INTRINSIC AND EXTRINSIC FACTORS PREDISPOSING FEMALE STUDENT DANCE TEACHERS TO INJURY

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ABSTRACT

The nature and physical demands of a dance degree programme can lead to injury. The aim of this thesis was to develop a statistical model to predict injury in female student dance teachers. The prevalence of injury was determined using a self reporting injury questionnaire. A hand notation system was devised, in conjunction with heart rate monitoring, to evaluate the activity patterns and the physiological demands of dancing. A laboratory based force analysis was used to record the physical loads associated with common dance movements and an epidemiological approach identified kinanthropometric and functional characteristics of student dance teachers. Analysis of the epidemiological and injury data, using logistic regression, enabled a predictive equation to be postulated.

Ninety three student dance teachers (52.2%) reported the prevalence of injury across the four styles of Jazz, Ballet, Contemporary and African Caribbean. Analysis revealed that Jazz dance recorded a significantly higher proportion of injuries ($P<0.05$) when compared to the other styles. Further analysis highlighted the knee (37.6%) and the back (25.8%) as the sites recording the highest frequency of injuries. Prevalence ratios for the site and type of injury noted that one in every five injuries was of a muscular nature at the knee.

The physiological demands of student dance was recorded using a hand notation system, which identified four movement intensities, coupled with heart rate monitoring. Analysis revealed significant interaction between the dance style and the occurrence of the movement intensity categories ($P<0.05$). Significant differences in the frequency of the dance movements, across the four styles, was also noted ($P<0.05$). The common movements of a jog step and a leap or jump were more prevalent in Jazz and Ballet. The heart rate profile was also significantly different between the four dance styles with Jazz and African Caribbean recording significantly higher mean heart rates ($P<0.05$).

The physical load of performing the dance movements was investigated using force analysis. No significant differences were found between the movements for peak vertical force (Fz). Average peak vertical forces were recorded in the range 1.51 BW to 2.71 BW. Instantaneous load rates were also calculated for the dance movements with the flat footed stamp step recording a significantly larger instantaneous load rate (454.1 BW/s) than the other dance movements.

Data were recorded on flexibility, strength, orthopaedic alignment and body composition characteristics for injured and non-injured dance teachers. No significant differences occurred between any of the strength, body composition or orthopaedic alignment measures between the two groups. Significant differences ($P<0.05$) were revealed between the left and right hamstring flexibility of the injured and non-injured groups. No other flexibility differences were noted.

A statistical model for injury prediction, using a logistic regression technique, was obtained from the epidemiological and injury data. The model contained seven variables. Odds ratios were calculated for each predictive variable. The overall predictive accuracy of the final model was 89.13%.

In conclusion female student dance teachers have a prevalence of injury similar to other sports activities. The physiological and physical demands of the dance degree programme may place a cumulative stress on the musculo-skeletal system resulting in injury. The functional and kinanthropometric characteristics of injured and non-injured dancers are similar with the exception of hamstring flexibility. This may be due to the insensitivity of current methodologies for identifying differences. In a statistical model of injury, in female student dance teachers, the variables of sitting height, Q angle and hamstring flexibility are significant predictive factors.

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Introduction to the Problem

Dance is part of the history of human movement, human culture and human communication. Whether for artistic, fitness, social or purely kinaesthetic purposes dance has become an integral aspect of our lifestyle and has involved an ever increasing number of participants at all levels of performance. Regardless of the level of participation, dance is not only a physically demanding activity but can lead to injury (Lavine, 1982; Clarkson and Skrinar, 1988). Parallels have been drawn between dancers and the traditional athlete across a number of factors including training regimes, fitness attributes, strength and flexibility (Nicholas, 1975; Chambers, 1981; Schell 1984). Similarities have also been reported on the occurrence and type of injury (Caine and Garrick, 1996).

Epidemiological studies have provided information concerning the distribution and causes of injury in the dance population with almost 7000 injuries reported in the surveys published (Clanin et al., 1984; Solomon and Micheli, 1986; Quirk, 1987; Caine and Garrick, 1996). From these, 63% of the injuries had been observed in student dancers (Ryan and Stephens, 1987), with up to 80% of the injuries involving the foot, ankle or knee (Washington, 1978).

Since its initial introduction into the tertiary sector of education in 1969, the popularity of dance has increased throughout the U.K. (Lawson, 1986). This has led to the development of degree courses specialising in the teaching of dance (Bowling, 1989). Further illustration has been its recent inclusion within the National Curriculum for England and Wales at secondary school level (Allen and Coley, 1995).

University based student dance teachers participate in, and must be proficient in, several different dance styles. They are introduced to many variations in techniques, teaching methods, movements and choreography. Their bodies are therefore exposed to numerous alignment postures, loading forces and demands on strength and flexibility. This being the case, the student dance teachers are at risk from injury that may be dance style specific. They may also be at a greater risk of injury due to the cumulative effects of participating in a variety of dance styles and the frequency and intensity of the activity on a class to class basis.

The forces acting on the dancer are affected by the style in which the dance actions are performed. These forces associated with the dance actions and the repetitive nature of dance actions have been proposed as contributory factors to the onset of injury in the dancer (Ryan and Stephens, 1987). However no published research has reported the magnitude of either peak impact forces or loading rates associated with dance activities common to student dance teacher classes.

Other factors implicated in dance injuries are musculoskeletal abnormalities and anthropometric characteristics. In separate studies these have been used as predictors of the onset of injury (Dalton, 1992; Hamilton et al., 1992). The authors have suggested that the activity of dance requires a specific body type that is reflected in an unusual pattern of musculoskeletal development. While evidence of a relationship between anthropometric profiles and injuries, and musculoskeletal profiles and injury do exist, combined effects of both have not yet been explored within a dance population.

Profiling seeks to uncover variations in body type that may be affected by the demands of one sport or another. Performance demands, risk factors for injury and individual musculoskeletal characteristics are three components of the musculoskeletal injury prevention profile (Hershman, 1984). Profiles have been established for Olympic and professional athletes as an aid in training, competition and injury prevention (Hamilton et al., 1992). Published studies to date have provided essential information on dancers (Micheli et al., 1984; Mostardi et al., 1983). However many are limited in that they often generalise from the professional company dancer to the student dancers, or fail to distinguish between the two. In addition no differentiation has been made between the professional dancer and the university based student dancer, where different standards for technique, duration of dancing season and an emphasis on participation in a variety of dance styles exist.

Injury occurs as the result of excessive load due to the interaction of movement factors, intrinsic factors and extrinsic factors. The delineation of cause and effect is difficult because of the multiplicity of these factors acting upon each athlete, including the type of sport engaged in, technique and level of participation. These variables interact with the physical characteristics such as strength, flexibility and physical fitness as determiners of an individual's performance. Jackson et al. (1978) suggested that if screening measurements of several personal characteristics were made it may be possible to determine statistically significant variables that predispose individuals to injury. The authors further proposed that if significant parameters could be delineated, a screening technique could be introduced to steer young athletes into sports where their individual characteristics would be protective and not detrimental to participation.

The framework for a screening technique is based on the ability to predict injury. In order to predict injury the risk factors must be identified. Identification of the factors is based on complex statistical analysis, specifically regression techniques. These techniques are prevalent in medical research where the onset of disease, musculoskeletal trauma and life expectancy are predicted from data collected on patients using epidemiological research tools. This type of statistical technique is not prevalent in the sport and exercise literature, nor the dance medicine literature, where injury can be as debilitating and can affect quality of life either through permanent musculoskeletal damage or in terms of earning potential.

Dance combines characteristics common in many traditional sports (aerobic endurance, flexibility and strength). The high physical demands of the activity present unique physiological and physical stresses on the participants. Additionally the aesthetic nature of the activity, the anthropometric profile and body positioning and posture, observed through biomechanical and orthopaedic alignment, provide further adjuncts to injury. Much of what has previously been written has been focused on one or two aspects of injury profiling and prediction. Thus, it is hoped that through this study a comprehensive and detailed insight will be gained into significant predictors of injury in dance.

The aim of this research was to develop an injury predictive statistical model containing explanatory variables, based on kinanthropometric and functional characteristics, identified as predisposing factors to injury, specific to female student dance teachers.

1.2 INTRODUCTION TO THE RESEARCH STUDIES

The predisposing factors of injury in dance will be investigated by considering three primary aspects:- the prevalence of injury, the functional and kinanthropometric characteristics of the participant and the demands of the activity itself. Information on the prevalence of injury and injury history can be obtained from self reporting questionnaires a common research tool in epidemiological research (Wallace, 1988; Meeuwisse, 1991; Winston et al., 1996). Information regarding the kinanthropometric characteristics of participants can provide essential information about the nature of the activity and the adaptations associated with participation (Macera et al., 1989). Although many physiological and kinanthropometric characteristics are genetically determined, most can be altered to varying degrees by intensive dance specific training (Rimmer et al., 1994; Weisler et al., 1996). The demands of the activity determine the relative importance of different aspects of physical fitness. It is therefore pertinent to make a comprehensive investigation into the typical characteristics of the student dancer, such as the body's strength and flexibility capabilities and kinanthropometric aspects, and to interpret the unique demands of participation in dance. These will be achieved by researching the physical form of the student dancer, their injury occurrences and training practices.

The distinctive demands of participation in dance will also be studied, providing a measure of the physiological and physical stresses of dance on the student performer. This will be achieved through heart rate measurement, analysis of the type and frequency of the actions being performed and laboratory based measurement of physical stresses, in terms of force analysis, imposed on the body.

This thesis is structured so that the studies in which the prevalence of injury in student dancers and the physiological and physical demands of dance are described in Chapters 3 and 4 respectively. The strength, flexibility and kinanthropometric characteristics of the student dancers are more specifically studied in the research reported in Chapter 5 with the development of a statistical model for predicting injury reported in Chapter 6. Synthesis of the findings are reported in Chapter 7.

1.3 AIM AND OBJECTIVES

The aim of the research was:-

To develop an injury predictive statistical model containing explanatory variables, based on kinanthropometric and functional characteristics, identified as predisposing factors to injury, specific to female student dance teachers.

In order to fulfil the aim the following four objectives were addressed:-

1. Establish the epidemiology of injuries in student dance teachers.

2. Determine the physiological and physical demands of the practical content of the curriculum of a dance degree programme.
3. Determine the functional (strength and flexibility) and kinanthropometric characteristics of student dance teachers.
4. Determine the relationships between epidemiology, functional and kinanthropometry characteristics and the physiological and physical demands of dance specific to the onset of injury.

2. LITERATURE REVIEW

It is the purpose of the literature review to highlight key issues involved in the scientific study of dance. This review is divided into aspects relating to the epidemiology of dance injury, biomechanics of dance injury and demographic aspects of the dancer. Reference is also made to literature specific to the demands of dancing, both physiological and physical. Further reference is made to the predictability of injury and the use of multifactorial statistical analyses for injury prediction.,

2.1 THE EPIDEMIOLOGY OF DANCE INJURIES

2.1.1 The origins of dance and dance movement

The type of dance style (ballet, contemporary, jazz, traditional folk) and the level at which it is performed (recreational, university student, pre-professional, professional) distinguish dancers from one another. Each dance style and the level at which it is performed is subject to somewhat different physical demands. However the general orientation of the activity is similar.

Many of the basic dance movements and steps in modern dance styles have originated from the classical ballet choreography introduced in the early 17th century (Sachs, 1965; Lawson, 1986). Ballet is characterised by strong linear postures and upright alignment of the body's torso to the lower limb. The common movements such as grand plie (deep knee bend), pirouette and jette (leap) rely on the ability of the dancer to control upper body posture while providing an aesthetic line through the body from imposing behaviour. The strong rhythm, often controlled through a drum beat, coordinates the ritual tribal stamping movement which quickens as the ritual progresses. Additional movements such as upper and full body twists and turns and demi pointe foot positions (toes plantar flexed with the body weight acting through the balls of the foot) can be argued to have similarities to that of classical ballet movement (Sachs, 1965; Adshead-Lonsdale and Layson, 1994).

While all these dance styles have a degree of idiosyncratic movement patterns and sequences there is a common hierarchy of participation across dance styles including ballet, jazz, contemporary and African Caribbean. At the top of the hierarchy there is the professional company dancer who is specialised in one style and performs this style regularly. There is then the pre-professional dancer who has completed a degree programme of dance study and continues with specific dance style training under the guidance of a professional company. The student dancer is at the degree programme stage learning the techniques in a variety of dance styles before specialising in one and moving into the pre-professional category (Ryan and Stephens, 1987). The student dance teacher is often a dancer who has not been successful in obtaining a place on a specialist dance degree programme and has chosen to have a career in teaching dance. In order to successfully achieve this, the student must be competent in a variety of dance styles and have experienced the common patterns of movement and choreography across the styles. The styles most common to dance teachers are ballet, jazz and contemporary as they not only cover the traditional and classic movement patterns but demonstrate development and variety in movement style and musical tempo (Adshead-Lonsdale and Layson, 1994).

2.1.2 Prevalence of dance injuries

Under properly controlled scientific circumstances epidemiological studies can provide valuable information about the distribution, prevalence, type and severity of injuries (Powell et al., 1986; Walter et al., 1985). Research into the prevalence of injury has reported on injury incidence (frequency of injury based on a time frame, i.e. number of injuries per hour of participation) and on a simple frequency count of the number of injuries reported (Caine et al., 1996). Direct comparison between the research is therefore difficult if the reports have used different reference points from which the injuries were recorded, however the published data suggests that injury in dance is prevalent and worthy of epidemiological study (Caine and Garrick, 1996).

The style of dance as well as the standard of dancer must be considered in any assessment of the prevalence of injuries in a given population of dancers. Each different style of dance places a particular demand on the human body and may therefore contribute, in some manner, to the overall frequency of injury in a specific dance population.

Shively et al. (1981) studied the frequency of injury in high school athletic participants and found that female athletes had a significantly greater number of knee injuries and major ankle injuries than male athletes. Clement et al. (1981) reviewed the clinical records of two sports physicians who identified 1,819 injuries in 1,650 running patients. The records revealed that both sexes had a similar distribution of injuries by major anatomical sites (hip, thigh, ankle, foot), however female runners suffered more from so-called patellar pain and tibial stress syndromes.

Pagliano and Jackson (1980) found that the knee accounted for 30% of 1077 injuries among runners in a study of running related injuries. The authors stated that women out numbered men two to one in the general population in terms of having symptomatic chondromalacia. The authors claimed that the typical patient complaining of chondromalacia was one who possessed a wide pelvis, knock knees and hyperpronated feet. Therefore it may be that the anatomical structure of women, which is more likely to have these characteristics, may predispose them to patellofemoral complaints when subject to the stress of weight-bearing physical training or activity.

A number of scientific studies have been done on professional dancers from international, national, and regional ballet companies (Calabrese et al., 1983; Cohen et al., 1982; Mostardi et al., 1983; Schantz and Astrand, 1984; Dolgener et al., 1980; Kuno et al., 1996). These reports demonstrated a degree of homogeneity in the overall physical characteristics of top ballet dancers. Data from previous studies are summarised in Table 2.1.2.1.

If viewed from the broad perspective of the individuals who participate in a wide variety of dance forms, the prevalence of injuries in dance does not differ much from other non-combative sporting activities. However, when ascending the hierarchy of dance into the highly competitive national and internationally ranked dance schools and companies, dance related injuries certainly become more prevalent and have more serious implications and repercussions (Hamilton et al., 1989).

Table 2.1.2.1*. Physical characteristics, training, work and injury histories of professional and advanced student ballet dancers'.

	Professional Dancers		Student Dancers	
	Men	Women	Men	Women
Number of dancers	15	24	11	71
Age	27.3 ± 5.6	26.6 ± 3.7	21.0 ± 2.9	16.0 ± 1.8
Height (cm)	178.1 ± 3.3	166.1 ± 4.3	178.3 ± 6.9	163.6 ± 4
Mass (kg)	69.4 ± 5.5	48.7 ± 3.6	65.5 ± 8.5	47.4 ± 5.6
% Body fat	13.0 ± 2.3	15.7 ± 1.2	11.7 ± 2.9	16.6 ± 1.5
Starting age in dance	12.3 ± 4.2	8.6 ± 2.1	16.3 ± 2.1	7.3 ± 3.4
Total years of dancing	13.0 ± 4.8	12.7 ± 3.6	4.0 ± 2.7	8.2 ± 2.8
Classroom work load (hours/week)	9.3 ± 0.9	10.2 ± 2.3	17.3 ± 7.7	13.6 ± 6.1
Rehearsal work load (hours/week)	26.1 ± 6.2	26.6 ± 6.1		
Performance work load (hours/week)	9.5 ± 5.3	7.9 ± 3.6		
Prevalence of injury	93.3%	87.5%	81.8%	60.6%

(* adapted from Ryan and Stephen, 1987)

Of the few studies providing information on the prevalence of injuries in dance most primarily deal with professional and advanced ballet dancers. In one published report on a professional ballet company, it was indicated that on any given day during the season 17% (15 / 90) of the dancers were not dancing because of injury (Calabrese et al., 1983).

A study of professional dancers and advanced student dancers indicated that almost 90% of the professional dancers (35 / 39) and 63% (52 / 83) of the students had a dance related injury at some time in their careers (Mostardi et al., 1983). The professional dancers had almost twice as many injuries per dancer as the students probably due to their greater work load and greater years of participation. Among the four groups of male and female student and professional dancers, the female students had the lowest injury frequency (61%) and they were also the youngest. The injury frequency (82%) of the male students was almost as high as that of the professionals, a somewhat unusual finding since they were the least experienced group.

2.1.3 Distribution of dance injuries

Over a 20 year period, almost 7,000 injuries were reported in 9 major surveys on the distribution and type of injuries in ballet (Quirk, 1983, 1987); modern (Solomon and Micheli, 1986); theatrical (Washington, 1978; Rovere et al., 1983) and university based dancers (Clanin et al., 1984). The vast majority of dance related injuries occurred in the lower extremities. Regardless of the style of dance most studies reported that 60-80% of these injuries involved the ankle, foot or knee. The specific order of distribution varied according to the type of dance, technique and experience of the population.

In all of the studies, ankle and foot injuries were collectively more frequent than knee injuries. In the studies of theatrical and modern dancers knee injuries were more common than either ankle or foot injuries (Solomon and Micheli, 1986; Washington, 1978). Other sites of injury have also been reported although with much less frequency. A summary of the injury data, from previous research, is displayed in Table 2.1.3.1. Although the injuries to the lower extremities in dance are not pathologically different from those in other sports, they may differ in their aetiology.

Many sports and exercise activities carry a certain risk of injury and dance is not an exception. Research has reported the incidence of injuries across different dance styles and levels of dance participation (Mostardi et al., 1983). This is important as a guide to the risk factors associated with dancing, however it does not take into consideration the occurrence of injury as a result of training for the activity. Furthermore as it is likely that university dancers will be participating in a greater range of dance styles and techniques, carrying out a greater amount of technical and choreographic training, it would suggest that they are potentially at a higher risk of injury due to their greater exposure. It then seems reasonable to suggest that this group of dancers should be studied in more detail with a view to injury prevention.

