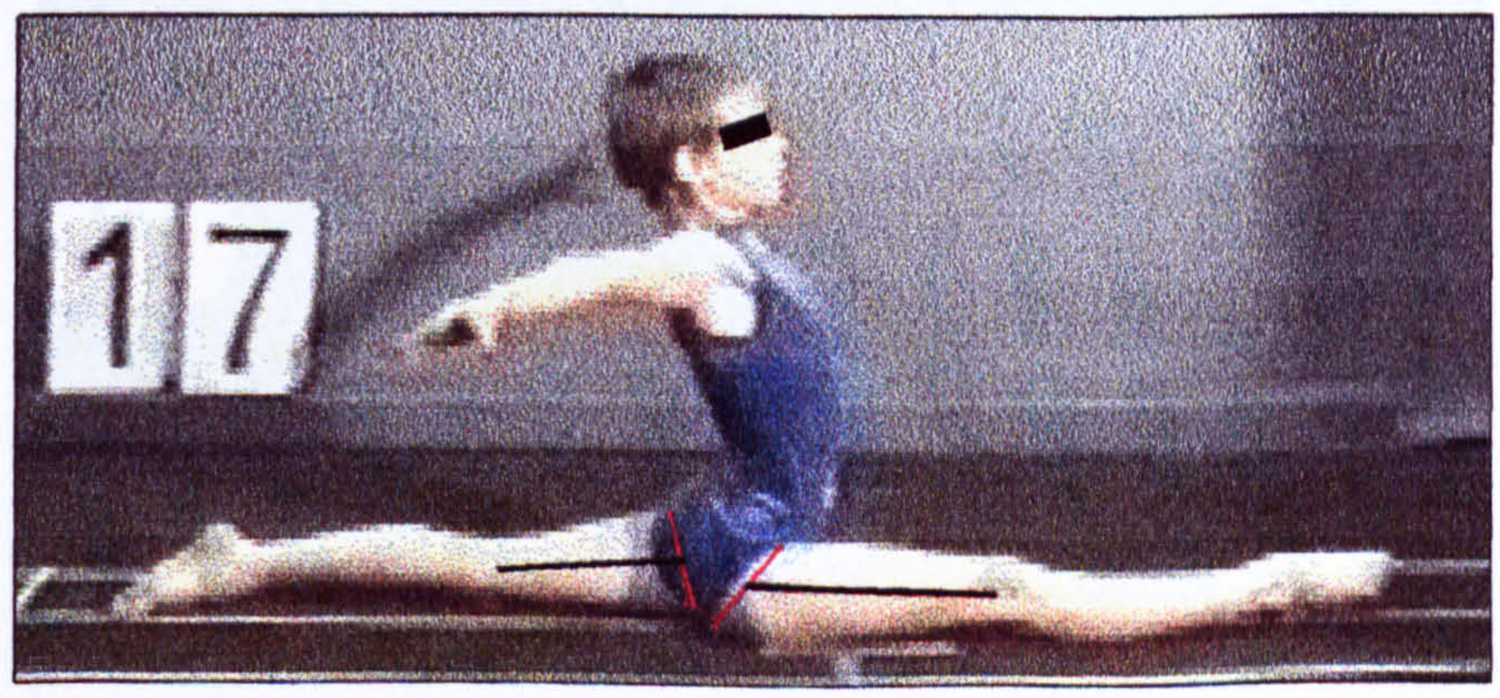


Figure 5.40. Functional measurement of 'D' angle.

Splits

The gymnast was instructed to perform the splits along a line on the floor. They were instructed to produce the maximum split while keeping the hip aligned in the frontal plane. The observer checked that this alignment was maintained throughout the exercise. Care was taken to ensure that the knee of the rear leg faced the floor at all times.



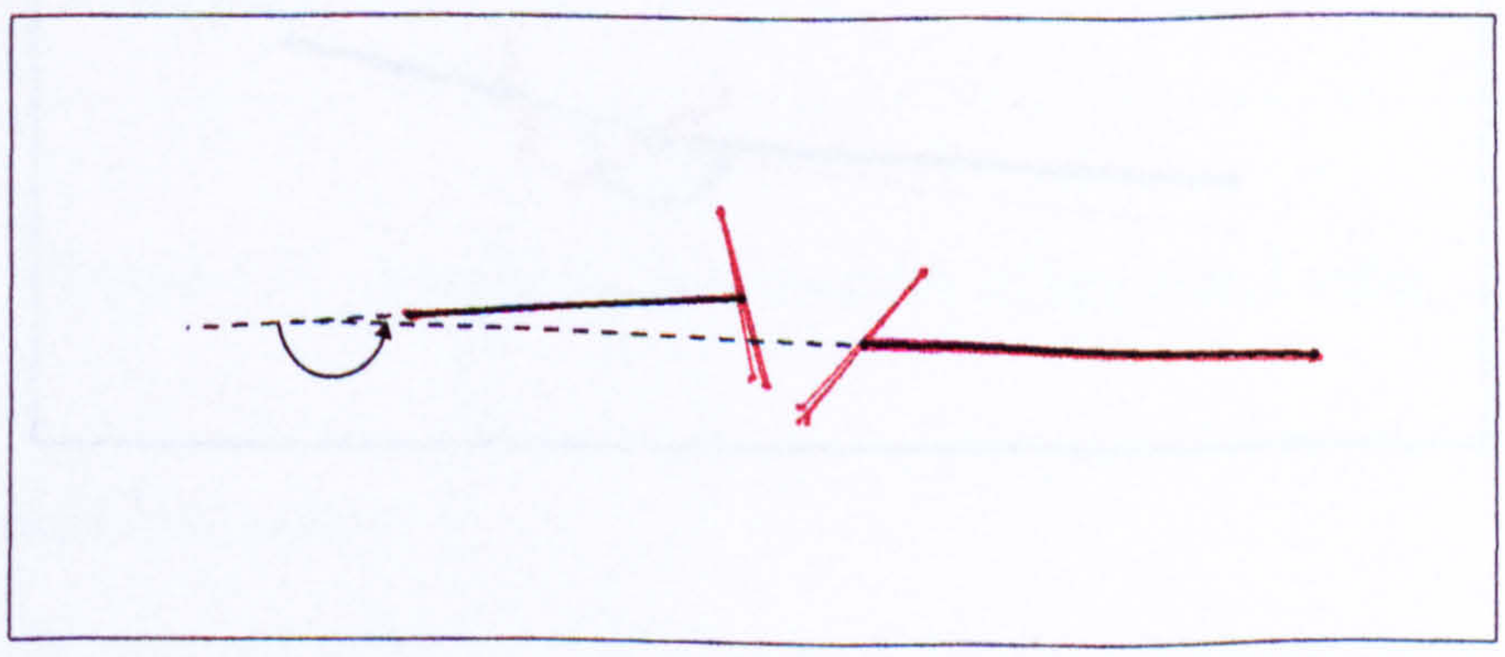



Figure 5.41. Functional measurement of splits.

Split jumps

The gymnast was required to perform a standing split jump demonstrating maximal amplitude in terms of jump height and split position. The gymnast was instructed to keep the knees extended throughout the jump. Points were digitised on the leotard to permit the location of the hip joint centres to be determined. For the front leg both the knee and ankle were digitised while for the rear leg only the knee was digitised. The angle between the rear leg and the front leg as defined by the digitised points was calculated.

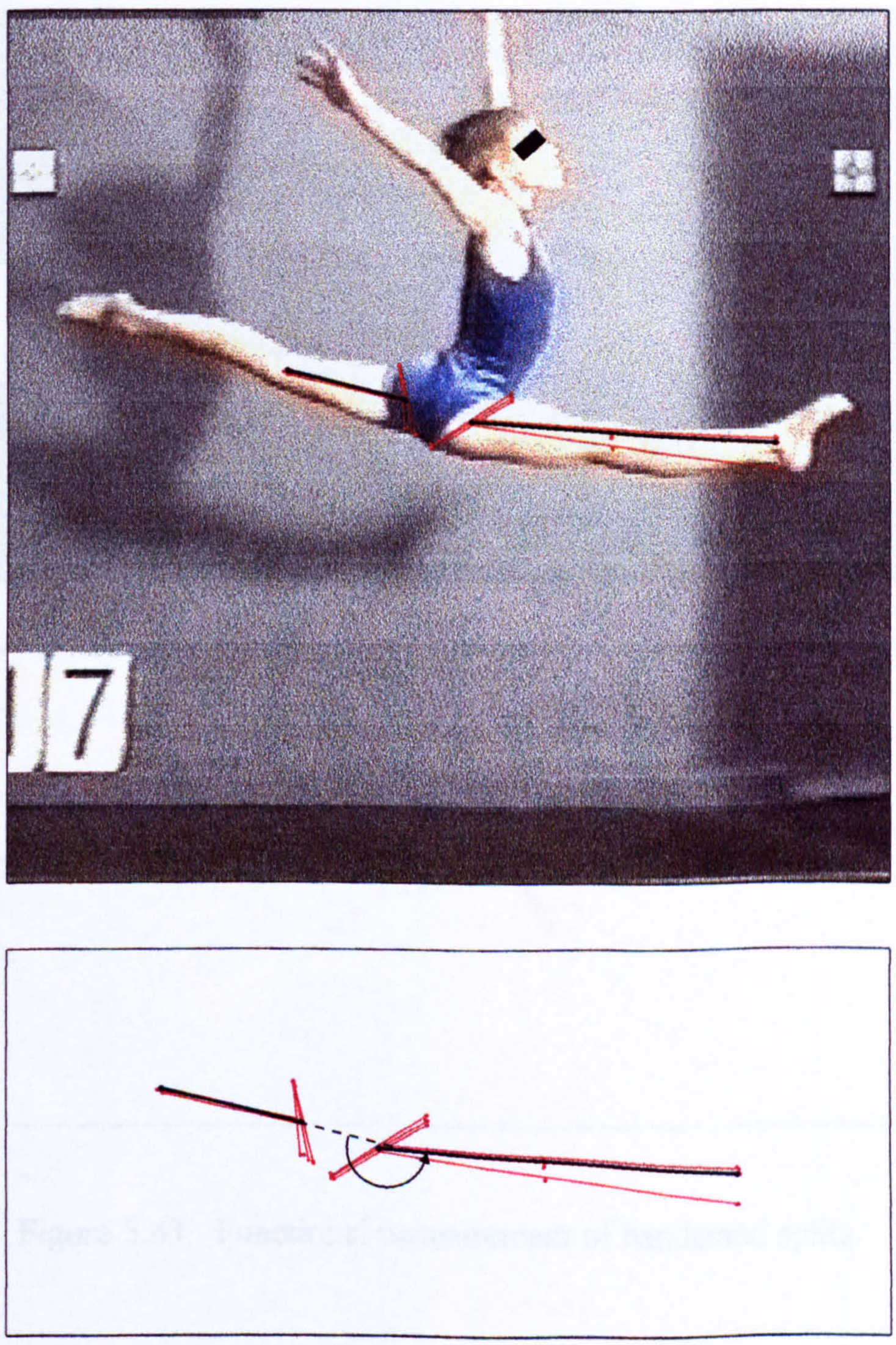



Figure 5.42. Functional measurement of split jumps.

Handstand splits

The gymnast was required to hold a still handstand with legs in a split position. The gymnast was instructed to show amplitude in the splits while maintaining the legs perpendicular to the axis of the camera lens. The observer held the gymnast's front foot to assist the gymnast to maintain balance. Points were digitised on the left and right knees and on the leotard to permit the location of the hip joint centres to be determined. The angle between the rear leg and the front leg as defined by the digitised points was calculated.

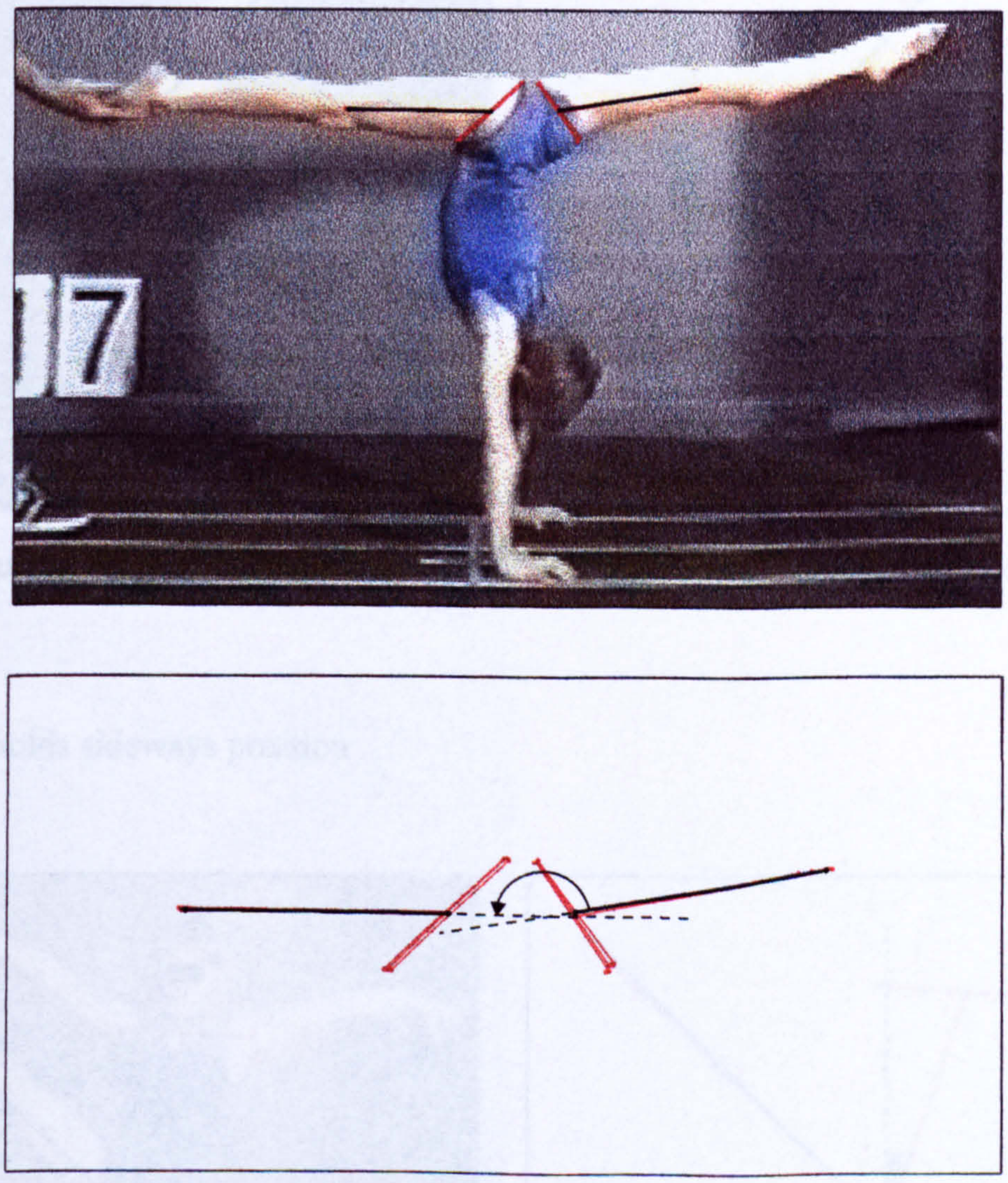



Figure 5.43. Functional measurement of handstand splits.

Leg lift and holds front position

The gymnast was required to lift the leg as high as possible and hold the position for five seconds. Instructions were given to extend the knees and maintain an erect posture

throughout the exercise. Points were digitised to determine the location of the hip joint centre of the raised leg. The hip of the support leg was assumed to be in line with that of the raised leg. Points were also digitised at the knee and ankle of the raised leg and the knee of the support leg. The angle between the support leg and the raised leg was calculated.

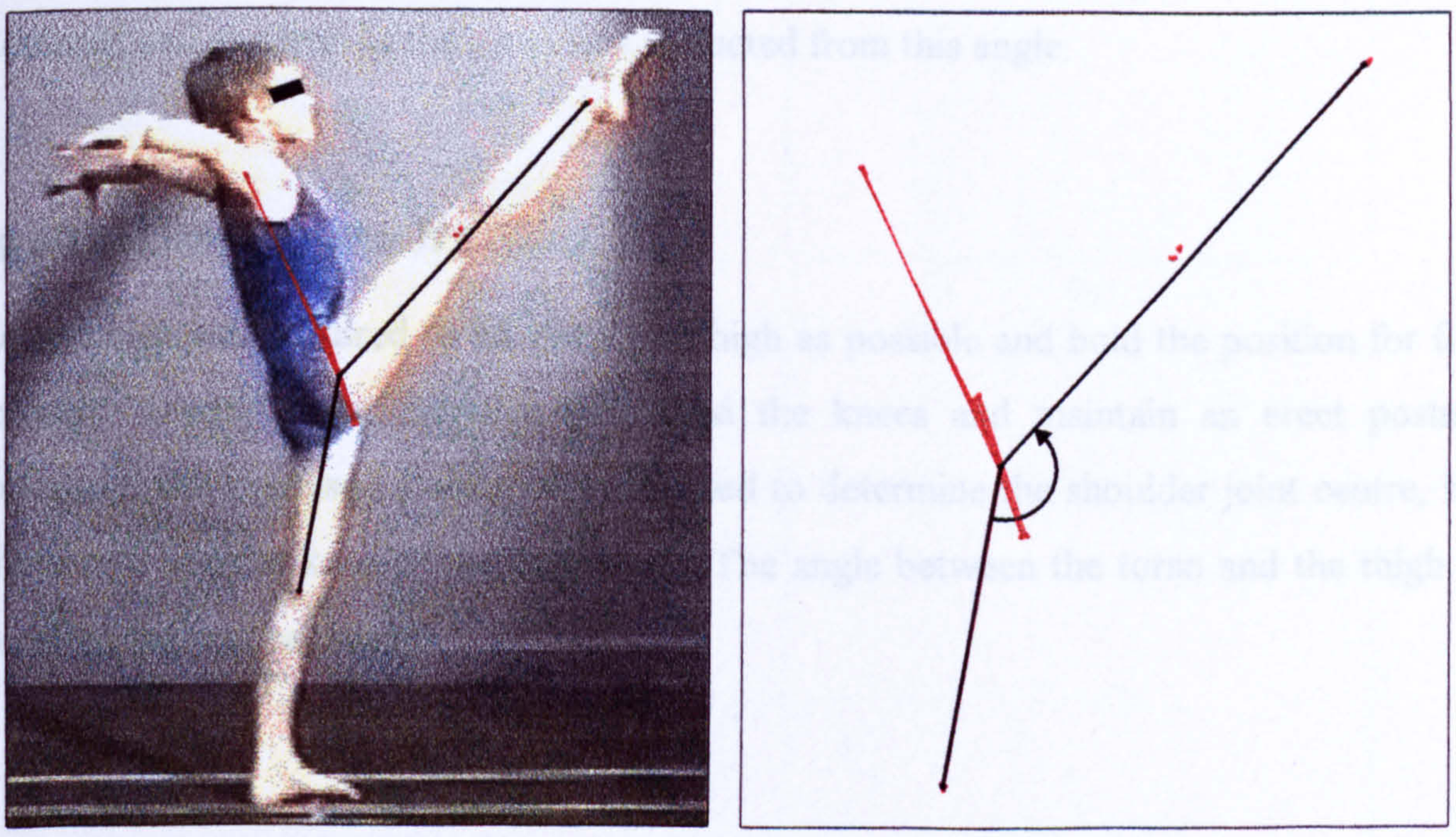


Figure 5.44. Functional measurement of leg lift and holds front position.

Leg lift and holds sideways position

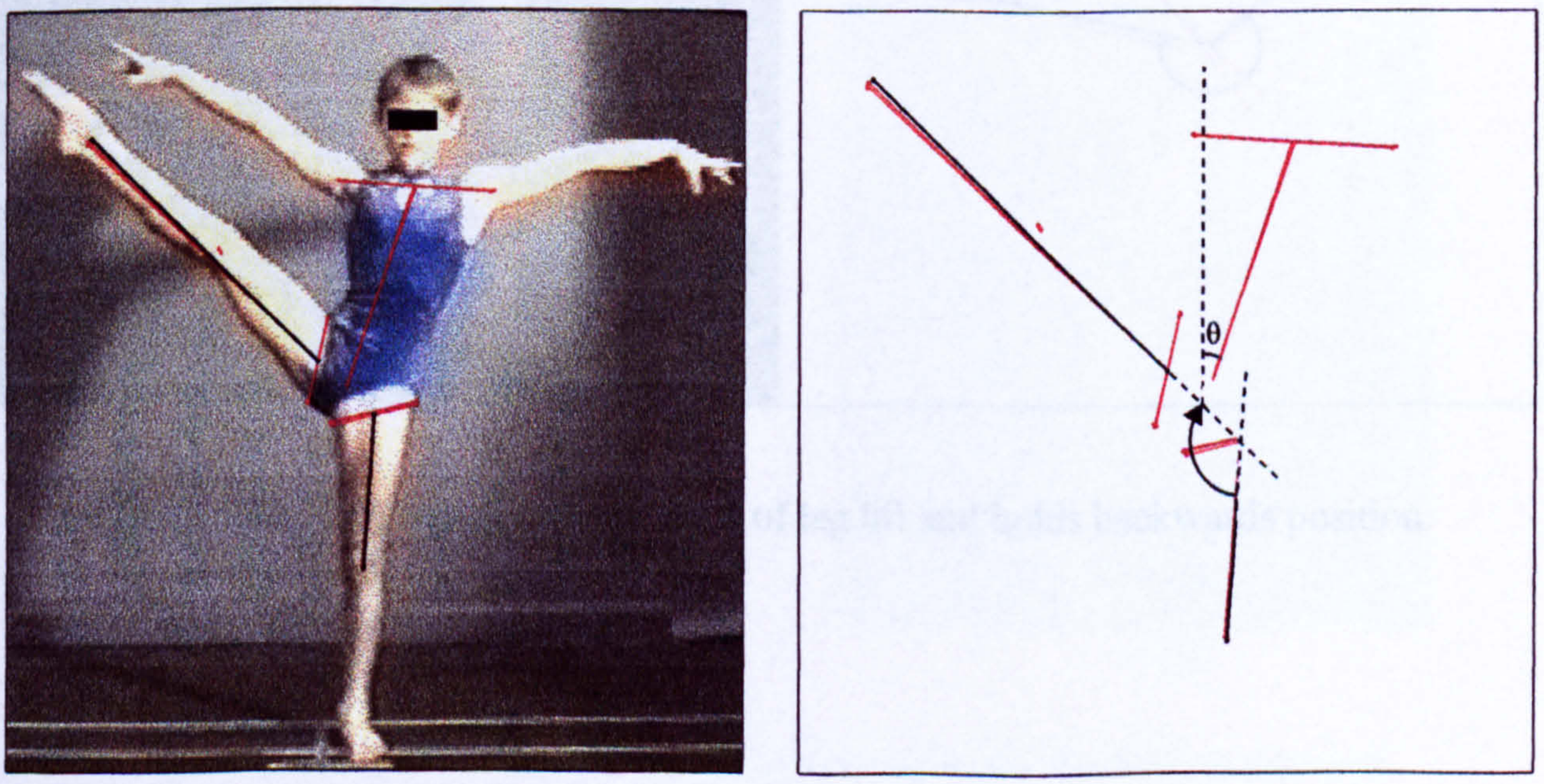



Figure 5.45. Functional measurement of leg lift and holds sideways position.

The gymnast was required to lift the leg as high as possible and hold the position for five seconds. Instructions were given to extend the knees and maintain an erect posture throughout the exercise. Points were digitised to determine the location of both hip joint centres, knees and the ankle of the raised leg. In addition, the shoulder joint centres were digitised so that the torso lean angle could be determined from the average hip and shoulder joint locations. The angle between the support leg and the raised leg was calculated and any lean of the torso was deducted from this angle.

Leg lift and holds backwards position

The gymnast was required to lift the leg as high as possible and hold the position for five seconds. Instructions were give to extend the knees and maintain an erect posture throughout the exercise. Points were digitised to determine the shoulder joint centre, hip joint centre and the knee of the raised leg. The angle between the torso and the thigh of the raised leg was calculated.

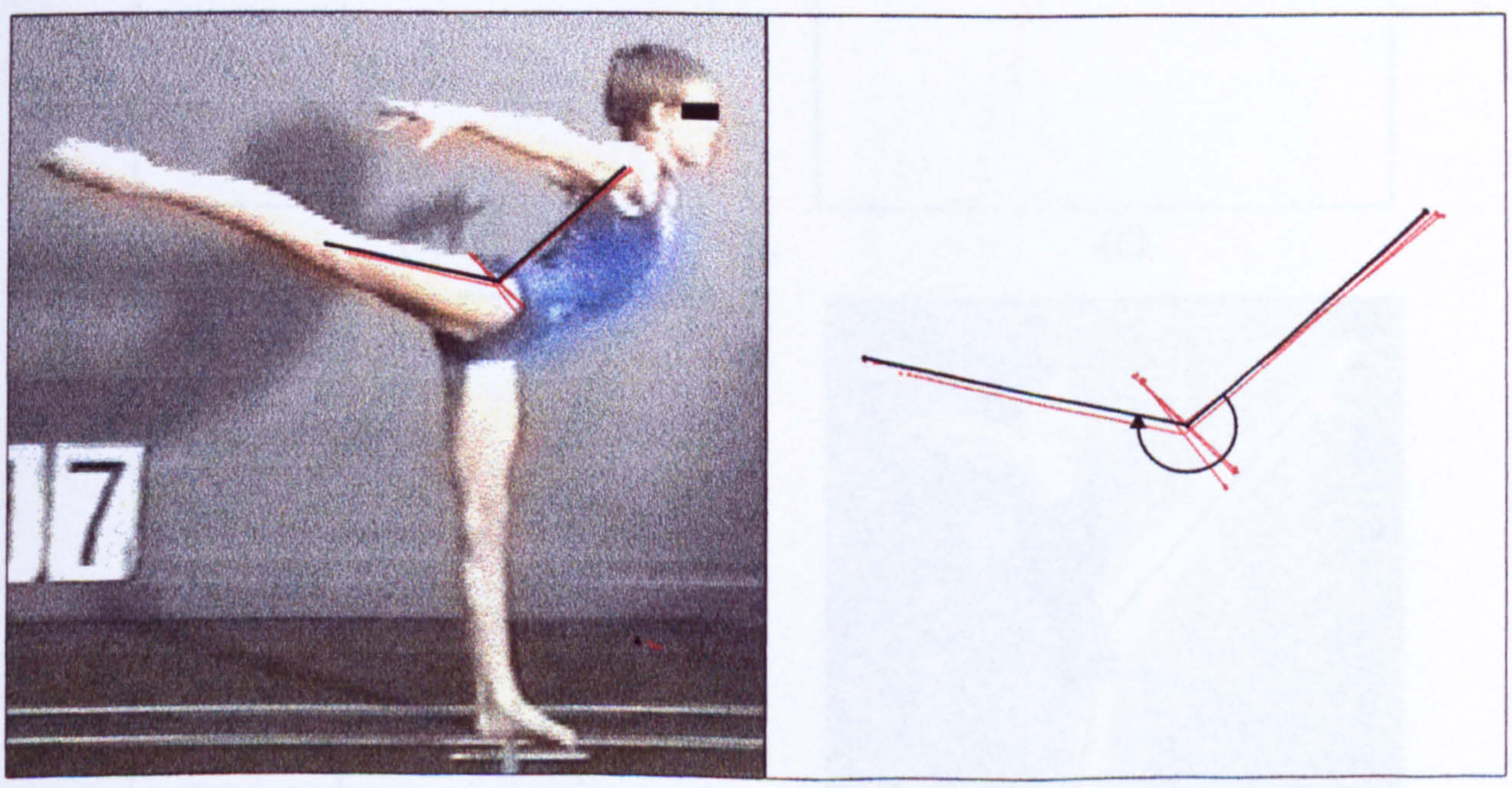



Figure 5.46. Functional measurement of leg lift and holds backwards position.

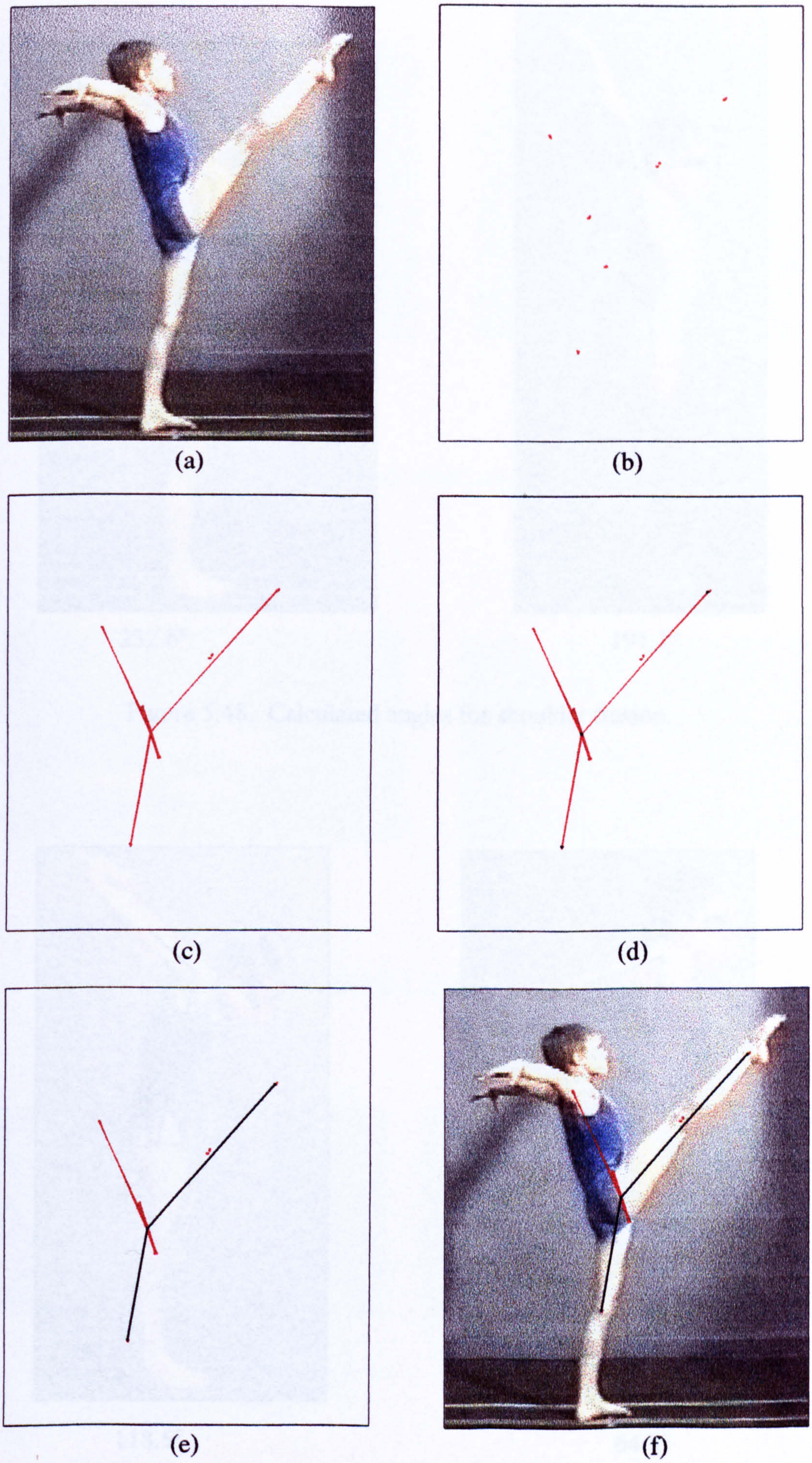
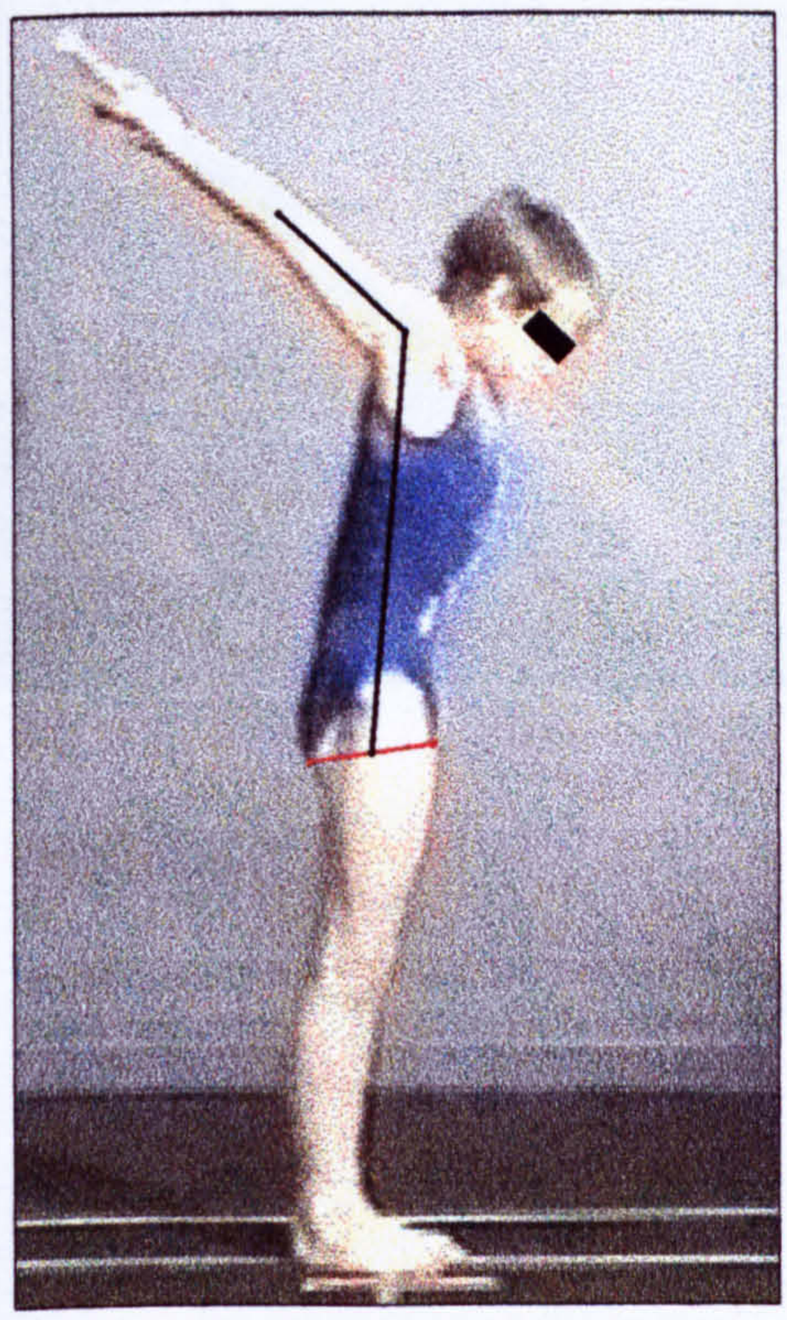
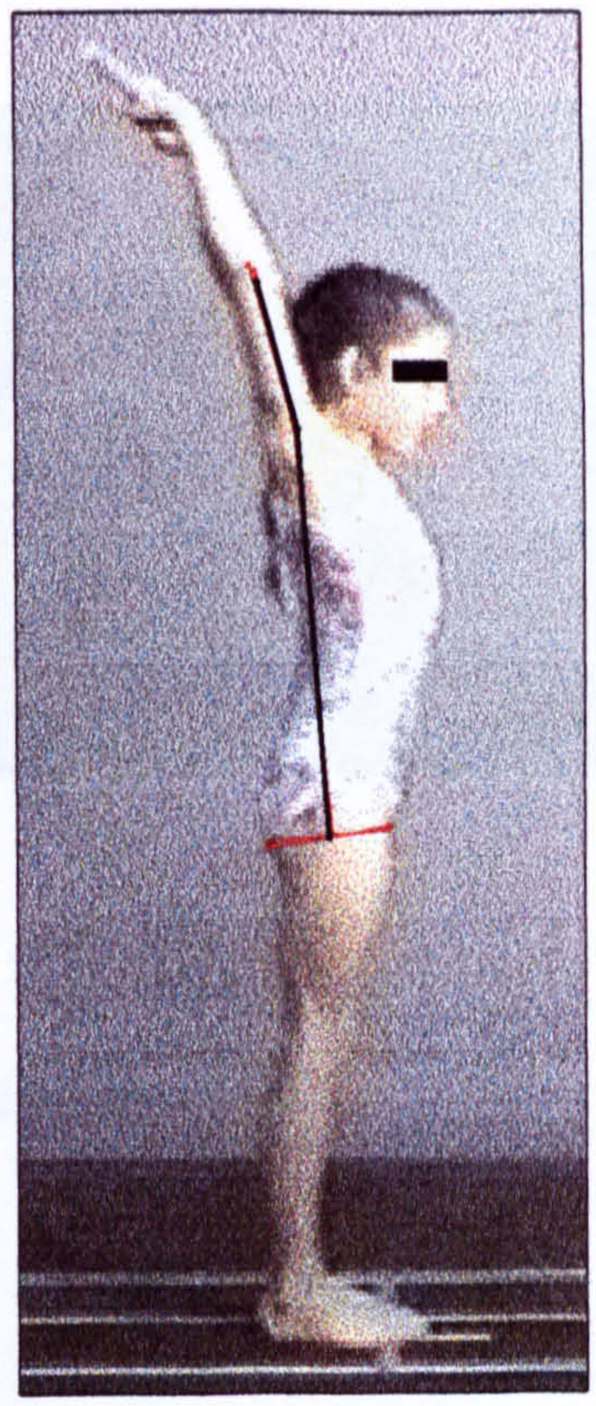



Figure 5.47. The process of deriving joint angles for the FRR assessment.

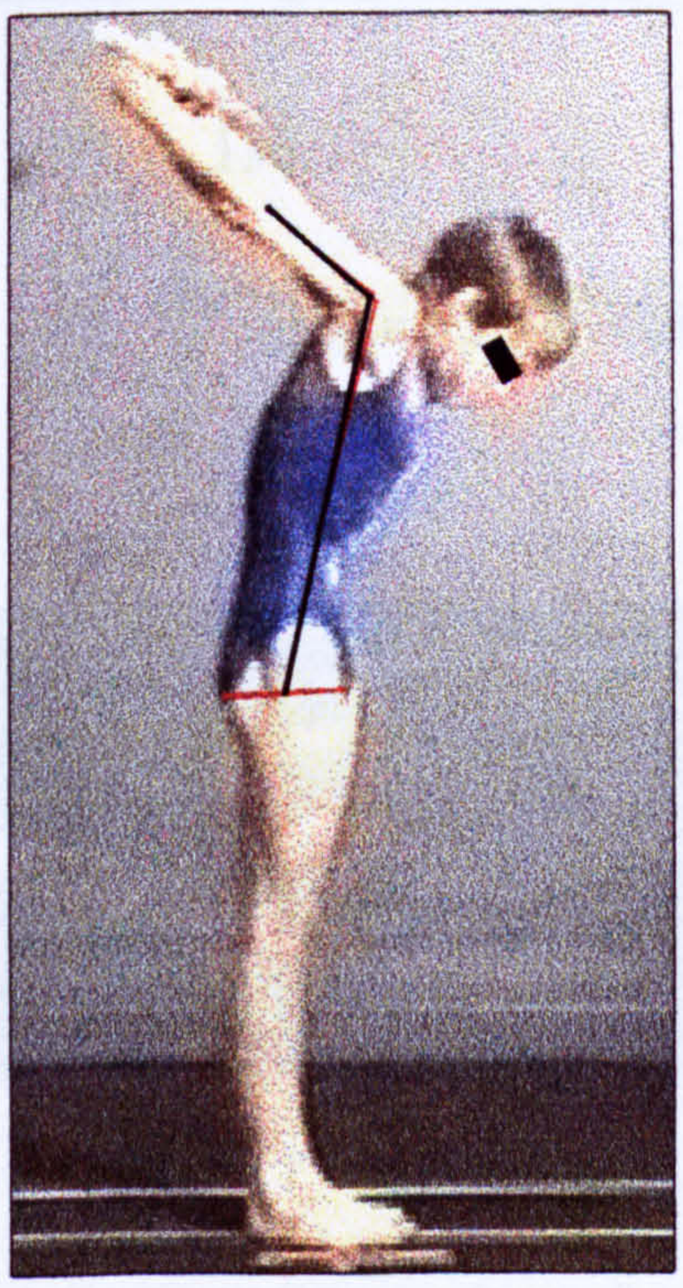


232.6°

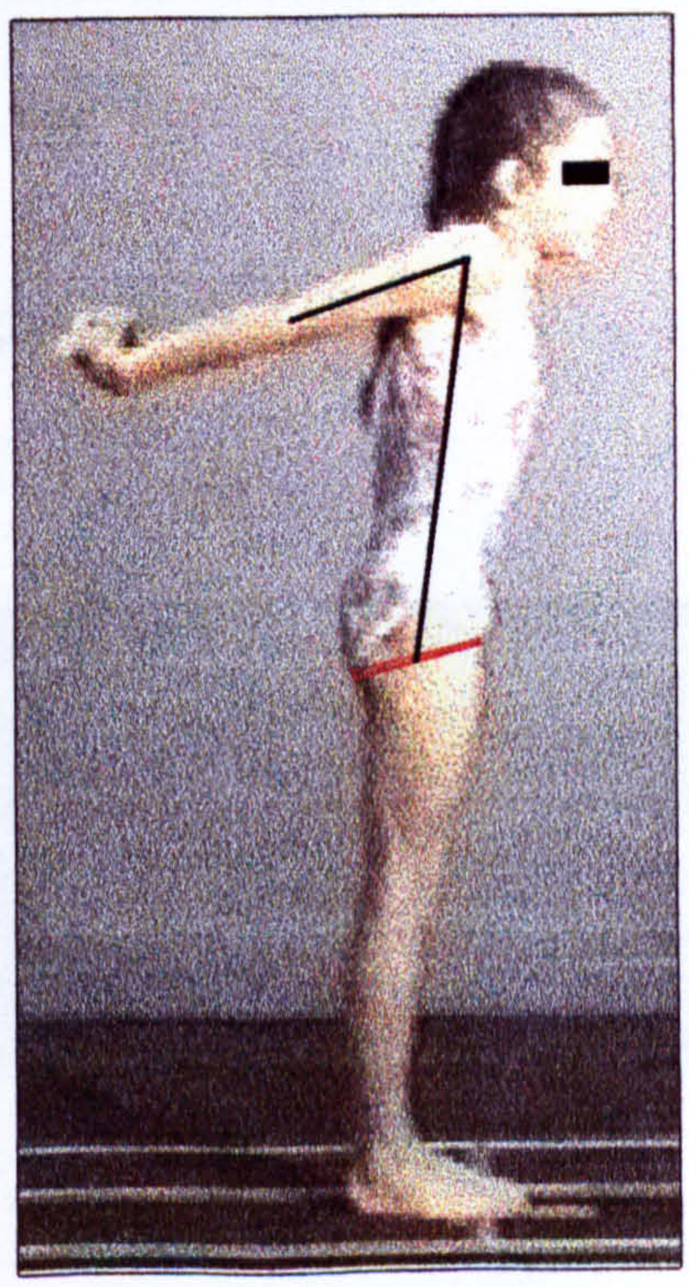


191.1°

Figure 5.48. Calculated angles for shoulder flexion.

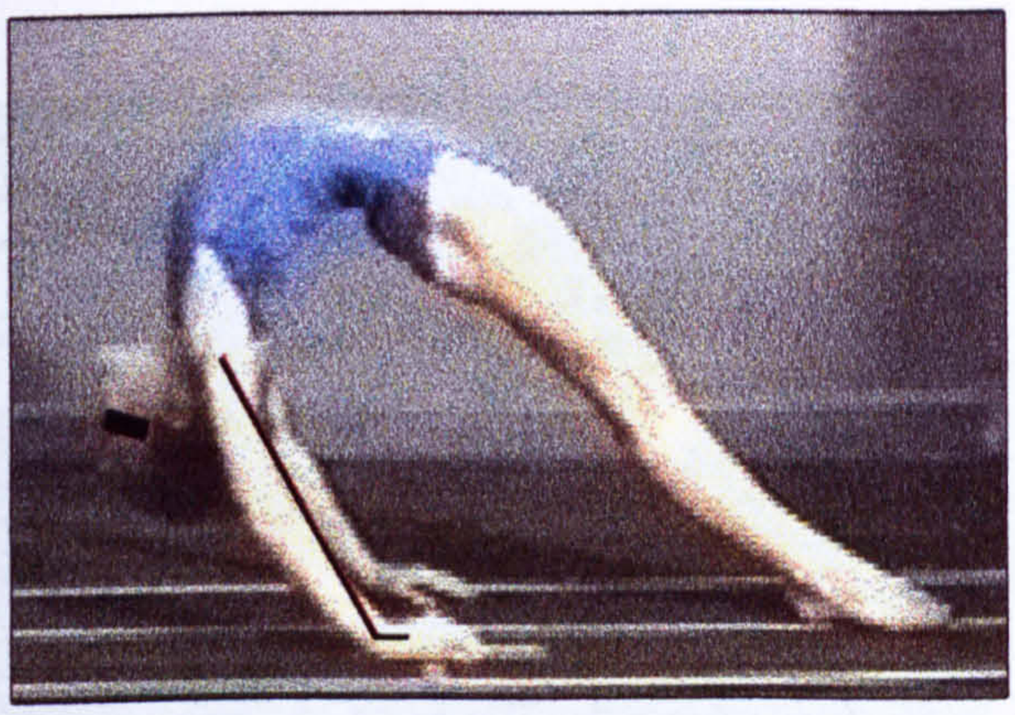


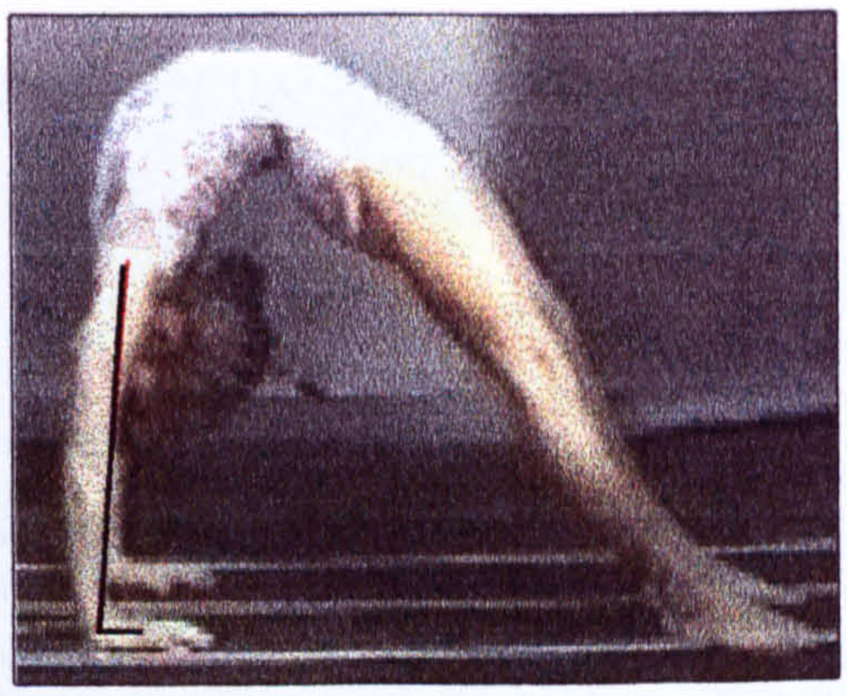
118.5°



64.5°

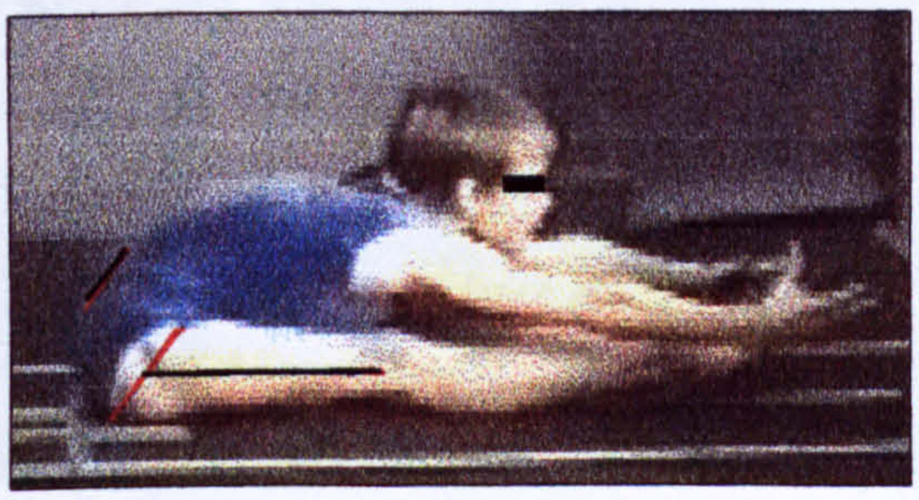
Figure 5.49. Calculated angles for shoulder extension.





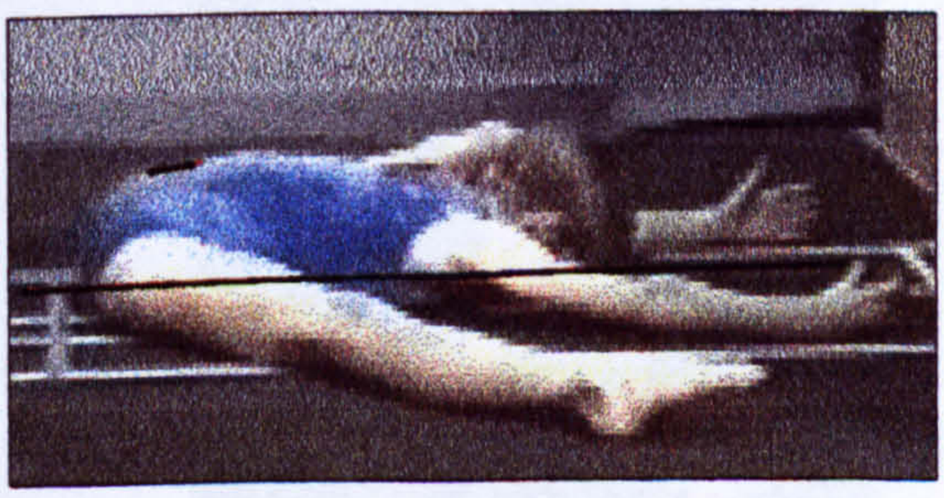
119.2° 86.0°

Figure 5.50. Calculated angles for bridge.



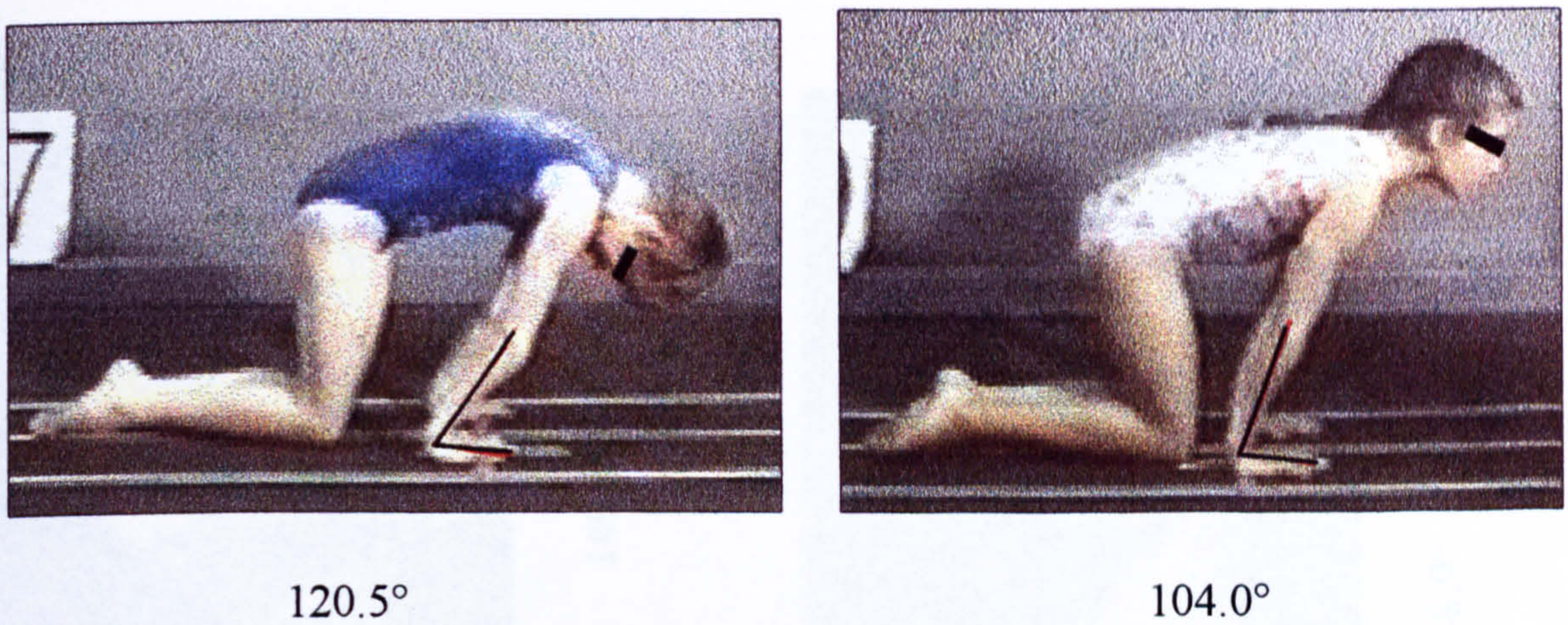
130.7° 111.0°

Figure 5.51. Calculated angles for seated fold.



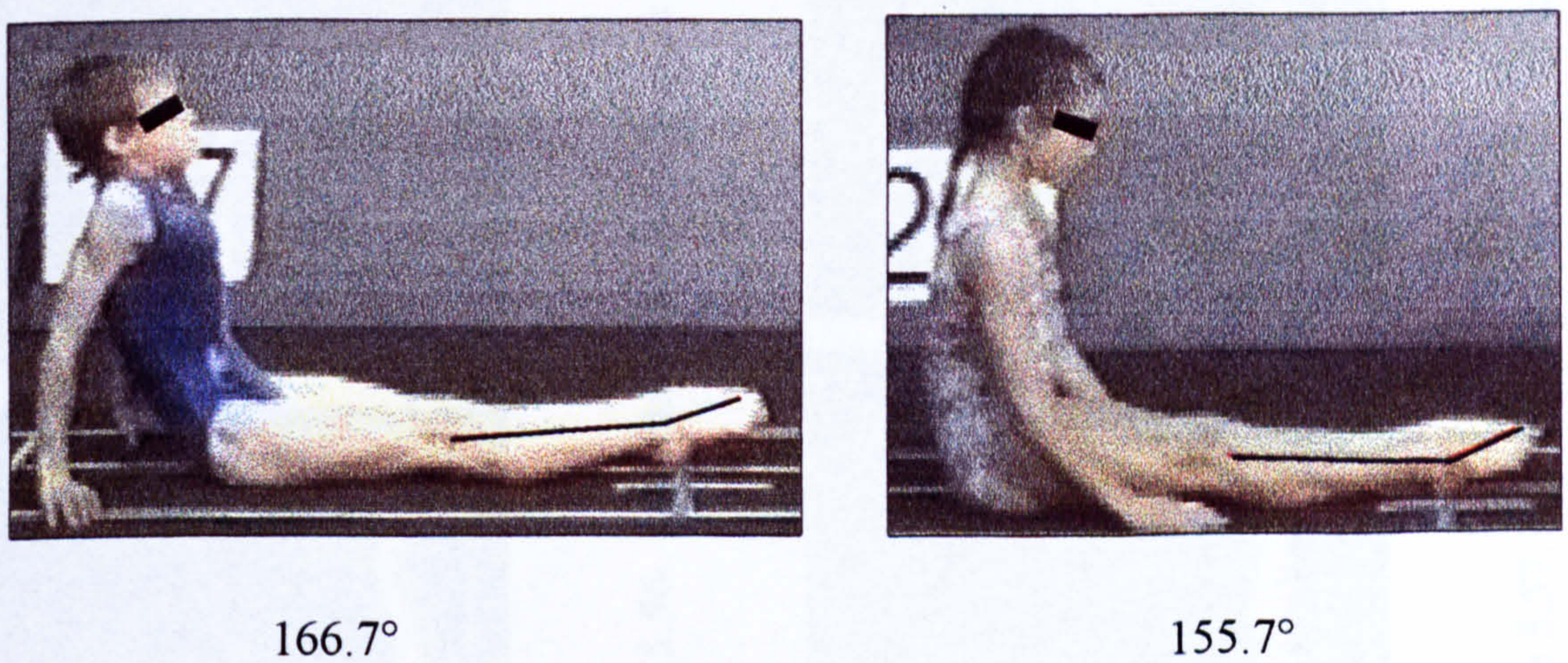
173.3° 146.1°

Figure 5.52. Calculated angles for straddle fold.