Table 2.1.3.1. Summary of surveys on the distribution of injuries in dance common to the lower extremity. (All values are shown as a percentage)

	Ballet' Prof. / Student	Modern#	Theatrical''	University Students**
Foot	27.5 / 22.0	7.0	14.8	13.0
Ankle	38.9 / 24.4	19.6	22.2	13.0
Leg	8.0 / 14.9	7.0	5.4	8.0
Knee	6.7 / 15.5	20.1	14.5	6.0
Hip	6.0 / 5.4	11.3	17.6	2.0
Total	87.1 / 80.2	65	74.5	42

' Ryan and Stephens, 1987

Solomon et al., 1986

'' Rovere et al., 1983

** Clanin et al., 1984

2.2 THE AETIOLOGY OF DANCE INJURIES

The aetiology of injury is the study and identification of the risk factors associated with injury onset (Walter et al., 1985; Ryan and Stephens, 1987; Mechelen et al., 1992). In dance these factors are predominantly threefold; (1) movement factors, i.e. the type of action or pattern of movement or sequencing of dance steps that preceded the onset of the injury; (2) extrinsic factors which are normally associated with the enviroment in which the injury occurred i.e. floor type, temperature of the classroom or performance arena or the size of the arena and; (3) intrinsic factors which include functional and kinanthropometric characteristics specific to the dancer i.e. joint range of motion, muscle flexibility, strength, body shape and body alignment. This section of the review attempts to identify the aetiological factors reported in the literature for the onset of dance injuries.

2.2.1 Dance training and technique

Over the course of 10 years, dancers take more classes per week at progressively higher levels of intensity, duration, frequency and proficiency. During this time, dancers may train in one particular style, however most dancers also train in modern, jazz and character dance (Ryan and Stephens , 1987). Similarly dancers in each of these other dance forms also commonly cross train in other techniques and styles.

To aid in identifying the incidence of injury in dancers it is important to determine the amount of exposure to injury a dancer may have during the course of a week, month or year. The number of hours per day devoted to class, rehearsal, performance and the number of performances per week are all important epidemiological considerations as they have been suggested to relate to overuse injuries. In addition, certain types of dance styles may influence the occurrence of injuries in terms of their respective training and choreography demands (Calabrese et al., 1983; Ryan and Stephens, 1987).

A typical work schedule during a season for professional ballet dancer can include 9 hours in class, about 26 hours in rehearsal, 8-12 hours in performance for a total of 43-48 hours during a 6 day period (Calabrese et al., 1983; Miller et al., 1975; Micheli et al., 1984; Kirkendall et al., 1984). Studies of female dance students indicate that they spend about 14 hours per week in class, covering a number of different styles and techniques within those styles (Chatfield et al., 1990).

Professional dancers have attributed many of the causes of their injuries to improper technique and/or training and have listed 6 major factors that have contributed to their injuries (Ryan and Stephens, 1987).

i) Inadequate warm-up

Professional dancers reported that the warm-up was inadequate in duration and in some cases was absent altogether. The dancers had no knowledge of how to effectively prepare their bodies for dancing and had difficulty in keeping their bodies warm and ready during a long rehearsal or class time when they were active only in short periodic bursts (Ryan and Stephens, 1987).

ii) Lack of training specificity

Ryan and Stephens (1987) reported that dancers where not specifically trained in the technique to be used in the performance, i.e. the performance technique was not replicated in the classroom. A number of complaints where documented by the dancers about the physical strain and injuries this type of conflict caused (Ryan and Stephens, 1987).

iii) Poor pre-season conditioning

The research reported by Ryan and Stephens (1987) noted that the majority of dancers did not embark on a pre-season conditioning programme. This often resulted in an overuse injury being acquired early on in the season which would plague the dancer throughout the season, eg. muscle strain. It was also noted that in some cases the injury went untreated and developed into a chronic complaint which reduced the dancers career (Ryan and Stephens, 1987).

iv) Scheduling of rehearsals and performances

Dancers reported that based on financial reasons the companies would increase the amount of shows being performed. This was often to the detriment of rehearsal time and would place increased demand on the ability of the dancer to perform at the highest level early in the season. The dancers suggested that, when linked to a poor pre season conditioning programme, this often led to overuse injuries very early in the season (Ryan and Stephens, 1987).

v) Improper performance and teaching of technique

The dancers continually reported concerns with the development, maintenance and improvement of their technique (Ryan and Stephens, 1987). Many dance techniques have evolved over the past 400 years in terms of ballet to form the historical, artistic and pedagogical heritage of modern ballet and modern dance (Lawson, 1986). However there is little scientific evidence to demonstrate safety of any one technique over the other with dancers often representing an amalgamation of techniques, physiques, training and choreographic styles (Ryan and Stephens, 1987).

Ryan and Stephens (1987) noted that most teachers of professional dancers had a good knowledge of basic technique but did not always understand or compensate for the physical limitations of their students. In some cases teachers tended to interpret technique as an absolute that did not allow for idiosyncratic limitations of the human body (Ryan and Stephens, 1987). The teachers suggested that if dancers did not have a perfect body for that particular style or technique then they should try another activity. However dancers will tend to compensate in order to achieve the appearance of good technique often to the detriment of their bodies (Howse and Hancock, 1992).

vi) Development of muscle imbalances

A well balanced class emphasises movement in all directions and a good training programme can help develop the muscles of the lower extremities symmetrically (Ryan and Stephens, 1987; Howse and Hancock, 1992). However excessive training and improper technique may cause imbalances of the hip musculature, affecting the dancers ability to externally rotate the feet (Hamilton et al., 1992). If an imbalance is present the dancer often attempts to compensate for this poor alignment and this may result in injuries of the hip, knee, ankle and foot. Tightness of the triceps surae or functional equinus tends to decrease the shock-absorbing capacity of the foot during jumps.

The literature suggests that professional dancers are exposed to injury via a number of factors. Professional dancers tend to perform in only one style and are therefore exposed to these factors through their participation in that one style. These factors were reported as generic in nature and could therefore be attributable to injury in dancers participating in any style of dance.

Student dancers, on a university degree programme, are expected to attend, and be proficient, in different dance styles and dance technique classes. Although not dancing to the same rigorous schedule as the professional dancer they are still exposed to the same factors for each and every different style and technique class they attend, albeit to a lesser extent. Although exposed to a lesser extent this may be off-set by the potential cumulative effect of each of the factors across the number of dance styles. Therefore student dancer teachers could be exposed to the same injury risk. However there is no data available at present to substantiate such a claim.

2.2.2 Anatomical factors

Lawson (1986) noted that many dancers complain that the techniques involved in dance impose "unnatural" positions, movements, and therefore stresses upon the body. This can be further exacerbated as the dancer ascends to the highest levels of technique where there is progressively less tolerance of anatomical or aesthetic variations (Ryan and Stephens, 1987).

In the general dance population anatomical factors are more likely to contribute to an injury than in selected pre-professional and professional dancers (Howse, 1982). In professional dancers variations in measurements of limb segment lengths and circumferences are usually slight (<8mm; Hardaker et al., 1986), and major bone variations in the alignment of the lower extremities are rarely seen (Ryan and Stephens, 1987). However by the time dancers reach this professional level anatomical factors have often separated the prospective professional dancer from the normal dance population. Anatomical factors do play a role in the injuries reported by the professional dancer but they are more likely to be more subtle and supplementary to other factors such as technique.

i) Somatotype

The aesthetically 'ideal' body type in professional dance companies often comprises long, lean lines formed by long limbs, a short torso, and a relatively small head (Gelabert, 1980). Other characteristics of the professional dancer include an ability for excellent turn-out, a high arched foot capable of overarching, and a lean androgenous appearance (Ryan and Stephens, 1987).

Although this type of body is aesthetically favourable it is not necessarily the most durable anatomical framework for performing dance movement. In certain balance postures the long lower extremity can act as a powerful lever on the lower back, and in doing so produce larger forces to be dissipated by the upper body and relatively weak abdominal muscles. The emphasis in ballet on higher extension of the thigh at the hip may further exacerbate the forces on the lower spine and lead to lower back syndrome. About 12% of a particular professional American ballet company complained of lower back syndrome (Ryan and Stephens, 1987).

ii) Femoral angle

The femoral angle is formed by the neck and shaft of the femur and is normally 125 degrees (Ryan and Stephens, 1987). However this angle varies inversely to the development of the width and stature of the pelvis (Gray et al., 1985). In a wider pelvis, which is more common in women, the femoral angle approaches a right angle (Hardaker et al., 1986). This maybe associated with genu valgum or "knock kneed " alignment and may lead to patellofemoral tracking problems, medial knee strain and excessive pronation of the foot (Clippinger-Robertson et al., 1985). Ryan and Stephens (1987) reported that this excessive pronation may cause a variety of injuries such as plantar fasciitis, Achilles tendinitis and posterio-medial tibial shin splints. Furthermore the authors reported that pronation also internally rotates the leg and may strain the medial aspect of the knee.

More obtuse femoral angles (>125 degrees) are more characteristic of genu varum, or "bow-legs". Of the two types of genu configurations, a slight genu varum is reported as being more favourable because it creates a wider opening or separation of the legs (Ryan and Stephens, 1987).

iii) Genu recurvatum

Genu recurvatum or slight hyperextension of the knees of about 10 degrees is fashionable in ballet (Lawson, 1986; Ryan and Stephens, 1987). This condition causes the dancer to stand with weight distributed primarily over the heels, a forward tilt of the pelvis and a sway to the lower back (Howse and Hancock, 1992). This posture may result in a lower back syndrome (Gray et al., 1985). Improper body alignment of this type will also cause problems in the correct performance of basic ballet technique and the development of technique related injuries (Gelabert, 1980; Ryan and Stephens, 1987; Gantz, 1990). For example when on pointe a female dancer with genu recurvatum may have difficulty maintaining her body weight over her foot. This poor alignment over stresses the plantar flexors of the foot and may lead to tendinitis.

iv) Tibial torsion

External tibial torsion in excess of 20 degrees has been reported to result in patellofemoral and knee disorders (Ryan and Stephens, 1987). These disorders are due to the inability of the dancer to align the knees over the toes during the plie. The exaggerated inward rotation can create tracking problems with the patella and increased shear forces in the knee (Ryan and Stephens, 1987). Furthermore this gait characteristic of excessive internal tibial torsion (<10 degrees) results in severe pronation of the foot and subsequent increased pronatory forces (Clippenger-Robertson et al., 1985).

v) Ankle joint plantarflexion

Osseus limitation of ankle joint plantar flexion or poor pointe will prevent professional ballet participation. The strongly pointed foot is an essential element in the aesthetic and technique of ballet (Ryan and Stephens, 1987). Limited ankle plantar flexion in female dancers prevents them from completing on pointe position, an essential technical component in the performance of most ballet movements (Lawson, 1986). Limited plantar flexion may be due to impingement of the posterior joint margin and the posterior edge of the tibia and the tibiotalar joint during extreme plantar flexion (Hamilton, 1982; Quirk 1982; Clippenger-Robertson et al., 1985; Ryan and Stephens, 1987).

As stated by Howse (1982) the anatomical (intrinsic) factors mentioned are more likely to cause injury to a more general dance population than the selected professional groups. In this case not all student dancers will become professional dancers, possibly due to the factors mentioned, and may in fact choose to teach dance i.e. become part of a more general dance population. In this situation the anatomical factors would become important contributors to injury in student dance teachers because of the nature of the dance teacher degree programmes (Section 2.2.1).

The degree to which these anatomical factors play a role in the onset of injury is not documented in the literature. Further, if these factors were identified and their severity rating to the onset of injury quantified potential screening techniques could be developed and implemented at an early stage to advise potential student dancers of their predisposition to injury. Preventative measures could be implemented to reduce the risk of the onset of injury. However no data exists to support such a situation.

2.2.3 Biomechanical factors

Dance movements require full range of motion of the joints especially of the lower extremity. In many instances there is an almost inseparable interrelationship among anatomy, biomechanics, dance technique and the development of injuries. A study of 54 biomechanical measurements and assessments indicated that four critical biomechanical factors were associated with the development of dance related injuries (Ryan and Stephens, 1987).

i) Inadequate hip range of motion and musculature

The hip normally has a total range of motion (ROM) of 90-100 degrees with a balance amount of external and internal rotation of 45-50 degrees (Howse, 1982). Deviations above of below this range of motion may indicate anatomical femoral torsion (i.e. anteversion or retroversion), the presence of muscle imbalances or the asymmetries of the ROM of each extremity (Howse, 1982; Ryan and Stephens, 1987).

Ryan and Stephens (1987) have reported that measurements of femoral torsion have demonstrated a significantly greater amount of total hip ROM in top female professional and student dancers than in the corresponding male groups. In addition the total hip ROM in all of the groups was generally less than reported control values.

A study of a professional American ballet company suggested a correlation between the age that a person started dancing and the ability to turn-out (Miller et al., 1975). The dancers also had significant increases in the total hip ROM when the hip was in the flexed position versus the supine position. Miller et al. (1975) and Ryan and

Stephens (1987) suggested that this difference usually indicated a soft tissue limitation associated with a muscle imbalance of the rotator musculature of the hip. External rotation was normal for a dance population (44-50 degrees) in all of the groups but was lowest in the male student group (39 degrees). The dancers also demonstrated some degree of limitation of internal rotation (range 24-37 degrees; Ryan and Stephens, 1987). Limitation of internal rotation may be due to the tightness of the external rotator musculature, ligamentous restrictions or the degree of femoral retroversion (Clippenger-Robertson et al. 1985). Limitation of hip rotation, especially external rotation, can have a profound effect upon a dancer's technique and vulnerability to injury. A dancer may attempt to compensate for limited turn-out by tilting the pelvis, increasing the lordotic curvature of the lumbar spine, twisting the knees, or abducting the forefoot (Hamilton, 1982; 1988). This is known among dancers as "forcing the turn-out." (Lawson, 1986). The inward torque of the hip rotators on the fixed externally rotated foot is devastating to the medial aspect of the knee. The resultant compensatory mechanisms also increase the amount of stress placed upon the joints of the lower extremities, prevent proper alignment and increase pronation of the foot (Ryan and Stephens, 1987).

ii) Turn-out

Turn-out involves 90 degrees of external rotation at each hip few. This technique involves a sufficient amount of external rotation at the hip (55-70 degrees), about 10 degrees of external rotation at the knee, 12 degress of tibial torsion and abduction of the forefoot at the midtarsal joint (Ryan and Stephens, 1987).

During a grand plie, (deep knee bend with heels on floor), the external rotation of the hip must simultaneously act with the flexion and abduction of the thigh at the hip joint. Dancers with soft tissue limitation of the hip will often compensate for decreased external rotation by tilting the pelvis (i.e., flexing the hip) which increases the ROM (Miller et al., 1975; Ryan and Stephens, 1987). The relative amount of anatomical femoral retroversion is less important that that of the complex compensatory mechanisms of the entire lower extremity and spine.

iii) Gastrocnemius-Soleus Equinus

The range of motion at the ankle joint is assessed by measuring the number of degrees of dorsiflexion of the neutral foot with the knee extended and flexed (Baumann et al., 1982). These two positions primarily test the flexibility of the gastrocnemius and soleus muscles respectively (Ryan and Stephens, 1987). Normal values for ankle dorsi-flexion are between 10-13 degrees when the knee is straight and about 20-23 degrees when the knee is flexed (Howse and Hancock, 1992). A minimum of 10 degrees of ankle joint dorsi-flexion is essential for the normal biomechanics of the foot. In some cases dorsiflexion of the ankle may be blocked by anterior tibiotalar impingement syndrome or tight calf muscles (Hamilton, 1988). An example of the data published on ankle dorsiflexion is shown in Table 2.2.3.1. In a study by Howse (1982) both male and female professional dancers demonstrated about a 10 degrees limitation of ankle dorsiflexion in both testing positions. This indicated the presence of a gastrocnemius-soleus equinus a functional dynamic muscle imbalance of the posterior calves (Hamilton, 1982). Ryan and Stephens (1987) reported this functional equines as a common biomechanical problem among professional, advanced university, and aerobic dancers as well as many competitive endurance athletes, such as runners. The authors stated that the condition was related to the frequency, duration, intensity and technique of training (Ryan and Stephens, 1987).

Table 2.2.3.1. Ankle Joint Dorsiflexion ** (All values in degrees)

	Control Values	Knee Neutral	Control Values	Knee Flexed
Female professionals N = 48	10-13	*1.4 ± 5.2	20-23	*11.7 ± 6.2
Male professionals N = 30	10-13	*-0.7 ± 3.8	20-23	*8.0 ± 3.5
Female students N = 144	10-13	4.1 ± 9.5	20-23	14.2 ± 6.7
Male students N = 22	10-13	6.3 ± 7.2	20-23	14.5 ± 7.6

*P<0.05

** Adapted from Ryan and Stephens, 1987

Professional dancers may acquire a functional equinus condition from years of extensive daily use of the calf muscles without a proportional amount of calf stretching or technical faults such as the failure to allow the heels to contact the floor during the landing and takeoff phases of a jump (Hamilton, 1988). These factors i.e. incorrect technique and inadequate warm up and stretching were also reported by

Ryan and Stephens (1987) as potential contributors to the onset of injury. Functional equinus alters the normal biomechanics of the foot during the fundamental jump movement and seriously predisposes the dancer to injury (Ryan and Stephens, 1987).

iv) Ankle Joint Plantarflexion

In professional ballet companies it is important for a dancer to be able to plantar flex (i.e., point or extend) the foot in such a way that the dorsum of the forefoot falls in a direct line from the anterior edge of the tibia (Lawson, 1986; Ryan and Stephens, 1987). In the demi-pointe (balancing on balls of the foot) position this aligns the foot in a manner that allows the bones to bear the weight properly and not the ligamentous and musculotendinous structures of the foot and ankle (Lawson, 1986).

Although overarching of the foot is common in many ballet companies it can create biomechanical problems. During on pointe (balancing on the distal aspect of metatarsal heads) the extension of the line of gravity in front of the foot increases the amount of stress on the ligamentous and tendinous structures on the dorsum of the foot (Ryan and Stephens, 1987). In a study reported by Quirk (1982) 40% of top female dancers had the ROM necessary to overarch the foot with a large percentage of these dancers reporting various strains on the dorsal aspect of the foot.

As mentioned previously plantar flexion may be limited by posterior talar impingement or other factors. This causes the line of gravity to fall directly beneath the heel rather than over the metatarsal heads or through the phalanges. This alignment increases the amount of stress placed upon the muscles, tendons, and ligaments of the posterior, medial, and lateral aspects of the ankle thus increasing the vulnerability of these areas to injuries such as tendinitis, tenosynovitis and shin splints (Ryan and Stephens, 1987). Evidence also indicates that the forefoot is able to abduct while supinated in the on pointe position thus permitting a degree of pronation and shock absorption in the foot (Quirk, 1983).

Limited plantar flexion is an unsatisfactory condition in professional dancers mainly due to fairly uncompromising aesthetic standards for beautifully pointed feet. A slightly dorsiflexed foot destroys the elongating illusion of the fully extended extremity. Female dancers must have linear plantarflexion in order to perform on pointe (Ryan and Stephens, 1987).

The literature has highlighted four biomechanical factors and the potential compensatory or adaptive mechanisms of the body in dealing with inadequate musculature or flexibility and its influence on technique and the onset of injury. Similarly different foot types have also been documented to influence the development of musculature around the ankle joint which may then manifest itself as a cumulative or adaptive effect upon the joints of the lower limb and ultimately affect dance technique. However the degree to which these factors influence the onset of injury and their potential cumulative or interactive effect is not documented. Further, the type of dance style or level of participation of the dancer mentioned in relation to all the roles of these biomechanical factors and injury is also not evident in the literature.

This section of the literature review (Section 2.2) has focused on the aspects associated with an epidemiological approach to injury in dance. The studies on the prevalence and distribution of dance injuries has demonstrated a plethora of data for the professional or pre-professional dancer participating in one style but a paucity of data related to student dancers in comparison. Of the data that is reported only one study has highlighted the nature of a multidisciplinary degree programme (Clanin et al. 1984). However within this study the students were training to become professional dancers highly skilled in only one dance style.

2.3 DEMOGRAPHIC, ANTHROPOMETRIC AND PHYSIOLOGICAL CHARACTERISTICS OF DANCERS

Demographic research in dance has been published from two main perspectives, the level of participation of the dancer and the style in which the dancer participates. The research has focused mainly on the professional and pre-professional dancer across a number of dance styles to identify similarities and differences in physiological and physical profiles (Micheli et al., 1984; Liederbach et al., 1994; Rimmer et al., 1994). This section of the literature review highlights the aspects associated with the demography, physiology and kinanthropometric characterictics of dancers.

2.3.1 Demographic profiles of dancers

Dance has been viewed primarily in the context of the professional participant most notably that of the ballet dancer (Micheli et al., 1984; Cohen et al., 1982; Kirkendall et al., 1984; Kirkendall and Calabrese, 1983; Mostardi et al., 1983; Schantz and Astrand, 1984; Calabrese et al., 1983). A few investigators have examined other styles such as ballroom dancing (Blanksby and Reidy, 1988) and modern dancing (Rimmer and Rosentwiegs, 1981), and levels of participation such as pre-professional (Chmelar et al., 1988a, 1988b) and university graduate (Novak et.al., 1978). Demographic data has been reported from these investigations and included age, height and mass of the dancer. These values have ranged from 15 – 31 years old, 153 – 173 cms and 51.5 – 68.6 kg for age, height and mass respectively. These values were reported for advanced and professional ballet and modern dancers. The studies on student dancers (Clanin et al., 1984; Chmelar et al. 1988a; Evans et al., 1985; Novak et al., 1978) have reported ages in the range 18-38 years, mass in the range 47-57 kg and heights in the range 155 – 169 cms. However the study by Clanin et al. (1984) was the only study to record dance students on a multidisciplinary dance programme incorporating the styles of jazz, ballet and modern. This suggests that there is a paucity of research on student dancers and student dance teachers participating on a multidisciplinary dance programme and the knowledge base surrounding their involvement in dance. Further, based on the data collated by Clanin et al. (1984), student dancers involved in a university dance degree programme are of a similar age, height and mass to those involved in professional companies which may be important intrinsic factors in the predisposition of injury.

Additional but limited data has been reported on the number of years of dance experience and the time spent in dance class and in rehearsal. Kuno et al. (1996) published data on professional Japanese ballet dancers. The authors reported data on time spent in ballet classes and in rehearsals. The dancers attended ballet classes 5.9 ± 0.6 days per week, for 83.8 ± 8.6 minutes in each class. The dancers spent 172.5 ± 61.4 minutes for rehearsal 4.6 ± 1.2 times per week. Mostardi et al. (1983) reported that an American based professional ballet company spent 90 minutes in class each day and up to 5 hours in rehearsal when preparing for performances.

Evans et al. (1985) and Novak et al. (1978) reported data for undergraduate dance students majoring in ballet. They reported mean dance experience values of 7.7 years and in the range 6-8 years respectively. They also reported time spent in class (hours per week) with values ranging from 6 to 20 hours/week. This data indicates that student dancers practice and rehearse with a similar frequency and duration as professional dance companies and in doing so may subject their bodies to similar physiological and physical stresses. This may be further exacerbated based on a lack of dance experience which may increase the stresses through a lack of technical information or physiological fitness and subsequently increase the risk of injury.

The literature reported has highlighted the similarities between the professional dancer and the university based student dancer in certain demographic characteristics. These have included age range, height and body mass. Further similarities were illustrated in terms of time spent dancing and rehearsing (hrs/week). If this is the case then it is possible that the student dancers are at a similar risk of injury in terms of injury prevalence and injury pattern and may also possess similar predisposing characteristics. However it should be noted that there is a paucity of data on student dancers and, as yet, there are no published studies specific to student dance teachers. Further, the student dancers reported on by Novak et al. (1978),Clanin et al. (1984), Chmelar et al. (1988a, 1988b) were training to be professional dancers with a view to working in private dance companies and hence it would not be unusual for these dancers to replicate the demographic characteristics found in the professional dancer albeit specific to one dance style. Therefore although the student dancers on an interdisciplinary dance degree programme demonstrate similar performance, rehearsal and demographic characteristics the content of each rehearsal or training dance class may not accurately reflect the content nor schedule of a student dance teacher class or programme. In this instance there is a lack of data with which to compare for this specific population.

2.3.2 Anthropometric profiles of dancers

High level performance in many sporting and exercise activities is associated with certain physical characteristics and the physiological and biomechanical requirements of the activity influence a participant's choice of activity (Bale et al., 1985). An anthropometric profile of an individual provides information about their physical characteristics. For the performing dancer the aesthetic ideals of the artistic director and choreographer must be met. The body composition, shape and structure of the dancer is therefore an important factor because the projected body image is of such great importance.

Measurements of percent body fat have been reported by several researchers for female professional, college, and adolescent dancers (Clarkson et al., 1985; Cohen et al., 1982; Dolgener et al., 1980; Micheli et el., 1984; Novak et al., 1978). Mean values have ranged from 12.9% to 17.4% in professional ballet dancers but variations in measurement technique, in relation to skinfold sites, make direct comparisons difficult. Using the Sinning (1978) anthropometric equation Micheli et al. (1984) reported a mean of 15.3% in professional ballet dancers. In a combined group of professional, university, ballet and modern dancers, a mean of 22.1% body fat using the Behnke/Wilmore equation was obtained by Dolgener et al. (1980). In a similar combined study Chmelar et al. (1988b) reported percent body fat measures of 14.1% and 12.2% in professional ballet and modern dancers respectively and values of 14.2% and 14.7% in university ballet and modern dancers. They suggested that rigorous demands on appearance for both groups, even though the university subjects were full time students, influence the process of natural selection with only the students that 'maintain a lean body composition' progressing to professional or elite dancing status.

Fleck (1983), published percentage body fat data from studies using hydrostatic weighing techniques. Means of 10.7% to 13.8% body fat characterised female distance runners, elite sprinters, elite long and high jumpers, and elite 800 m runners. Gymnasts, elite volleyball players, speed skaters, and elite rowers average from 15.6% to 18.4%. Extrapolating from the anthropometric literature female dancers are comparable to gymnasts and middle distance runners in terms of percentage body fat (Mostardi et al., 1983; Fleck, 1983). Dancers therefore tend to have a lower body fat content than other elite sports participants.

Although there is evidence of percent body fat data specific to dancers comparison is difficult due to a variety of techniques used. The data reported is also based on the professional or pre-professional dancer with no comparative data on the student dancer nor the student dance teacher.

2.3.3 Physiological profiles of dancers

A substantial body of knowledge concerning the physiological characteristics of dancers has been reported. These studies were based on the premise that before the problem of injury can be addressed it is first important to know about the individual who is presented with the problem (Caine and Garrick, 1996). Physiological profile data has included oxygen consumption, heart rate, muscle strength and flexibility of the dancer. Similar to the demographic and anthropometric data the published research has focused on the professional or pre-professional dancer with no information on the student dancer nor the student dance teacher.

2.3.3.1 Aerobic fitness

Studies by Mostardi et al. (1983), Micheli et al. (1984), Cohen et al. (1982) and Schantz and Astrand (1984) have reported extensive physiologic data on elite professional ballerinas. Mostardi et al. (1983) and Micheli et al. (1984) monitored cardiorespiratory fitness using a treadmill based protocol. They reported oxygen consumption values of 48.6 ± 1.3 ml O_2 kg^{-1} min^{-1} and 41.8 ± 1.8 ml O_2 kg^{-1} min^{-1} respectively. The authors pointed out that years of ballet training dictated that running is contraindicated for the development of sound musculature in female dancers (Mostardi et al. 1983). However it was felt that even under the unfamiliar treadmill and running conditions that the dancers achieved true levels of maximal aerobic capacity. Maximum heart rate values were also reported and they ranged from 155 to 195 beats.min^{-1}. For the data reported by Micheli et al. (1984) that would be equivalent to a percentage range, based on age predicted maximum heart rate and a mean age of 25 years, of 79.5% to 100% maximum heart rate.

The studies by Schantz and Astrand (1984) and Cohen et al. (1982) reported data on similar characteristics but specific to technique dance classes, rehearsals and performance. Schantz and Astrand (1984) reported oxygen uptake values of 42% of the maximal value during class time (21.4 ml O_2 kg^{-1} min^{-1}), and up to 80% of the maximal during rehearsal (40.8 ml O_2 kg^{-1} min^{-1}). Heart rate values were also reported for the rehearsals and they ranged from 101 beats.min^{-1} to 198 beats.min^{-1}. The authors however did not report on the duration of the class but diagrammatically represented the duration of the rehearsal as approximately 80 minutes. No mean heart rate for this duration was reported. Due to the complexity and awkwardness of the Douglas bag experimentation only heart rate values were recorded during performances. A 12 minute choreographed act was recorded with values ranging from 170 beats.min^{-1} to 185 beats.min^{-1}. Based on the age of the dancers (mean = 28 years) this was equivalent to 88.5% and 96.3% of their age predicted maximum heart rate. Cohen et al. (1982) reported similar values for heart rates during class time (mean = 137 beats.min^{-1}, range 107 – 176 beats.min^{-1}). The mean maximal oxygen consumption value reported was 43.7 ± 4.32 ml O_2 kg^{-1} min^{-1}. The authors concluded that consistent with the non-endurance nature of classical ballet, the elite ballet dancers' maximum oxygen consumption values were similar to those of non-endurance athletes such as female collegiate team sport players in volleyball, basketball and field hockey.

Of the limited studies published on university based dancers only two studies have reported heart rate or maximum oxygen consumption vales (Novak et al. 1978; Chmelar et al., 1988a). The values reported were maximal and did not reflect time spent in class nor in rehearsal nor performance. Novak et al. (1978) reported maximum heart rate values of 185 ± 7 beats.min^{-1} and maximal oxygen consumption values of 41.5 ± 6.7 ml O_2 kg^{-1} min^{-1} following a treadmill based protocol. These values were reported as being significantly higher, by more than 5 ml O_2 kg^{-1} min^{-1}, than the control group. The control group consisted of female students who did not take part in any regular physical exercise. Chmelar et al. (1988a) however reported a 12.2% higher mean oxygen consumption value of 47.3 ± 3.1 ml O_2 kg^{-1} min^{-1}. This difference may have been due to a number of factors including dance experience, level at which each student group was performing at in terms of academic year and the styles in which they would be performing depending on the programme.

The studies reported on quantifying the aerobic fitness of dancers have demonstrated the difficulty in collecting data that accurately reflects or represents the true aerobic capacity of the dancer. The studies suggest that traditional treadmill based protocols using on-line gas analysis (Mostardi et al., 1983) and the clumsiness of Douglas bag gas collection (Schantz and Astrand, 1984) are inadequate methods for accurately measuring aerobic fitness in dancers. However the studies have incorporated heart rate monitoring and have reported maximal values as a percentage of age predicted maximum. One objective for providing maximal oxygen consumption and heart rate data is for training. By establishing heart rate at maximal oxygen consumption athletes, or dancers, may train at a given percentage heart rate to increase or maintain aerobic fitness (MacDougall et al., 1991). The reported studies suggest that traditional methods for establishing maximal oxygen consumption do not reflect the true aerobic capacity of a dancer therefore an alternative method for estimating aerobic fitness for dancers maybe required. A further objective for recording and reporting heart rate and oxygen consumption data may be as a gross indicator of physical stress based on the fitness of the individual dancer. As the body is physically loaded i.e. required to do work, the heart rate will normally increase accordingly. An aerobically fitter dancer may record a lower heart rate when compared to a colleague performing a similar routine. If this is the case the fitter dancer may have a reduced risk to injury in terms of being able to cope with the demands of the performance. However the authors who reported on heart rate did not attempt to link this physiological component to the physical stress and potential risk to injury.

The American College of Sports Medicine (ACSM, 1991) have suggested that exercising between 60-70% of age predicted heart rate, for 15-20 minutes, will elicit a cardiovascular training response. The ACSM (1991) point out that this is only an estimate and provide an additional equation for estimating the specific target or training heart rate. This equation incorporates the product of exercise intensity, estimated heart rate maximum and a corrective factor of 1.15. However a measurement criteria for exercise intensity must be established before an accurate training heart rate can be recommended. With this in mind a dance specific exercise intensity method of measurement maybe more reasonable to establish. This maybe a combination of time and beats.min^{-1}, reflective of the specific dance rhythm, or the number of actions performed per minute (physical load) within that dance style. However, as yet, there are no published studies which suggest alternative methods.

2.3.3.2 Strength

Strength is defined as the capacity of the individual to exert force against a resistance in a single effort (Cabri, 1991). Each dance technique requires specific strength. Many dancers lack strength in the hamstring muscle group, abdominal muscle group and front of the lower leg (Dunn, 1990). It has been assumed that specific strength and flexibility imbalances may be associated with athletic injuries (Ross and Schuster, 1983; Mechelen et al., 1992). These imbalances may manifest as differences between the right and left leg or as abnormal ratios between antagonistic muscle groups. Previous attempts to find a relationship between muscular imbalances and injuries (Agre and Baxter, 1987; Burkett, 1970; Laird, 1981) have met with limited success. A study by Knapik et al., (1991) demonstrated that specific strength and flexibility imbalances were associated with the first incidence of a lower extremity injury in female collegiate athletes. They suggested that for knee flexion athletes with a right leg stronger than the left by 15% or more were 2.6 times more likely to get injured than athletes with imbalances less than 15%. Strain and sprain types of injuries were much more likely to occur on the weaker left side. A possible explanation was that knee flexor muscle group was operating at a high contractile velocity and was unable to absorb or properly transfer that force. Their data did suggest that imbalances in knee flexor strength on either side of the body impart a greater risk of injury. Several researchers have speculated that muscular strength is the most important physiological factor in the prevention of dance injuries (Howse & Hancock, 1992; Arnheim 1986). It has been shown that strength is an important factor both in injury prevention and for correct execution of many dance movements (Howse and Hancock, 1992). Although adequate muscular strength is required dancers must ensure that they do not over develop muscle as this is a disadvantage both aesthetically and in the performance of choreographed movement.

Muscular strength can be broadly categorised into dynamic and static strength (Arnheim, 1986). Dynamic strength is the ability of the individual to overcome resistance through a complete range of movement, e.g. isotonic and isokinetic strength. Static or isometric strength is the ability to apply resistance against an immovable force (Wells, 1985). Dance involves constant movement of the body therefore previous studies have measured dynamic strength.

Several devices are available to measure strength. Computer controlled isokinetic dynamometers measure muscle strength accurately and reliably (Coldwells et al., 1994). These devices can be used to measure muscular strength across a joint for a number of muscle groups and have the advantage of being able to effectively isolate the muscle group (Lido Active, USA). The main drawback with these devices are that they are expensive and they are not portable enough to measure muscle strength in field conditions.

A cheaper alternative is the use of portable spring loaded dynamometers. Coldwells et al. (1994) conducted a study which compared strength measures obtained from a portable dynamometer and an isokinetic dynamometer. They found that if a set protocol was adhered to measurements from the portable device compared well for back strength (r=0.79) and leg strength (r=0.90). Amongst the portable devices available to measure upper body strength is the grip strength dynamometer (Takei Kiki Kogyo). Spijkerman et al. (1991) standardised grip strength measures and stated that reliable and valid results were recorded if a set protocol was followed.

In the comparison of professional and modern dancers Chmelar et al. (1988a) examined differences in the hamstrings/quadriceps peak torque ratios using an isokinetic dynamometer. It was found that the ratio was significantly higher for ballet (65.8%) than modern dancers (57.8%). The explanation for ballet dancers having stronger hamstrings was in the nature of their training.

Hamilton et al. (1992) measured isokinetic strength of hip abduction/adduction, knee flexion/extension and ankle plantar flexion/dorsiflexion in professional dancers. An imbalance in strength was noted between the abductors (+21%) and adductors (-24%) of the hip. This gave an abduction/adduction ratio of 1.6 higher than the norm of 0.70. The knee flexor/extensor ratio was found to be normal (1.67). Ankle strength was increased through the plantar flexors (+33%) and dorsiflexors (+26%) however the plantar flexion/dorsiflexion ratio was normal (4.4). It was suggested that the imbalance in abduction/adduction strength was due to time spent standing on one leg whilst holding the other leg in various positions. Actions such as this caused abductor strength to increase isometrically.

Howse and Hancock (1992) highlighted that muscle strength balance across a joint is important since imbalances could predispose a dancer to injury. Balance of strength is also required between the left and right sides of the body for aesthetic and medical reasons (Howse and Hancock, 1992). Micheli et al. (1984) measured isokinetic strength in dancers knees and ankles and compared values for left and right extremities. No significant difference was found between left and right legs and ratios for plantar/dorsiflexion (6.2) and knee flexion/extension (1.72). The data were also comparable to the findings of Chmelar et al. (1988a) and Hamilton et al. (1992).

Imbalances of muscular strength at the ankle, knee and hip joints can contribute to the occurrence of overuse injuries such as tendinitis which are common in dancers (Hamilton, 1982, 1986). Identification of such muscular imbalances could help to prevent dance injuries at all levels. Previous research (Chatfield et al., 1990; Hamilton et al., 1992) has used isokinetic strength measures but by using a validated protocol appropriate field methods can be applied such as measures of back, grip and leg strength.

2.3.3.3 Flexibility

Flexibility, defined as the range of motion about a joint or a joint series, is considered a contributing factor in the performance of a skilled movement, an index of overall physical fitness (Enoka, 1988), and a predisposing factor to injury (Ryan and Stephens, 1987). In dance the development of extreme flexibility is common. Dancers must be highly flexible in order to perform the range of movement (ROM) required in dance (Sapega and Nicholas, 1981).

Micheli et al. (1984) assessed the range of motion and flexibility in 25 young ballet dancers (mean age = 16.4 years). Flexibility was measured using a Leighton flexometer. Mean flexibility values (degrees) were recorded for hip flexion-extension (198.1 degrees), abduction-adduction (80.1 degrees) and internal-external rotation (82.2 degrees). Knee flexion-extension was also reported with a value of 176.9 degrees.