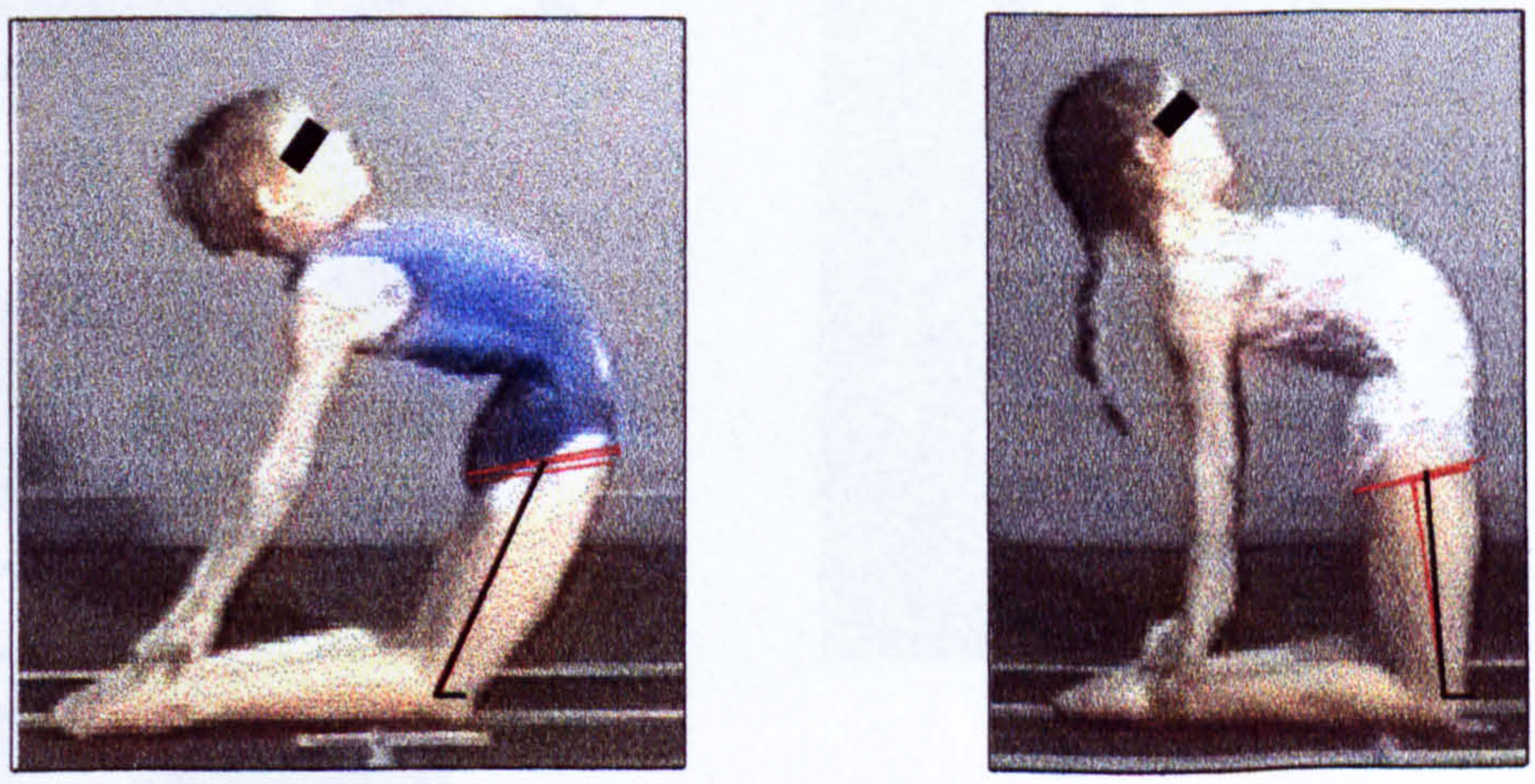
120.5° 104.0°

Figure 5.53. Calculated angles for wrist flexion.



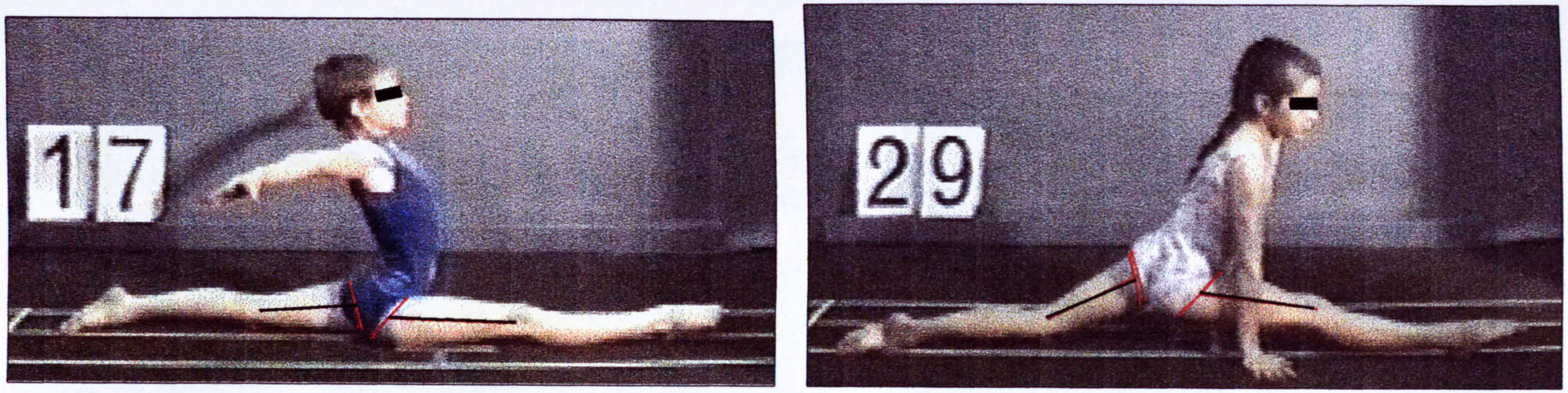
166.7° 155.7°

Figure 5.54. Calculated angles for ankle plantar flexion.



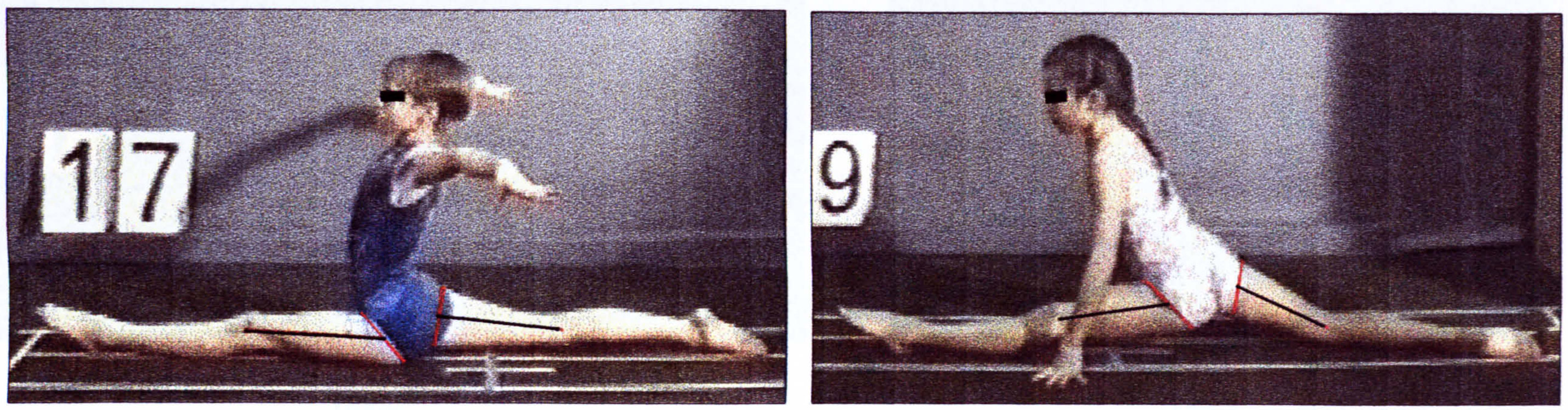
115.6° 85.9°

Figure 5.55. Calculated angles for 'D' angle.




174.6° 149.8°

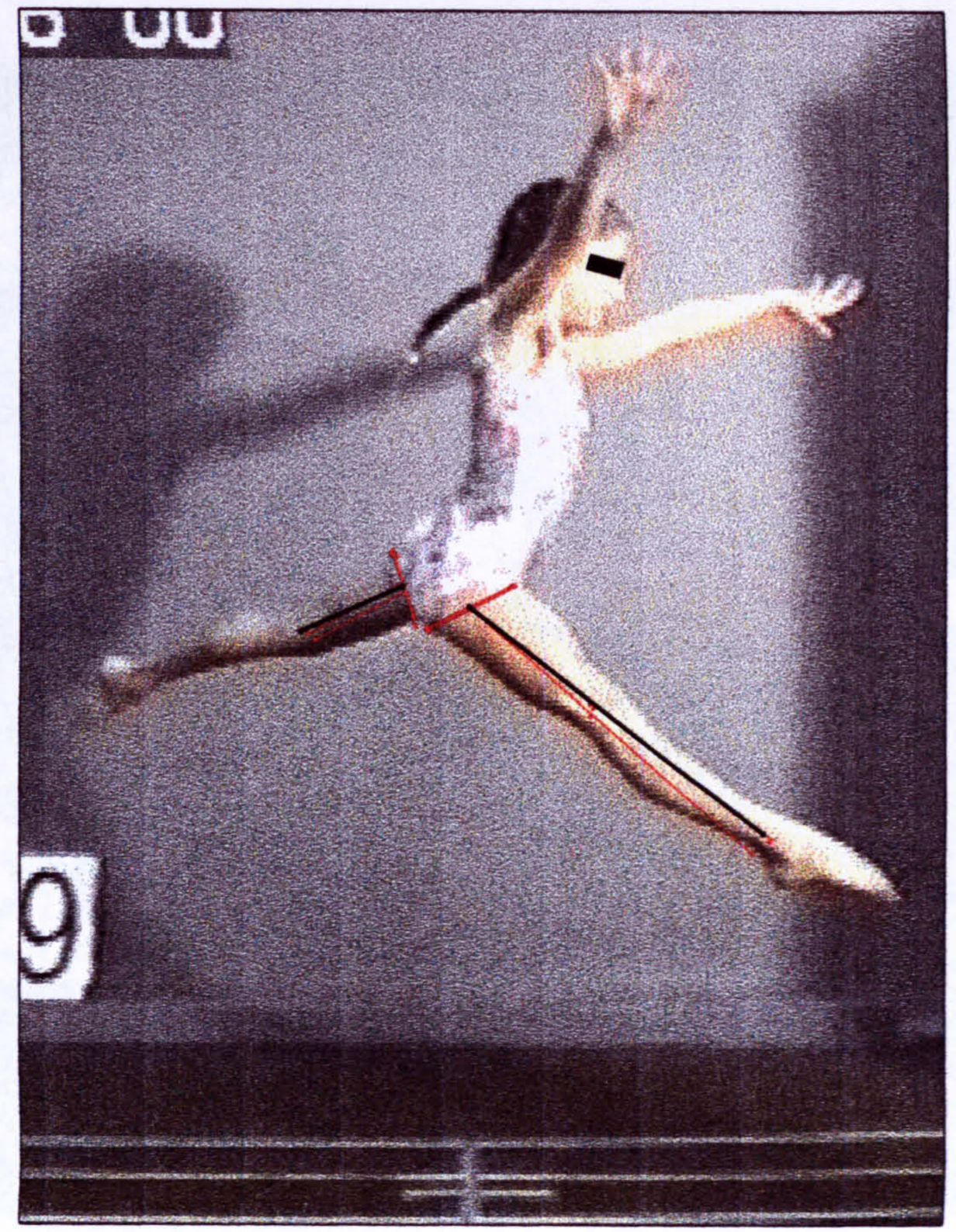
Figure 5.56. Calculated angles for splits right.




177.8° 148.9°

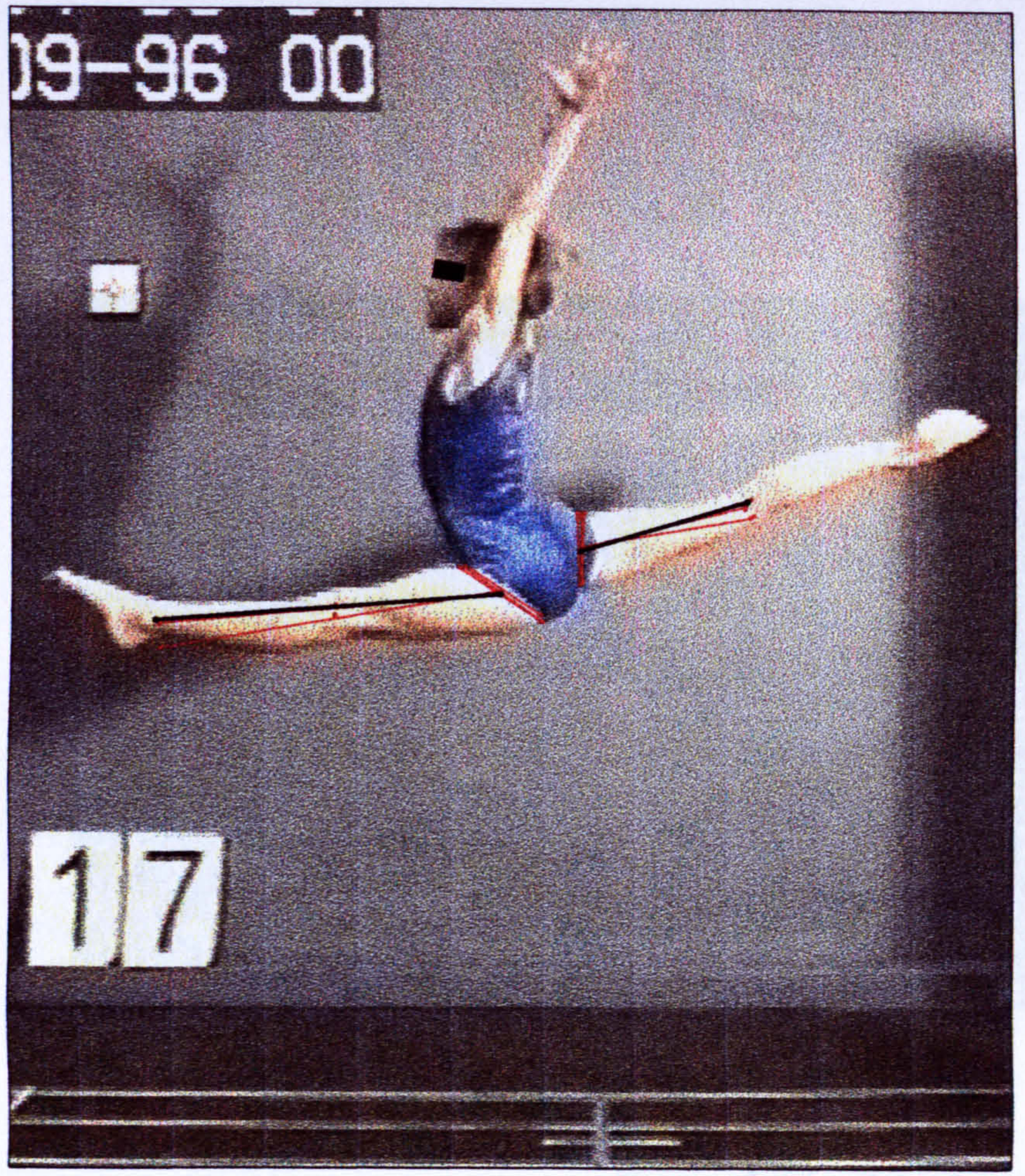
Figure 5.57. Calculated angles for splits left.

189.4°




118.1°

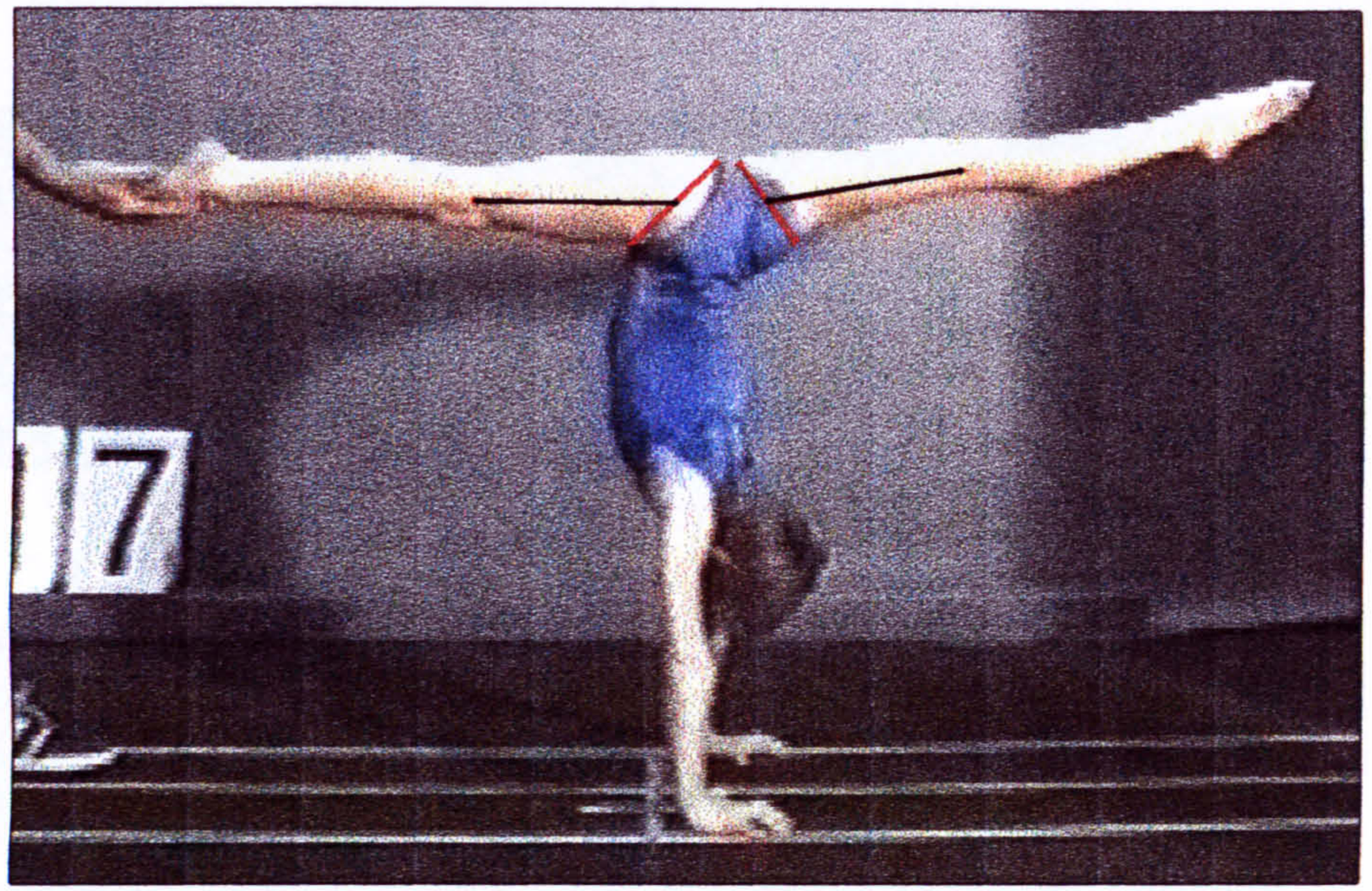
Figure 5.58. Calculated angles for split jump right.



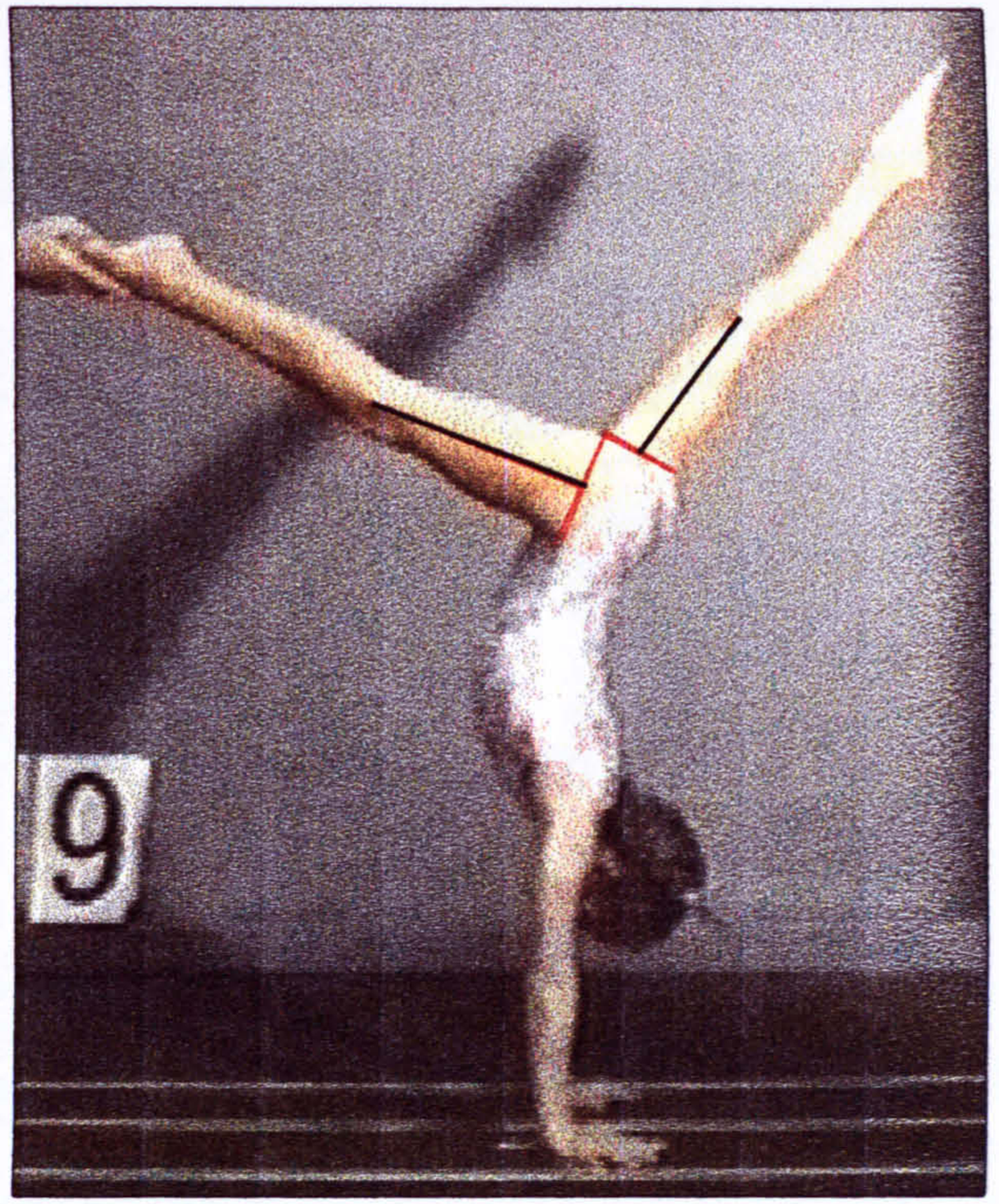

192.2°

143.6°

Figure 5.59. Calculated angles for split jump left.

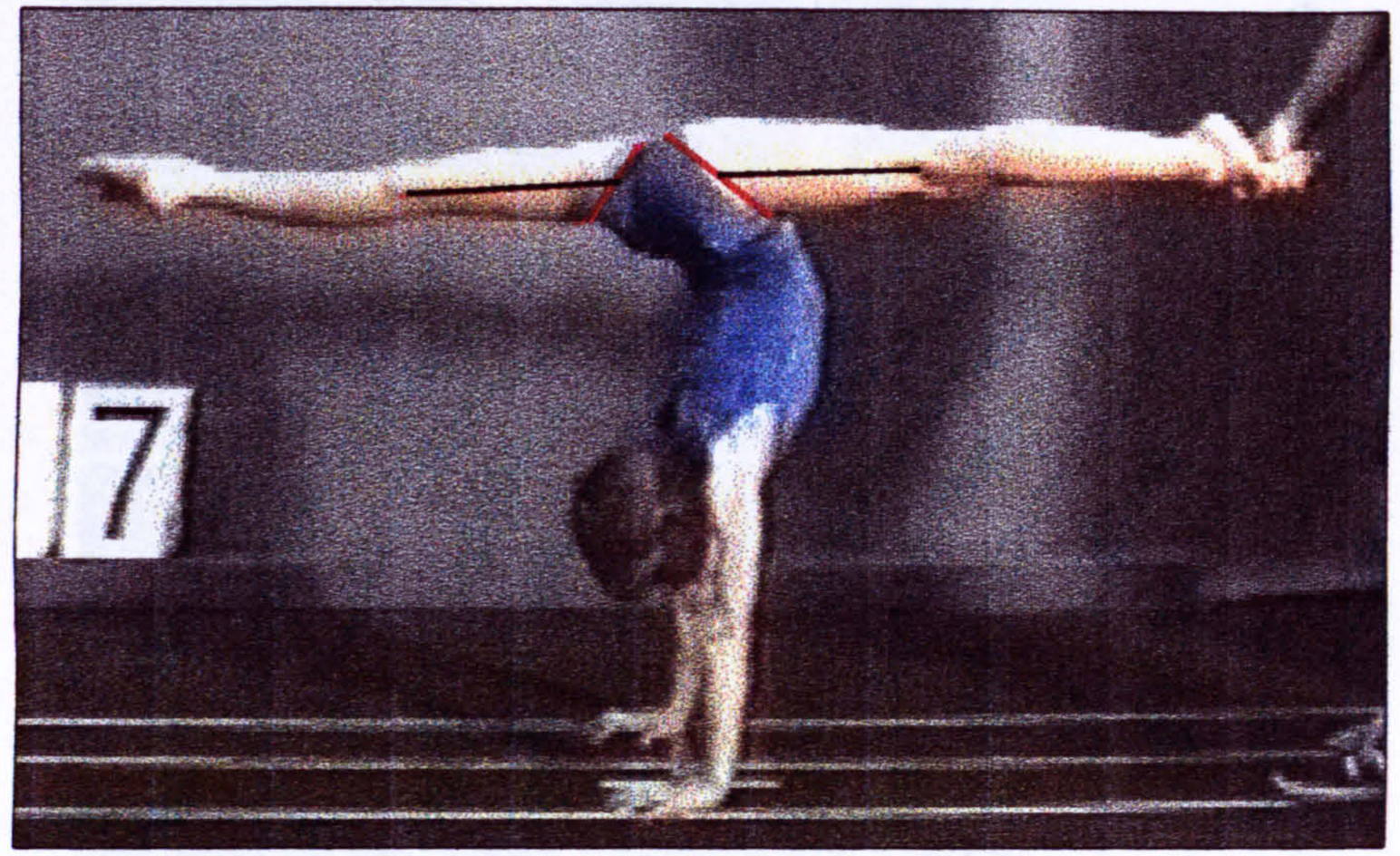



170.1°

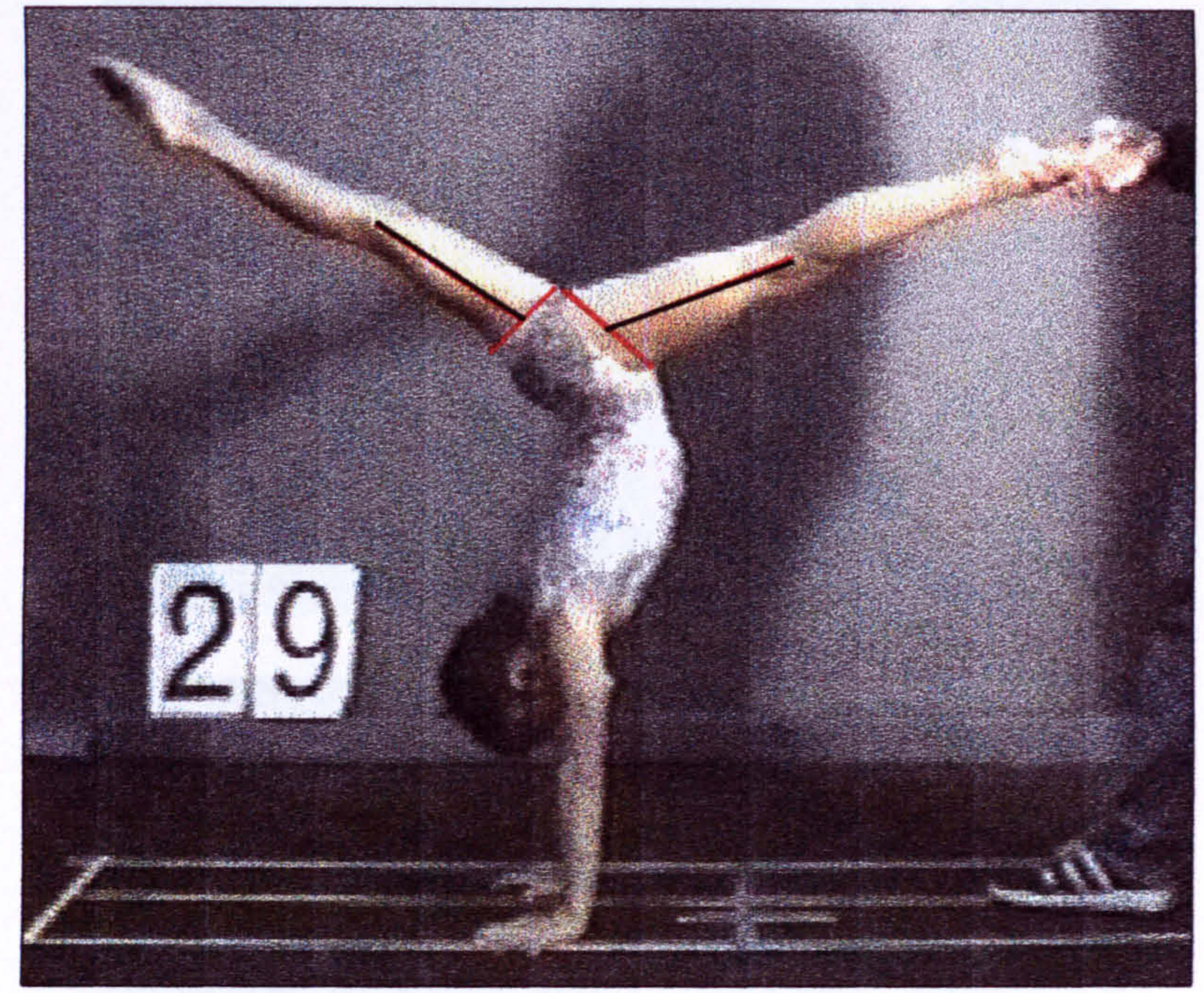



105.3°

Figure 5.60. Calculated angles for handstand splits right.