Mean values for dancers and age matched controls for range of motion at the hip were also reported (Micheli et al., 1984). Values for hip abduction 54.2 degrees, 40 degrees, hip adduction 19.9 degrees, 21.2 degrees, hip external rotation 48.1 degrees, 34.2 degrees and hip internal rotation 40.4 degrees, 36.2 degrees were reported for dancers and age matched controls respectively. An ankle range of motion value was also reported with 85.3 degrees and 89.0 degrees for dancers and controls respectively. Of the range of motion values recorded the dancers were found to have a statistically significant increased external rotation (48.1 degrees) and abduction (54.2 degrees) at the hips but otherwise demonstrated no significant difference in internal rotation, adduction or ankle motion when compared to age matched controls. Micheli et al. (1984) also noted that external hip rotation in these dancers was not excessive in any case and they did not show a reciprocal decrease in internal rotation suggesting that these findings were due to task-related flexibility not femoral retroversion.

Range of motion of the lower extremity was also recorded by Hamilton et al. (1992). In a study of 14 principle female dancers from the American Ballet Theatre joint range of motion was recorded for the hip, knee and ankle. Hip abduction values of 55 degrees (norm = 48 degrees) were recorded while values of 113 degrees (norm = 48 degrees) and 10 degrees (norm = 18 degrees) were reported for plantar and dorsi flexion of the ankle respectively. The authors stated that the dancers had full abduction but ankle motion was 'markedly abnormal'. A significant 123% increase in plantar flexion and 50% loss in dorsi-flexion was reported over the norm with a total range of motion (plantar + dorsi-flexion) 78% greater than normal (123 degrees for dancers, 66 degrees for the norm).

In a study of female collegiate athletes, Knapik et al. (1991) measured the flexibility of the hip flexors and extensors, knee flexors and ankle dorsiflexion of the gastrocnemius and soleus in an attempt to relate the incidence of injury to joint flexibility. Values of 20 degrees and 19 degrees were reported for the right and left hip flexors and 130 degrees were reported for right and left knee flexors respectively. Values of 13 degrees and 14 degrees were reported for right and left dorsiflexion of the gastrocnemius, and 15 degrees 16 degrees were reported for dorsiflexion for the right and left soleus muscle respectively. Analysis of the injury and flexibility data demonstrated that athletes whose hip extensors had a 15% greater range of motion on the right side were 2.6 times more likely to get injured than athletes with less than a 15% imbalance. It seemed reasonable to expect that a hip extensor flexibility imbalance on either side of the body may predispose that athlete to injury. Further analysis of the data demonstrated that subjects with a greater range of motion on the left side were 1.7 times more likely to experience injuries when compared to subjects with a more balanced range of motion. The subject groups with hip extensor imbalance had more ankle sprains and quadriceps strains.

The concept that some individuals have more flexibility than others is not a new one. Orthopaedic surgeons have recognised the striking relationship between degrees of flexibility and a number of pathological conditions such as subluxing shoulders, dislocating patellae, chronic instability of the ankle, lordodic backs and other predilections for subluxation and dislocation. The hypermobility syndrome has been associated with numerous musculoskeletal complications (Nicholas, 1975). In a study published by Nicholas (1970, cited by Nicholas, 1975), a relationship of knee injuries to limb looseness and tightness in professional American football players was undertaken. The author observed that some athletes while they possess great flexibility do not have the same muscle strength as other athletes with less flexibility. Significant quantitative differences in flexibility (spinal and upper and lower extremity) were found among the footballers, school athletes and gymnasts. Strength, endurance and anatomical differences are additional factors in the analysis of an individual's performance characteristics.

Tests devised by Baumann et al. (1982), although concentrating on the lower extremity, were measured and recorded in degrees of motion. They also enabled the isolation of certain muscle groups. An example of the results obtained from the protocol from Baumann et al. (1982) where published by Ryan and Stephens (1987) and are displayed in Table 2.3.3.3.1. Each of the flexibility manoeuvres were selected to be representative of joint actions whose maximal range is typically utilised during modern dance class training and performance.

Both the advanced and intermediate dancers were significantly better than the non-dancers on four of the eleven flexibility manoeuvres measured. The four manoeuvres that both the advanced and intermediate dancers performed better than the non-dancers were concentrated at the hip. No differences were found in the active manoeuvres of the ankle. For dorsi-flexion it is the case that most frequently the maximal range of motion is utilised in passive circumstances such as plies.

Table 2.3.3.3.1. A Comparison of Hip Flexibility* between non-dancers and beginners, intermediate and advanced dancers.

	Flexion	Outward rotation	Horizontal Abduction
Non-Dancers	87.1	27.4	58.5
Beginners	91.4	31.7	63.7
Intermediate	101.7	34.5	70
Advanced	116.8	40.3	70.8

(Ryan and Stephens, 1987; * All measurements in degrees)

Due to the nature of the rigorous movements that must be performed in dance, a successful dancer should have a high degree of flexibility. The ability to increase the range of motion not only helps to achieve the desired aesthetic line but also decrease the risk of injury (Howse and Hancock, 1992). Clippinger-Robertson (1985) suggested that a muscle with inadequate flexibility is more prone to injury and that poor flexibility in a region can lead to compensations which are injurious.

Hamilton et al. (1992) examined flexibility and range of motion (ROM) of the lower extremities in female dancers. Values were obtained using standard goniometers and then compared to norms for the general population. It was found that dancers had increased external hip rotation (+30%) coupled with a loss of internal rotation (-15%). ROM for hip abduction/adduction was less than normal but hip flexion (+8%), and plantar flexion (+135%) were significantly increased. The results suggested that dancers were flexible but not hypermobile. Hypermobility was not recommended as a selection factor for dancers because it was often associated with injury.

Flexibility of the lower extremities is important for the assumption of certain positions in dance. It therefore appears that dancers are more flexible in their lower limbs compared to non-dancers. This flexibility may be due to training or it may be that individuals who are flexible are more successful in dance. A combination of the two is most probable (Hamilton et al., 1992). In either case flexibility below a certain level is suspected to predispose a muscle to injury when stressed (Baumann et al., 1982). Flexibility measures are therefore an essential element in profiling dancers and in assessing susceptibility to injury.

2.3.3.4 Strength and Flexibility Relationship

Howse and Hancock (1992) stated that if the muscles controlling a joint are weak the joint will not be stabilised sufficiently for it to be fully flexible. Dancers must therefore ensure that flexibility and stretching exercises are mirrored with a strength training programme. The relationship between joint mobility and muscular strength has been reported in several studies. Research by Burkett (1970) on a variety of athletic performers stated that imbalances in muscle strength and joint flexibility are precipitating factors leading to muscle strains. 67% of athletes with muscular strength imbalance of 10% or greater, between the right and left knee flexors, suffered hamstring strains.

Fry et al. (1991) investigated the relationship between shoulder flexibility and isometric strength in women volleyball players. They found that over the course of a training programme shoulder flexibility was increasingly related to sport specific isometric strength. This finding highlights the need for strength and conditioning programmes to be combined. They also stated that strong muscular contractions at the hip joint prior to a flexibility manoeuvre restricted its extensibility.

Jones (1994) investigated the relationship between strength and flexibility in female gymnasts. A significant negative relationship was found between strength and flexibility at the knee joint and the vertebral column i.e. as strength at the joint increased flexibility decreased. This was due to an increase in muscle size obstructing flexibility. It was concluded that a large range of movement at the knee and vertebral column coexisted with weak musculature due to ligament laxity or bone deformity.

Dance has many movements and elements common to gymnastic activity particularly floor exercises which require balance, posture control, aesthetic lines and a need for flexibility and strength. Stark (1991) highlighted that the relationship between muscular power and flexibility was strongest for floor exercises as opposed to other gymnastic disciplines. It was also noted that as skill level improved the differences among gymnasts were determined substantially by the differences in the muscular power and flexibility level.

Studies do exist to support the relationship between strength and flexibility but there is no evidence relating these functional characteristics to dance injury in the literature. Similarly, although gymnastics and dance may have some common elements of movement, there is no evidence to substantiate the role of a strength and flexibility relationship in identifying skill level in dance. Therefore it may be pertinent to consider strength-flexibility ratios in dancers as an additional factor in the onset of injury. This can affect the onset of injury either directly from an exaggerated imbalance or from an inadequate skill level which may lead to technical difficulties in the performance of the dance movement.

Therefore investigation into the strength-flexibility relationships of dancers muscles could help to identify causes of injury due to weak musculature or inflexibility. Additionally this could also be a useful predictor of skill level.

2.3.3.5 Alignment

Efficient body mechanics is essential in order for a dancer to move effectively and to defend against the possibility of injury (Arnheim, 1986). For effective movement each body segment must be in proper relationship to adjacent segments. The measurement of body segments and their relationship to each other is referred to as an orthopaedic alignment examination (Howse and Hancock, 1992). The purpose of such examinations are to determine whether there are any anatomical areas which are likely to cause physical problems during dance training or when performing a particular style of dance.

Research in the pre-participation screening of dancers has shown that awareness of proper body alignment contributes to a less injury prone dancer (Solomon et al., 1990). It has also been speculated that the differences apparent in the female anatomy, when compared to males, may account for women's propensity for certain types of injuries. Women have a wider pelvis and therefore the angle of the femur to the pelvis is more acute than in men (Harris, 1976; Haycock and Gillette, 1976). Women also possess a greater degree of elasticity in the connective tissue which increases flexibility and may contribute to a greater susceptibility to ligamentous injury (Albohm, 1976).

Baumann et al., (1982) suggested that the purpose of obtaining data on orthopaedic alignment is to construct a lower body model as a means of individual comparison. Their plan was to eventually have sufficient data for a computer to generate a lower body structural profile for each athlete to permit comparisons between injured and uninjured subjects and thus identify predisposing structural differences.

In dance a faulty stance can cause injury to almost any part of the body because the misuse of any set of muscles in one part affects those elsewhere and thus the whole posture of the body is adjusted to compensate for the fault. This can lead to muscles being used that are not commonly utilised for the purpose of standing and in doing so are not sufficiently strong enough to cope with the weight of the body. This in turn will not only affect balance but also damage the muscles compensating for the fault (Ryan and Stephens. 1987; Lawson, 1986).

Arnheim (1986) stated that in order to maintain proper alignment the dancer's body must continually combat gravity. Body segments that are misaligned react more adversely to gravity than segments in proper alignment thus resulting in a higher incidence of injury. Since it is the lower extremities of female dancers that are subjected to the most stress, a model of the lower limbs is useful in the prediction of injury (Baumann et al., 1982).

Enneking et al. (1979, cited in Baumann et al., 1982) standardised the procedure for orthopaedic examination. The measurements taken were leg length and lower body segment lengths using a tape measure, limb widths using an anthropometer and the quadriceps angle using a goniometer. A combination of these measurements allowed the authors to construct a lower body profile that could be used as a standard to compare injured and uninjured athletes.

The quadricep angle (Q angle) is an angle of alignment formed by the anterior superior iliac spine (ASIS), midpatella and tibial tubercle. The magnitude of the angle can be increased or reduced depending on the alignment of the lower leg, i.e. genu valgum (knock kneed) or genu varum (bow legged). In a normal female population it is 20 degrees (Nisonson et al., 1984). Misalignment of the hip and knee are contributors to injuries in dance. In the profiling of ballet dancers Micheli et al.

(1984) stated that in order to obtain turnout a dancer must achieve 45-60 degrees of external rotation at the hip. A dancer with femoral anteversion may attempt to increase turnout by twisting below the knee resulting in an increased Q angle and thus the chance of patellofemoral injury. Quirk (1987) stated that an enlarged Q angle (>20 degrees) can lead to patellar subluxation, this is where the patella is displaced laterally but some of its articular surface remains in contact with the trochlear notch of the femur. This can result in acute anterior knee pain associated with exertion and can result in a long absence from performance and practice.

Many dancers are genu varum (bow legs) although this may be exaggerated by hyperextension of the knee (Hamilton, 1986). Genu valgum (knock knees) can be identified in dancers as extensive valgus and may be associated with an increased Q angle. Arnheim (1986) stated that correction of leg alignment problems is difficult and must be carried out as early as possible. Corrective footwear which strengthens weak musculature and extends tight musculature can help to solve the problem. Therefore early diagnosis of lower limb misalignments would help to avoid injury later in a dancer's career.

Few profiling studies have investigated alignment in dancers. Although guidelines for measuring alignment have been provided by Hershman (1984) and Baumann et al. (1982) these studies do not give results of the testing having been applied. Therefore a profile of dancers which included orthopaedic alignment could be used to highlight misalignment and, with intervention following early diagnosis, may aid in the prevention of injury.

The reported literature on strength, flexibility and alignment has highlighted the importance and potential involvement of each profile component in the onset of injury. Studies have attempted to demonstrate a cause-effect relationship between flexibility and injury (Knapik et al. 1991), strength and injury (Agre and Baxter, 1987) and alignment and injury (Solomon et al., 1990) but the results are inconclusive. There is an agreement in the literature that a combination of strength and flexibility imbalances (Barton et al., 1986) may have an influence in the onset of injury but as yet no published evidence exists to support this based on an athletic or dance population. There is also agreement that lower limb alignment has an influence in the onset of injury (Hershman 1984, Baumann et al. 1982) but, similarly, there are no results from which conclusive relationships can be drawn from either an athletic or dance population. It may therefore be that some combination of strength, flexibility and lower limb alignment could be influencing the onset of injury. As yet no published studies have reported results pertaining to this combination.

2.4 PHYSIOLOGICAL AND PHYSICAL STRESS OF DANCE ACTIVITY

2.4.1 Physiological Stress

Physiological profiling has become an important research tool in analysing the specific components of athletic activities (Nicholas, 1984). Dance has been recognised as physically demanding, with many similarities to sports (Nicholas, 1975; Miller et al., 1975). While aesthetic goals are of utmost importance, dancers remain subject to the same unyielding physical laws as athletes. Injury, strength and flexibility play a strong role in the quality of dance performance. Assessment of the physiological characteristics of dancers may help to determine better standards of health maintenance and injury prevention and rehabilitation as well as to improve training techniques.

The physiological capacity of a dancer to participate in dance is an important component and a potential intrinsic risk factor in the onset of injury. The dancer must have the physiological capacity to cope with the demands of the activity (Rimmer and Rosentwiegs, 1981; Schantz and Astrand, 1984; Peterson et al., 1986; Liederbach et al., 1994; Rimmer et al., 1994). As the physical demands of the dance activity increase so the ability of the dancer to sustain a level of dance performance stresses the dancers physiological capacity. Heart rate has been reported as a gross indicator of physiological capacity and energy expenditure (Astrand and Rodahl, 1990). Therefore if the physical demands of the dance activity increase then a corresponding increase in heart rate, and energy expenditure, would be recorded (Bell and Bassey, 1994; Liederbach et al., 1994). An increase in heart rate would represent a higher volume of physical load and stress on the body therefore in order for the dancer to cope with the increase in physical load a certain level of fitness must be maintained. The inability to cope with an increase in physical load, identified by a higher heart rate, may demonstrate a relatively lower level of fitness which may predispose the dancer to injury, i.e. the inability to cope with the physical stress on the body. A level of fitness specific to the requirements of the dancer needs to be established. The use of heart rate as an indirect measure of energy expenditure may also relate to the physical load experienced by the body based on the cumulative effect of dance actions and movement (Blanksby and Reidy, 1988; Thomson and Ballor, 1991). If the dancer is not capable of sustaining the physical stresses on the body then this may increase the risk of injury. The literature has identified heart rate as a gross indicator of physical fitness in pre-professional and professional dancers (Cohen et al., 1982; Micheli et al., 1984; Chatfield et al., 1990; Leiderbach et al., 1994) however there is no published literature on heart rate data related to student dance teachers.

Several research teams have investigated the heart rate responses of elite level performers in various dance styles (Blanksby and Reidy, 1988; Rimmer et al., 1994; Schantz and Astrand, 1984; Chmelar et al., 1988b). Blanksby and Reidy (1988) recorded heart rates of 173 beats/min and 177 beats/min for the ballroom dancing styles of Modern and Latin American respectively, approximately 87.3% and 89.3% of age predicted maximum for the participants within the two styles. Rimmer et al. (1994) reported that, on average, the dancers during rehearsal elevated their heart rate into a training zone (60%-90% maximum) 56% of the time for 45.1 min, and during ballet class 52% of the time for 46.8 min. However the researchers described the dancers' activity as "interval" in nature, since they did not elevate their HR into a training zone for longer than 1 to 6 minutes at any given time. This intensity level, they believed, and the movements being performed required power and anaerobic energy as well as aerobic energy. Hence the dancers used and trained both their anaerobic and aerobic systems.

Only one published study has reported heart rate and maximal oxygen consumption data on student dancers (Novak et al. 1978). However this study was limited in that it only reported the maximal oxygen consumption values and maximum heart rate values based on an exercise to exhaustion treadmill protocol. To date there have been no data published on student dancers with a view to estimating physiological stress.

2.4.2 Physical Stress

The previous section (2.4.1) reported literature on the physiological stress associated with dancing and the link with the physical loading on the body and injury. It is the purpose of this section to review the quantification of the physical load on the body specific to dance and dance movements.

Movement sequences found in various dance styles are similar in repetitive frequency to sports in which running is considered imperative in order to participate. Although running is not typically viewed as a jumping activity it does consist of a series of repeated take-offs followed by repeated landings. For the participants in repetitive impact-oriented activities some research teams have attributed some types of trauma and injury to repeated impacts from landing but did not publish data to substantiate such claims (James et al., 1978; Lees, 1981; Francis et al., 1985; Valiant and Cavanagh, 1985; Nigg, 1986). This lack of data on the quantification of repetitive impact forces and the occurrence of injury is apparent across all exercise activities including dance.

The study of ground reaction forces during dance activity provides insight into the basic mechanisms of the common movements. Lower extremity injuries have been associated with 'overuse phenomena' resulting from the repeated impact loading of the foot (Francis et al., 1985).

Researchers have studied vertical ground reaction forces in an attempt to quantify impact and load upon the human body during running and the relationship of impact or shock to injury. When an athlete is running at 4.5 m/s, vertical impact forces typically reach a peak of 2.0 - 2.4 BW in 20-30 ms (Cavanagh and Lafortune, 1980; Clarke et al., 1983; Hennig and Lafortune, 1991). Munro et al., (1987) found that peak impact force and loading rate were running speed dependent; peak impact increased from 1.6 BW at 3.0 m/s to 2.3 BW at 5.0 m/s and loading rate increased from 77 BW/s at 3.0 m/s to 113 BW/s at 5.0 m/s.

Studies involving the quantification of ground reaction forces in dance have concentrated on aerobic dance movements. Ricard and Veatch (1990) compared the vertical ground reaction forces in low and high impact aerobic dance movement in front knee lifts. Peak impact force was significantly lower in the low-impact movement (1.0 BW) than in the high-impact movement (2.0 BW). Elliott et al. (1991) studied the kinetic factors during four different modes of aerobic dance locomotion (walking, high intensity walking, jogging and running). Peak ground reaction forces recorded were 1.4 BW, 1.3 BW, 2.2 BW and 2.4 BW for the four modes respectively. The authors concluded that the ground reaction forces associated with jogging were smaller than those for running yet larger than the forces reported for walking and high intensity walking. This they suggested increased the implications for injury associated with this movement as compared to the walking movement.