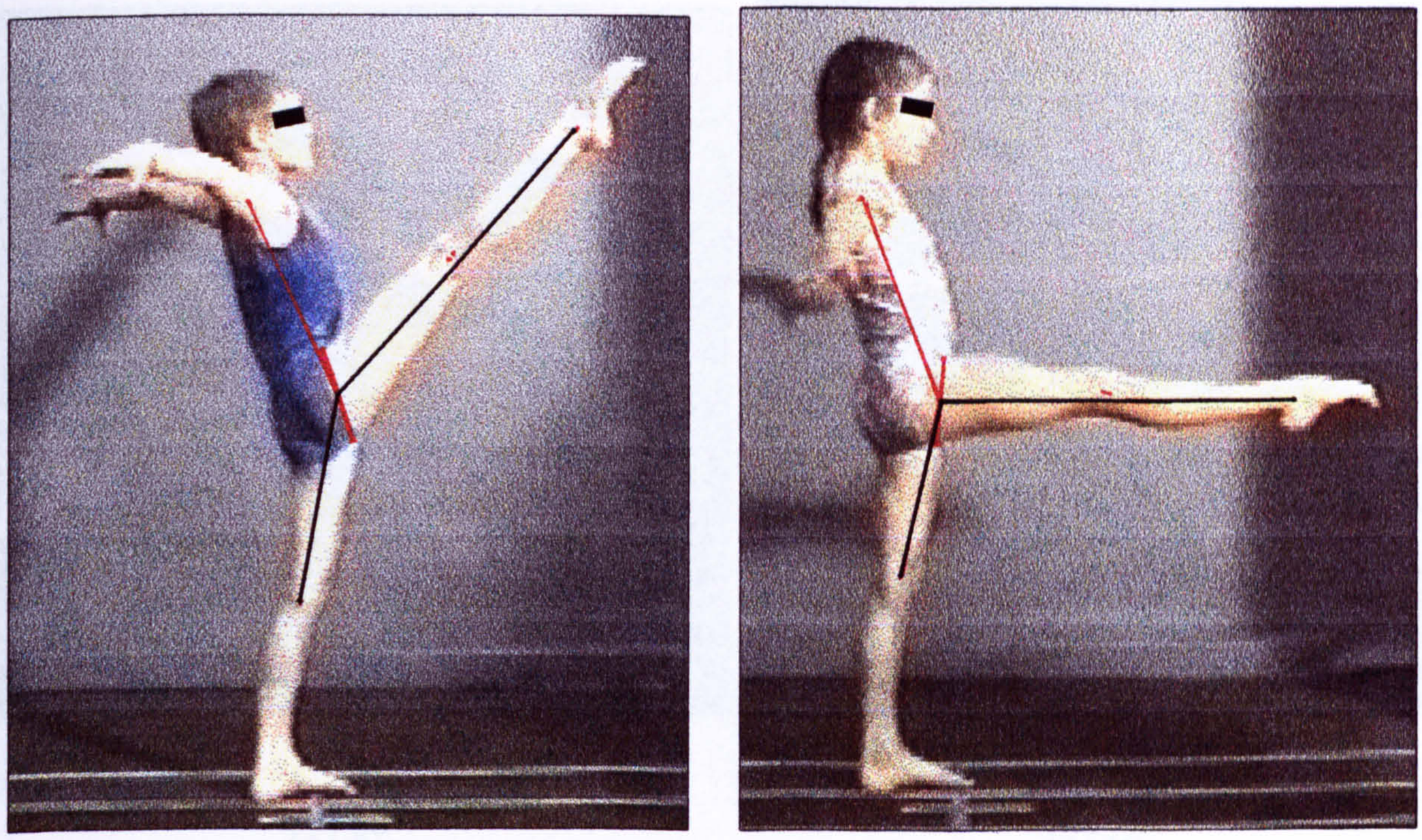



181.1°



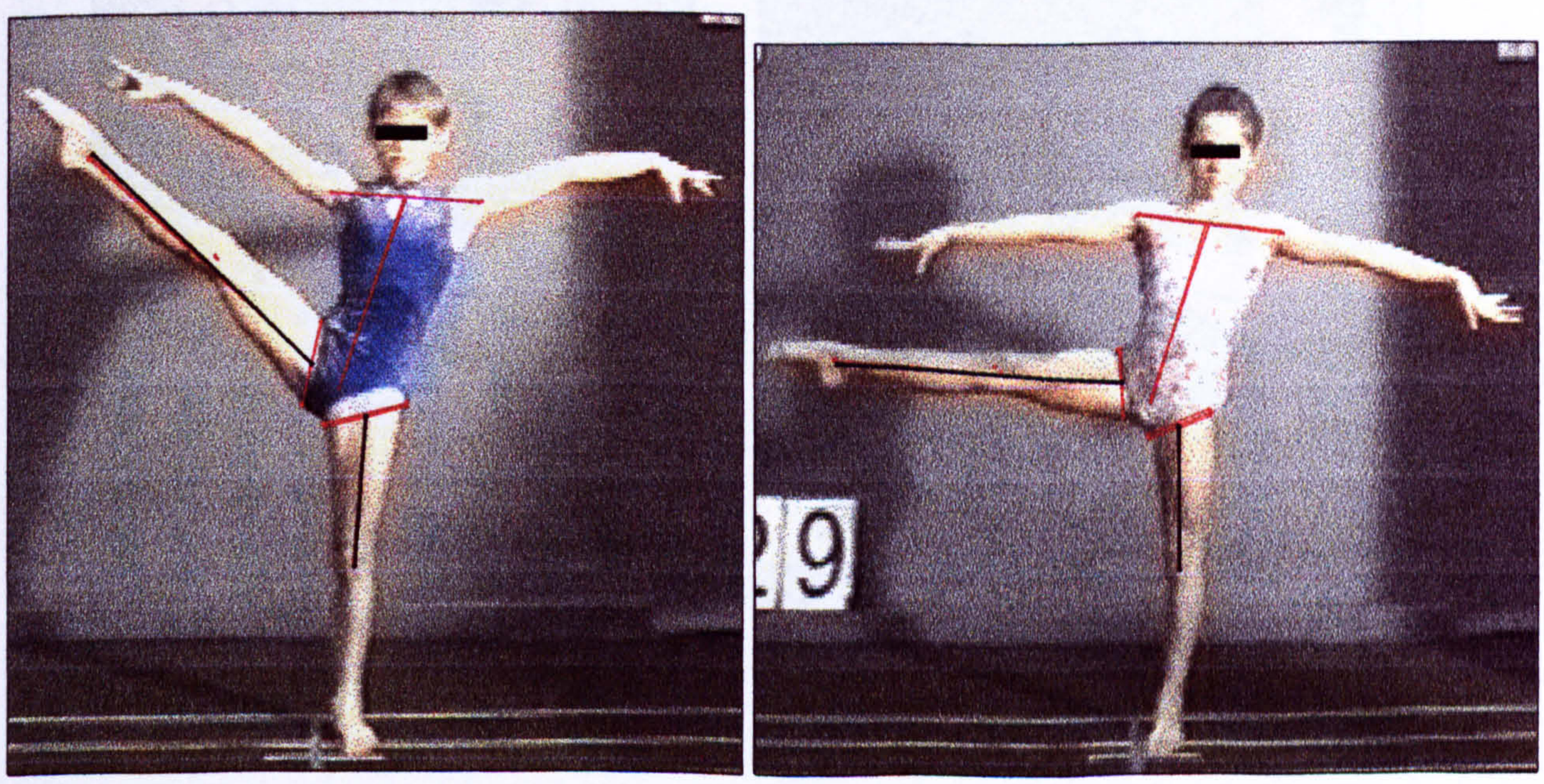

126.9°

Figure 5.61. Calculated angles for handstand splits left.



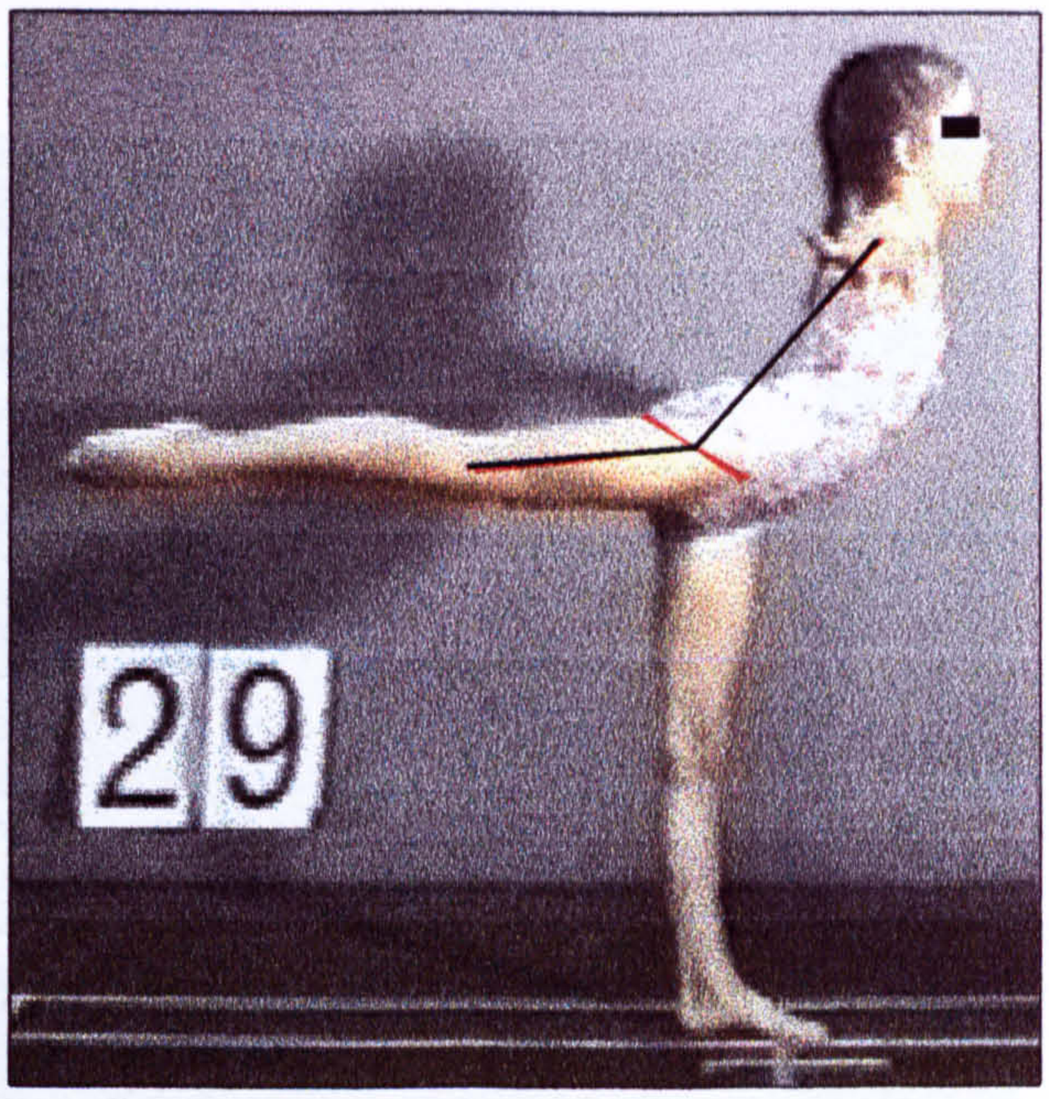
148.2° 103.6°

Figure 5.62. Calculated angles for lift and hold right leg front.



110.6° 76.8°

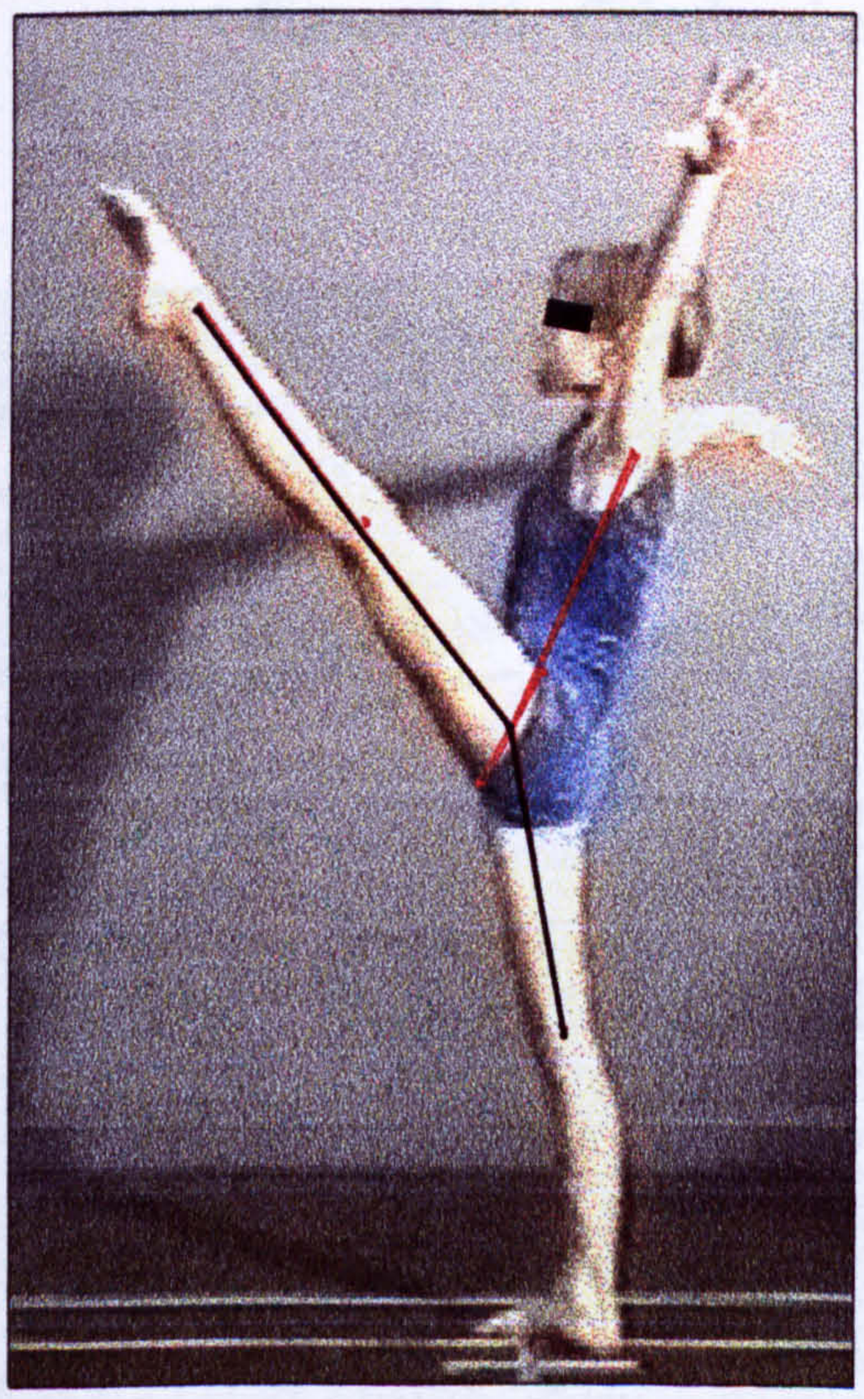
Figure 5.63. Calculated angles for lift and hold right leg side.

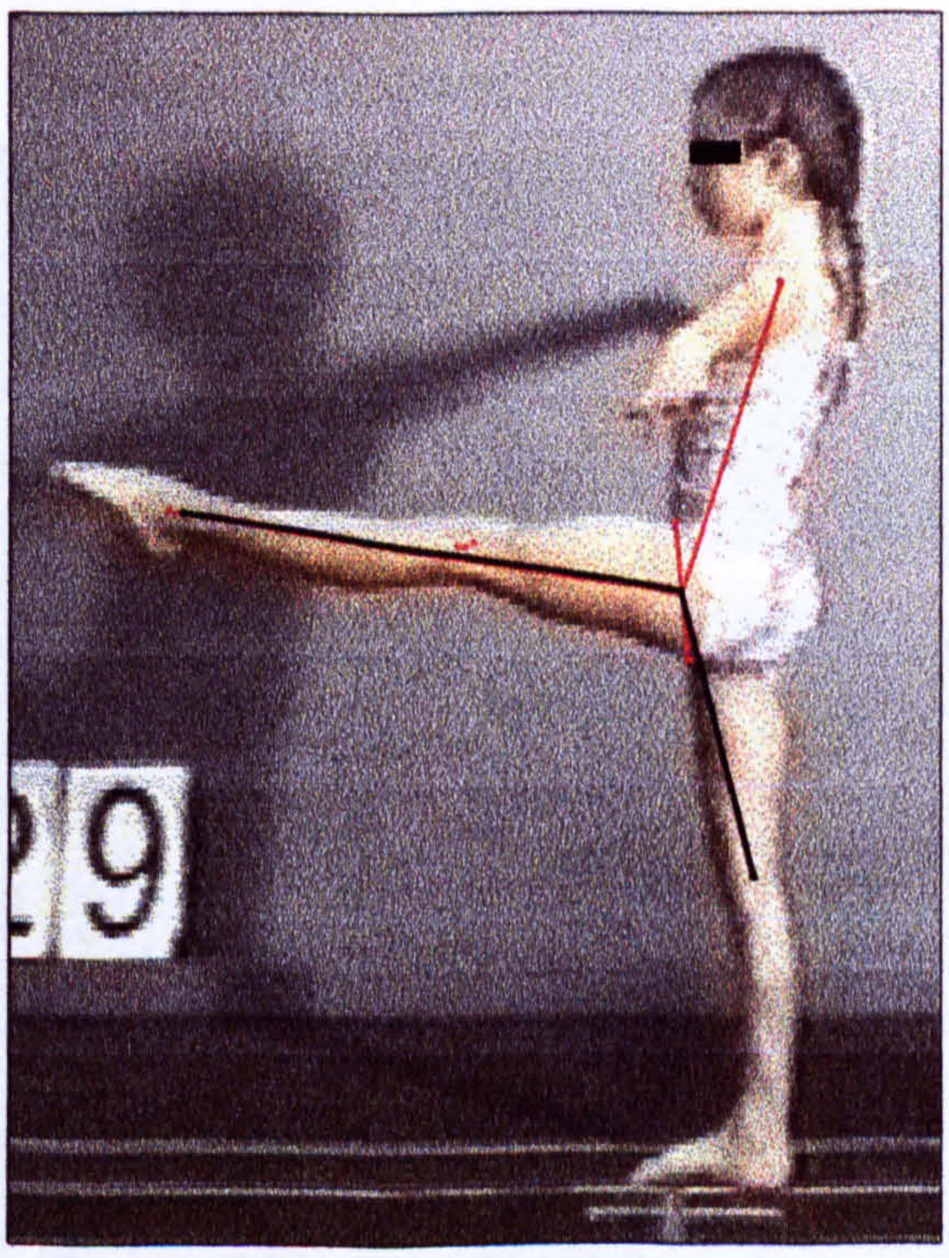



232.8°

222.0°

Figure 5.64. Calculated angles for lift and hold right leg back.

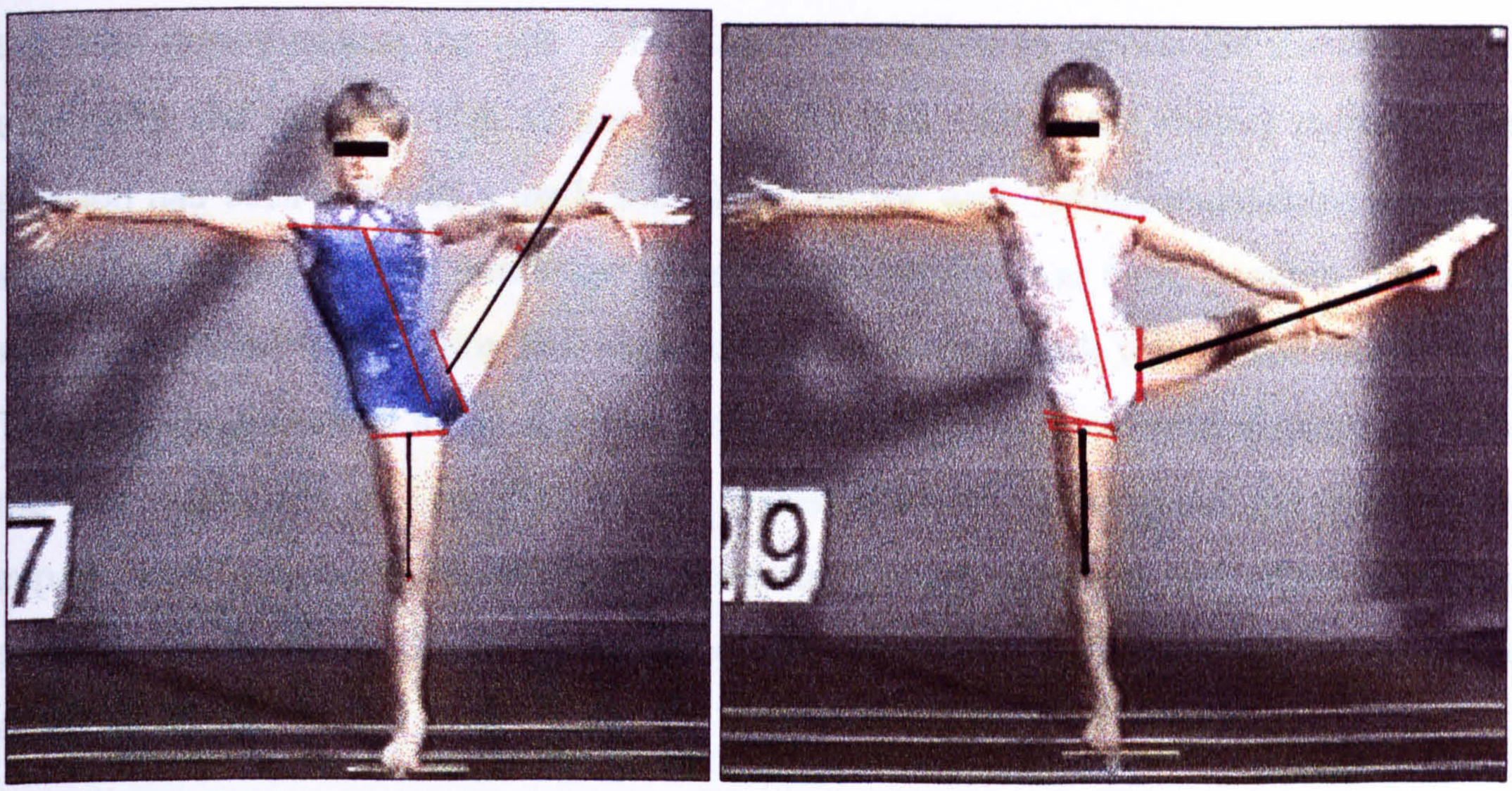





153.0°

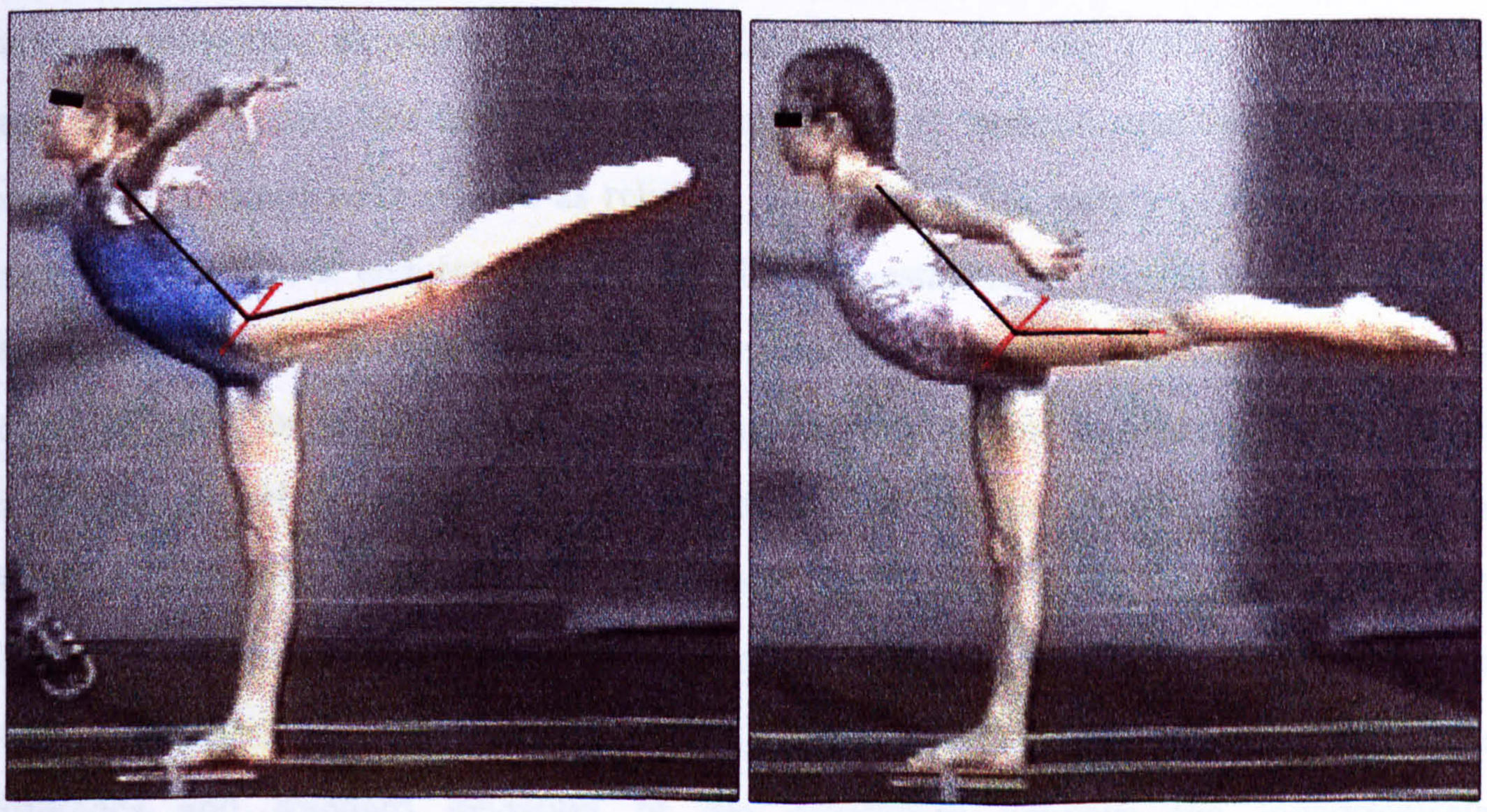
113.6°

Figure 5.65. Calculated angles for lift and hold left leg front.



127.8° 94.2°

Figure 5.66. Calculated angles for lift and hold left leg side.



240.0° 226.4°

Figure 5.67. Calculated angles for lift and hold left leg back.

*Shoulder girdle range of movement*

The subject stood facing the wall, with body and head adjacent to the wall and arms above the head resting against the wall. The subject was asked to elevate the shoulder girdle maximally and reach as high as possible up the wall. Once the subject indicated this position had been achieved a mark was placed on the wall. While maintaining the body alignment, the subject was then asked to depress the shoulders as far as possible. Once the subject indicated this position had been achieved a second mark was placed on the wall. The range of movement in the shoulder girdle was defined as the vertical distance between the two marks and was recorded to the nearest 0.001m. Throughout the exercise the experimenter ensured the subject maintained the correct alignment and where necessary assisted to prevent backwards movement of the upper body during the depression of the shoulder girdle.

## 5.4 RESULTS

### 5.4.1 RELIABILITY

Force platforms have been used to reliably measure vertical and horizontal forces across a range of movement activities (Kerwin & Challis, 1985; Kerwin, 1997). Therefore, the tests conducted using this data capture system (isometric strength, counter movement and bounce drop jump) were treated as reliable. In addition, the battery of tests adopted to assess local muscular endurance were part of a well-established national system and were therefore also assumed to be reliable. For the remaining variables test-retest reliability was estimated using the modified limits of agreement method (Bland & Altman, 1986) outlined in Chapter 3. Heteroscedasticity, as indicated by a positive relationship between the absolute difference between each test-retest measurement and the mean test-retest difference, was observed in 48% of physical measurements. To overcome the problem of heteroscedastic errors the raw test-retest data were logarithmically transformed. The mean difference and standard deviation of the differences between the logarithmically transformed test and re-test scores provided estimates of measurement bias and variability respectively. In line with the recommendations by Nevill (1999, personal communication), physical variables were considered to demonstrate adequate reliability if the bias did not

exceed 0.05 and the variability was not greater than 0.12. The results of the reliability study are provided in Tables 5.5-5.10.

Table 5.5. Test-retest reliability of anthropometric variables

| | n | systematic bias (log mean difference) | variability (log SDD) | reliability |
|---|---|---|---|---|
| Height | 10 | -0.001 | 0.008 | ✓ |
| Sitting height | 10 | 0.001 | 0.017 | ✓ |
| Mass | 10 | 0.004 | 0.015 | ✓ |
| Body mass index | 10 | 0.006 | 0.018 | ✓ |
| Upper leg length | 10 | -0.002 | 0.017 | ✓ |
| Lower leg length | 10 | -0.000 | 0.009 | ✓ |
| Foot length | 10 | -0.000 | 0.007 | ✓ |
| Upper arm length | 10 | 0.008 | 0.009 | ✓ |
| Lower arm length | 10 | 0.003 | 0.009 | ✓ |
| Hand length | 9 | -0.004 | 0.015 | ✓ |
| Biacromial width | 10 | -0.002 | 0.008 | ✓ |
| Biiliac width | 10 | -0.003 | 0.006 | ✓ |
| Elbow width | 10 | -0.003 | 0.009 | ✓ |
| Wrist width | 10 | -0.001 | 0.034 | ✓ |
| Knee width | 10 | 0.003 | 0.005 | ✓ |
| Ankle width | 10 | 0.003 | 0.015 | ✓ |
| Armspan | 10 | -0.000 | 0.003 | ✓ |

where: ✓ denotes that the variable was adequately reliable

Table 5.6. Test-retest reliability of body composition variables

| | n | systematic bias (log mean difference) | variability (log SDD) | reliability |
|---|---|---|---|---|
| Triceps skinfold | 10 | -0.007 | 0.118 | ✓ |
| Biceps skinfold | 10 | -0.043 | 0.179 | |
| Subscapular skinfold | 10 | -0.008 | 0.071 | ✓ |
| Supra-iliac skinfold | 10 | 0.013 | 0.166 | |
| Sum of four skinfolds | 10 | -0.003 | 0.048 | ✓ |

Table 5.7. Test-retest reliability of inertia variables

| | n | systematic bias (log mean difference) | variability (log SDD) | reliability |
|---|---|---|---|---|
| IF1 layout | 10 | 0.002 | 0.024 | ✓ |
| IF1 pike | 10 | 0.012 | 0.021 | ✓ |
| IF1 tuck | 10 | 0.030 | 0.048 | ✓ |
| IF1 pike as % layout | 10 | 0.011 | 0.013 | ✓ |
| IF1 tuck as % layout | 10 | 0.028 | 0.031 | ✓ |
| IF3 wide arm | 10 | -0.027 | 0.048 | ✓ |
| IF3 straight | 10 | -0.033 | 0.061 | ✓ |
| IF3 straight as % wide arm | 10 | -0.006 | 0.065 | ✓ |

Table 5.8. Test-retest reliability of standing broad jump variables

| | n | systematic bias (log mean difference) | variability (log SDD) | reliability |
|---|---|---|---|---|
| SB Jump | 10 | 0.030 | 0.076 | ✓ |
| SB Jump/ht | 10 | 0.032 | 0.075 | ✓ |

Table 5.9. Test-retest reliability of functional flexibility variables

| | n | systematic bias (log mean difference) | variability (log SDD) | reliability |
|---|---|---|---|---|
| APF | 9 | -0.010 | 0.051 | ✓ |
| BKL | 9 | 0.009 | 0.062 | ✓ |
| BKR | 9 | 0.028 | 0.034 | ✓ |
| BKAV | 9 | 0.018 | 0.038 | ✓ |
| BRG | 9 | 0.002 | 0.093 | ✓ |
| D1_ | 8 | -0.003 | 0.045 | ✓ |
| FFD | 9 | 0.030 | 0.068 | ✓ |
| FRL | 9 | 0.030 | 0.068 | ✓ |
| FRR | 8 | -0.033 | 0.111 | ✓ |
| FRAV | 8 | 0.024 | 0.071 | ✓ |
| HSL | 8 | -0.003 | 0.055 | ✓ |
| HSR | 7 | -0.023 | 0.060 | ✓ |
| HSAV | 7 | -0.011 | 0.031 | ✓ |
| SDL | 8 | 0.015 | 0.060 | ✓ |
| SDR | 9 | -0.022 | 0.077 | ✓ |
| SDAV | 9 | -0.003 | 0.041 | ✓ |
| SFD | 9 | -0.015 | 0.065 | ✓ |
| SFX | 9 | 0.002 | 0.028 | ✓ |
| SJL | 9 | 0.015 | 0.081 | ✓ |
| SJR | 9 | 0.015 | 0.066 | ✓ |
| SJAV | 9 | 0.014 | 0.065 | ✓ |
| SXT | 9 | 0.030 | 0.090 | ✓ |
| WFX | 9 | -0.021 | 0.029 | ✓ |
| Box Splits | 9 | -0.017 | 0.025 | ✓ |
| Shoulder girdle | 9 | 0.054 | 0.177 | |

Table 5.10. Test-retest reliability of clinical flexibility variables

| | n | systematic bias (log mean difference) | variability (log SDD) | reliability |
|---|---|---|---|---|
| EHXT | 10 | 0.012 | 0.511 | |
| HAB | 10 | 0.021 | 0.119 | ✓ |
| HER | 10 | 0.028 | 0.376 | |
| KHXT | 10 | -0.011 | 0.306 | |
| SER | 10 | -0.006 | 0.056 | ✓ |
| SFX | 10 | -0.005 | 0.038 | ✓ |
| SIR | 10 | 0.041 | 0.129 | |
| SXT | 10 | -0.062 | 0.115 | ✓ |
| TFX | 10 | 0.011 | 0.089 | ✓ |
| TXT | 10 | 0.141 | 0.178 | |
| WFX | 10 | -0.002 | 0.063 | ✓ |
| WXT | 10 | 0.003 | 0.128 | |

Members of the measurement team questioned the validity of two physical tests which were subsequently excluded prior to data analysis. Splits left and right (functional flexibility) were eliminated due to gymnasts persistently twisting the hip girdle to achieve a greater range of motion despite instructions to the contrary. Times to peak force and various percentages of peak force (isometric strength) were also excluded since the gymnasts did not appear to react consistently in response to the audio signal. It may be hypothesised that the gymnasts did not fully understand the test or that the information processing system was not sufficiently mature to cope with the demands of the task. In addition, the results of functional flexibility and assessments of local muscular endurance, which were performed on both the left and right sides, were averaged (lift and hold front, side and back, split jump, handstand splits and leg dips). Moreover, for flexibility, some duplication was observed between clinical and functional measurements. In such cases the most reliable variable was selected. Finally, the sum of four skinfolds demonstrated greater reliability than individual skinfold measurements and was therefore selected as the

sole measure of body composition. In general the reliability of the physical tests was good. However, a total of 43 physical variables which failed to demonstrate adequate reliability or were not considered appropriate within the present investigation were excluded from all subsequent analyses.

### 5.4.2 PHYSICAL TALENT CHARACTERISTICS AND FUTURE GYMNASTIC PERFORMANCE.

The extent to which physical talent characteristics were able to predict the likelihood of future gymnastic performance was investigated using principal components analysis and logistic regression. The data were initially screened for skewness and kurtosis, with positively skewed data transformed using a logarithmic transformation and negatively skewed data reflected prior to logarithmic transformation. Using a combination of raw and transformed data as appropriate, principal components analysis with varimax rotation was applied within each category of physical variables to reduce the large number of reliable variables to a smaller number of components.

*Principal components analysis*

Anthropometry components

The rotated component matrix presented in Table 5.11 indicates that four anthropometric components were derived which accounted for 80.1% of the variance in the data. Anthropometry component 1 (zant1) comprised skeletal lengths, whole body skeletal widths and body mass. This component accounted for a large proportion of the variance within the data (40.1%) and was interpreted to represent physical size. The second anthropometric component 2 (zant2) accounted for a smaller percentage of the variance (20.8%) and was interpreted to represent the physique and frame of the gymnast. Epiphyseal width measurements, the ratio of biacromial to biiliac widths, body mass index (BMI) and mass all loaded on this component. The third anthropometric component (zant3) comprised two ratio variables, armspan and sitting height both expressed in relation to stature. Since standing height was common to both ratios the component was interpreted to represent stature ratios. The component loadings presented in Table 5.11

indicate that the variables were negatively related with the armspan ratio

Table 5.11. Principal components analysis of anthropometric data

| | COMPONENTS | | | |
|---|---|---|---|---|
| | **zant1** | **zant2** | **zant3** | **zant4** |
| **Variance explained** | **41.0%** | **20.8%** | **11.6%** | **6.7%** |
| Height | 0.919 | | | |
| Sitting height | 0.860 | | | |
| Upper leg length | 0.719 | | | |
| Lower leg length | 0.811 | | | |
| Foot length | 0.768 | | | |
| Upper arm length | 0.765 | | | |
| Lower arm length | 0.861 | | | |
| Hand length | 0.742 | | | |
| Biacromial width | 0.800 | | | |
| Biiliac width | 0.880 | | | |
| Armspan | 0.862 | | | |
| Mass | 0.744 | 0.602 | | |
| Wrist width | | 0.683 | | |
| Knee width | | 0.725 | | |
| Ankle width | | 0.739 | | |
| Biacromial to biiliac ratio | | 0.611 | | |
| BMI | | 0.780 | | |
| Armspan to stature ratio | | | 0.724 | |
| Sitting height to stature ratio | | | -0.732 | |
| Predicted adult ht | | | | 0.831 |
| Elbow width | | | | |

demonstrating a positive loading while the sitting height ratio loaded negatively. This suggests that as the armspan to stature ratio increases the sitting height ratio decreases. Predicted adult height derived using the formula proposed by Tanner (1989) was the single variable which loaded highly on the fourth anthropometric component, (zant4). This component explained 6.7% of the variance in the data.

Inertia components

Data screening revealed that the variable pkas%lay which expressed moment of inertia in the pike shape as a percentage of moment of inertia in the layout configuration about the transverse axis was negatively skewed and demonstrated extreme kurtosis. This variable did not achieve normality upon transformation and was therefore excluded. Principal components analysis of the remaining variables highlighted two clear components which explained a cumulative variance of 87.7%. All variables expressing the absolute value of moment of inertia in a given body configuration loaded positively on inertia component 1 (zinert1), which accounted for a large proportion of the variance (68.2%).

Table 5.12. Principal components analysis of inertia data

| | **COMPONENT** | |
|---|---|---|
| | **zinert1** | **zinert2** |
| **variance explained** | **68.2%** | **19.5%** |
| IF1 layout | 0.988 | |
| IF1 pike | 0.986 | |
| IF1 tuck | 0.970 | |
| IF3 straight | 0.961 | |
| IF3 wide | 0.971 | |
| IF1 tuck as % layout | | 0.797 |
| IF3 straight as % wide arm | | 0.817 |

Inertia component 2, (zinert2), accounted for almost 20% of the variance and consisted of two ratios which expressed the change in moment of inertia as gymnasts moved between common body shapes. These ratios represented changes in moment of inertia about the twist and the somersault axes of rotation respectively. It is interesting to note that the components were distinguished according to whether moments of inertia were expressed as an absolute value or combined as a ratio and not according to the principal axes about which the values were expressed.

Isometric strength components

Data screening revealed that variables representing average and normalised rate of force development for shoulder joint flexion and shoulder girdle extension demonstrated skewness and kurtosis. The normalised rate variables did not achieve normality upon transformation and were therefore excluded.

Table 5.13. Principal components analysis of isometric strength data

| | **COMPONENT** | | |
|---|---|---|---|
| | **zisom1** | **zisom2** | **zisom3** |
| **Variance explained** | **29.3%** | **27.5%** | **23.9%** |
| HXT MRFD | 0.971 | | |
| HXT ARFD | 0.934 | | |
| HXT NMIF | 0.759 | | |
| HXT NRFD | 0.620 | | |
| SFX MRFD | | 0.788 | |
| LN (SFX ARFD) | | 0.941 | |
| LN (SEL ARFD) | | 0.778 | |
| SFX NMIF | | | 0.663 |
| SEL MRFD | | | 0.695 |
| SEL NMIF | | | 0.932 |

Variables representing the average rate of force development for both activities demonstrated normality after natural log transformation and were subsequently included in the principal components analysis. Three principal components were identified which accounted for 80.7% of variance in the data. The first isometric component (zisom1) was interpreted to represent isometric hip strength. This included rate and force parameters and explained 29.3% of the variance. The second and third components related to shoulder strength and were termed 'shoulder rate' (zisom2) and 'shoulder force' (zisom3) respectively. Maximal rate of force development in shoulder elevation also loaded highly on the shoulder force component (zisom3), however, this variable was not consistent with the interpretation of the component and was therefore assigned a weighting of zero and its contribution to the component was hence removed.

Jumping (lower extremity power) components

As a result of non-normality several jump variables were excluded prior to the principal components analysis. A total of six jump components were identified, with the first four explaining approximately 71.1% of the variance. The remaining two components, which accounted for a combined variance of 11%, could not be clearly interpreted and were therefore excluded. Jump component 1 (zjump1) accounted for 25.3% of the variance and represented the ability of the gymnast to generate large push-off impulses and therefore to produce large jump heights/lengths across a range of jump styles. Jump component 2 (zcomp2) accounted for 21.6% of the variance. The pattern and sign of the loadings suggested that this component represented power production in the bounce drop jump. Specifically, variables indicating the magnitude of power and force development demonstrated high positive loadings while variables associated with the time of force application loaded negatively. Similarly, component 3 (zjump3) represented power production in the counter movement jump with normalised mean push off force and power loading positively and the push-off time loading negatively. Finally, component 4 (zjump4) represented the ability of gymnasts to produce maximal force and power during the push-off phase of the counter movement jump.

Table 5.14. Principal components analysis of jump data

| | COMPONENTS | | | |
|---|---|---|---|---|
| | **zjump1** | **Zjump2** | **Zjump3** | **Zjump4** |
| **variance explained** | **25.3%** | **21.6%** | **14.4%** | **9.8%** |
| DJ jump height | 0.701 | | | |
| DJ peak jump height | 0.615 | | | |
| DJ push off impulse | 0.692 | | | |
| VJ jump height | 0.896 | | | |
| VJ push off impulse | 0.836 | | | |
| VJ peak jump height | 0.862 | | | |
| Standing broad jump | 0.923 | | | |
| Normalised standing BJ | 0.876 | | | |
| LN (DJ compression time) | | -0.920 | | |
| LN (DJ peak force pre t-off) | | 0.840 | | |
| LN (DJ push off time) | | -0.860 | | |
| DJ NMFz | | 0.969 | | |
| DJ NPPP | | 0.881 | | |
| DJ NMPP | | 0.822 | | |
| LN (VJ push off time) | | | -0.971 | |
| VJ NMFz | | | 0.977 | |
| VJ NMPP | | | 0.961 | |
| VJ NPPP | | | | 0.813 |
| VJ norm peak force pre t-off | | | | 0.825 |
| DJ peak jump height | | | | |
| DJ ratio impulse | | | | |
| VJ compression time | | | | |
| VJ ratio impulse | | | | |
| VJ time peak force to t-off | | | | |

Flexibility components

A number of joint angles were derived using both clinical and functional procedures. Where measurements were duplicated the most reliable variable was selected for inclusion in the PCA. Three components were identified which explained a total variance of 62.9%. The first component (zflex1) accounted for 27% of the variance in the data and represented flexibility at the hip and shoulder regions across a variety of joint actions. The second component (zflex2) was more distinct and included lifting and holding the leg in forwards and sideways positions and the average angle obtained in handstand splits. This component was interpreted to indicate the extent of active flexibility about the hip joint. Shoulder external rotation, also loading above 0.6 (Table 5.15), was not considered to be consistent with the other measures loading on zflex2 and was therefore assigned a weighting of zero. The third component (zflex3) accounted for 14.9% of the variance and consisted of variables relating primarily to the gymnast's range of motion in the hamstrings and lumbar region of the spine.

Table 5.15. Principal components analysis of flexibility data

| | **Components** | | |
|---|---|---|---|
| | **zflex1** | **Zflex2** | **zflex3** |
| **variance explained** | **27.0%** | **21.0%** | **14.9%** |
| FBOX | 0.740 | | |
| FBRG | 0.674 | | |
| FSJAV | 0.734 | | |
| FSXT | 0.810 | | |
| FD1 | 0.689 | | |
| CSER | | **0.681** | |
| FFRAV | | 0.798 | |
| FHSAV | | 0.638 | |
| FSDAV | | 0.771 | |
| FFFD | | | 0.801 |
| FSFD | | | 0.686 |

Local muscular endurance components

A number of variables representing local muscular endurance demonstrated skewness and kurtosis. Departures from normality were particularly prevalent in the speed-strength tests where data were collected after 10 s. As shown in Appendix 5.5 the standard deviations for the speed strength measurements were small, supporting qualitative observations that most gymnasts achieved similar scores for these assessments. As such, the high prevalence of non-normality was anticipated. Three components were identified which represented muscle groups/actions rather than temporal aspects of local muscular endurance. The first component (zlme1) was derived from the leg dip exercise and explained 40.3% of variance. The second component (zlme2) included exercises which demanded strength and endurance in the hip flexor and abdominal muscles. The final component (zlme3) was represented by a single variable, the number of reverse leg lifts completed in 60 s and therefore assumed to indicate local muscular endurance in the lumbar region.

Table 5.16. Principal components analysis of local muscular endurance data

| | **component** | | |
|---|---|---|---|
| | **zLME1** | **zLME2** | **zLME3** |
| **variance explained** | **40.3%** | **33.2%** | **16.1%** |
| Leg dips average 10 s | 0.911 | | |
| Leg dips average 30 s | 0.934 | | |
| Leg dips average 60 s | 0.899 | | |
| Leg lifts 30 s | | 0.873 | |
| Leg lifts 60 s | | 0.827 | |
| Straddle lever | | 0.818 | |
| Reverse leg lifts 60 s | | | 0.956 |
| Ln (Reverse leg lifts 10 s) | | | -0.867 |
| Back-ups 60 s | | | |

*Logistic regression analysis*

In the following section, the relationship between the physical components identified using principal components analysis and the future classification of gymnasts as successful or unsuccessful will be examined within each category of physical variables. The range of estimated tolerance values across the range of physical components with decimal age included as an additional independent variable in each category was 0.370-0.996. All values were above the critical value of 0.20 suggested by Menard (1995) which indicated an acceptable level of multicollinearity in all categories of physical variables. The contribution of physical components was examined in terms of the extent to which model fit and predictive efficiency were enhanced over and above the contribution of decimal age. To achieve this, standardised decimal age was forced into the regression model in the first 'block' of variables with the components within each category entered in the second block using stepwise procedures. For all categories of physical variables, identical regression models were produced using forwards and backwards stepwise entry methods indicating the absence of suppressor variables. Therefore in the following section a single regression equation will be presented within each category.

Decimal age

When standardised decimal age was included as the sole independent variable, the following regression model was produced:

$$\text{Logit(successful)} = 1.1091(\text{zdecage}) - 0.6931$$

With the inclusion of standardised decimal age the log likelihood (-2*LL) was reduced by 7.425 which was significant at the 1% level (p=0.006). This indicated that in comparison to the inclusion of a constant term only, decimal age improved the fit of the logistic regression model. However, when expressed in substantive terms, this corresponded to an $R^2_L$ of 0.172 (a reduction in the log likelihood of 17.2%), which indicated that the fit of the model was still relatively poor. The classification table presented in Table 5.17 shows that 75.8% of gymnasts were correctly classified. Predictive efficiency, expressed quantitatively through the calculation of Lambda ($\lambda$), was 0.333 which indicated that the

inclusion of standardised decimal age as an independent variable reduced the error of classification by approximately one third. However, the reduction in misclassification did not attain statistical significance at the 5% level (p=0.074). In conclusion, the positive coefficient associated with standardised decimal age indicated that the probability of being classified as successful was greater for older gymnasts. However, the poor model fit and non-significant reduction in predictive efficiency suggested that factors other than decimal age are likely to be important in determining future success within this particular sample of young female gymnasts.

Table 5.17. Classification table for the logistic regression model including standardised decimal age as an independent variable

| | unsuccessful | successful | Correct |
|---|---|---|---|
| unsuccessful | 17 | 4 | 80.95% |
| successful | 4 | 8 | 66.67% |
| | | overall | 75.76% |

Anthropometry

The logistic regression model presented below indicates that decimal age, zant2 and zant4 are potential predictors of future gymnastic success.

$$\text{Logit(successful)} = 0.6242(\text{zdecage}) + 1.4137(\text{zant2}) - 1.3935(\text{zant4}) - 0.7903$$

An $R^2_L$ of 0.359 indicates that the independent variables reduced the 'badness of model fit' by a moderate amount. The anthropometric components entered in the second block reduced the log likelihood by 8.099 (18.7%), which was significant at the 5% level (p=0.017). According to the classification table presented in Table 5.18 a total of seven gymnasts were wrongly classified. Lambda was calculated to be 0.417 which indicates that the anthropometric components included in the model reduced misclassification by over 40%. Moreover, the d statistic (1.809) indicated that this reduction was significant at the 5% level (p=0.035).

Table 5.18. Classification table for the logistic regression model including anthropometric components

| | Unsuccessful | successful | Correct |
|---|---|---|---|
| Unsuccessful | 19 | 2 | 90.48% |
| Successful | 5 | 7 | 55.33% |
| | | overall | 78.79% |

Components zant1 (general size) and zant3 (ratios) did not appear in the final model. The exclusion of zant1, the component representing general physical size, which included the majority of the body's linear measurements and whole body widths, was somewhat surprising. However, the gymnasts involved in the study had been involved in gymnastics for approximately 4.5 years and it may therefore be hypothesised that as a result of some form of selection, natural or systematic, the gymnasts were all of a similar physical size. The positive regression coefficient for zant2 suggested that the probability of future success was greater for those gymnasts who possessed a relatively large skeletal frame in relation to their less successful peers. Considering the variables which comprise this component, successful gymnasts appear to possess relatively large epiphyseal widths, a greater biacromial to biiliac ratio and were heavier and had a higher body mass index than their less successful peers. The observation that future gymnastic success may be associated with wide shoulders, narrow hips and relatively wide epiphyseal widths confirmed the findings of previous investigations (Beunen et al., 1981; Broekhoff et al., 1986; Claessens et al., 1991a). The positive association between mass, body mass index and the probability of future success was less consistent with the results of previous research (Eiben et al., 1986; Schmidt, 1987; Claessens et al., 1991a; Hadjiev, 1992). However, in relation to the reference population of 9 year old children reported by Frisancho (1990) the mass and BMI of the pooled population of gymnasts were approximately located at the 25$^{th}$ and 35$^{th}$ percentile respectively. Therefore, while the gymnasts as a pooled sample were light and had a low body mass index in comparison to control subjects, the successful gymnasts were heavier and had a greater BMI than their less successful peers. However, as reported in Table 5.11, mass has factor loading of 0.602 which was only just above the cut-off threshold of 0.600 and therefore its inclusion in the zant2 component may be questioned and requires further investigation with a larger

sample size. The negative coefficient associated with zant4 indicated that the more successful gymnasts had a lower predicted adult height derived using the formula proposed by Tanner (1989). The predictive validity of this component was expected and confirms the findings of previous investigations which have reported an association between stature, predicted adult stature and the competitive level of female gymnasts (Peltenburg et al., 1984; Calderone et al., 1986; Theintz et al., 1989; Claessens et al., 1991a).

Body Composition

Following the forced entry of standardised decimal age, the standardised sum of four skinfolds was considered for inclusion in the model using stepwise procedures. However, the change in the log likelihood (-2*LL) did not attain statistical significance and the standardised sum of four skinfolds was excluded from the model. The final model was therefore identical to that reported above when decimal age was included as the sole independent variable.

Moment of Inertia

The model for the stepwise logistic regression of the moment of inertia components is presented below:

$$\text{Logit(successful)} = 1.1912(\text{zdecage}) + 1.1146(\text{zinert2}) - 0.7712$$

The substantive significance of the model expressed in terms of $R^2_L$ was moderate at 0.270. The unique contribution of the moment of inertia components entered in the model in block two resulted in a reduction in the log likelihood of 4.257 (9.8%), which attained statistical significance at the 5% level (p=0.039). The classification presented in Table 5.19 revealed that according to this model eight gymnasts were wrongly classified. Lambda was estimated to be 0.333 (p=0.074) which indicated that the regression model reduced misclassification by one third which was equivalent to the reduction in misclassification using decimal age as the sole independent variable.

Table 5.19. Classification table for the logistic regression model including inertia components

| | unsuccessful | successful | Correct |
|---|---|---|---|
| unsuccessful | 18 | 3 | 85.71% |
| successful | 5 | 7 | 58.33% |
| | | overall | 75.76% |

The component representing the absolute values of moment of inertia about the somersault and twist axes (zinert1) did not appear in the final model. However zinert2, which represented inertia ratios was retained. The positive coefficient indicates that the probability of future success is associated with a relatively large change in moment of inertia upon moving from a shape in which the mass is widely distributed to a shape in which the mass is closer to the axis of rotation. The face validity of zinert2 is apparent when one considers the changes in body configuration which occur during multiple somersault and twisting elements which are a feature of contemporary gymnastics. When body shape is changed during free flight, for example when a gymnast moves from a layout to a tuck shape while rotating about the somersault axis, the gymnast with a high ratio would experience a relatively large change in angular velocity. Gymnasts with a large ratio will therefore possess a greater potential to accelerate rotation during twist and somersault activities giving them greater control.