Reeves et al. (1992) compared the vertical forces between high (HIM) and low (LIM) impact aerobic dance sequences. The dance sequences consisted of 10 aerobic dance movements which were choreographed into five 3 minute routines each using 4-5 different dance steps. Analysis revealed a significant difference between the high and low impact dance sequences with vertical forces and loading rates greater for HIM (2.51 BW; 10.75 BW/s) than those recorded for LIM (1.45 BW; 7.94 BW/s). Based on the results of this study the authors concluded that in terms of vertical forces and cumulative degenerative responses, aerobic dance participants that engage in LIM aerobic dance may reduce their susceptibility to developing an overuse injury due to the lower loading rates and passive forces associated with LIM dance manoeuvres.

A similar study by Ricard and Veatch (1994), comparing running speeds and jump heights during aerobic dance classes, revealed an increase in both peak impact force and loading rates as running speed and jump height increased. Peak impact force values increased from 1.96 BW to 2.62 BW for jumping, and from 1.30 BW to 2.01 BW for running. Loading rates increased from 16.26 BW/s to 73.12 BW/s for jumping and from 65.06 BW/s to 112.55 BW/s for running. While these results suggest that aerobic dance may be less stressful than running, aerobic dance movements tend to load the forefoot thus placing stress on different anatomical structures, when compared to running. Aerobic dance participants often report injuries to the forefoot, lower leg and knee (Garrick and Requa, 1988).

The above studies into dance have concentrated on aerobic dance exercise. No literature has been published on the forces involved in other dance activities from other dance styles nor on actions common to student dance teacher movement. However the actions in aerobic dance are based on movements emanating from traditional dance styles. Force analysis of these actions may therefore provide a starting point from which traditional dance styles and their actions may be based and compared.

Although there is evidence to suggest that there is a similar pattern of injury prevalence and distribution for both professionals and students there is no recognition of a specific student dance teacher population or group. The injuries in this group may substantiate this pattern and hence maybe explained by the existing theories surrounding the factors affecting the onset of injury. However if the pattern was not the same this may then require a different approach or perspective to understanding the reasons behind this, which may not replicate the existing theory base in the present published literature.

If the pattern of injury was similar it may also be possible, that due to the nature of a university dance teacher training programme, the existing theory based explanations may not adequately delineate the reasons behind the onset of injury in this population. This may be because of the potentially cumulative effects of continually moving between dance styles or dance technique classes based on the scheduling of class timetables. Additionally, if the theories could be used to explain the onset of the injury there is still little evidence to explain the degree to which each of the anatomical or biomechanical factors affect the onset of injury. This would include the individual factor or the interactive contribution of factors to the onset of injury in a student dance teacher population.

2.5 DANCER PROFILING AND INJURY PREDICTION

Athletic performance is influenced by a multitude of intrinsic and extrinsic variables including, aerobic capacity, strength, flexibility, body composition and environmental factors (Caine et al., 1996). These factors can also contribute to the aetiology of an injury in that strength and flexibility imbalances or inadequate aerobic fitness levels or environmental conditions can influence the ability of the body to perform and hence may increase the risk of the onset of injury. One method of determining the relative importance of these factors in the performance of sports is profiling. Profiling is the gathering of information about the physical attributes of athletes (Nicholas, 1984). It provides the means to determine and evaluate performance characteristics. A typical profile may include measurements of an individuals cardiac output during performance, muscular strength, flexibility, body composition, body alignment. The value of profiling lies in its many applications to successful participation in sport.

Hershman (1984) suggested that one of the clear goals for the individual responsible for the care of athletes is the prevention of injury. This can be attained in large part by taking the known performance demands of the sport, for example technique, frequency, duration and intensity of movement and the intrinsic and extrinsic risk factors that may predispose to injury and apply these to the individual athlete. This would lead to a rational assessment of the athletes potential for injury. Application of these concepts is best undertaken prior to participation in sports. This may be accomplished in a thorough pre-participation examination.

Pre-participation profiling can provide a means of determining whether the individual possesses the ability to participate without excessive risk. Findings from the profiling examination may also be the basis for directing an individual to an appropriate sport. This form of sports medicine counselling is extremely important because it represents preventive medicine by reducing the potential risk of participation in sports. In this application of profiling the goal is to decide which sports an individual can play or what can be done to prepare someone to meet the demands of the activity (Sapega et al., 1984).

The pre-participation screening programme created is tailored to the individual and their specific sport. The pre-participation examination concentrates upon the musculoskeletal system, yielding potential weaknesses. The implementation of this type of programme could diminish injury rates in sports participants (Hamilton, 1986) Hershman (1984) and Bennell et al. (1998) suggested that more importance should be placed on abnormalities in strength and flexibility as these two areas are the most easily influenced by training techniques. Therefore, since the examination is intended to prevent injury, those factors most easily influenced should be the target of intervention.

A study by Jackson et al. (1978) screened measurements of several personal characteristics in an attempt to determine statistically significant variables that predisposed individuals to athletic injuries. These authors thought that if significant parameters could be delineated, a screening profile to counsel young athletes into sports where their individual characteristics would be protective, or at least not detrimental, should become possible. However they did not find anything from the physical examination that was predictive of injury occurrence. This they suggested was due to the tests not being specific enough for the sports tested i.e. those of American football and gymnastics.

Ross and Schuster (1983) believed that the information derived from routine podiatric biomechanical examination of a patient might also be used in the predicting of sports related injuries. Pre-season screening examinations of long distance runners included 6 examination tests in both a weight bearing and non weight bearing position of the lower extremity. When the method was evaluated using the total biomechanical function and structure, they were able to predict and prevent athletic injuries with an 89% success rate.

Baumann et al. (1982) reported on the possibility of developing a musculoskeletal profile which would identify biomechanical abnormalities, as well as strength imbalances, to see if these abnormalities or imbalances may predispose women to certain types of injury. Although no data has yet been published, regarding the examination technique, they suggested that by identifying physical characteristics which either exceed or fall short of the accepted norms certain characteristics or combinations of characteristics could be predictive of specific injuries.

Although the theoretical concepts underpinning a pre-participation screening technique are clearly reported the actual implementation of such programmes are not widely reported. Baumann et al. (1982) has yet to report any data on the use of the msuculoskeletal profiling technique and while Jackson (1978) and Ross and Schuster (1983) have reported some data little conclusive evidence is available on their overall success. Furthermore this type of pre-screening technique has yet to be applied in a dance environment or to a dance population. Therefore there is a need to apply the theoretical concepts to a dance specific practical screening technique from which baseline data could be obtained.

Multifactorial statistical techniques have been employed by statisticians and doctors in an attempt to predict disease from a variety of medical parameters. These techniques have included regression (Knuiman et al., 1998), multivariate analysis of variance (Williamson et al., 1996) and logistic regression (Blair et al., 1984; Dunn et al., 1997). These studies attempted to produce either predictability equations designed to pre-empt those patients who were susceptible from medical conditions common to the disease, or an odds risk ratio which indicated the risk of acquiring a disease based on the conditions. Blair et al. (1984) calculated that the relative risk of hypertension in a low fitness group was 1.52 times the risk of a person in a high fitness group. This data had been adjusted for sex, age, baseline blood pressure and body mass index. A study by Selker et al. (1995) into the identification of patients with acute cardiac ischemia compared three predictive techniques. The authors concluded that, when limited to eight measureable clinical variables, logistic regression was the most accurate technique for predicting ischemia with a success rate of 88.7%. They further stated that the advantage of logistic regression was the ability of the technique to identify the relative contribution of each variable to the overall result. This could be expressed as odds ratios which would give a clear idea of the relative contributions to the prediction of each variable. However the authors did not report these values for the variables of age, sex, chest pain, arm pain and the electrical output from the heart.

In a separate study on cardiovascular disease risk factors, Dunn et al. (1997) used multiple logistic regression to produce odds ratios on cognitive and behavioural factors between a structured programme of exercise and a non structured approach to lifestyle. The authors wanted to highlight the important factors that would reduce the onset of coronary heart disease based on a structured approach to exercise. Odds ratio values were calculated for 'Substituting Alternatives to Exercise' and 'Enlisting Support' among others. The values reported were 15.8 for alternatives, and 3.5 for enlisting the help of others for the non structured group. These values suggest that for the non structured exercise programme by substituting alternatives to exercise the subject was 15.9 times more at risk of acquiring the symptons of heart disease than the structured exercise programme group. Similarly they were 3.9 times more at risk by not enlisting the help of others to support themselves in their programme. The authors concluded that the use of a structured approach to exercise, in a normally sedentary lifestyle, would help reduce death rates from coronary heart disease over the long term.

The effectiveness of such statistical techniques lends objective, reliable and valid support to the theories of medical practitioners in terms of identifying risk factors predisposing to disease. The application of such statistical techniques to predict sports injury is limited and to date no published research has utilised this form of analysis in the prediction of dance injury.

A measure of injury-proneness in female competitive gymnasts was predicted from measures of flexibility, anthropometry and injury history (Steele and White, 1986), Using nine independent variables multiple regression for injury prediction was obtained with 79% of injury scores being correctly classified. This indicated that the injury risk status of gymnasts, identified by past injury history, and flexibility traits, could be determined with reasonable accuracy using relatively simple physical tests.

Sports profiling is a method by which performance characteristics can be determined and evaluated. By identifying the performance characteristics and the demands of the sport an objective performer assessment can be undertaken prior to involvement in the sport. This pre-participation screening can then be used for identifying the individuals potential for injury. This type of profiling has been used and reported in the sports medicine literature, however it has yet to be reported in the dance medicine literature from neither the perspective of the performance demands of professional or student dance activity nor in terms of detailed performer characteristics. Subsequently data does not exist on the success of such a method of profiling, at any level of dance participation, for reference or analysis.

Although data does exist on sport performer profiles, and the literature does suggest that this type of data would be useful for identifying performers at risk of injury, no published studies have utilised a practical approach to obtain information. Further, no studies have attempted to predict injury using the profiling data and incorporating similar statistical techniques employed by medical practitioners in identifying risk factors in the onset of disease. Therefore a study into the profiling of dancers identifying performance and performer characteristics and potential injury risk factors, may provide valuable information for the development of an injury model. This model could be further analysed with a view to identifying predictive injury risk factors which may be implemented in a pre-participation dance screening technique.

2.6 SUMMARY

The review has documented the importance of combining epidemiological and scientific methods of data collection in providing a comprehensive profile of dancers' and their activity. It has focused on a number of epidemiological and aetiological aspects associated with the onset of injury. These have included the prevalence and distribution of injury in dance; the intrinsic physiological and physical stress associated with dancing; the demographic and anthropometric profiles of the dancer; the anatomical and biomechanical factors associated with injury in dance; and the use of sports profiling with a view to injury prediction.

The literature has clearly identified the prevalence and common types of injury in the professional and pre-professional dancer. It has further identified a similar pattern of injury prevalence and type in student dancers involved in a multidisciplinary dance programme. However although this similarity in injury pattern has been identified there is no data specific to student dance teachers who are also involved in a multi-disciplinary degree programme. Therefore, while the demands of the degree programme may be similar to professional dancers, the pattern of injury may differ due to the lack of detailed technical teaching and practice and a rigorous schedule to complete a dance teacher curriculum. The present study addresses this through the fulfilment of objective 1 (Chapter 3).

The literature has highlighted the physiological capacity of professional dancers. Heart rate analysis has been reported and although successful in quantifying physiological stress, on its own, does not identify the movements or movement patterns which represent the intensity of the dance activity. Further, the analysis of the physiological stress as an intrinsic risk factor to the onset of injury in student dance teachers has not been reported. The present study addresses this through the use of a laboratory based notation analysis system coupled with heart rate monitoring and in doing so fulfils objective 2 of the present study (Chapter 4, Sections 4.1, 4.2).

The physical stress of dancing has been reported via the analysis of load rates and impact forces associated with dance movements. The literature has only reported on the analysis of movements apparent in aerobic dance and has not considered the more common movements associated with the traditional dance forms. Additionally the link between the physical and physiological stresses and injury have not been reported. The present study addresses this limitation in the literature by fulfilling objective 2 (Chapter 4, Section 4.3).

Functional and anthropometric characteristics of the dancer are well reported in the literature in terms of strength, flexibility, body composition and body alignment. However the specificity of the techniques, the use of a standardised protocol and the applicability in terms of the student dance teacher population have yet to be established. The fulfilment of objective 3 goes someway to address the imbalance and provides data on student dancer alignment, and student dancer specific flexibility, from which future comparisons may be made (Chapter 5).

The final section of the review (Section 2.5) referred to the importance of sports profiling as a potential injury preventative tool and the potential role of statistical procedures in the prediction of injury with a view to its use in the form of a pre-participation screening technique. As yet no data have been published which attempts to provide baseline profiling data on dancers or student dancer teachers, nor are there data reported which provides a base from which an injury model could be developed. Also, although profiling data exist on certain sports, there is no published evidence demonstrating the use of these data in identifying the important factors associated with the onset of injury. Similarly this does not exist in the dance literature. Objective 4 in the present study attempts to address this gap in the literature (Chapter 6).

The summary has provided an overview of the literature as related to dance and highlighted the lack of information and data specific to injury profiling and the student dance teacher. By identifying the gaps in the literature the summary has also highlighted the objectives of the present study and how these objectives address the paucity in the literature relative to injury profiling and the student dancer. In fulfilling the objectives pertinent to the gaps in the literature the aim of the present study is addressed.

3. DANCE TRAINING, PARTICIPATION AND INJURIES IN STUDENT DANCE TEACHERS

This chapter contains data collected on dance injuries from a student dance teacher population and meets objective 1 of the research. The data were collected using a descriptive epidemiological approach involving the use of a self reporting questionnaire. This study analysed the training and practice schedules and detailed descriptive information on injury patterns.

3.1 Introduction

Dance is a form of artistic expression. Dancers are foremost artists but they also possess the same high degree of fitness and endurance attributes and sustain many of the same injuries as other athletes (Chambers, 1981; Bejjani, 1987). Dance as a physical activity for fitness or social or artistic purposes has increased numbers of participants at all levels of commitment (Caine and Garrick, 1996).

Dance involves a number of different movements performed in a variety of sequences, rhythms and tempos. The rhythms and tempos are also varied across a number of dance styles. Dance students, participating in teacher training courses, must be able to perform and adapt to these movements and rhythms with technical precision across a number of styles. They must also cope with the rigorous demand of scheduling and duration of the dance classes incorporated into their programme.

Ryan and Stephens (1987) and Chatfield et al. (1990) reported that student dance teachers spend up to 14 hours per week in practical dance classes over a 15 week semester programme. The 14 hours are structured to include classes up to 3 hours in duration however they report the average duration to be approximately 100 minutes. A typical daily programme would include two 90 minute classes. The classes would also have varying intensities in terms of work load and include technique work (developing the basic steps and movements), rehearsal work for a dance performance (repetitive refining of movement sequences with a controlled low tempo music accompaniment) and performance work loads involving movement sequences and choreography performed in real time to accompanying music (Ryan and Stephens, 1987). Therefore a typical weekly practical dance degree programme would include at least three technique classes, two rehearsal classes and two performance classes (Chatfield et al., 1990). However the weekly schedule would include two different dance styles with the students having to adapt to the different demands of each style and class work load. This would not only expose them to injury risks from each dance style through insufficient warm up periods, inadequate pre and post class training and technical errors, but also the cumulative effect of moving from class to class. The ability to adapt to the technical and choreographic components of each style is imperative for success.

Injuries in dancers have been documented (Washington, 1978; Quirk, 1983; Solomon and Micheli, 1986; Caine and Garrick, 1996; Schon and Weinfeld, 1996). Regardless of the type of dance, most studies reported that 60-80% of these injuries involved the ankle, foot or knee, with over 70% of all participants reporting an injury (Weisler et al., 1996). The bulk of the reported literature on dance injuries has focused on professional or pre-professional dancers. Although relevant to that specific population it lends little information to the college student dancer because the professional dancers are performing in predominantly one style and their schedules differ to the student dancer. Further, student dance teachers spend more time on the technical aspects of learning dance (Gray, 1998), approximately three 90 minute classes per week, rather than the choreography, which dominates the professional dancers' schedule (26 hours per week; Ryan and Stephens, 1987) and so dance activity patterns will be different.

The aforementioned research teams used a combination of medical examination, interviews and questionnaires to obtain the data on injury. This type of descriptive epidemiology attempts to quantify the occurrence of injury and as suggested by Wallace (1988), Taunton et al. (1988) and Winston et al. (1996) is an extremely useful method for documenting the magnitude of injury problems, identifying high risk groups and generating hypotheses of injury risk factors. In epidemiology, prospective studies are the most suitable way of obtaining reliable information about the type, site and frequency of injuries experienced by athletes (Llana et al., 2002). However there are a number of disadvantages to using this type of method including financial cost and the human resource cost in obtaining the information (Bloomfield et al., 1994). In contrast, retrospective studies have been reported to underestimate the type and frequency of injuries because injured athletes do not always report the injury nor seek medical help especially if the injury is perceived to be of a minor nature by the athlete (Garrick, 1987). However retrospective studies adopting structured questionnaires with support and guidance from the researcher on how to accurately complete the questionnaire allow the researcher to collect a large amount of data at reasonable human and financial cost (Giannini et al. 1986 cited in Llana et al., 2002).

Caine et al. (1996) stress the importance of clarifying the analysis of the injury data in terms of prevalence, incidence or frequency of injury. In the present study prevalence of injury was used as the descriptor for analysis of the injuries recorded. The prevalence is the total number of new or old cases of injury that exist in a population at risk at a specific time (Caine et al., 1996). This study focused on a retrospective cross section of student dance teachers exposed to injury through dance.

The aim of the study was to identify the epidemiological characteristics and aetiological factors (i.e. preceding dance movement) of injury in female student dance teachers. This study fulfils objective 1 of the research project.

3.2 Method

3.2.1 Pilot Study

A pilot study was conducted to assess the suitability of a self reporting injury questionnaire. Injury was defined as any physical ailment that prevented participation in dance, or any other physical activity, for at least one week and was caused as a direct result of dancing. The questionnaire was designed to cover four primary areas of interest; dance experience including starting age and the number of years of regular dance experience; training details; participation styles and injury. Details of training were based on quantitative assessment of the time spent in class (practice) and the time spent outside normal class time (training). In the participation section questions referred to the styles that the subjects had previously performed in, and the styles that they were currently involved with. In the injury section, questions referred to specific injuries, detailing the site and the nature of the injury, and also the dance style in which the injury occurred and the preceding dance action that caused the injury.

The pilot questionnaire was randomly distributed to 45 student dance teachers from three university degree programmes in semester one of their final year. The subjects completed the questionnaire under the supervision of the researcher. This permitted immediate feedback to the researcher indicating ambiguous or misleading questions or if the students required assistance to detail their injury. The main result from the pilot study indicated that the injuries reported where acquired from a wide range of dance styles. A total of nine dance forms, techniques and/or styles were recorded as reporting injury. Similarly the students reported having participated in a wide variety of dance styles. However all students had participated in, or were presently participating in, four common styles to the degree programmes including Ballet, Jazz, Contemporary and African Caribbean. Therefore, in order to make the study more feasible and control for the scope and analysis of the data from of the study, these four styles were used as the mainstay of the research and injuries that occurred in these styles only were reported. Although nine dance idioms were reported, the injuries occurring in the additional five that were omitted recorded only 6% of the total number of injuries. Had these styles been included then statistical analysis would not have been valid or practical in terms of using the Chi square statistic due to the style categories not fulfilling the requirement of Chi square in that a minimum of five counts must be obtained in each appointed cell of the test. Based on this, it was felt that the additional dance idioms could be omitted.