Isometric strength

The only isometric component included in the regression model was interpreted to represent the rate of isometric force development in the shoulder region. This component was associated with a positive coefficient indicating that gymnasts who were able to develop force quickly had a greater probability of being classified as successful.

$$\text{Logit(successful)} = 0.9274(\text{zdecage}) + 0.7298(\text{zisom2}) - 0.6749$$

However, the fit of the model was relatively poor ($R^2_L$=0.217) and moreover, the unique contribution of the isometric component resulted in a minor reduction in the log likelihood

(4.5%). Finally, as shown in Table 5.20 the classification accuracy of the model was also poor. A lambda ($\lambda$ ) value of 0.333 (p=0.074) indicated that the regression model reduced errors in misclassification by one third which was equivalent to the reduction achieved when including decimal age as a single independent variable.

Table 5.20. Classification table for the logistic regression model including isometric components

| | unsuccessful | successful | Correct |
|---|---|---|---|
| Unsuccessful | 19 | 2 | 90.48% |
| Successful | 6 | 6 | 50.00% |
| | | overall | 75.76% |

Jumping (lower extremity power)

The initial logistic regression analysis conducted within this category resulted in a model which moderately fitted the observed data ($R^2_L$=0.388). Two of the identified jump components (zjump2 and zjump4) were retained in this model:

$$\text{Logit(selected)} = 1.4553(\text{zdecage}) - 1.9521(\text{zjump2}) + 1.3595(\text{zjump4}) - 1.0781$$

The reduction in the log likelihood for the block containing the jump variables was 9.504 (22%), which was statistically significant at the 1% level (p=0.009). The classification table presented in Table 5.21 indicates that jump components were excellent predictors of future gymnastic success with an overall classification accuracy of 90.9%.

Table 5.21. Classification table for the logistic regression model within the jump category

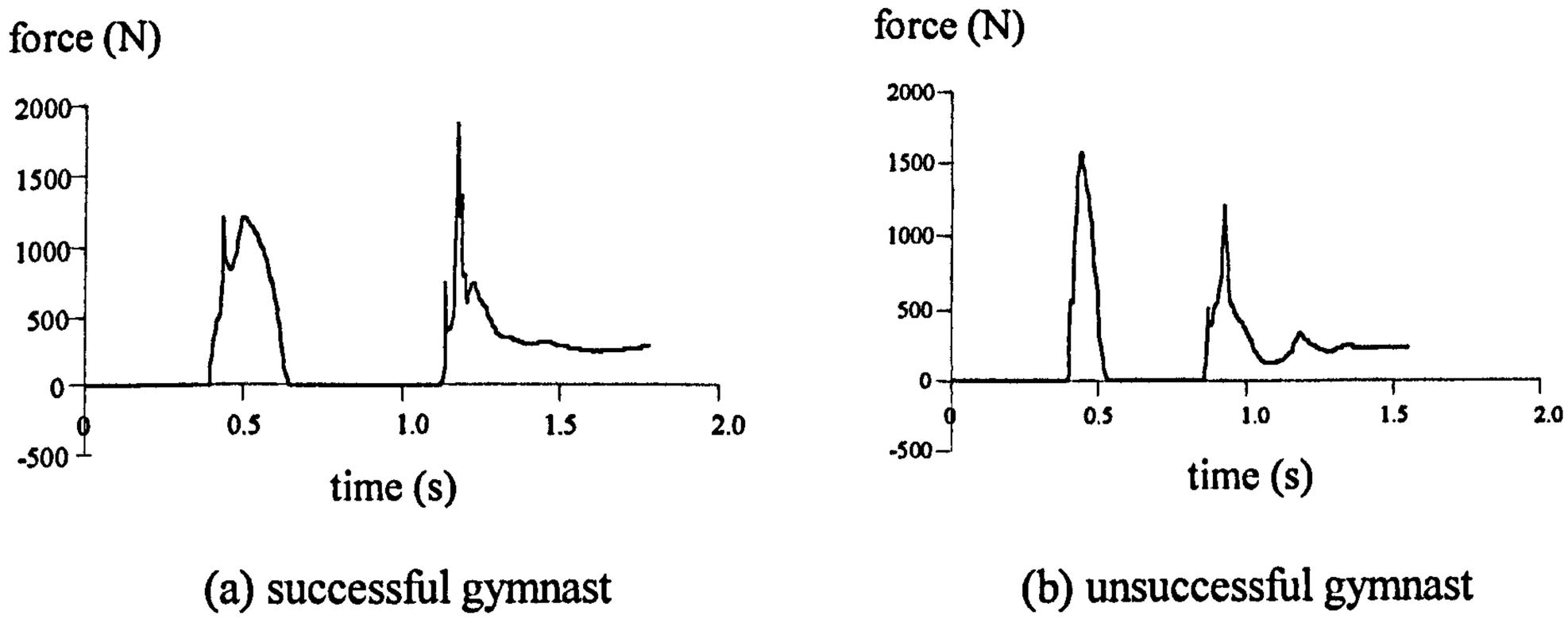
| | unsuccessful | successful | Correct |
|---|---|---|---|
| Unsuccessful | 20 | 1 | 95.24% |
| Successful | 2 | 10 | 83.33% |
| | | overall | 90.91% |

Lambda revealed that the model reduced the error in prediction by approximately 75% which was statistically significant at the 1% level (p=0.000). Components relating to the ability to generate impulse (zjump1) and to produce power during the counter movement jump (zjump3) were not included in the final model. Examination of the regression coefficients revealed that greater scores on zjump2, which represented power production during the bounce drop jump, were associated with lower probabilities of future success. For example, the probability of success for a gymnast with mean scores for decimal age, zjump2 and zjump4 was estimated to be 0.25. However, the probabilities of being classified as successful for gymnasts scoring one standard deviation above and one standard deviation below the mean value for zjump2 were 0.06 and 0.64 respectively. Given that many elements in contemporary gymnastics require large impulses to be produced during short periods of contact with the apparatus, this result was clearly in contrast to theoretical expectations.

Close examination of the video data revealed that although the gymnasts were given clear instructions and time to practice the bounce drop jump there was evidence of the two styles of drop jump (counter drop jump (CDJ) and bounce drop jump (BDJ)) identified by Bobbert et al. (1986). The distinction between the bounce drop jump and the counter drop jump was difficult to determine but it was apparent that the majority of successful gymnasts had adopted a counter drop style. The difference in jump style between successful and unsuccessful gymnasts is hypothesised to explain the results observed in the logistic regression analysis. Specifically, the successful gymnasts who adopted the counter drop style had patterns of force development which were consistent with longer contact times and greater push-off impulses than their less successful peers as shown in Figure 5.68.

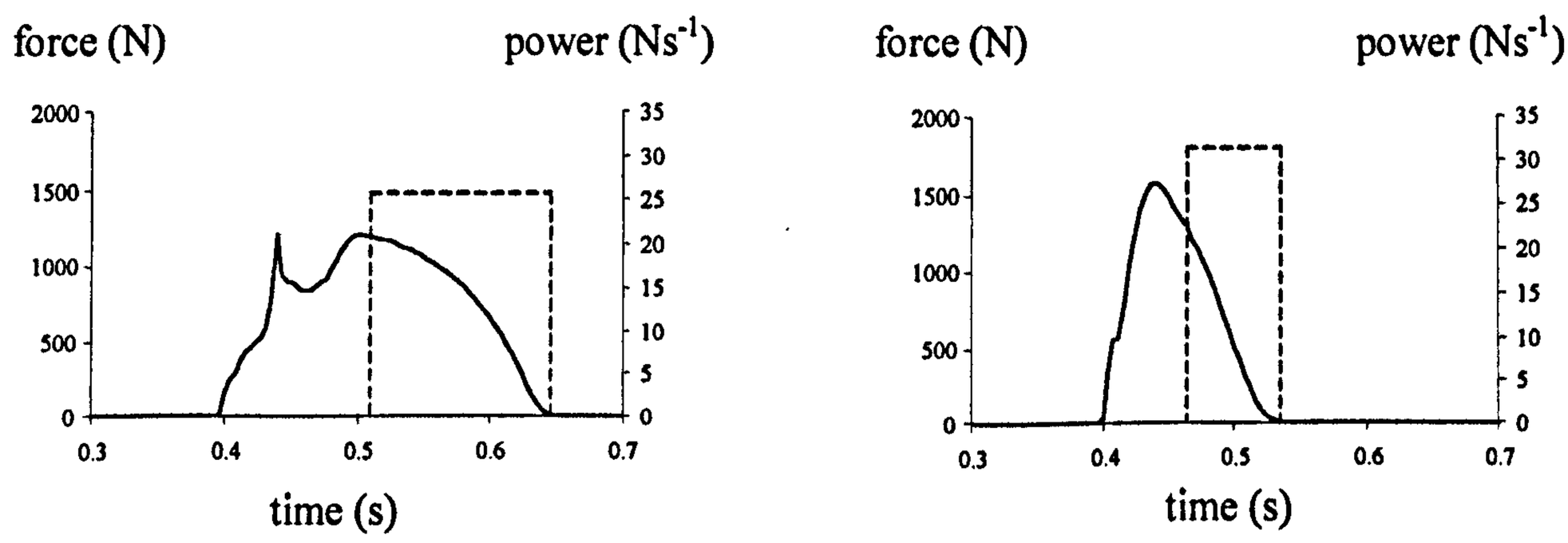
The normalised mean power produced during the push-off phase of the bounce drop jump (NMPP) also loaded on this component which suggests that this variable may also be a function of the jump style adopted by the gymnasts. However, as shown in Appendix 5.5 the mean values for normalised mean power produced during the push-off phase were similar for successful and unsuccessful gymnasts. This may be interpreted with reference to Figure 5.69, which presents an enlarged view of the contact phase of the two jumps presented in Figure 5.68. The normalised mean power produced during the push-off phase

is also illustrated by a dotted line. Analysis of these force-time curves reveals that although the average power produced by the successful and unsuccessful gymnasts were similar, the area under the power-time curve (energy) was greater for the successful gymnast who sustained a longer push-off phase. These results indicate that the use of NMPP may be misleading in the assessment of bounce drop jump performance.




(a) successful gymnast (b) unsuccessful gymnast

Figure 5.68. Typical force-time curves for successful and unsuccessful gymnasts performing the bounce drop jump.




(a) successful gymnast (b) unsuccessful gymnast

Figure 5.69. Force-time curve and average power output during the push-off phase of the bounce drop jump.

It appears that when performing the bounce drop jump the successful gymnasts adopted the counter drop jump style as described by Bobbert et al. (1986). However, the adoption of this alternative jump strategy was not sufficiently different from the bounce drop jump style to be detected at the time of testing and only became apparent upon close inspection

of the video data. It may be concluded that while 'rebound ability' is likely to be a prognostic indicator of future gymnastic success it could not be assessed using the bounce drop jump protocol in the present investigation. The adoption of the counter drop strategy by many of the successful gymnasts may be attributed to the inability of these gymnasts to understand and complete the task. However, it may be speculated that the successful gymnasts consciously or unconsciously adapted the style of the jump to permit a greater jump height to be achieved. In the light of these results all parameters associated with the bounce drop jump were excluded from the analysis. The principal components analysis was re-run to include variables associated with the counter movement jump and standing broad jump respectively. The results of this analysis are presented in Table 5.22.

Table 5.22. Principal components analysis of jump data

| | **COMPONENTS** | | | |
|---|---|---|---|---|
| | **zmjmp1** | **zmjmp2** | **zmjmp3** | **Zmjmp4** |
| **Variance explained** | **35.2%** | **27.5%** | **12.4%** | **9.6%** |
| VJ jump height | 0.904 | | | |
| VJ push off impulse | 0.871 | | | |
| VJ peak jump height | 0.895 | | | |
| Standing broad jump | 0.909 | | | |
| Normalised standing BJ | 0.864 | | | |
| VJ NMFz | | 0.983 | | |
| LN (VJ push-off time) | | -0.969 | | |
| VJ NMPP | | 0.948 | | |
| VJ NPPP | | | 0.808 | |
| VJ norm peak force pre t-off | | | 0.893 | |
| VJ PFdt | | | | -0.855 |
| VJ ratio impulse | | | | 0.700 |
| VJ compression time | | | | |

The derived components (Table 5.22) were similar to those obtained in the initial principal components analysis. The first component (zmjmp1) was interpreted to describe the gymnast's ability to generate push-off impulse across the two jump styles considered (counter movement and standing broad jumps). The second component (zmjmp2) comprised three variables associated with the counter movement jump, normalised mean push-off force and normalised mean push-off power which were positively related and push-off time which was negatively related. High scores on zmjmp2 were associated with the production of high mean push-off forces and power and short contact times and therefore, this component was interpreted to represent power production in the push-off phase of the counter movement jump. The third component (zmjmp3) was associated with peak values of power and force produced during the push-off phase of the counter movement jump. The final component (zmjmp4) comprised two variables, the ratio of positive to negative impulse which loaded positively and the time from peak force to take-off which loaded negatively. The negative loading associated with the time from peak force to take-off is consistent with the principle of late development of force as proposed by Hochmuth & Marhold (1977) who suggested that the attainment of maximum force late in the movement as the joints approach full extension may be associated with superior jump height. Therefore this component was interpreted to represent co-ordination during the counter movement jump. The results of the logistic regression analysis using the modified jump components revealed that the change in the log likelihood (-2*LL) associated with the stepwise entry of the four modified jump components in block 2 did not attain statistical significance.

Flexibility

The first general flexibility factor (zflex1) was retained within the flexibility regression model which demonstrated a moderate fit to the observed data ($R^2_L = 0.321$). Moreover the contribution of the block containing the flexibility components (block $\chi^2 = 6.458$) was significant at the 5% level (p=0.011):

$$\text{Logit(successful)} = 1.1665(\text{zdecage}) + 1.6217(\text{zflex1}) - 0.8284$$

The positive coefficient associated with zflex1 indicated that the probability of future success was related to good range of movement in the hip and shoulder joints which concurs with the results of previous investigations (Kirby et al., 1981; Nelson et al., 1983; Régnier & Salmela, 1987; Sol, 1987). It was surprising that the second flexibility (zflex2) component defined as active hip flexion did not appear in the final model. The combination of flexibility and muscular strength is intuitively important in gymnastics and has received much emphasis in the British Development Programme with the recent introduction of range and conditioning exercises into the compulsory programme for young female gymnasts. The classification table presented below indicates that 75.8% of gymnasts were correctly classified using the flexibility regression model (Table 5.23). However the calculation of Lambda ($\lambda = 0.333$) revealed that the reduction in misclassification was no better than when decimal age was included as the sole independent variable.

Table 5.23. Classification table for the logistic regression model including flexibility components

| | unsuccessful | successful | correct |
|---|---|---|---|
| unsuccessful | 18 | 3 | 85.71% |
| successful | 5 | 7 | 58.33% |
| | | overall | 75.76% |

Local muscular endurance

Of the three identified components only zlme2, which was interpreted to represent local muscular strength and endurance in the abdominal and hip flexor muscle groups, was included in the model. The fit of the model was moderate with an $R^2_L$ of 0.331 with the specific contribution of the local muscular endurance characteristics included in block 2 resulting in a reduction in the log likelihood of 6.905 (16%), which was significant at the 1% level (p=0.009).

$$\text{Logit(successful)} = 1.0564(\text{zdecage}) + 1.5552(\text{zlme2}) - 0.7589$$

The regression coefficient associated with zlme2 was positive which indicated that greater local muscular endurance in the abdominal and hip flexor muscle groups was associated with an increased probability of the future performance of gymnasts being classified as successful. Using this regression model the future performance of 84.85% of gymnasts was correctly classified (Table 5.24). A lambda of 0.583 indicated that errors in misclassification were reduced by almost 60%, which according to the d statistic was significant the 1% level (p=0.006).

Table 5.24. Classification table for the logistic regression model including local muscular endurance components

| | Unsuccessful | successful | correct |
|---|---|---|---|
| Unsuccessful | 20 | 1 | 95.24% |
| Successful | 4 | 8 | 66.67% |
| | | overall | 84.85% |

Summary

The results of the logistic regression analyses conducted for each category of variables within the physical dimension are summarised in Table 5.25. The inclusion of modified jump components and the sum of four skinfolds did not improve the fit of the separate regression models when compared with the use of decimal age as the sole independent variable. Given the conservative threshold for the stepwise inclusion of variables (p=0.20) it may be concluded that these components are of limited use in classifying the future performance of gymnasts. This observation may be interpreted in three different ways. Firstly, the components which were not included in the final logistic regression model within each category may be of little importance in determining future performance. Secondly these components may be important but as a result of selection (natural or systematic) or training, successful and unsuccessful gymnasts possess similar profiles (e.g. zant1). Finally, the apparent unimportance may simply indicate that the component could not be accurately measured using the procedures employed in the present investigation (e.g. zjump2).

Table 5.25. A summary of the results of the logistic regression analyses conducted within each category of the physical dimension

| | Lambda ($\lambda$) | D | p | Block $\chi^2$ (%) | p | $R^2_L$model |
|---|---|---|---|---|---|---|
| Decimal age | 0.333 | 1.447 | 0.074 | 7.425 | 0.006 ** | 0.172 |
| Anthropometry | 0.417 | 1.809 | 0.035 * | 8.099 | 0.017 * | 0.359 |
| sum of 4 skinfolds | 0.333 | 1.447 | 0.074 | - | - | 0.172 |
| Inertia | 0.333 | 1.447 | 0.074 | 4.257 | 0.039 * | 0.270 |
| Isometric strength | 0.333 | 1.447 | 0.074 | 1.968 | 0.161 | 0.217 |
| Modified jumping | 0.333 | 1.447 | 0.074 | - | - | 0.172 |
| Flexibility | 0.333 | 1.447 | 0.074 | 6.458 | 0.011 * | 0.321 |
| LME | 0.583 | 2.533 | 0.006 ** | 6.905 | 0.009 ** | 0.331 |

* significant at the 5% level
** significant at the 1% level

The logistic regression models including anthropometric (zant2, zant4) and local muscular endurance (zlme2) components improved the fit of the model and significantly reduced the errors associated with misclassification. Flexibility, isometric strength and inertia components (zflex1, zisom2 and zinert2) were retained in the respective regression models, however, while these components improved the fit of the model they did not significantly reduce misclassification errors.

*Logistic regression analysis (summary physical model)*

It was hypothesised that the errors of misclassification may be further reduced when those components which improved classification accuracy or improved model fit within each category were included in a single regression model. To permit the relative importance of each category to be evaluated a single component was derived to represent the anthropometric category. The procedure used to generate this component was consistent with the method of summation applied to generate the principal components. The positive regression coefficient associated with zant2 was assigned a weighting of +1 with the negative coefficient associated with zant4 assigned a weighting of -1. The standardised component scores were multiplied by their respective weightings and averaged to compute

a mean score 'zantsum'. A series of logistic regression models were computed to examine all possible subsets of the following components; zflex1, zinert2, zlme2, zantsum and zisom2. In line with the computation of regression models within each physical category standardised decimal age was forced into the regression model in the first block of independent variables with the selected components entered in the second block.

As highlighted in Table 5.26 when all five components were included in the regression model a 'perfect fit' was detected indicating that a unique solution could not be obtained. This indicated that more than one combination of the independent variables would result in the future performance of all gymnasts being correctly classified as successful or unsuccessful. The series of regressions including all possible subsets of components revealed that zantsum, zlme2 and zflex1 was the combination of components responsible for producing a perfect fit. The contribution of zantsum and zlme2 was unsurprising given the significant reductions in misclassification errors associated with the inclusion of these components in the separate regression models. It was interesting to observe that the inclusion of zflex1 in the flexibility regression model did not reduce misclassification errors but when zflex1 was included in combination with zantsum and zlme2 it did assist in reducing the number of gymnasts who were wrongly classified.

Table 5.26 indicates that the next best model in terms of classification accuracy included zlme2 and zantsum. The lambda ($\lambda$) for this model (0.917) suggests that for the current sample of gymnasts, the errors in misclassification could be reduced by 92% by assessing the size/shape of the skeletal frame and the local muscular endurance in the abdominal and hip flexor muscle groups. When an additional independent variable representing inertia ratios, zinert2, was included, the model fit in terms of $R^2_L$ improved but prediction accuracy decreased. It is therefore concluded that the optimum combination of components for classifying the future performance of gymnasts as successful or unsuccessful comprised skeletal frame size/physique, local muscular endurance in the abdominal/hip flexor muscle groups and flexibility about the hip and shoulder joints.

Table 5.26. A summary of the results of the combined logistic regression analyses conducted within the physical dimension of performance

| | Change 2*LL (block 2) | p | $R^2_L$ | Lambda | d | p |
|---|---|---|---|---|---|---|
| a, b, c, d, e | perfect fit | n/a | n/a | n/a | n/a | n/a |
| a, b, c, d | perfect fit | n/a | n/a | n/a | n/a | n/a |
| a, c, d, e | perfect fit | n/a | n/a | n/a | n/a | n/a |
| a, b, d, e | 28.884 | 0.000 ** | 0.839 | 0.833 | 3.619 | 0.000 ** |
| b, c, d, e | 27.843 | 0.000 ** | 0.815 | 0.833 | 3.619 | 0.000 ** |
| a, b, c, e | 15.480 | 0.004 ** | 0.529 | 0.667 | 2.895 | 0.002 ** |
| a, c, d | perfect fit | n/a | n/a | n/a | n/a | n/a |
| a, b, d | 28.485 | 0.000 ** | 0.830 | 0.833 | 3.619 | 0.000 ** |
| b, c, d | 27.636 | 0.000 ** | 0.810 | 0.833 | 3.619 | 0.000 * |
| a, b, c | 13.438 | 0.004 ** | 0.482 | 0.667 | 2.895 | 0.002 ** |
| a, c, e | 9.720 | 0.021 * | 0.396 | 0.667 | 2.895 | 0.002 ** |
| a, d, e | 23.420 | 0.000 ** | 0.713 | 0.667 | 2.895 | 0.002 ** |
| a, b, e | 13.780 | 0.003 ** | 0.490 | 0.583 | 2.533 | 0.006 ** |
| b, c, e | 11.065 | 0.011 * | 0.427 | 0.500 | 2.171 | 0.015 * |
| b, d, e | 11.191 | 0.011 * | 0.430 | 0.500 | 2.171 | 0.015 * |
| c, d | 25.925 | 0.000 ** | 0.817 | 0.917 | 3.981 | 0.000 ** |
| c, e | 7.807 | 0.020 * | 0.352 | 0.667 | 2.895 | 0.002 ** |
| a, b | 10.874 | 0.004 ** | 0.423 | 0.667 | 2.895 | 0.002 ** |
| a, c | 8.509 | 0.014 * | 0.197 | 0.667 | 2.895 | 0.002 ** |
| a, d | 23.196 | 0.000 ** | 0.708 | 0.667 | 2.895 | 0.002 ** |
| a, e | 8.693 | 0.013 * | 0.373 | 0.667 | 2.895 | 0.002 ** |
| b, e | 6.459 | 0.040 * | 0.321 | 0.583 | 2.533 | 0.006 ** |
| b, c | 13.053 | 0.002 ** | 0.473 | 0.500 | 2.171 | 0.015 * |
| b, d | 10.974 | 0.004 ** | 0.425 | 0.500 | 2.171 | 0.015 * |
| d, e | 8.241 | 0.016 * | 0.362 | 0.417 | 1.809 | 0.035 * |
| C | 6.905 | 0.009 ** | 0.331 | 0.583 | 2.533 | 0.006 ** |
| D | 8.098 | 0.004 * | 0.359 | 0.417 | 1.809 | 0.035 * |
| A | 6.458 | 0.011 * | 0.321 | 0.333 | 1.477 | 0.074 * |
| B | 4.257 | 0.039 * | 0.270 | 0.333 | 1.477 | 0.074 * |
| E | 1.968 | 0.161 | 0.217 | 0.333 | 1.477 | 0.074 * |

n/a = not applicable

* significant at the 5% level
** significant at the 1% level

where:
a = zflex1 c = zlme2
b = zinert2 d = zantsum
e = zisom2

### 5.4.3 LONGITUDINAL STABILITY

The longitudinal stability of the talent components was estimated using rank order autocorrelations. The autocorrelations indicated the extent to which the gymnasts maintained their relative position or rank across the three measurement intervals. The estimates of stability derived in the present study were compared with published values from the literature. However, since gymnasts represent a select sample in terms of their physical characteristics and training environment, these comparisons have been interpreted cautiously.

Anthropometric components

The rank order autocorrelations for three anthropometric components are presented in Table 5.27. The final component (zant4) represented predicted adult height and was therefore identical across all three measurement intervals. The autocorrelations for the first anthropometric component (zant1) were high indicating that body size, defined in terms of skeletal lengths and whole body skeletal widths, tracked well over the study period.

Table 5.27. Longitudinal stability of anthropometric components

| | Zant1 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | 0.983** | 0.984** |
| time 2 | ---- | 0.980** |

| | zant2 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | 0.921** | 0.956** |
| time 2 | ---- | 0.947** |

| | zant3 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | 0.868** | 0.908** |
| time 2 | ---- | 0.913** |

Previous studies of twins have reported that linear skeletal measurements demonstrated high heritabilities in comparison with other anthropometric indices (Bouchard et al., 1980; Bouchard et al., 1997). Therefore, the high stability reported for zant1 may be attributed to the large number of linear skeletal measurements loading on this component. The magnitude of autocorrelations for zant2 indicate that stability is high but is slightly lower than that observed for zant1. This is in line with the results of previous heritability studies which have reported that the genetic effect associated with epiphyseal width measurements is lower than that reported for skeletal lengths (Bouchard et al., 1997). The stability of

zant3, interpreted to represent stature ratios, was also high but was lower than the other two anthropometric components. This confirms the results of the longitudinal study of athletic subjects by Ackland & Bloomfield (1996) which highlighted the relative instability of lower limb anthropometric ratios during adolescence. The lower stability of zant3 is suggested to be the consequence of maturational differences between subjects and specifically individual differences in the timing of the adolescent spurt in leg length which occurs early in the maturational sequence.

Body composition components

The results of large scale family studies employing path analytic techniques reported that summary skinfold measures were associated with moderate transmissibility (Bouchard et al., 1985; Bouchard, 1988; Pérusse et al., 1988). However, the majority of this transmissible variance was reported to be the result of cultural factors with a negligible genetic effect (Bouchard et al. 1985; Bouchard, 1988). The results of the present investigation, presented in Table 5.28, indicated that the sum of four skinfolds tracked well and demonstrated a high level of stability over the 12 month period of study.

Table 5.28. Longitudinal stability of the body composition component

| | zsum4 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | 0.817** | 0.881** |
| time 2 | ---- | 0.706** |

The high level of stability found in the present study was in agreement with Marshall et al. (1998) who observed rank order autocorrelations in the range of 0.71-0.75 over the three year period of study. These high levels of stability may in part be attributed to the age and in particular the prepubertal status of the subjects (Roche et al., 1982). Moreover, the particularly high level of stability observed in the present study is suggested to be a function of the short measurement period and the intensity and relative homogeneity of the training environment.

Moment of inertia components

As shown in Table 5.29 the stability of the first moment of inertia component (zinert1) was high indicating that the distribution of mass about the somersault and twist axes was relatively stable throughout the one year period of measurement. This supports the findings of Jensen (1981) who found that although large inter-individual differences were observed in moments of inertia over a 12 month period the increases were most stable among 9-10 year old children. The stability of moment of inertia ratios (zinert2) has not previously been reported. According to the classification proposed by Malina (1996b), the stability of these inertia ratios was moderate to high (0.518-0.809) but was lower than observed for the principal moments (zinert1). This may be attributed to the limited range of inter-individual differences in inertia ratios across gymnasts, as indicated by the small standard deviations (Appendix 5.5). It is also suggested that changes associated with growth and maturation are likely to have greater influence on inertia ratios than on the whole body moments of inertia.

Table 5.29. Longitudinal stability of moment of inertia components

| | Zinert1 | |
|---|---|---|
| | time 2 | time 3 |
| Time | 0.910** | 0.971** |
| Time | ---- | 0.944** |

| | zinert2 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | 0.518* | 0.809** |
| time 2 | ---- | 0.557* |

Isometric strength components

The longitudinal stability of the isometric components in the present study was low to moderate which indicated inconsistency in the relative rank order of gymnasts over time (Table 5.30). While this result is in agreement with the large scale family studies employing path analytic techniques it was in contrast to traditional heritability studies which have indicated that the development of maximal isometric strength has a moderate to high genetic component (Sklad, 1973; Kovar, 1974; Malina & Mueller, 1981). These discrepancies may be interpreted to be a consequence of the isometric parameters investigated and/or the problems associated with the interpretation of task requirements in the present study.

Table 5.30. Longitudinal stability of isometric components

| | Zisom1 | |
|---|---|---|
| | Time 2 | time 3 |
| time 1 | 0.153 | 0.435* |
| time 2 | ---- | 0.547* |

| | zisom2 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | 0.179 | 0.145 |
| time 2 | ---- | 0.661** |

| | zisom3 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | 0.450* | 0.357 |
| time 2 | ---- | 0.383 |

Firstly, previous heritability studies have focused almost exclusively upon the development of maximal force whereas the components within the present study comprised a number of rate parameters which may demonstrate lower levels of stability. Secondly it is suspected that, as a consequence of their young age, the gymnasts did not all fully understand the goal of the task which was to produce maximal isometric force as quickly as possible. Therefore this component should not be considered a leading contender in the process of initial identification.

Jumping (lower extremity power) components

It is clear from Table 5.31 that the longitudinal stability of jump components varied according to the particular component under investigation.

Table 5.31. Longitudinal stability of jump components

| | Zmjmp1 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | 0.801** | 0.702** |
| time 2 | ---- | 0.917** |

| | zmjmp2 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | 0.091 | 0.046 |
| time 2 | ---- | 0.197 |

| | Zmjmp3 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | 0.465* | 0.528** |
| time 2 | ---- | 0.725** |

| | zmjmp4 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | 0.301 | 0.028 |
| time 2 | ---- | 0.404 |

The first jump component (zmjmp1), which was interpreted to represent the ability to generate positive impulse across a range of jump styles, demonstrated high stability over the measurement period (0.702-0.917). Of the four jump components, zmjmp1 may be considered comparable to the estimates of jump performance cited in published heritability studies. Moreover, the high stability observed in the present study is in close agreement with previous reports indicating that vertical jump performance is a highly heritable characteristic (Maes et al., 1996). The jump component representing the gymnast's ability to produce peak values of force and power in relation to body weight (zmjmp3) was also found to demonstrate moderate to high stability. In contrast, the components relating to the production of mean power throughout the push-off phase (zmjmp2) and the pattern of force application (zmjmp4) tracked poorly over the period of study. These low levels of stability are interpreted to be the consequence of an immature pattern of coordination. While a general propulsive strategy in terms of the proximal to distal sequencing in the timing of peak extension velocities has been reported in children from a young age (Hudson, 1986; Bobbert & Ingen Schenau, 1988; Clark et al., 1989; Jensen & Phillips, 1991) the 'optimal' strategy may not be achieved until a mature movement pattern is established later in development. It is hypothesised that vertical jump ability may develop in a manner analogous to the stage like development of postural control described by Woollacott & Sviestrup (1992).

Flexibility components

The first two components representing flexibility in the hip and shoulder regions (zflex1) and active flexibility in the hip joint (zflex2) tracked well across the measurement period (Table 5.32).

Table 5.32. Longitudinal stability of flexibility components

| | zflex1 | |
|---|---|---|
| | Time 2 | time 3 |
| time 1 | 0.901** | 0.884** |
| time 2 | ---- | 0.876** |

| | Zflex2 | |
|---|---|---|
| | time 2 | Time 3 |
| time 1 | 0.790** | 0.818** |
| time 2 | ---- | 0.936** |

| | zflex3 | |
|---|---|---|
| | time 2 | time 3 |
| Time | -0.031 | 0.383 |
| Time | ---- | 0.294 |

The high levels of stability observed for these components may be attributed to the nature of gymnastic training and may reflect the emphasis placed upon range and conditioning within the current programme of gymnastic development. The tracking of zflex3 which primarily represents flexibility in the hamstrings was less consistent demonstrating at best moderate stability. This result was surprising considering the relatively high inter-age correlations reported in the literature for sit and reach flexibility (Branta et al., 1984; Marshall et al., 1998). It is possible that this instability may reflect the limited attention paid to the maintenance and development of hamstring and lumbar range of motion when compared with hip and shoulder flexibility.

Local muscular endurance components

The components of local muscular endurance were measured at the beginning and end of the study and therefore, a single autocorrelation will be presented to indicate temporal stability. Local muscular endurance within the lower extremity (zlme1) and the abdominal and hip flexor muscle groups (zlme2) tracked reasonably well as indicated by the moderate autocorrelations shown in Table 5.33. In contrast, the stability of zlme3 (local muscular endurance in the lumbar region) tracked poorly.

Table 5.33. Longitudinal stability of local muscular endurance components

| | zlme1 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | ---- | 0.440* |

| | zlme2 | |
|---|---|---|
| | time 2 | time 3 |
| time 1 | ---- | 0.580 ** |

| | zlme3 | |
|---|---|---|
| | time 2 | time 3 |
| Time | ---- | -0.219 |

## 5.4.4 PHYSICAL TALENT CHARACTERISTICS - GYMNASTS AND CONTROLS.

To determine the extent to which the physical talent characteristics were able to distinguish between gymnasts and age matched controls, a modified test battery was administered to a group of 15 control subjects. Tests which required previous gymnastic experience were omitted from the battery, which included certain flexibility assessments and all tests of local muscular endurance. Moreover, since it was not possible to gain access to parental data the predicted adult heights could not be estimated. The data from the control subjects was pooled with data from the sample of 33 gymnasts. In comparison to the 'gymnasts

only' sample, a greater percentage of talent characteristics demonstrated unacceptable levels of skewness. Variable transformation was applied as described previously, with the data which did not demonstrate normality upon transformation excluded from all subsequent analyses. Principal components analysis with varimax rotation was conducted within each category of physical variables to derive a new set of talent components.

*Principal components analysis*

Anthropometry

Table 5.34. Principal components analysis of anthropometric data

| | **COMPONENTS** | | |
|---|---|---|---|
| | **zantc1** | **zantc2** | **zantc3** |
| **Variance explained** | **62.1%** | **11.6%** | **10.6%** |
| Height | 0.958 | | |
| upper leg length | 0.898 | | |
| lower leg length | 0.932 | | |
| foot length | 0.926 | | |
| upper arm length | 0.917 | | |
| lower arm length | 0.943 | | |
| hand length | 0.885 | | |
| Biacromial width | 0.824 | | |
| Armspan | 0.967 | | |
| ln (mass) | 0.873 | | |
| wrist width | 0.601 | | |
| ankle width | 0.777 | | |
| elbow width | 0.768 | | |
| sitting height to stature ratio | | 0.910 | |
| Biacromial to biiliac ratio | | | 0.866 |
| Armspan to stature ratio | | | 0.820 |

Three components were derived which explained a total variance of 84.2% (Table 5.34). The first component (zantc1) accounted for the majority of variance in the data (62.1%) and was interpreted as a general anthropometric component which combined information concerning the size and shape of the skeletal frame. This was in contrast to the results obtained using the 'gymnasts only' data set which resulted in distinct size and shape/physique components. The second and third components were clearly ratio components which accounted for a combined variance of 22.2%. The second component (zantc2) was associated with the relative proportionality of the upper and lower body and accounted for 11.6% of the variance. The third component (zantc3) was interpreted to represent ratios of biacromial widths. The emergence of this component was to be expected given that the characteristic anthropometric profile of the elite gymnast includes relatively broad shoulders in relation to both stature and pelvic width (Beunen et al., 1981; Claessens et al., 1991a).

Moment of inertia

Within the pooled sample of gymnasts and controls all moments of inertia expressed about the somersault and twist axes were positively skewed which reflects the observation that the a large proportion of the sample were gymnasts who had low moments of inertia in relation to the mean. However, with the exception of moment of inertia in the straight position about the longitudinal axis all variables achieved normality after transformation using natural logarithms. With respect to the ratio variables, pkas%lay and stras%wide were skewed and did not achieve normality upon transformation. Therefore the solution of the unrotated factor matrix presented in Table 5.35 revealed a single component (zinertc1) which accounted for 81.2% of the variance in the data. All the logarithmically transformed whole body moments of inertia produced high positive loadings on this factor. It was interesting to note that the single untransformed ratio variable (tuas%lay) loaded negatively (-0.421) which may indicate that in a large normally distributed sample a two component solution may be obtained. Once again, the pattern of component loadings did not support the differentiation of moment of inertia variables according to the principal axis about which the distribution of the mass was considered.

Table 5.35. Principal components analysis of inertia data

| | COMPONENT |
|---|---|
| | **zinertc1** |
| **variance explained** | **81.2%** |
| ln (IF1 layout) | 0.997 |
| ln (IF1 pike) | 0.991 |
| ln (IF1 tuck) | 0.971 |
| ln (IF3 wide) | 0.981 |
| tuas%lay | |

Isometric strength

Three components were identified which accounted for a cumulative variance of 83.1%. From the rotated component matrix presented in Table 5.36 it is clear that the components obtained were similar to those derived using the 'gymnasts only' sample with components identified to represent isometric hip strength (zisomc1), shoulder isometric force (zisomc2) and the rate of force development in the shoulder region (zisomc3).

Table 5.36. Principal components analysis of isometric strength data

| | COMPONENT | | |
|---|---|---|---|
| | **zisomc1** | **zisomc2** | **zisomc3** |
| **variance explained** | **31.8%** | **30.0%** | **21.3%** |
| HXT MRFD | 0.924 | | |
| HXT ARFD | 0.895 | | |
| HXT NRFD | 0.889 | | |
| SFX NMIF | | 0.810 | |
| SEL NMIF | | 0.921 | |
| SEL MRFD | | 0.646 | |
| LN SEL NRFD | | | 0.914 |

As in the 'gymnasts only' sample, maximal rate of force development in shoulder elevation (SELMRFD) loaded on shoulder force component. In line with the treatment of this variable in the previous section, SELMRFD was assigned a weighting of zero.

Jumping (lower extremity power) components

In contrast to the 'gymnasts only' sample, three components were obtained which accounted for 78.2% of the variance (Table 5.37).

Table 5.37. Principal components analysis of jump data

| | **COMPONENTS** | | |
|---|---|---|---|
| | **Zjumpc** | **zjumpc2** | **zjumpc3** |
| **variance explained** | **37.4%** | **23.6%** | **17.2%** |
| VJ jump height | 0.930 | | |
| VJ peak jump height | 0.895 | | |
| VJ NPPP | 0.786 | | |
| Standing broad jump | 0.888 | | |
| Normalised standing BJ | 0.877 | | |
| VJ NMFz | | 0.878 | |
| VJ NMPP | | 0.919 | |
| LN VJ PFdt | | | -0.736 |
| LN VJ ratio impulse | | | 0.659 |
| LN normalised peak force | | | 0.736 |

The different component solutions may be due in part to the exclusion of variables (vertical jump push-off impulse and push-off time) from the current principal components analysis on the basis of non-normality. The composition of the first component (zjumpc1) was similar to zjmp1 which was interpreted to represent the ability to generate impulse in the push-off phase across jump styles. The second component comprised normalised mean push off force and power in the counter movement jump and was considered equivalent to zjmp2 (power production in the push-off phase of the counter movement jump). Variables

relating to the pattern and timing of force development loaded highly on zjumpc3 which was therefore interpreted to represent coordination in the counter movement jump. The component associated with peak values of power and force during the push-off phase of the counter movement jump was not found using this pooled sample of gymnasts and controls. Instead the variables which loaded on this component in the 'gymnasts only' sample were dispersed between zjumpc1 and zjumpc3.

Flexibility components

Given that a number of gymnastic specific flexibility measurements were omitted from the test battery a different component structure may be expected for the pooled sample. Three components emerged which accounted for a cumulative variance of 71.5% (Table 5.38).

Table 5.38. Principal components analysis of flexibility data

| | **Components** | | |
|---|---|---|---|
| | **zflexc1** | **zflexc2** | **zflexc3** |
| **variance explained** | **35.6%** | **20.4%** | **15.5%** |
| FFFD | 0.932 | | |
| FSFD | 0.938 | | |
| CTFX | 0.910 | | |
| FAPF | | 0.646 | |
| FSFX | | 0.765 | |
| FD1 | | 0.632 | |
| CSER | | | 0.794 |
| CWXT | | | 0.707 |

The first component (zflexc1) explained 35.6% of the variance and included seated fold, straddle fold and trunk flexion. This may be interpreted as a 'trunk flexibility' component which combines hip flexion, and flexibility in the hamstrings and lumbar spine. Component two (zflexc2), which explained 20.4% of the variance, comprised shoulder flexion, 'D' shape and ankle plantar flexion. This component does not appear to represent the

flexibility of the subject about a given joint centre. Given the nature of gymnastics, these flexibility measures are likely to highlight differences between gymnasts and controls. Component three (zflexc3), which explained 15.5% of the variance, comprises shoulder external rotation and wrist extension. Again this component does not represent the range of motion at a specific joint. Given the expected difference in levels of flexibility between gymnasts and controls it is not surprising that components yielded by the pooled sample were not as clearly defined as those derived from the 'gymnast only' sample.

*Logistic regression analysis*

According to the procedures described in Section 5.4.2 a series of logistic regression models were produced to determine which linear combination of physical talent components was best able to distinguish between gymnasts and control subjects. There was no evidence that the levels of multicollinearity in the data were problematic within the pooled sample of gymnasts and controls. The estimated tolerance values ranged between 0.660-0.998 all of which were above the critical value of 0.20 proposed by Menard (1995).

Decimal age

The mean decimal age was similar between groups of gymnasts (9.61±0.64) and controls (9.73±0.71) and therefore decimal age was not expected to significantly contribute to the classification of gymnasts and controls. This expectation was confirmed by the results of the logistic regression analysis. When decimal age was included as the sole independent variable both model fit ($R^2_L$=0.004, a reduction in the log likelihood of 4.0%) and classification accuracy were poor. Indeed, the classification table presented in Table 5.39 shows that the regression model which included decimal age was unable to correctly classify any of the control subjects. The poor prediction accuracy was confirmed by the small value of lambda ($\lambda$) 0.000 which did not attain statistical significance at the 5% level (p=0.500). However, consistent with the procedures adopted for the 'gymnasts only' sample the forced entry procedure was retained for all subsequent models with decimal age entered into the regression model in the first block and all other independent variables included in the second block using stepwise procedures.

Table 5.39. Classification table for the logistic regression model including only decimal age

| | controls | gymnasts | correct |
|---|---|---|---|
| controls | 0 | 15 | 0.0% |
| gymnasts | 0 | 33 | 100.0% |
| | | overall | 68.8% |

Anthropometry

Components zantc1 (general physical size/shape) and zantc3 (biacromial ratios) were included in the anthropometric regression model presented below:

$$\text{Logit(gymnast)} = 0.6271(\text{zdecage}) - 2.8609(\text{zantc1}) + 55.9303(\text{zantc3}) - 66.7170$$

This model resulted in a large reduction in the log likelihood ($R^2_L = 0.537$) which was indicative of a good fit with the observed data. Moreover, the anthropometric components in block two reduced the log likelihood by 31.791 (a reduction in the log likelihood of 53.3%), which was significant at the 1% level (p=0.000). In addition, the model demonstrated a high level of classification accuracy as shown in Table 5.40. Indeed the calculated lambda value ($\lambda$=0.800) suggested that this linear combination of anthropometric components and decimal age reduced classification errors by approximately 80%.

Table 5.40. Classification table for the logistic regression model within the anthropometry category

| | controls | gymnasts | correct |
|---|---|---|---|
| controls | 12 | 3 | 80.0% |
| gymnasts | 0 | 33 | 100.0% |
| | | overall | 93.75% |

In contrast to the anthropometric model for the 'gymnasts only' sample, a general anthropometric component (zantc1) was included in the model for the pooled sample. The sign of the coefficient associated with this component indicated that those children with a smaller size/skeletal frame had a greater probability of being classified as gymnasts. This relationship is in line with theoretical expectations and the results of previous investigations which have reported that female gymnasts have small absolute skeletal dimensions in comparison to age matched controls (Claessens et al., 1991a). Component zantc2 which was interpreted to represent the relative proportionality of the upper and lower body did not appear in the regression model. This result was expected given the failure of previous studies to identify a sitting height to stature profile in young female gymnasts which was distinct from the selected reference population (Claessens et al., 1991a). Inter-individual differences in biological maturity status and in particular variations in the timing of peak growth velocities between individuals confirm the results of the logistic regression analyses which indicate that this ratio component is likely to be of limited utility in the identification and profiling of young female gymnasts. In contrast, the third anthropometric component (zantc3) interpreted to represent biacromial ratios was included in the model and assigned a positive coefficient. The sign of the coefficient indicates that a large biacromial ratio expressed in relation to both stature and pelvic width was associated with a greater probability of being classified as a gymnast. Once again these observations confirmed the results of previous studies indicating that while gymnasts possess smaller absolute skeletal dimensions in relation to controls, gymnasts of all competitive levels have relatively broad shoulders and narrow hips (Beunen et al., 1981; Vercruyssen, 1984; Broekhoff et al., 1986; Claessens et al., 1991a).

Body composition

In contrast to the 'gymnasts only' sample, the sum of four skinfolds was included in the logistic regression model for the pooled sample and appeared to accurately distinguish between gymnasts and controls (Table 5.42). The proportional reduction in the log likelihood associated with the inclusion of the independent variables ($R^2_L$ = 0.644) indicated that the model fitted the observed data well. The body composition components in block two reduced the log likelihood by 38.161 (a reduction in the log likelihood of 64.0%), which was significant at the 1% level (p=0.000). Moreover, the value of lambda

($\lambda$=0.867) suggested that the inclusion of the standardised sum of four skinfolds in combination with standardised decimal age dramatically reduced classification errors.

Table 5.41. Classification table for the logistic regression model for the skinfolds model

| | controls | gymnasts | correct |
|---|---|---|---|
| controls | 14 | 1 | 93.3% |
| gymnasts | 1 | 32 | 97.0% |
| | | overall | 95.8% |

The standardised sum of four skinfolds was associated with a relatively large negative coefficient which is in line with previous studies which have consistently reported that young female gymnasts have lower amounts of subcutaneous fat in comparison with selected reference populations (Moffatt et al., 1984; Verycrussen, 1984; Carter & Brallier, 1988; Claessens et al., 1991a; Baxter-Jones, 1994b).

$$\text{Logit(gymnast)} = -1.0246(\text{zdecage}) - 5.8066(\text{zsum4}) + 0.8544$$

It was interesting to note that the standardised sum of four skinfold measurements appeared to be useful in distinguishing between gymnasts and controls but not between successful and unsuccessful gymnasts. It may be hypothesised that among the 'gymnasts only' sample, the training stimulus may be sufficiently intense to ensure that inter-individual differences in subcutaneous adipose tissue remain relatively small in this preadolescent sample. The inability of skinfold measurements to differentiate between gymnasts of various ability parallels the observation of Blanksby et al. (1994) that body composition parameters were unable to discriminate between elite and less elite performers in certain sports and controls until the later stages of adolescence.

Moment of inertia

As previously described, a single talent component (zinertc1) emerged from the principal components analysis to represent variables associated with the distribution of body mass about the three principal axes of rotation. Although the change in the log likelihood was

sufficient for this component to be retained within the regression model, the model demonstrated a poor fit to the observed data as indicated by the relatively low value for $R^2_L$ (0.233). Moreover, the inertia component in block two reduced the log likelihood by 14.287 (24.0%), which was significant at the 1% level (p=0.000). The inclusion of zinertc1 as an independent variable was associated with a reduction in the errors of prediction which was statistically significant at the 5% level (p=0.015) and it may therefore be assumed that zinertc1 plays an important role in classifying gymnasts and controls. The negative coefficient associated with zinertc1 was in line with theoretical expectations indicating that the probability of being classified as a gymnast was greater for those individuals with lower whole body moments of inertia. In addition to the reduced resistance to rotation about the principal axes, lower whole body moments of inertia are generally associated with small body size.

$$\text{Logit(gymnast)} = 0.3933(\text{zdecage}) - 1.6547(\text{zinert1}) + 0.9026$$

However, according to the classification table (Table 5.41) eight of the control subjects were misclassified by this regression model and therefore the accuracy with which zinertc1 was able to distinguish between gymnasts and controls may be questioned.

Table 5.42. Classification table for the logistic regression model within the inertia category

| | controls | Gymnasts | correct |
|---|---|---|---|
| controls | 7 | 8 | 46.7% |
| gymnasts | 0 | 33 | 100.0% |
| | | overall | 83.3% |

Moreover, given the magnitude of the physical differences between gymnasts and controls and the enhancements in classification accuracy associated with other physical components, zinertc1 was considered to be of limited value in the context of talent identification and profiling. The relatively minor contribution of this talent component is surprising given that whole body moments of inertia have been reported to detect changes associated with maturation and development with greater sensitivity than traditional

indices of growth (Jensen, 1981; Jensen, 1986). Finally, it may be speculated that given a larger, more representative sample, an alternative component structure and regression model may be obtained. Specifically, it is anticipated that the distribution of the ratio data would approximate normality and emerge from the principal components analysis as a distinct component which would be better able to distinguish between potential gymnasts and controls.

Isometric strength

In contrast to the results of the 'gymnasts only' sample, isometric strength components distinguished well between gymnasts and controls with all three components included in the logistic regression model.

$$\text{Logit(gymnast)} = -0.3595 + 2.1083(\text{zisom1}) + 4.6554(\text{zisom2}) + 1.4935(\text{zisom3}) + 2.9850$$

This model demonstrated a close fit with the observed data as indicated by an $R^2_L$ of 0.733. The isometric components in block two reduced the log likelihood by 41.617 (a reduction in the log likelihood of 69.8%), which was significant at the 1% level (p=0.000). However, as shown in Table 5.43 a total of four children were misclassified, which suggests that although the errors of prediction were reduced by over 70% in comparison with a model containing a constant term only, the model was not optimal in terms of classification accuracy.

Table 5.43. Classification table for the logistic regression model within the isometric category

| | controls | Gymnasts | correct |
|---|---|---|---|
| controls | 13 | 2 | 86.7% |
| gymnasts | 2 | 31 | 93.9% |
| | | overall | 91.7% |

The positive coefficients associated with the independent variables indicated that gymnasts may be differentiated from age matched controls according to their ability to produce high levels of isometric force rapidly during shoulder and hip joint actions. Moreover, the size

of the coefficients associated with the standardised components showed that the probability of being classified as a gymnast was most closely related to zisomc2 which represents the ability of the individual to generate maximal isometric strength during shoulder joint flexion and shoulder girdle elevation. This result may be attributed in part to the specificity of the training programme followed by young female gymnasts. A high level of strength in these two muscle actions is necessary for the successful completion of a number of elements within Women's Artistic Gymnastics, particularly for skills relating to contemporary asymmetric bar work and tumbling. Therefore, it may be concluded that the ability to develop high levels of isometric strength rapidly is an important attribute of the young female gymnast. However, since these attributes are likely to be influenced by gymnastic training their inclusion in batteries designed to identify gymnastic talent is unclear and in need of further examination.

Jumping (lower extremity power)

When all three jump components were entered into the logistic regression model a 'perfect fit' was detected which indicated that a unique solution could not be attained. The 'all possible subsets' approach revealed that the combination of zjumpc1 (the ability to generate positive impulse) and zjumpc3 (coordination in the counter movement jump) was the combination of independent variables responsible for the perfect fit. The series of regressions in which each of the independent variables were entered into the logistic regression model in isolation indicated that the zjumpc1 was associated with the greatest reduction in the classification errors. In this model only two subjects were misclassified with lambda ($\lambda$) calculated to be 0.867 (a reduction in the log likelihood of 1.5%), which was statistically significant at the 1% level ($p=0.000$). This result may be considered to be interesting given that the ability to generate positive impulse was not included in the jump logistic regression model for the 'gymnasts only' sample. It was also interesting to observe that when the all possible subsets approach was adopted and the variables in the second block were entered using forwards stepwise procedures, zjumpc2 (ability to produce mean values of power and force during the push-off phase) was only included in the regression model in the presence of the coordination component. This was interpreted to indicate that the production of force/power was only important when an appropriate pattern of coordination was in place.

Flexibility components

The combination of three flexibility components also resulted in a 'perfect fit' to the observed data. The all possible subsets approach revealed that zflexc1 (the trunk flexibility component combining hip flexion, and flexibility in the hamstrings and lumbar spine) was the component uniquely responsible for creating the perfect fit. When zflexc1 was not included in the regression model all combinations of zflexc2 and zflexc3 resulted in poor classification accuracy. This result is interesting since the equivalent component derived from the 'gymnast only' data was unable to distinguish between successful and unsuccessful gymnasts. It is therefore suggested that during initial selection trunk flexibility (hamstring and possibly lumbar flexibility) may be used to distinguish potential gymnasts from the general population. However, after initial selection trunk flexibility appears to be less important when compared with shoulder and hip ranges of movement.

Summary

Results of the series of logistic regression analyses conducted to determine the extent to which physical talent characteristics were able to distinguish between gymnasts and controls are summarised in Table 5.44. In general, the physical talent components distinguished between gymnasts and controls with a high level of classification accuracy. The regression models produced within the anthropometric, isometric strength and body composition categories fitted the observed data well and were associated with large reductions in the errors of prediction all of which were significant at the 1% level. In comparison, the component interpreted to represent whole body moment of inertia was less proficient in distinguishing between gymnasts and controls. This result was somewhat surprising given the reported sensitivity of this measure and its theoretical relationship to performance in Women's Artistic Gymnastics. However, it is likely that the apparent unimportance of this component may be a function of the limited sample size and in particular the non-normality of the ratio data which resulted in the exclusion of these talent characteristics from the principal components analysis. Regression models including the flexibility and jump components produced a 'perfect fit' which indicated that a unique solution could not be obtained and several combinations were able to 'perfectly' distinguish between gymnasts and controls. This result was attributed to the prognostic

validity of the physical talent components and the small, heterogeneous sample of gymnasts and controls involved in the current investigation.

Table 5.44. Summary statistics indicating the results of the logistic regression models for gymnasts and controls within the physical dimension of performance

| | lambda ($\lambda$) | d | P | block $\chi^2$ (%) | p | $R^2_L$ model |
|---|---|---|---|---|---|---|
| Decimal age | 0.000 | 0.000 ** | 0.500 | 0.233 (4.0%) | 0.629 | 0.004 |
| Anthropometry | 0.800 | 3.737 | 0.000 ** | 31.791 (53.3%) | 0.000 ** | 0.537 |
| Body comp. | 0.867 | 4.098 | 0.000 ** | 38.161 (64.0%) | 0.000 ** | 0.644 |
| Inertia | 0.467 | 2.180 | 0.015 * | 14.287 (24.0%) | 0.000 ** | 0.244 |
| Isom. strength | 0.733 | 3.425 | 0.000 ** | 41.617 (69.8%) | 0.000 ** | 0.702 |
| Jumping | perfect fit | perfect fit | perfect fit | perfect fit | perfect fit | Perfect fit |
| Flexibility | perfect fit | perfect fit | perfect fit | perfect fit | perfect fit | Perfect fit |

* significant at the 5% level
** significant at the 1% level

## 5.5 DISCUSSION

The results of the test-retest reliability study highlighted that the physical talent characteristics were measured with a high degree of precision in the current sample of young female gymnasts. There was little evidence of systematic bias or variability in the test-retest data and less than 9% of variables were excluded as a result of insufficient reliability. The results presented in Tables 5.9 and 5.10 indicate that the gymnastic specific functional flexibility measurements demonstrated greater test-retest reliability than the equivalent clinical measurements. However, the manual digitisation process through which joint angles were estimated in the functional assessments, although reliable, was extremely time consuming and therefore would not be feasible to implement within the context of a large scale talent identification system.

In the first stage of analysis, the data reduction technique of principal components analysis was conducted within each category to reduce the large number of reliable talent characteristics to a smaller number of talent components. In all physical categories the component loadings were high and in most cases the component structure could be clearly interpreted. For all categories, the rotated components accounted for a large proportion of variance in the data (62.9%-87.7% 'gymnasts only' sample, 71.5%-84.2% pooled sample). It was notable that for both samples, the rotated component matrix for flexibility explained the smallest amount of the variance and therefore represented the observed data least well. With few exceptions, the derived components were in line with theoretical expectations. However, the loading patterns of several components merit discussion. For example, it was interesting to observe that the local muscular endurance components were organised according to muscle function and were not distinguished according to the relative contribution of the metabolic pathways. However, this pattern of components supports the assumption that anaerobic performance is a local characteristic with training adaptations occurring in specific muscle groups in the absence of systematic adaptations (Bar-Or, 1987; Cahill et al., 1997). In addition it was surprising to note that for both samples a generic component was derived to represent whole body moments of inertia with no distinct components representing the distribution of mass about the somersault and twist axes respectively. Finally, with respect to isometric strength, it was interesting to observe that separate components were derived to represent maximum force and maximum rate of force development in the shoulder region whereas a single component including force and rate variables was derived for the hip region.