In terms of the design of the questionnaire two further changes were implemented. These changes related to the description of the injury, in terms of injury site and injury type, and also to the reporting of hours spent rehearsing or practicing outside scheduled class time. A proportion of the students did attend private classes and, although not in the degree programme, these classes could be argued as structured class time. In order to address the first problem a detailed verbal description was given to the participants prior to answering the injury questions. The second problem was addressed by suggesting to the participants that if the classes were not part of the compulsory degree programme schedule then all other classes should be considered as practice time.

3.2.2 Content of Questionnaire for Final Version

The questionnaire was designed to cover three primary areas of interest. Initial questions were posed to establish the level of dance experience in relation to the age at which the subjects started regular dance classes. The three sections of the questionnaire then followed, consisting of (a) training details, (b) participation styles and (c) injury. A full copy of the questionnaire is shown in Appendix 1.

3.2.3 Questionnaire distribution

The questionnaire was distributed to 178 student dance teachers across three universities. All students were studying on a similar degree programme. The questionnaires were completed at the beginning of a class. The researcher was available to give guidance on any areas of the questionnaire that the students felt unsure off. Specific information was given to injured dancers regarding the site and type of injury if required. The injured dancers were also asked to remain behind at the end of the class so that the researcher could verbally check the information given on the injury section.

3.2.4 Data Analysis

The analysis of the data was primarily based on descriptive assessment with the use of frequency counts and percentage values. Chi square Goodness of Fit test was used to analyse the distribution of the frequency data, across the four styles, when compared to the expected frequency. Statistical significance was assumed at the $P<0.05$ level.

3.3 Results

A total of 178 student dancers completed the questionnaire. The initial questions were asked about the subjects dance history including the age at which they started attending dance classes regularly and the length of time they had been dancing regularly. The age at which the subjects started regular dance participation (2 classes per week) ranged from 3 to 35 years old, with a mean of 9.4 ± 6.9 years old. The dance experience of the subjects had a mean of 10.8 ± 5.8 years, with a range of 1 to 27 years. All students had participated, or were participating in, the four styles.

The second part of the questionnaire asked the dancers to record training details in hours per week. This was divided into two categories; (1) time spent dancing in class and (2) time spent in rehearsal or non class time. The mean time spent in class was 8.5 ± 5.4 hours per week, and 3.6 ± 2.6 hours per week for rehearsal or non class time. Training time was then further categorised. This included low training time (<2 hrs/wk), medium (2-5 hrs/wk) and high (>5 hrs/wk) categories. These categories were analysed in relation to the percentage of dance students participating in class time and non class time. The results are shown in Table 3.3.1.

Table 3.3.1 Percentage of dance students participating in the three training time categories

	Low (<2 hrs)	Medium (2-5 hrs)	High (>5 hrs)
Non class time	7.1%	21.4%	71.5%
Class time	0%	10.7%	89.3%

For the purposes of this study an injury was recorded when, as a direct result of dancing in one of the four styles, the injury prevented the student from participating in any form of dance for at least one week. Ninety three student dance teachers (52.2%) reported the prevalence of injury as a direct result of dancing. All injured students had missed one or more weeks of participation. The distribution of the injuries, due to the participation of the dancers in the different styles, is shown in Table 3.3.2.

Chi square analysis revealed that the observed number of injuries across the styles was significantly different from what would be expected ($X^2_3 = 12.25$; $p<0.05$). Jazz dance (34.4%) has therefore a significantly higher proportion of injuries than the other styles.

Table 3.3.2 Source of injury across the four styles

	No. of injuries (n=93)	Percentage of total injuries
Jazz	32	34.4
Ballet	23	24.7
Contemporary	28	30.1
African Caribbean	10	10.8

Table 3.3.3 displays the frequency and distribution of the injury site across the four styles. Seven sites were identified from the questionnaires including three from the upper body (back, wrist and shoulder), and four from the lower extremity (hip, knee, shin and ankle). A total of 29 (31.2%) injuries were recorded for the upper extremity,

including the back, wrist and shoulder, the remainder of the injuries were reported in the lower extremity 68.8% (n=64). The knee was the site recording the highest frequency of injuries, across the four styles, with 35 (37.6%), while the back recorded the second highest with 24 injuries (25.8%).

In order to test for significance using Chi-square it was necessary to group the frequency counts of injury from the wrist, hip, and shoulder. These injuries were then analysed under the injury site category of 'other'. This was necessary to fulfil the criteria for the use of Chi-square.

Table 3.3.3 Distribution of injuries across site and the four dance styles

	Dance Style				
	Jazz	Ballet	Cont'pory	African Caribbean	Total
Knee	12	9	9	5	35
Back	9	6	7	2	24
Ankle	7	5	4	2	18
Shin	4	2	4	0	10
Shoulder	0	0	2	1	3
Wrist	0	0	2	0	2
Hip	0	1	0	0	1
Total	32	23	28	10	93

The analysis calculated a significant difference between the observed frequencies at the injury sites and expected outcomes, $X^2_4 = 26.41$; $p<0.05$. This suggests that there is a significant difference in the proportion of injuries occurring at the anatomical sites with the knee (n=35) and back (n=24) recording the highest frequencies.

Possible causes of the injury were identified, in relation to common dance movements, and the participants were asked to indicate what action may have contributed to the injury (Table 3.3.4). Ten movements were reported, from the questionnaires, as movements that the students felt contributed to their injury. The most common movements causing injury were jumps or leaps. These movements were cited 25 times (26.8%), across the four styles, as the activity leading to injury.

Table 3.3.4 Occurrence of movements contributing to injury across the four dance styles

	Style				
	Jazz	Ballet	Cont'pory	African Caribbean	Total
Jump/Leap	8	6	7	4	24
Back twist	6	4	6	0	16
Stretch	4	3	3	2	12
Fall	2	1	6	1	10
Back arch	3	1	4	0	8
Other	8	9	2	4	23

Twisting or arching of the back or torso were also reported as movements pre-empting injury. These two movements together were also responsible for 24 injuries across the styles. It was also noted that a fall or contact injury had a frequency of 10 cases, with 70% of this movement reported in contemporary dance.

A similar situation, to that of injury site, arose when attempting to test the frequency of the movements statistically. In order to fulfil the criteria for Chi square the frequency of the movements of demi plie, turnout, kick and splits were grouped together to form an 'other' dance movement category. Subsequent analysis revealed a significant difference in the frequency of the observed movement categories contributing to injury when compared to the expected outcomes, $X^2_6 = 13.05; p<0.05$. This suggests that there is a significant difference in the proportions of the dance movements contributing to injury. The movements associated with leaps or jumps (n=25) and arching or twisting of the back (n=24) were the preceding actions most frequently reported as leading to the onset of injury.

The final part of the questionnaire relating to injury analysis was on the type of injury acquired. Seven types of injury were reported as shown in Table 3.3.5. The Chi square analysis calculated a significant difference between the observed frequencies of the injury types and the expected outcomes, $X^2_5 = 44.74; p<0.05$. A muscle strain was the most common injury with 41.9% (n =39). This type of injury had the highest frequency across all four styles.

Shin splints also reported a high frequency with 14 (15.1%). The frequency of dislocations was further noted. A total of 11 dislocations were reported across the styles, with 45.5% of these dislocations (n=5) recorded in contemporary dance.

Table 3.3.5 Distribution of injuries across injury type and the four dance styles

	Style				
	Jazz	Ballet	Cont'pory	African Caribbean	Total
Pulled/Torn muscle	14	8	10	7	39
Shin Splints	5	4	4	1	14
Sprain	7	0	5	1	13
Dislocation	4	2	5	0	11
Ligamentous	1	5	1	1	8
Other	1	4	3	0	8

3.4 Discussion

The very nature of a university degree programme in teaching dance dictates that student dancers should be efficient and skilled at dancing in various styles. The greater emphasis during class time should thus be on technique. Research has however attributed many of the injuries to improper technique and/or inadequate training (Ryan and Stephens, 1987; Howse and Hancock, 1992).

The research published on injury in dance is predominantly centered around either the professional dancer or focusing on one style (Solomon and Micheli, 1986; Washington, 1978). Chmelar et al. (1988b) published physiological data on dancers participating in different styles and at different levels but did not mention injury patterns. Only one published study has reported the incidence of injury in student dancers (Clanin et al., 1984). When compared to the present study, Clanin et al. (1984) reported the lower extremity as the most common location for injury, with 42% of the injuries emanating in that area. The present study reported a value of 68.8%, with the knee being the most susceptible with 37.6%. Clanin et al. (1984) however reported the foot, with 13%, as being the most susceptible to injury. This may have been due to the dance style that the students were participating in, although this was not reported.

In the present study the dancers were participating in a number of styles, often continuously rotating on a weekly and even daily basis. The demand on the students to learn the styles is reflected on the scheduling and rotation of the classes from style to style. Each of the dance styles have a different degree of technical, choregraphical, and movement pattern demand, i.e. ballet has a higher technical demand in terms of the precision of the dance steps in relation to body posture whereas jazz dance would have a greater demand on the choreography of the movements and the tempo at which they are performed. Therefore the techniques in the styles and their demands are complex and it may be that not enough time is spent, during class time, on the teaching of these important aspects. This may be coupled with the need to progress and the choreography involved in each style. As a result of this the tutor may opt not to spend time on warm up periods so as to progress sufficiently during the class. This has the potential to induce injury, in the form of muscle strains. The data in the present study reflect this with muscles strains having a significantly higher ($p<0.05$) injury type frequency (n=39; 41.9%).

In the present study the actions of jumping or leaping were reported as producing the highest frequency of injury, 25.8%. These actions are common in most styles but more predominant in Ballet and Jazz. Jazz was reported as having the highest frequency of injury (34.4%). This style often includes actions of a high impact nature, that is, movements that involve both feet off the floor simultaneously. These actions produce the largest forces, when landing, and must be effectively dissipated through the body (Ricard and Veatch, 1990, 1994). If the technique of jumping and more importantly landing is incorrect then this may result in injury. A further point to note on movement is the occurrence of injury due to a fall. A fall can occur in a variety of ways such as losing balance or during performance duets with a partner. Ten injuries, due to falling, were recorded across the styles. Contemporary dance recorded the highest frequency (n=6). This dance idiom is based on a controlled slower tempo where the actions may have to be 'held' in a balance position for several seconds or where a dancer may have to maintain the weight of a partner during a routine. In these cases balance, coordination and body alignment for weight bearing are imperative not only for the aesthetic quality of the dance but also for safety. Therefore the dancer must be technically proficient and kinaesthetically aware of the factors involved during such choreography.

An additional factor to be considered in dance activity is that of the frequency and intensity at which these actions are performed. Choreography in dance incorporates the combination of various movements often repeated through a 'motif'. The demand of this repetition and the intensity at which it can be performed, across the different dance styles, may also influence the occurrence of injury through dancer fatigue. The quantification of the repetition and intensity may provide useful information into the prevalence of injury in the student dance teachers.

As a semester programme for the dancers progresses, the rehearsal schedules outside of normal class time increase in frequency and duration in preparation for forthcoming performances. A large percentage of students participate in a number of final performances and this is reflected in the values shown in Table 3.3.1. The rehearsals involve the dancers performing in different styles highlighting the continual change in technique and increasing the risk of overuse injuries such as shin splints. Shin splints, in the present study, had an occurrence value of n=14 (14.3%). When unsupervised, and partly due to time constraints, the students tend not to incorporate a warm up period prior to rehearsals. This may be a reflection on the attitude and demands placed on the tutors who do not always spend time on adequate warm up. Coupled with the different techniques and the different dance styles, the student teachers may develop these potentially dangerous habits and the cycle of injury occurrence remains unchanged.

The accuracy of the data collected using the questionnaire is based on the memory, integrity and honesty of the subject. As previously mentioned the students had a demanding schedule and students may have feigned an injury to miss the following class. The authenticity and overall reliability of the information is limited based on this, however the definition of injury which required the student to miss at least one week of dance participation often identified the unreliable data. A further limitation on the data may be related to the sample of student dance teachers used for the study, i.e. sampling error. Sampling error refers to the amount of error in the estimate of a population parameter (occurrence of injury) that is based on a sample (Vincent, 1999). The sample in the present study was based on 178 student dance teachers participating in dance teacher degree programmes in one geographical area. The error associated with this sample is based on the proportion of injuries recorded in relation to the population at risk, i.e. all student dance teachers. Therefore the proportion of injuries recorded from the present sample may or may not be representative of the population at risk. Vincent (1999) however suggests a method for calculating confidence limits in which the true proportion of injuries may lie. The confidence limits are based on the standard error of proportion of the sample used i.e. the odds of another random sample from the same population producing the proportion of injured students as 52.2%. The standard error of proportion from the present study was calculated to be 0.03. This was based on the proportion (percentage) of injuries recorded (52.2%) and the sample size (n=178). The confidence limits were calculated at the 95% level of confidence and produced the range 46.2% to 58.2%. Based on this analysis, i.e. the fact that the proportion of injuries from the present sample (52.2%) fell within the 95% limits, it was suggested that the sample was representative of the population at risk in terms of the percentage of injuries recorded.

As noted by Tenvergret et al. (1992) and Caine et al. (1996) the comparison of injury data is often difficult due to the variety in the definition of injury used in the studies published. In the present study most of the injuries did not require clinical diagnosis and the questionnaire was relatively general in that it did not request a precise medical diagnosis. It therefore must be noted that direct comparison across the published literature must be treated with care when drawing conclusions relative to previously reported data. Similarly, in the present study, the same caution must be viewed. However, as no previous literature exists, specific to the present sample of the population, i.e. student dance teachers, specific comparisons, in terms of injury type and site, may not be appropriate other than offering guidelines or general injury patterns for the present population.

The data discussed thus far has been predominantly based on frequency counts and percentage ratios. Clarkson et al. (1981, cited in Caine et al., 1996) pointed out that the use of percentage calculation is limited due to the denominator in the calculation being the total number of injuries from the injured participants and not reflecting the population at risk. For example in the present study 18 injuries were recorded at the ankle, equating to a percentage value of 19.4%. This is therefore interpreted as 19.4% of all injuries recorded occurred at the ankle across the four styles for the injured participants. However if this was calculated on the total sample at risk i.e. prevalence, then this would equate to 10.1%. This percentage is however difficult to interpret. It is suggested that this could be reported as a ratio, i.e. 18:178 or 1:9.8. In this format it could be interpreted as an injury specific prevalence ratio were an ankle injury could occur once in every ten dancers. Similar ratios could be calculated for each injury site and type. A sample of such ratios are shown in Table 3.4.1.

Comparative data does not exist specific to this type of prevalence ratio. The previous methods reported have used either percentage values or injury rates pertinent to the number of injuries per hour of dance participation. It may be that this prevalence ratio technique could provide another means by which direct comparisons and analysis of injury date could be made.

Table 3.4.1 Prevalence ratio for injury site and type

	Prevalence ratio	
Knee	1 : 5.1	(35:178)
Ankle	1 : 11.9	(15:178)
Back	1 : 7.4	(24:178)
Muscular	1 : 4.6	(39:178)
Shin Splints	1 : 12.7	(14:178)
Dislocation	1 : 16.2	(11:178)

3.5 Summary

In summary, on the evidence gathered from the injury reporting questionnaire, injuries occurred in 52.8% of respondents, with jazz dance style reporting 34.4% of all injuries. A significant difference was found between the dance styles in terms of the frequency of injuries reported ($p<0.05$), in the site of injury ($p<0.05$), injury type ($p<0.05$) and in the movement associated with the injury ($p<0.05$).

Knee injuries were the most common (37.6%), while landing from jumps or leaps proved to be the most common movement prior to injury (25.8%). Injuries to muscles (41.9%), associated with the movements, were reported as the most common type of injury. In this respect the aim of the present study was fulfilled in that the main injury sites and types, and the movements associated with injury where identified in student dance teachers.

It was suggested that reporting injury specific prevalence ratios were more representative of the risk of injury to the participating population. Student dancers had a prevalence ratio of 1:1.9 (93:178), that is an injury occurred in every second student dancer. Specific prevalence ratios were also reported for injury site and type, indicating that the knee and a muscular injury were the most prevalent injury site and type respectively. This data fulfils the aim of this study in identifying the prevalence of injury in student dance teachers. It was further evident that student dancers suffer certain dance style specific injuries such as muscular back pain in Contemporary dance and pulled muscles about the knee in Jazz. The cumulative effect of participation and exposure to movements, tempos and choreographed sequences in a variety of dance styles, a demand required of prospective dance teachers, is likely to increase the risk of sustaining an injury.

4. QUANTIFICATION OF THE PHYSIOLOGICAL AND PHYSICAL DEMANDS OF DANCE

An analysis of the stresses associated with participation in dance is carried out in the three studies reported in this chapter and meets objective 2. In the first study a notation analysis technique was utilised to determine the type of dance actions, their frequency of occurrence and the relative intensity of the actions when they were performed. This study (4.1) analysed the dance activity patterns of four styles as identified in Chapter 3. The physiological intensity of participating in four dance styles, as estimated from heart rate data, was investigated in Study 4.2. The physical load on the musculoskeletal system, which involved a kinetic analysis of dance actions common to the four styles, was investigated in Study 4.3.

4.1 A NOTATION ANALYSIS OF DANCE ACTIVITY PATTERNS

The preliminary findings of this study were presented as a Communication to the Annual British Association of Sport and Exercise Science Conference, Manchester, 1993. The abstract appeared in the Conference Proceedings.

Doggart, L., Lees, A. and Cable, N.T. (1993) A Comparison of Activity Patterns in Four Dance Styles. Conference Proceedings, BASES Conference, Manchester.

4.1.1 Introduction

Participation in dance as a form of exercise has increased over the past decade (Gray, 1998). The growth of aerobic dance as a pastime and as an exercise inducing activity has spread throughout the United Kingdom (Arnheim, 1986; Reeves et al., 1992; Ricard and Veatch, 1994). Other forms of dance have also benefitted from the increased publicity and popularity given to this form of dance. This has taken the form of increased frequency of performances by regional and national dance companies, the introduction of dance related qualifications within colleges and universities and the inclusion of dance within the National Curriculum for Physical Education for schools in England and Wales (Allen and Coley, 1995). These developments have continued to encourage participation in dance (Gray, 1998).

Numerous extrinsic factors contribute to dance injuries. These factors include not only the style of dance participated in and the frequency of typical dance actions, as highlighted in Chapter 3, but also the duration and movement intensity of the style. Different dance styles impose different demands on participants. Comparative data on the specific types of actions, action frequency and the movement intensity of the actions between different forms of dance have yet to be documented but it could be suggested that different dance styles would have their own individual movement patterns.

The physiological demands of dance can be examined by making relevant observations and quantification of dance steps, movement and movement patterns during dance classes, or performances, or obtaining physiological measures during class. The application of notation analysis to dance allows the objective recording and interpretation of dance movements. The data, as a consequence, may be used to determine dance activity patterns, specific to a dance style, and the classifications of actions being made with respect to type, intensity, duration and frequency of activities. Additionally the data can be set against a time base to provide an indication of the exercise : rest ratios observed. This analytical technique has yet to be used for quantifying the demands or movement patterns in dance.