Given that the data of 33 gymnasts were common to both samples it was anticipated that the derived components would be similar across samples. However, several notable differences were observed. Firstly, within the 'gymnasts only' sample, separate components were derived to represent physical size and the shape of the skeletal frame whereas in the pooled sample a composite 'size' component emerged. The inertia component matrices were also different between samples with no distinct ratio component observed in the pooled sample. This was suggested to be due to the exclusion of two of the three ratio variables on the basis of non-normality and it was anticipated that the ratio component may emerge given a larger and more representative pooled sample. Finally, notable differences were observed in the structure of the flexibility components, with the

only common component representing trunk flexibility and in particular flexibility in the hamstrings and the lumbar spine. The flexibility components derived within the 'gymnasts only' sample could be clearly interpreted according to the particular joint action with which they were associated. In contrast, with the exception of the component representing trunk flexibility, the components which emerged from the pooled sample were less clearly interpretable and could not be distinguished on the basis of joint actions.

The results of the logistic regression analyses revealed that the physical talent components were able to distinguish between future successful and unsuccessful gymnasts and between gymnasts and controls with a high degree of accuracy. However, the linear combinations of physical components which best predicted group membership were not consistent across samples. This result indicated that a different combination of components will be required in the initial identification of talent and the subsequent profiling of female gymnasts. This observation was expected considering that while gymnasts of various ability made up the successful and unsuccessful groups, even the less successful gymnasts had been selected by their coaches to progress to 'serious' training and therefore in relation to the untrained control subjects the 'gymnasts only' sample could be considered a relatively homogeneous group.

The anthropometric components classified group membership with a high degree of accuracy in both samples and tracked well across the measurement period indicating their potential utility in the long term prediction of future gymnastic performance. As previously highlighted the nature of the derived components differed between samples which was attributed in part to differences in the heterogeneity of groups between the pooled and 'gymnasts only' samples. In the more heterogeneous pooled sample, a general component was derived to represent body size whereas in the relatively homogeneous 'gymnasts only' sample the variance in the data was best explained using separate components to represent linear anthropometric dimensions and frame size/shape respectively. While differences in the structure of the rotated component matrices prevented the direct comparison of regression parameters across samples, several important points may be highlighted. Firstly, while gymnasts were distinguished from controls on the basis of their smaller absolute physical size, the probability of future gymnastic success in the 'gymnasts only' sample was not associated with linear skeletal

measurements. Instead, successful and unsuccessful gymnasts were distinguished on the basis of the size and shape of their skeletal frame with successful gymnasts possessing a larger frame size compared with their less successful peers. Moreover, given that decimal age was forced into the regression equation prior to the anthropometric variables, the larger skeletal frame of the successful gymnasts could not be attributed solely to their more advanced chronological ages. This observation was in line with previous studies which have reported that elite gymnasts possess similar absolute and larger relative epiphyseal widths than untrained controls (Broekhoff et al., 1986; Claessens et al., 1991a). It may be speculated that the greater epiphyseal widths enhance the robustness of the skeletal frame which may be important in young gymnasts considering the impulsive nature of many gymnastic skills and the weight bearing function of the upper extremities.

If the results of both samples are considered together it appears that smaller anthropometric dimensions may be associated with a greater probability of success up to a point after which smaller skeletal measurements (particularly frame size) may be associated with a reduced probability of future success. Therefore, while linear combinations of talent components may be appropriate when models are applied to distinguish between successful and unsuccessful gymnasts and gymnasts and controls, a non-linear polynomial function may most accurately represent the relationship between anthropometric talent components and future gymnastic success. Given the distinct profile of the elite female gymnast and the high levels of stability associated with the linear skeletal measurements and frame size, these components are considered to be essential aspects of the initial identification process. Therefore, it is recommended that the precise nature of the non-linear relationship between linear skeletal measurements, frame size and future gymnastic success is investigated using appropriate longitudinal investigations.

The results of the anthropometric regression model also revealed that predicted adult height estimated using the method proposed by Tanner (1989) distinguished between future successful and unsuccessful gymnasts. The sign of the coefficient indicated that smaller predicted adult heights were associated with a greater probability of future gymnastic success and while this variable was not assessed in the control subjects, it was expected that it would play a similar role in distinguishing between gymnasts and controls. However, it is hypothesised that if the purpose of the regression model is to identify

children with the potential to excel in gymnastics from a large representative sample of the general population then higher order terms may need to be included in the model to reflect the non-linearity of the relationship and to highlight that there may be an optimal predicted adult height above and below which the probability of future gymnastic success may be reduced.

In the present investigation, predicted adult height was estimated as mean parental height after correcting for the average difference in stature between the sexes. More sophisticated methods are currently available to predict adult stature, however, the majority of these require an estimate of the child's skeletal age (Bayley & Pinneau, 1952; Roche, Wainer & Thissen, 1975b; Tanner et al., 1983) and are therefore inappropriate to apply within a mass screening situation. A number of non-invasive procedures based upon multiple linear regression have recently been devised (Khamis & Roche, 1994; Beunen et al., 1997c), however, the extent to which these methods may be generalised to other samples has not been conclusively determined. The Khamis-Roche method (Khamis & Roche, 1994) which is based upon data derived from the Fels longitudinal study, was used to determine the predicted adult heights of the gymnasts involved in the present study. The adult heights predicted using this method were far in excess of anticipated values and of the values derived using corrected mean parental heights. The apparent over-prediction of adult statures may be attributed to differences between the current sample of highly trained British children and the reference sample of American children from which the regression coefficients were derived. As a result of the unusually high estimates, the predictions of adult stature derived using the Khamis-Roche method were excluded from all statistical analyses. It is recommended that in light of their potential contribution to the long term prediction of gymnastic talent further research be directed towards the development of non-invasive methods of predicting adult stature in young athletic females.

The results of the logistic regression analyses indicated that the relationship between biacromial and biiliac widths was an important indicator of future success in young female gymnasts. Gymnasts were distinguished from controls and successful gymnasts from their less successful peers according to the shape of their skeletal frame and in particular their wide shoulders in relation to pelvic width. This observation was in agreement with previous studies which have reported that in comparison to untrained controls, gymnasts

of varying levels of ability possess wide shoulders and relatively narrow hips (Beunen et al., 1981; Vercruyssen, 1984; Broekhoff et al., 1986; Claessens et al., 1991a). The role of relative shoulder width appeared to be particularly important in the pooled sample in which biacromial to biiliac width and armspan to stature ratios comprised a distinct anthropometric component and this component was associated with a large regression coefficient. Given the extent to which skeletal widths are influenced by the genotype and their apparent resistance to training stimuli (Bouchard et al., 1973; Rich et al., 1991; Bouchard et al., 1997) the biacromial to biiliac ratio appears to be an essential measurement to be included in the initial identification of gymnastic talent.

In contrast, anthropometric components associated with the proportionality of the upper and lower body/extremities did not appear to have long term prognostic value. Proportionality components were not included in the logistic regression models within either sample and tracked less well over the measurement period than the majority of anthropometric measurements. However, while proportionality assessments are not recommended for inclusion in the initial screening process, they may provide important information concerning the changes associated with growth and maturation and the consequences of these changes for skill development. It is also recommended that as young female gymnasts approach puberty the growth of the upper and lower extremities should be assessed regularly. In so doing, the timing of peak growth velocities may be estimated, at which point the skeleton of the young gymnast may be at most risk of sustaining skeletal damage (Bailey et al., 1990). By adopting this approach the nature and intensity of the training load may be carefully controlled to reduce the risks of injury.

It may be concluded that once the nature of the non-linear relationship between anthropometric talent components and future success in Women's Artistic Gymnastics has been determined, components representing predicted adult height, general physical size and the shape of the skeletal frame may be included in the initial identification of talent. Anthropometric measurements relating to proportionality and the length of the upper and lower extremities are not necessary in the initial identification of talent. However, it is recommended that these characteristics are measured on a regular basis throughout development and with increased frequency during the pubertal period and that the estimated velocities are used to regulate the nature and intensity of training.

Within the pooled sample, the component representing the absolute values of moment of inertia about the somersault and twist axes significantly reduced the errors associated with the misclassification of gymnasts and controls. The negative coefficient indicated that smaller whole body moments of inertia were associated with a greater probability of being classified as a gymnast. However, in comparison with other physical talent components, whole body moments of inertia were of limited prognostic value. Moreover, given the large number of anthropometric measurements required to estimate whole body moments of inertia it is recommended that these assessments do not form part of the initial screening process.

Whole body moments of inertia were not important in distinguishing between successful and unsuccessful gymnasts. However, the probability of future gymnastic success was associated with large values for the moment of inertia ratios indicating that successful gymnasts experienced a proportionally greater change in their moment of inertia when moving between the specified body configurations. It is suggested that higher inertia ratios provide successful gymnasts with a greater potential to control rotation about the principal axes which may be considered important given the complex rotational skills performed in contemporary gymnastics. However, inertia ratios improved the fit of the model only marginally and did not improve the accuracy of classification. Therefore it is recommended that neither whole body moments of inertia, nor inertia ratios are included in the selection process.

The limited amount of previous research which has been conducted with children has reported that whole body moments of inertia are more sensitive to changes associated with pubertal development than traditional indices of growth such as height and weight (Jensen, 1981). Therefore, it is recommended that changes in whole body moments of inertia and the corresponding ratios are monitored annually in the prepubertal period with the frequency of measurement increased to once every six months during the pubertal years. Coaches should be aware that changes in the inertia parameters may influence the ability of a gymnast to execute rotational skills and that these changes should be evaluated in relation to the gymnast's ability to generate angular momentum about the three principal axes.

The sum of four skinfolds distinguished between gymnasts and controls with a high degree of accuracy which confirmed previous observations that gymnasts may be differentiated from controls on the basis of skinfold measurements at selected sites (Moffatt et al., 1984; Vercuyssen, 1984; Carter & Brallier, 1988; Claessens et al., 1991a; Baxter-Jones, 1994b). However, studies have consistently reported that the influence of the genotype upon the prevalence of subcutaneous adipose tissue is negligible (Bouchard et al., 1985; Bouchard, 1988). Therefore the high level of classification accuracy associated with skinfold measurements was assumed to be the result of environmental factors and in particular differences in the level of physical activity between gymnasts and controls. This assumption was confirmed when the physical activity status of gymnasts and controls was assessed. The gymnasts trained for an average of 19.2 hours per week while in contrast, two thirds of the control group were classified as 'inactive' according to the classification system for activity proposed by Cale (1993) which was based on estimated daily energy expenditure (Gill, 1999). It is possible that the differences in the sum of four skinfolds observed between gymnasts and controls may have existed prior to their participation in gymnastics and were magnified by inter-individual differences in physical activity status. However, given the young age at which children enrol in gymnastics and the importance of environmental factors, skinfold measurements are not considered to be an important component of the initial identification battery.

The results of the logistic regression analysis revealed that it was not possible to classify the future performance of gymnasts as successful or unsuccessful on the basis of their skinfold measurements. Moreover, the skinfold measurements tracked well across the period of study. However, in accordance with the results of Blanksby et al. (1994) it may be anticipated that the longitudinal stability of skinfolds will decline during adolescence and differences in subcutaneous adipose tissue will begin to emerge between successful and unsuccessful gymnasts as they progress through puberty and as training levels between groups becomes increasingly heterogeneous. While regular assessments of subcutaneous adipose tissue may provide useful information, they may be associated with potentially negative behaviour and may contribute to the development of eating disorders within the elite female gymnast. As a result, their use is not recommended with this population.

Maximum isometric force and rate of force development were assessed during isometric shoulder girdle elevation, shoulder joint flexion and hip extension at angles considered to be of specific relevance to Women's Artistic Gymnastics. The components identified using principal components analyses were common across samples and represented combined strength/rate of force development in the hip, shoulder strength and shoulder rate of force development. All three components were included in the regression model for the pooled sample and positive coefficients indicated that gymnasts were able to produce more force and generate force more quickly than the untrained controls. It is speculated that the differences observed between gymnasts and controls in terms of maximal isometric strength were to a large extent due to the intensive training programmes followed by the gymnasts. The size of the regression coefficients indicated that shoulder strength was the most important component in terms of distinguishing between gymnasts and controls. This is to be expected given that a large amount of gymnastics training is directed towards developing strength in the upper body while the majority of the non-specific physical activity experienced by the control subjects may be associated with strength development in the lower limbs.

According to the regression model produced for the 'gymnasts only' sample a single component, isometric rate of force development in the shoulder joint, was associated with the prediction of future gymnastic performance, although its contribution in terms of enhancing classification accuracy was negligible. Maximal isometric strength in the hip and shoulder regions did not distinguish between future successful and unsuccessful gymnasts. This was in contrast to the results of previous studies which reported that high level gymnasts demonstrate greater dynamic strength in comparison to lower level participants (Nelson et al., 1983; Lindner & Caine, 1992). The discrepancies between the current investigation and previous studies may be attributed to the mode used to assess maximal strength given the structural, mechanical and neural differences which have been reported between isometric and dynamic modes (Pryor et al., 1994; Baker et al., 1994; Wilson & Murphy, 1996; Nakazawa et al., 1993; Ter Haar Romeny et al., 1982, 1984).

It may therefore be concluded that the extent to which parameters of the isometric force-time curve may be important in the initial identification of talent remains unclear. The results of the present study indicate that the rate of force development in the shoulder

region may be a particularly prognostic component. This observation was consistent with the results of previous studies which have reported a strong positive relationship between isometric rate of force development and dynamic performances (Viitasalo & Komi, 1978; Viitasalo et al., 1981; Viitasalo & Aura, 1984; Häkkinen et al., 1986). However, the inconsistency with which the isometric strength components and particularly the shoulder rate component tracked over the study period may limit their utility with respect to long term predictions. It is also anticipated that the inclusion of rate parameters in the initial identification of talent may be limited by the young child's ability to understand the goal of the task and by their ability to produce a consistent response.

To further clarify the role of the parameters of the isometric force-time curve, attention must be directed towards modifying the assessment procedure adopted in the present investigation to permit reliable estimates of maximum strength and rate of force development to be estimated in young children in a mass screening situation. Once this has been achieved longitudinal research will be necessary to determine whether the observed differences between gymnasts and controls are the result of innate ability or the function of several years of specific physical preparation. Pending the results of such research, it is recommended that isometric parameters are used and interpreted cautiously in the context of talent identification and development. It will be also be necessary to examine the ease with which isometric force and the rate of force development may be modified by training in the young female gymnast and thereby determine the extent to which these parameters may be considered critical antecedents of future gymnastic performance. Irrespective of their role in the initial identification, the regular assessment of both maximum force and rate of force development will be essential to highlight the gymnast's weaknesses and to guide the training process.

In previous studies of talent identification and development, jump ability has been treated as a generic characteristic with performance evaluated on the basis of field-based approximations of the height or distance jumped (Vankov, 1978; Rozin, 1979; Salmela et al., 1979; Radoulov, 1986; Bajin, 1987; Sol, 1987; Poelvoorde & Levarlet-Joye, 1990; Fadeev, 1993). A combination of simple field testing and laboratory-based force plate measurements were conducted in the present investigation to permit multiple aspects of jump performance to be examined. This approach was adopted to determine whether a

more sophisticated analysis may reveal details of jump performance which have prognostic value in the identification and development of gymnastic talent. The performances of gymnasts during three jump styles, counter movement jump, bounce drop jump and standing broad jump, were examined. However, a number of gymnasts failed to demonstrate a rebound action during the bounce drop jump and instead adopted the counter drop style reported by Bobbert et al. (1986). Therefore the results of the bounce drop jump were excluded and only parameters representing performance in the counter movement and standing broad jumps were included in the principal components analysis.

The logistic regression analysis resulted in a 'perfect fit' for the pooled sample which indicated that more than one linear combination of jump components 'perfectly' distinguished between gymnasts and controls. Further analysis revealed that the component representing the ability of gymnasts to produce positive impulse during the push-off phase of the counter movement jump was primarily responsible for the enhancement of classification accuracy which resulted in the perfect fit. Autocorrelations revealed that the ability of gymnasts to generate positive impulse tracked well over the 12 month period of study which concurs with the heritabilities reported in traditional twin and family studies (Sklad, 1973; Maes et al., 1993, 1996). It therefore appears that the generation of positive impulse is both a prognostic and stable component which should be assessed in the initial identification of gymnastic talent. Preliminary testing conducted as part of the Leuven Growth Study highlighted that vertical jump, assessed using the jump and reach test, was not appropriate for children in the first three grades of primary education (6-8 years) (Simons et al., 1990). Given that the initial screening for gymnastic talent is aimed at primary school children aged 5-6 years, standing broad jump performance may be the most appropriate single measures to represent the generation of net positive impulse. The validity of this impulse component as an indicator of gymnastic talent will only be confirmed by monitoring the longitudinal development of gymnasts from their entry in the sport through to maturity. Only by following this approach will it be possible to determine whether the superior impulses generated by gymnasts are due to innate ability or the result of specific physical training.

Once gymnasts have been identified based, in part, on their ability to produce a large net positive impulse it may be desirable to monitor the development of coordination within

their jumping. While the Leuven study indicated that the vertical jump was not appropriate for use with young children this conclusion may be partly due to their use of the jump and reach procedure. Rather than assessing the child's ability to raise the mass centre, performance in the jump and reach is largely dependent on the child's ability to coordinate the jump and reach actions optimally. The assessment of vertical jump performance using a force plate may reduce the complexity of the task sufficiently to permit the assessment to be used to monitor the development of coordination in young female gymnasts.

It has been suggested that coordination and specifically the production of peak forces late in the push-off phase of the jump as the joints approach full extension contributes to a high take-off velocity and is therefore important in vertical jump performance (Hochmuth & Marhold, 1977; Dowling & Vamos, 1993). The importance of coordination in the vertical jump was supported by the results of the logistic regression analysis. When the jump components were entered into the model using forwards stepwise procedures the mean power/force component was only included in the regression model in combination with the coordination component. This indicated that the ability to produce forces/power was only important when accompanied by an appropriate pattern of coordination. This agrees with the results obtained using simulation models of vertical jumping, which found that increases in muscle strength only resulted in greater vertical jump height when accompanied by modifications in the pattern of coordination (Bobbert & Soest, 1994). Given the apparent importance of coordination, relatively little attention is paid to the development of coordinated jumping in young female gymnasts. This is surprising as many of the complex skills performed by gymnasts rely upon a proficient jumping action. Therefore it is recommended that the longitudinal development of vertical jump performance is monitored in young female gymnasts with specific reference to the changes which occur in the pattern of force application prior to the establishment of a mature pattern of coordination.

In contrast to the results of the pooled sample, the derived jump components were unable to distinguish between successful and unsuccessful gymnasts. It is hypothesised that this result reflects limitations of the current measurement procedures rather than the low prognostic validity of jumping activities. In particular, the forced omission of the bounce drop jump test was disappointing since the impulsive nature of gymnastics and the short

apparatus contact times indicate that rebound ability is an intuitively important attribute of the elite female gymnast (Komi, 1992; Takei, 1990; Brüggemann, 1983; Webb, 1997). The observation that it was mainly the successful gymnasts who failed to achieve a bounce drop jump action suggests that the assessment is not limited by the immaturity of the gymnasts. The successful gymnasts were older and assumed to be more proficient and therefore the adoption of the counter drop style was interpreted to reflect a conscious/unconscious strategy to improve jump performance rather than their inability to perform the rebound action. It is speculated that 'rebound ability' may be a critical indicator of future gymnastic performance and it is therefore recommended that attention is directed towards developing a reliable measurement of this characteristic which may be applied in a screening environment with young children.

Different flexibility components were derived to explain the variance in the data in pooled and 'gymnasts only' samples respectively. The component which represented the flexibility of the trunk and specifically range of motion in the hamstrings and lumbar spine was the only component common to both samples. This component was responsible for producing a 'perfect fit' in the pooled sample which indicated that gymnasts could be distinguished from controls on the basis of their superior trunk flexibility. In contrast, trunk flexibility was not found to be important in distinguishing between future successful and unsuccessful gymnasts. Previous studies which have examined the heritability and/or stability of the sit and reach test have reported a moderate to high contribution of the genotype (Maes et al., 1993; Marshall et al., 1998). In contrast, within the present study the longitudinal stability of the component representing lumbar and hamstring flexibility was low and inconsistent. In light of these inconsistencies, it is recommended that an assessment of trunk flexibility should be included in the battery of tests used to identify gymnastic talent and the longitudinal development of this component closely monitored.

The results of the logistic regression conducted in the 'gymnasts only' sample revealed that the probability of future success was related to good range of movement in the hips/pelvic region and shoulder joints. This confirmed the results of previous research and provided further evidence in support of the importance of assessing range of motion in the hip and shoulder joints (Kirby et al., 1981; Nelson et al., 1983; Régnier & Salmela, 1987; Sol, 1987). It was surprising that the component representing active hip flexion did not appear

to be important in distinguishing between successful and unsuccessful gymnasts given the emphasis placed upon the development of active range of motion in the current range and conditioning exercises. However, gymnasts are rarely required to maintain a range of motion for several seconds as is required in active flexibility assessments, rather the sport requires extreme joint angles to be attained at relatively high angular velocities. This observation was supported in the present study since the single measure of dynamic hip flexibility (average of left and right split jumps) included in the battery loaded highly on the component which distinguished between future successful and unsuccessful gymnasts. It may therefore be speculated that while development of active flexibility is essential within the young female gymnast, it is the ability to produce large joint angles at high velocities which is more closely related to future gymnastic success.

The results of the present investigation indicate that young female gymnasts require appropriate levels of flexibility in the trunk, hip and shoulder regions. It has been well established that flexibility is specific to each particular joint action (Corbin & Noble, 1980; Alter, 1996; Bouchard et al., 1997) and therefore a number of measurements will be required to fully assess this quality. It is therefore recommended that in the initial identification battery the child's range of motion is assessed in the hamstrings and lumbar spine using the seated fold, in the pelvis using the 'D' shape and in the shoulders by assessing shoulder flexion. It is speculated that given a representative sample, the relationship between flexibility components and the probability of future gymnastic success may be non-linear. It is speculated that an optimum range of motion exists above which further increases in flexibility, which may be associated with reduced articular stability, would be associated with a reduction in the probability of future success. The consequences of an excessive range of motion have not been extensively researched however, in support of this hypothesis previous studies have confirmed that elite gymnasts do not demonstrate greater joint laxity than control subjects (Kirby et al., 1981; Bird et al., 1988 op cit. Bird & Barton, 1993).

An essential requirement of future research will be to determine whether any of the components suggested to be prognostic indicators of talent are limited by factors which cannot be modified through the training process. For example, to determine whether the shape of the bony articulating surfaces may limit range of motion in the hip, shoulder or

pelvic regions in certain individuals. It is also recommended that longitudinal research is conducted to examine the extent to which each component of flexibility may be enhanced through training in relation to other talent characteristics. For example, observations of elementary gymnastic classes reveal that when young children are screened to enter the sport they are usually either flexible or strong but rarely do they possess high levels of both attributes. While a number of factors may be responsible for such an observation the relationship outlined between the stiffness and the functional properties of skeletal muscle may be a contributing factor. Procedures for the identification of talent should seek to identify those few children who possess a high level of strength and flexibility, however, which of these characteristics is most important in the initial identification process will only be addressed by considering the stability of these characteristics over time and the extent to which flexibility and the various parameters of muscular strength may be modified through the training process.

Variables within the final physical category, local muscular endurance, were assessed at two points in time in the 'gymnasts only' sample to coincide with the initial (September, 1996) and final (September 1997) testing sessions. Given that the assessments of local muscular endurance were specific to gymnastics this aspect of the test battery was not considered to be appropriate for control subjects. With the exception of the leg dips exercise, all gymnasts scored similarly in the speed strength measures (assessed in terms of the number of repetitions completed in 10 s) and therefore the results of these measures were excluded from the statistical analyses on the basis of non-normality. The logistic regression analysis within the 'gymnasts only' sample revealed that local muscular endurance in the abdominal and hip flexor muscle groups was an important indicator of future gymnastic performance. This component distinguished between successful and unsuccessful gymnasts with a high level of accuracy and demonstrated moderate stability over the 12 month period of study. It is therefore recommended that a test of local muscular endurance is included in the initial identification battery. It is important that the test selected for inclusion in the battery is of an appropriate level of difficulty to permit children to be distinguished based upon their level of local muscular endurance. The establishment of appropriate task difficulty may be particularly important when designing upper extremity assessments. For example, Marshall et al. (1998) reported that the pull-up test was of limited value in assessing local muscular endurance in the upper extremity, as

the majority of children were unable to complete a single repetition. It is suggested that the number of sit-ups completed in 30 s is the most appropriate test to be included in the initial assessment battery. However, it is recommended that several modifications are made to the traditional assessment protocol to isolate the abdominal muscles and to enhance the precision of measurement.

## 5.6 SUMMARY

Physical talent components distinguished between groups with a high level of classification accuracy. As a result of the high predictive validity of the physical components and the relatively small sample size, several logistic regression models resulted in a 'perfect fit' to the data. For these models a unique solution could not be obtained which indicated that more than one linear combination of talent characteristics was able to perfectly classify group membership. Within the 'gymnasts only' sample, a 'perfect fit' was obtained when physical talent characteristics from several categories were combined within a single regression model. Specifically, the linear combination of anthropometry (frame shape/size), local muscular endurance (abdominal and hip flexor muscle groups) and flexibility (hip and shoulder regions) components was responsible for producing a perfect fit. Within the more heterogeneous pooled sample a 'perfect fit' was obtained at an earlier stage of the analysis with linear combinations of talent components within both flexibility and jump categories able to perfectly distinguish between gymnasts and controls.

A different combination of talent components best distinguished between successful and unsuccessful gymnasts and between gymnasts and controls respectively. This indicated that different sets of physical talent components were required in the initial identification of talent and in monitoring the development of gymnasts once involved in the sport. From the large number of physical talent components measured in the present study the following assessments were recommended for inclusion in the initial battery based upon their predictive validity and longitudinal stability:

## INITIAL IDENTIFICATION

| | |
|---|---|
| anthropometry: | mass, height, biacromial width, biiliac width, epiphyseal widths, predicted adult height |
| jumping: | normalised standing broad jump |
| flexibility: | seated fold, shoulder flexion, 'D' shape |
| muscular endurance: | situps (30 s) |

In the present investigation linear combinations of talent components were appropriate to model the relationship between physical talent components and future gymnastic success. However, inspection of the regression parameters indicated that if the purpose of the model was to distinguish between control subjects and future successful gymnasts, which is the goal of talent identification systems, a non-linear relationship will be required. This concept is best illustrated using the results obtained from the anthropometric regression model. It was found that gymnasts, as a group, had a smaller skeletal frame than the untrained controls. However, those gymnasts defined as successful had a relatively large frame in relation to their less successful peers. This suggests a non-linear relationship which may be more appropriately modelled using higher order terms. It is recommended that once gymnasts have been selected and are involved in regular gymnastic training the following physical talent characteristics are assessed on a regular basis:

## MONITORING DEVELOPMENT (PROFILING)

| | |
|---|---|
| anthropometry: | mass, height, sitting height |
| moment of inertia: | whole body moments of inertia and inertia ratios |
| isometric strength: | maximal isometric force (shoulder flexion/hip extension)<br>maximal rate of force development (shoulder flexion/hip extension) |

| | |
|---|---|
| jump: | patterns of force application in the counter movement jump |
| flexibility: | seated fold, shoulder flexion, 'D' shape, dynamic flexibility (hip) and active hip flexion, |
| muscular endurance: | abdominals/hip flexors, lower extremity, lumbar region |

Several of these characteristics were shown to be important predictors of future gymnastic success but demonstrated low levels of stability and may therefore be modified through training. For example, components representing isometric strength in the hip and shoulder regions. Other physical characteristics are sensitive to the growth and development of the gymnast and it is therefore important to monitor their development in relation to the nature of the training process and the development of other physical characteristics.