The aim of this study was to identify common dance movements and movement patterns, across four dance styles and quantify these movements in relation to the physiological and physical demand of dance activity.

4.1.2 Method

4.1.2.1 Subjects

Forty female dance students from two dance colleges were video taped during normal class time and instruction following informed consent. All subjects (age = 23.1 ± 4.6 years; experience = 14.1 ± 8.3 years) were participating in the four styles of jazz, contemporary, ballet and African Caribbean. All filming was completed during the students' final term when they were preparing for performance. A total of 40 hours of dance instruction was recorded and notated including the styles of Jazz (13 hours; mean class duration 94.6 ± 6 min), Contemporary (9 hours; mean class duration 85.4 ± 4 min), Ballet (6 hours; mean class duration 62.3 ± 5 min) and African Caribbean (12 hours; mean class duration 118 ± 9min).

4.1.2.2 Procedure

The notation system was adapted from Reilly and Thomas (1976) and updated with the use of video equipment. The system recorded the movement intensity at which the actions were performed, i.e. performance, marking, general or rest intensity, the duration of the intensity period and the dance actions performed during the intensity period. Four movement intensity categories were identified: **performance intensity** in which the subjects completed the actions in time to the music at a display or performance level; **marking intensity** in which the actions were executed in slow time or slow motion without the music; **general movement** intensity which incorporated actions involved in preparation for marking or performance intensity; and finally **rest** when the subjects were standing motionless. From this the **action frequency**, defined as the number of actions per minute, was calculated for each minute within each movement intensity category for the duration of the dance class.

The type of actions, that repeatedly occurred in combination with each other, recorded by the notation technique were step (st), side step (ss), jump (jp), jog (jg), leg kick (lk) and knee raise (kr). Further actions which were technically demanding and required correct body alignment and coordination included plie (pl), demi plie (dp), demi-pointe (dpt) and pirouette (pr).

4.1.2.3 Reliability and Objectivity

Methods employed for the quantification of variables in observational analysis must be reliable, objective and valid. Atkinson and Nevill (1998) have stated that assumptions regarding the repeatability and objectivity of an observational system are dependent upon the statistical procedures employed. Therefore it was necessary to utilise the appropriate statistical techniques to ensure reliability and objectivity of the data.

Reliability is a measure of the consistency of the data where the first measure is compared to a second or third measure on the same subjects performing the same dance movements in the same dance class. Objectivity of the data means that there is no researcher bias during data collection (Nevill and Atkinson, 1997; Vincent, 1999). This can be established by comparing the researchers data on a dance class with the data collected by a dance expert observing the same dance class. In the present study objectivity and reliability were assessed by re-analysing one dance class.

Objectivity and reliability were assessed by re-analysing one 40-minute period of a jazz dance class. Reliability of the data was performed by the researcher recording the movement intensity category, intensity duration and dance steps for the jazz class on three separate occasions. This was initially assessed 2 days and 7 days after completion of the first analysis. Therefore a total of three data sets were recorded for the 40 minute jazz class under the movement intensity category, movement intensity duration and dance steps.

Objectivity was assessed with the aid of an expert dance teacher who had had previous experience of notating dance. Prior to the evaluation of the designated tape (40 minute jazz class) for the assessment of objectivity both the dance teacher and the researcher examined another similar jazz class. This examination involved a verbal coding of the movement intensity category, movement intensity duration and the dance steps. This allowed some level of agreement in the classification of the variables to be established between the researcher and the dance expert before the determination of objectivity. The dance expert then recorded the occurrence of the three variables for the 40 minute period of the jazz dance class.

The notation system could only be deemed to be reliable if there was agreement between the first, second and third data sets on the variables recorded by the researcher. The system could also only be deemed objective if there was agreement between the first data set of the researcher and the data set recorded by the dance expert on the variables assessed. Coefficient of variation and limits of agreement were used to assess the agreement (reliability and objectivity) between the three notated variable scores of movement intensity category, movement intensity duration and the dance steps across the three data sets recorded by the researcher and when comparing the data set recorded by the dance expert. These statistical methods were recommended by Bland and Altman (1986) and Bland (1991).

4.1.2.4 Statistical Analysis

Differences in the occurrence of the movement intensity categories were investigated using a two-way ANOVA (dance style v intensity category). A one-way ANOVA was used to compare the action frequency (number of actions per minute), in the performance intensity category between the four styles and in the marking intensity category between the four styles. Further one-way analysis was used to compare the occurrence (number) of different dance steps across the styles, i.e. the differences between the styles in the occurrence of jog steps or in the occurrence of side steps. Tukey post-hoc analysis enabled the styles which produced significant differences between each other to be identified. A probability of $p<0.05$ was taken to indicate statistical significance.

4.1.3 Results

Reliability and Objectivity of the notation analysis system

Reilly (1994) stated that for the methodologies employed for the measurement of activity patterns from observational studies, they must be reliable and objective. The vast majority of studies, using notation analysis, have utilised correlation coefficients to assess agreement (Hughes and Franks, 1997). Such analyses are strongly influenced by the range of scores and provide a measure of the relationship rather than the agreement between the test and re-test (Bland and Altman, 1986; Drust et al., 1997).

The current notation system could only be deemed reliable and objective if there was agreement between the classification of the movement intensity categories and their duration during the class and agreement in the dance actions performed during each movement intensity category.

The level of agreement between the two variables, movement intensity category and movement intensity duration, for both reliability and objectivity was determined using the number of exact agreements observed. The observations obtained for each analysis were then compared manually and recorded in the form of a contingency table to allow the calculation of the exact number of agreements between data sets to be compared. This approach was then supplemented by the calculation of the number of agreements that could be expected by chance (Altman, 1991). The name of this measure of agreement is Kappa (*k*). This statistic relates the number of exact agreements observed to that which can be expected by chance. Kappa has a maximum value of 1.0 when agreement is perfect and a value of zero when the agreement is no better than that which is expected by chance. Altman (1991) provided guidelines for the interpretation of kappa values between zero and 1, shown in Table 4.1.3.1.

Table 4.1.3.1 Guidelines for the assessment of kappa values (adapted from Altman, 1991)

Value of *k*	Strength of agreement
< 0.20	Poor
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	Good
0.81-1.0	Very good

Table 4.1.3.2 shows the number of exact agreements, k values and the strength of the agreement according to Altman (1991) for the two reliability assessments (when compared to the first data set) for the two variables. The percentages of the exact agreements for reliability assessments were all observed to be between 0.9 and 0.97. This range of agreement has been determined as suitable for a complex system (van der Mars, 1989). All *k* values were in the band indicated a very good agreement, again suggesting a suitable level of agreement with respect to the two variables assessed.

Table 4.1.3.2 Number of exact agreements and k values for reliability for the occurrence of the Movement Intensity Category and Duration.

	Exact agreements (%)	k value	Strength of agreement
Initial reliability			
M'ment Intensity category	95	0.92	v.good
M'ment Intensity duration	90	0.85	v.good
Second reliability			
M'ment Intensity category	97	0.96	v.good
M'ment Intensity duration	90	0.85	v.good

The exact agreement for the objectivity for the two variables, as shown in Table 4.1.3.3, ranged from 0.93 (93%) with a k rating of 0.89 (v.good agreement) for the dance actions to 0.98 (98%) with a k rating of 0.97 (v.good agreement) for the movement intensity category.

The repeatability and objectivity for the number of dance actions, in each movement intensity category, were examined using limits of agreement (Bland and Altman, 1986). A one way ANOVA was used to determine if any large systematic bias existed between the 4 sets of data recorded from the same jazz class (initial assessment, initial reliability, second reliability and objectivity data sets). If significant bias is detected, the method employed should not be considered as reliable or objective. Results from the ANOVA indicated no significant differences across the four sets of data, for the dance actions, in the jazz class $F_{(3,10)} = 2.14$; $p > 0.05$.

Table 4.1.3.3 Number of exact agreements and *k* values for objectivity for the Movement Intensity Category and Duration.

	Exact agreements (%)	*k* value	Strength of agreement
Objectivity			
M'ment Intensity Category	93	0.89	v.good
M'ment Intensity Duration	98	0.97	v.good

Table 4.1.3.4 Mean and Standard Deviation (SD) of the differences and Limits of Agreement for Reliability and Objectivity assessments for the number of actions performed.

	Mean of Differences	SD of Differences	Limits of agreement
Initial reliability	1.83	0.80	1.83 ± (1.57)
Second Reliability	1.79	0.63	1.79 ± (1.23)
Objectivity	2.01	0.97	2.01 ± (1.90)

Table 4.1.3.4 shows the limits of agreement in the number of dance actions occurring in each intensity category. Bland and Altman (1986) suggested that the amount of variation should be ascertained correctly and meaningfully in context to what the equipment or test is to be used for. The limits of agreement ranged from ± 1.23 to ± 1.57 actions for repeatability checks and ± 1.90 for objectivity. This suggests that if 22 side step actions were performed by the dancer, using the present notation system and objectivity limits, the 95% limits of agreement would range from 3.91 actions above the 22, to 0.11 actions below the 22 recorded (21.89 – 25.91). No other data are available in relation to notation systems using this type of reliability data nor specifically in dance which makes the comparison of the current data difficult.

The data would seem to suggest that the method for the determination of the occurrence of the movement intensity categories and their duration, along with the occurrence of the dance actions, within each movement intensity category, satisfies the criteria of reliability and objectivity based on current results.

Dance Activity

The mean number of each movement intensity category, per class, for each dance style are shown in Table 4.1.3.5. The rest category produced the highest mean number, for the movement intensity categories, for all four styles. Ballet, although having the highest mean number of rest periods, also had the highest mean number of high (performance) and low (marking) movement intensity periods (categories).

Table 4.1.3.5 Mean number of movement intensity categories, per class, for the four dance styles.

	Movement Intensity Category			
	High (performance)	Low (marking)	General movement	Static (rest)
Jazz	46	21	5	74
Contemporary	41	9	4	55
Ballet	47	29	4	78
African Caribbean	40	25	7	70

The two-way analysis (dance style v movement intensity category) revealed that there was a significant difference in the occurrence of the four movement intensity categories across the four dance styles $F_{(3,95)}=17.1$; $p<0.05$. The Tukey post-hoc revealed significant differences ($p<0.05$) between contemporary dance and the other three styles across three movement intensity categories with significantly fewer marking, general movement and rest categories than the other styles. No significant differences were found between the other styles across the four movement intensity categories. The test for the occurrence of the four movement intensity categories, within each dance style, was also significant $F_{(3,95)} = 475.9$; $p<0.05$. The Tukey post hoc analysis highlighted significant differences between all movement intensity categories within each dance style. The test for interaction, dance style v movement intensity category proved to be significant $F_{(9,95)} = 163.3$; $p<0.05$. Thus the occurrence of the movement intensity categories depends on the dance style.

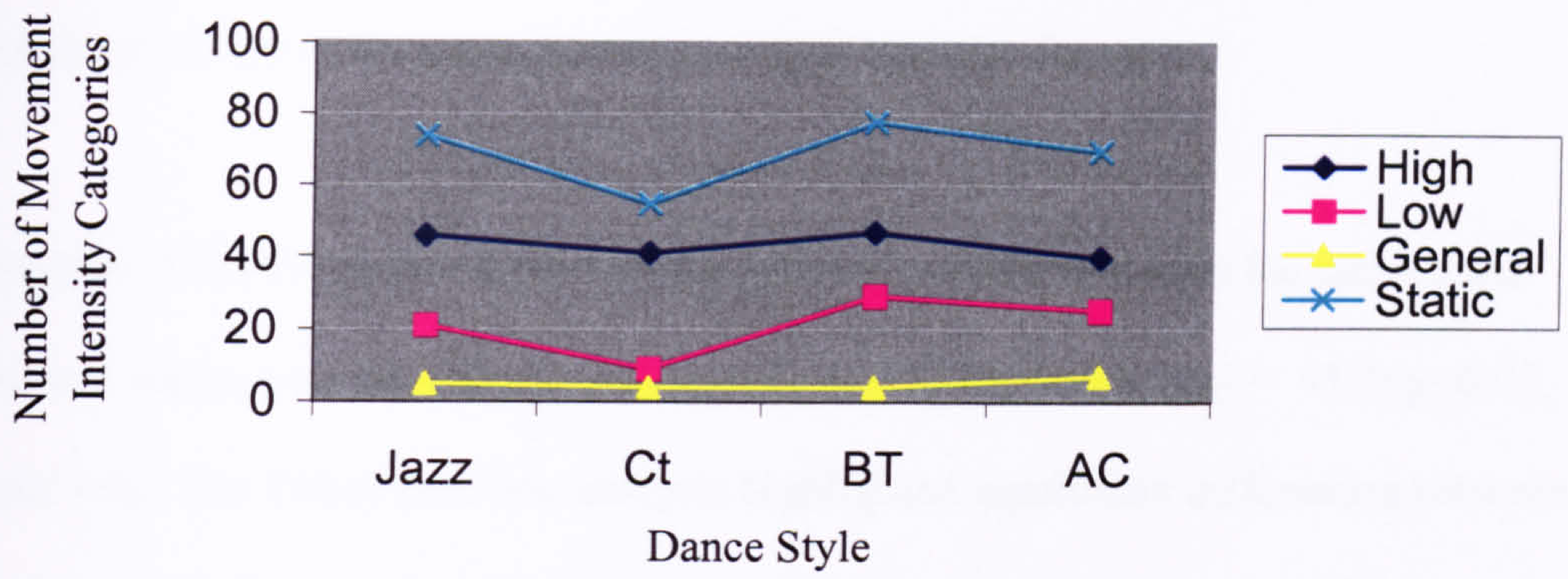

Figure 4.1.3.1 Mean Number of Movement Intensity Categories, per class, across the four dance styles

Figure 4.1.3.1 illustrates the mean number of movement intensity categories across the four dance styles. The previous analysis and Figure 4.1.3.1 suggest that the contemporary style of dance has a different pattern in terms of the number of movement intensity categories. Although there were no significant differences between the other three styles Figure 4.1.3.1 illustrates a small variation between the styles of jazz, ballet and African Caribbean in terms of the occurrence of the movement intensity categories. Therefore the dance styles could impose different physiological loads as defined by the number of the movement intensity categories.

The mean number for each action across the four styles is shown in Table 4.1.3.6. The actions common to the four styles varied in their occurrence. The data show that the step activity with values of 153, 115 and 718 flat footed steps per class for Jazz, Contemporary and African Caribbean respectively, was the dominant action within the three styles. However ballet performed a higher number of jumps (93 per class) than the stepping action (68 steps per class). This pattern was emphatically reversed in the African Caribbean style which was dominated by the low impact actions of the flat footed step (718 steps per class) and plie (29 plies per class) as opposed to the high impact nature of the jump movements (6 jumps per class).

A two-way ANOVA (dance style v dance action) revealed that both the dance style and dance action were significant, $F_{(3,121)} = 21.4$; $p<0.05$, and $F_{(9,121)} = 45.7$; $p<0.05$, respectively. The Tukey post hoc analysis highlighted significant differences between all four styles with regard to the frequency of the dance actions. Further Tukey post-hoc analysis, on the dance actions, revealed significant differences in the mean number of the flat footed step actions (263) and toe-heel steps (102) when compared to the other actions (range = 23 – 79), but no difference between each of these two steps.

A significant interaction (dance style v dance action) was also apparent $F_{(27,121)} = 38.9$; $p<0.05$. Therefore the number of times a dance action occurs is dependent on the dance style. This suggests that the dance styles may have unique movement patterns, based on the occurrence of the dance actions, and could impose different physiological and physical demands on the dancer dependent on the movement patterns associated with the dance actions.

The mean number of the individual dance actions across the four styles was investigated using a one-way ANOVA. Significant differences were noted for the toe-heel step ($F_{(3,14)} = 67.9$; $p<0.05$), flat footed step ($F_{(3,14)} = 89.2$; $p<0.05$), demi-pointe ($F_{(3,14)} = 11.4$; $p<0.05$), jog step ($F_{(3,14)} = 20.7$; $p<0.05$) and the jump or leap step ($F_{(3,14)} = 5.67$; $p<0.05$).

Table 4.1.3.6 Mean number of actions, per class, for the four styles.

	Style					
	Jazz	Cont'porary	Ballet	African Caribbean	Total	Mean
Toe-heel Step	72	8	6	321	407	102
Knee lift	22	28	0	43	93	23
Plie	49	16	33	29	127	32
Demi Plie	82	29	155	48	314	79
Kick	125	10	10	83	228	57
Pirouette	23	18	11	177	229	57
Flat Footed Step	153	115	68	718	1054	263
Demi pointe	44	14	114	35	207	52
Jog	144	29	0	0	173	43
Jump/Leap	93	62	93	8	256	64

Post-hoc analysis revealed significant differences in the occurrence of the flat footed and toe-heel step actions between African Caribbean and the other styles; the occurrence of demi-pointe between Ballet and the other styles; the occurrence of the jog step between Jazz and the other styles; and the occurrence of the jump/leap action between Jazz and Contemporary, Jazz and African Caribbean, and Ballet and African Caribbean.

Table 4.1.3.7 displays the mean number of actions per minute for the marking and performance movement intensity categories. A one way analysis produced significant differences in the action frequency during a marking intensity category, $F_{(3,24)} = 34.0$; $p<0.05$, and in the action frequency during the performance intensity category, $F_{(3,24)} = 388.6$; $p<0.05$, across the four styles.

The performance intensity category produced the higher action frequency for all styles. Jazz dance had the greater action frequency for both movement intensity categories across all four dance styles. In the low intensity category (marking) jazz dance displayed a higher action frequency than the other three styles at their respective performance intensities.

Table 4.1.3.7 Mean number of actions per minute for performance movement intensity and marking movement intensity categories. (All values in actions per minute)

	Movement Intensity Category	
	Performance	Marking
Jazz	109.8	62.4
Contemporary	38.5	7.5
Ballet	36.8	24.5
African Caribbean	54.9	48.9

All four styles showed a similar pattern in terms of percentage time spent at the three movement intensity categories of performance, marking and rest (Table 4.1.3.8). For most of the class time the students were at rest, with values of 49%, 45.9%, 48.4% and 48.1% for Jazz, Contemporary, Ballet and African Caribbean respectively. Similarly all four styles displayed a greater percentage of high intensity activity than low intensity activity for the duration of the class.

Table 4.1.3.8 Percentage of class time spent at the four movement intensity categories. (All values in percentages, %)

	Movement Intensity Category			
	High (performance)	Low (marking)	General movement	Static (rest)
Jazz	34.1	6.7	10.2	49
Contemporary	38.2	7.8	8.1	45.9
Ballet	29.9	17.8	3.9	48.4
African Caribbean	38.8	11.2	1.9	48.1

Figures 4.1.3.2 through 4.1.3.5 illustrate the intermittent nature of dance activity as represented by intensity category (1=static; 2=general; 3=low; 4=high). The figures highlight the intensity at which the students are working over a typical five minute period of a class for each of the four dance styles. Although there is a general pattern

of intermittency the Jazz dance style has only two periods were the students are static compared to the other three styles.

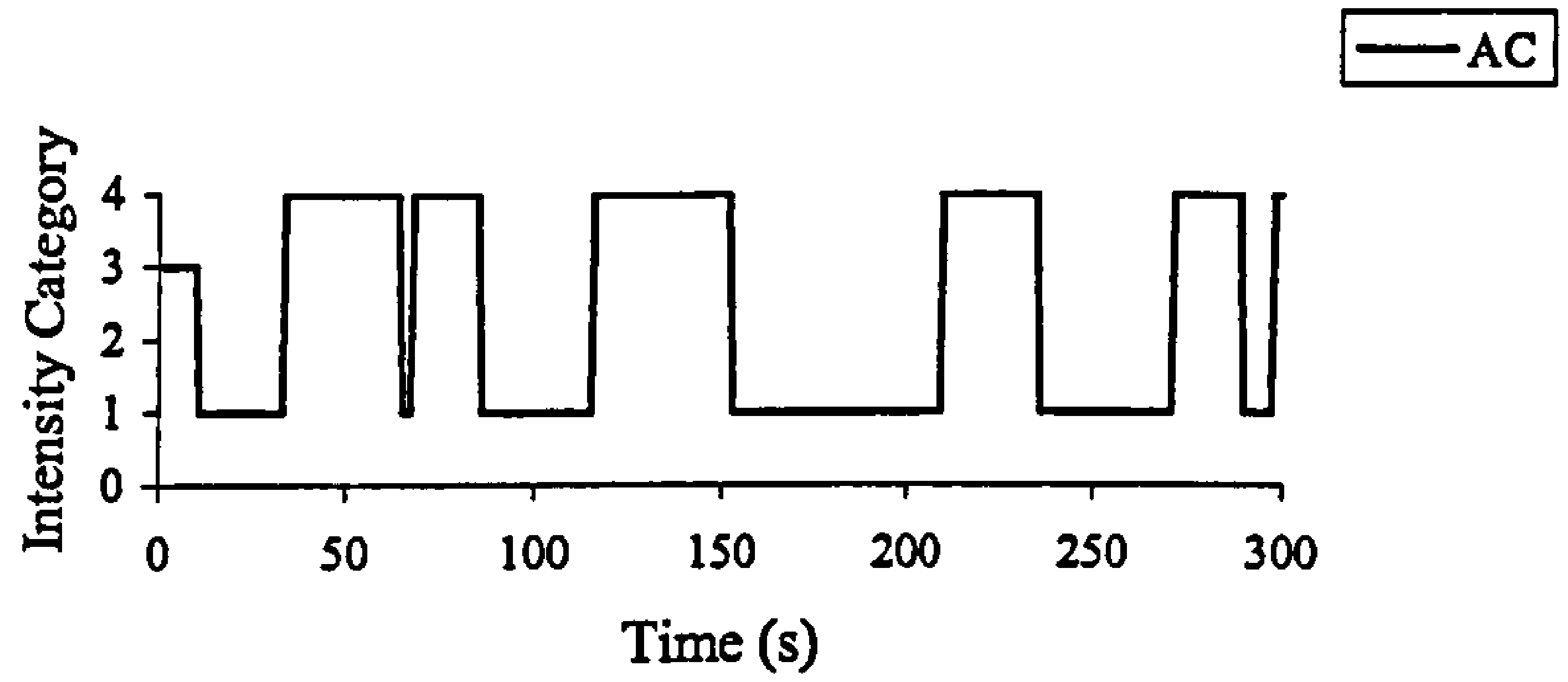

Figure 4.1.3.2 African Caribbean Movement Intensity Profile

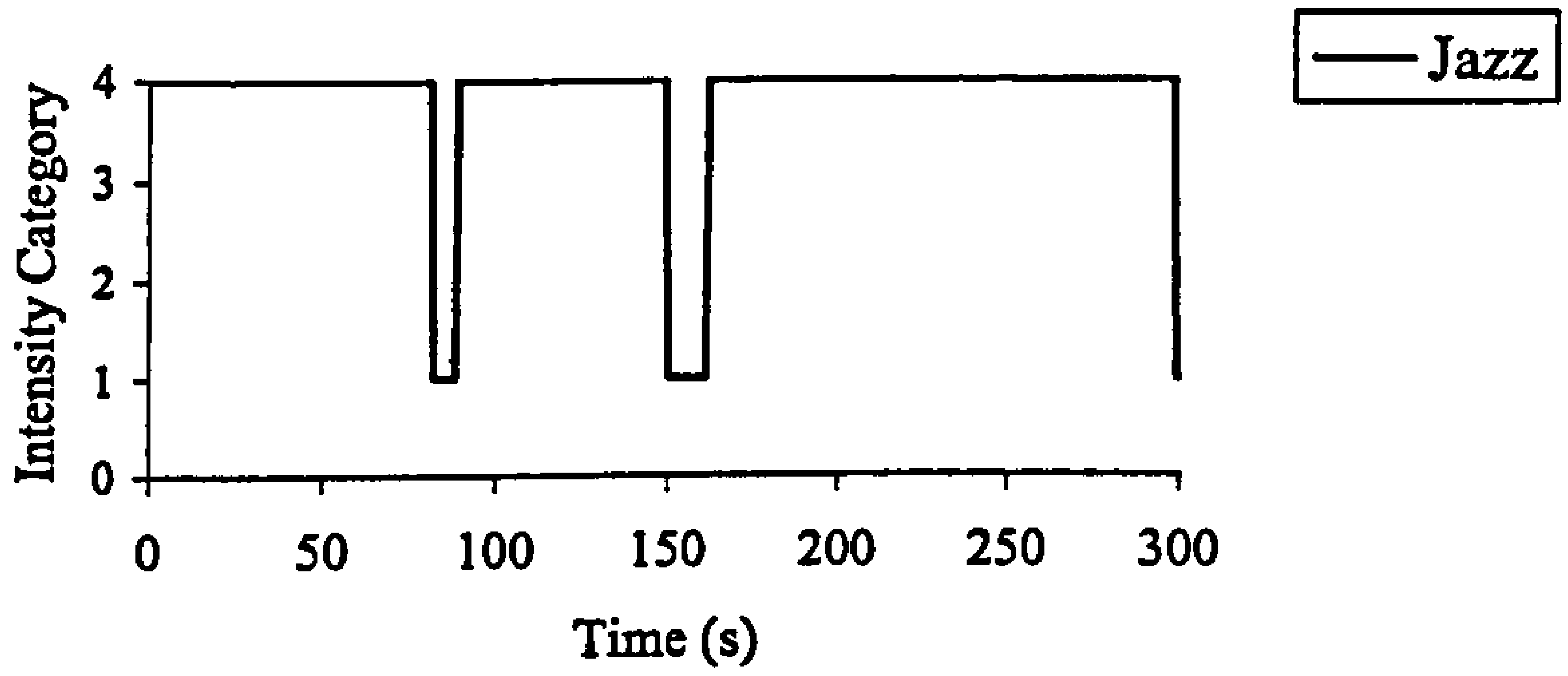

Figure 4.1.3.3 Jazz Movement Intensity Profile

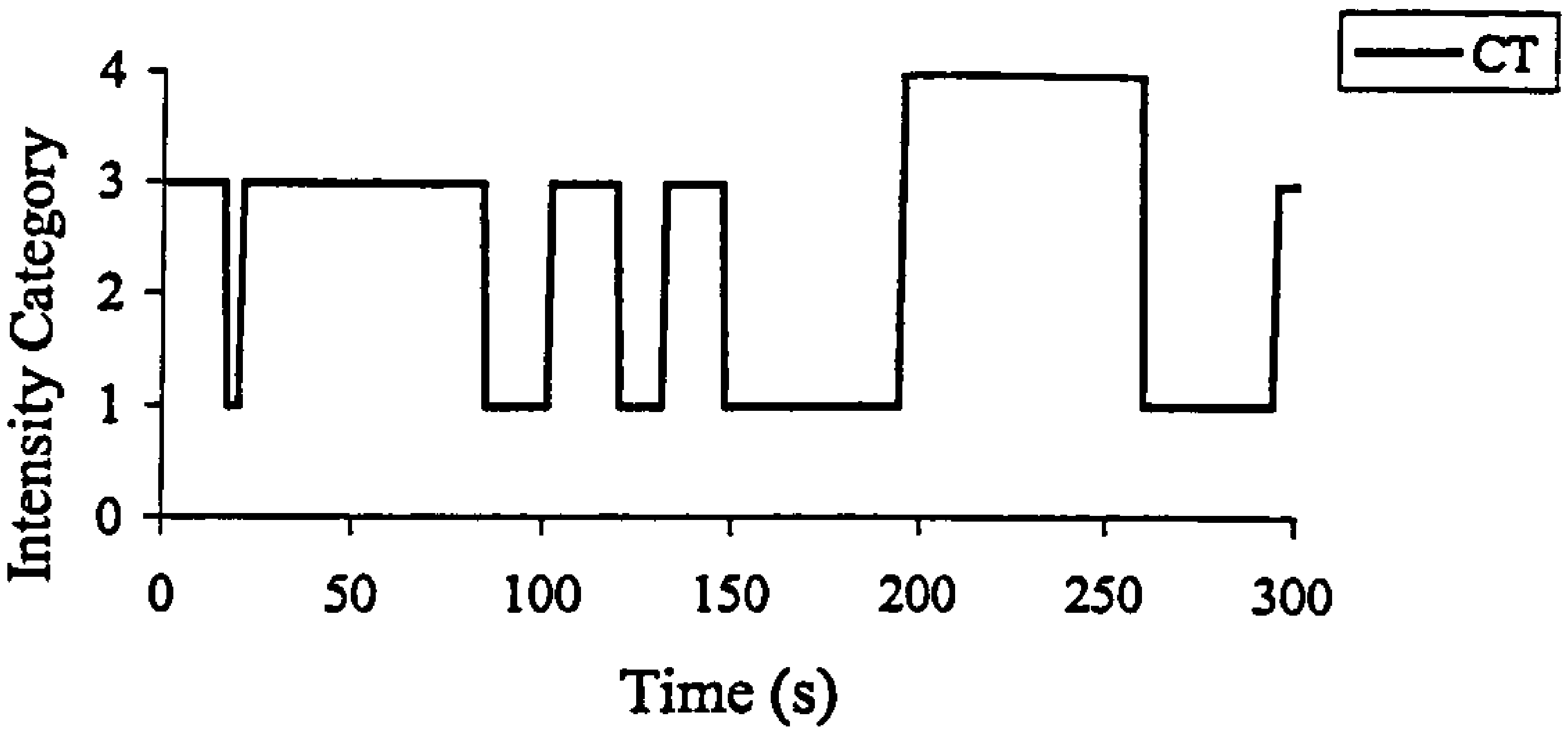

Figure 4.1.3.4 Contemporary Movement Intensity Profile

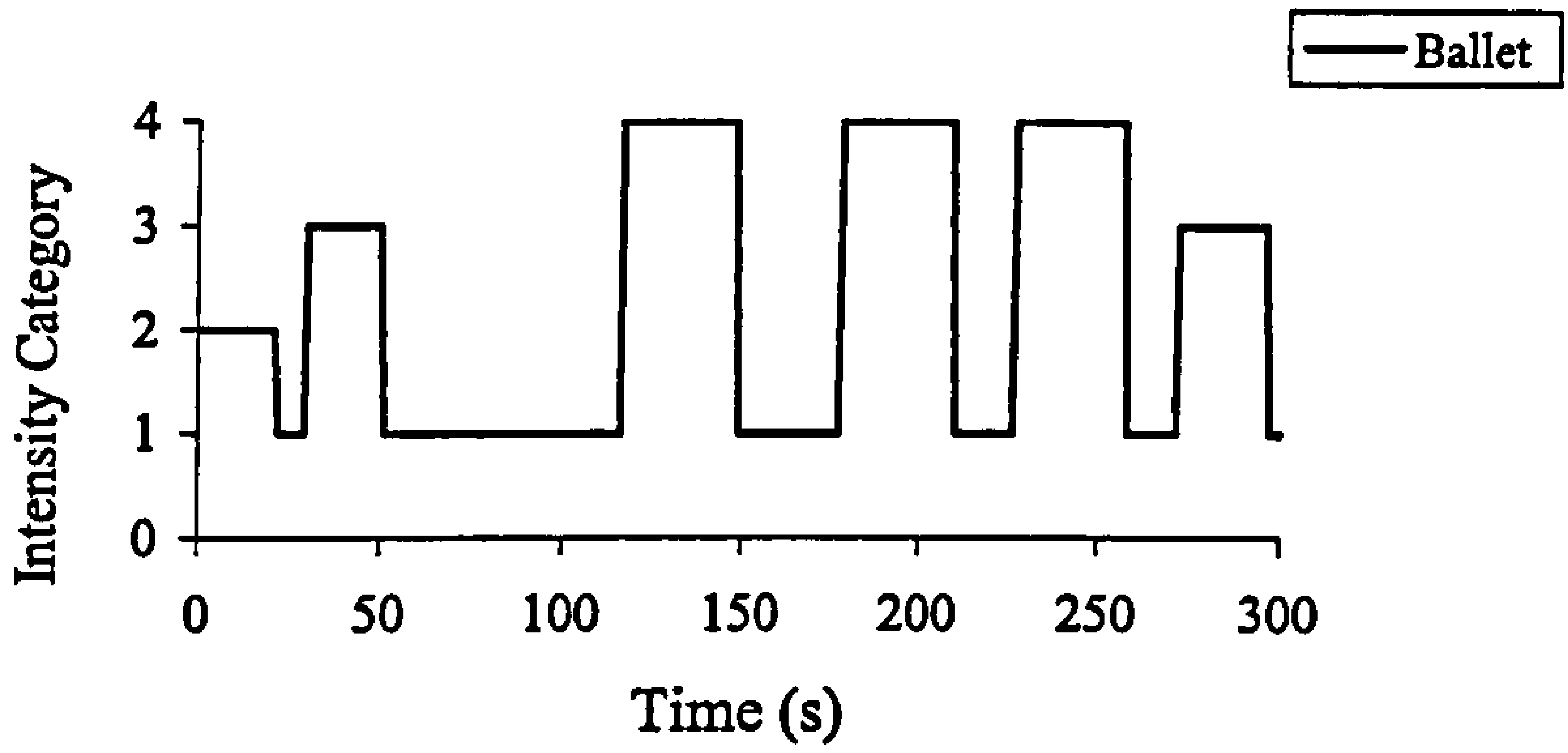

Figure 4.1.3.5 Ballet Movement Intensity Profile

It is also interesting to note that the Contemporary dance style, Figure 4.1.3.4, has a longer period of low intensity activity, the Ballet profile (Figure 4.1.3.5) shows intermittent activity mainly between high and static movement intensities, whilst the African Caribbean style (Figure 4.1.3.2) shows periods of static activity punctuated by high movement intensity activity.

4.1.4 Discussion

The data collected on the duration, content and choreography of the classes was recorded over a 15 week semester period. Each semester the students work towards a final dance performance with the dance class sessions being supported by theoretical and cultural lecture based instruction. Based on this structured approach it was felt that the data collected was representative of a semester schedule for student dance teachers and reflected the contents of the National Curriculum guidelines for training dance teachers (Allen and Coley, 1995).

Based on the statistical procedures used to assess reliability and objectivity and the results reported, it was suggested that the hand notation system was a reliable and objective method for recording the movement characteristics in the four dance styles. There are no published studies using a hand notation for quantifying dance activity, nor the statistical techniques employed for assessing reliability, therefore comparison of the results, in terms of the objectivity and reliability of the system, was difficult.

Each dance style had a certain pattern with respect to the movement intensity categories (Table 4.1.3.5), the type and mean number of dance actions per class (Table 4.1.3.6) and in the mean number of actions per minute for the performance and marking intensity categories (Table 4.1.3.7). This was suggested by the significant differences between the styles in terms of the total number of times each movement intensity category occurred, the significant differences in the mean number of times a dance step occurred and in the significant differences between the styles on the performance and marking intensity categories for actions per minute. However these differences were not reflected in the mean total time spent in each movement intensity category between the styles (Table 4.1.3.8).

Ricard and Veatch (1990) described low impact steps as movements where one foot is in contact with the floor at all times, whereas high impact movements typically consist of a variety of flight phases involving hopping, jogging and jump movements. Contemporary, Ballet and African Caribbean styles tended to involve actions of a low impact nature, reflected in the lower occurrence of jog or jump steps when compared to the jazz dance style (Table 4.1.3.6). Jazz incorporated a significantly larger occurrence of actions that were of a high impact nature than the other styles. The effect of impact on vulnerable areas such as the shins, knees and vertebral column has thought to have led to a high incidence of injuries (Garrick et al., 1986; Richie et al., 1985; Baitch, 1987; Rothenberger et al., 1988). Therefore in the present study the type of action, the intensity with which it is completed and the frequency with which it occurs are suggested as important factors in terms of injury risk.

The nature, intensity and frequency at which dance actions are performed in class may have implications for the onset of injury. However, in order for student dance teachers to attain the skill levels required to teach they must be technically competent to perform all the necessary actions at the required tempo and rhythm. Further, Ricard and Veatch (1990) have reported that high impact actions (jumps or jogging) impose greater forces on the lower extremity than low impact actions and therefore increase the likelihood of the onset of injury. In the jazz dance, on average, the high movement intensity category occurred 46 times (Table 4.1.3.5). From Table 4.1.3.8 this would equate to approximately 32 minutes (34.1%) based on an average class time of 94 minutes. Every minute at this movement intensity 109.8 actions per minute would be completed (Table 4.1.3.7). A typical sequence of actions would have an average of 118 actions per minute of which 96 are jog steps and 22 are jumps. If these frequency counts of the dance actions are related to the force values reported by Ricard and Veatch (1990, 1994) then the musculo-skeletal system of the dancers is stressed considerably, comparable to the repetitive nature of the stress imposed during a jogging activity. Additionally there is the coordination and sequencing of the different actions during a choreographed dance pattern which would add to the strain on the musculoskeletal system. When the actions per minute of Jazz dance are compared to a similar duration sequence (233 seconds) in African Caribbean dance which produces a sequence including only low impact actions (178), such as side steps and demi plie, at a rate of 44.8 actions per minute the difference in movement patterns is highlighted as are the differences in the potential physical demands placed on the musculoskeletal system of the performers. Although all of the actions in African Caribbean dance are low impact, they nevertheless require a certain degree of coordination and stress the musculoskeletal system albeit at a lower level when compared to that of Jazz dance. Thus the Jazz style of dance could have a higher injury risk potential. The study by Reeves et al. (1992) concluded that aerobic dance participants who engage in low impact aerobic may reduce their susceptibility to overuse injury due to the lower impact forces associated with the low impact dance movements. Therefore the rate at which the actions occur may increase the potential for injury and are most notably performed in Jazz and Ballet classes. Classes might be modified to include more low impact dance movements, or to have a progressive introduction of high impact movements if this injury risk potential was to be reduced. The classes could still incorporate a large number of actions per minute and thus maintain an aerobic training effect. However this may affect the training required to achieve the skilled performance level in the dance style.

The type and frequency of certain actions reflect the general characteristics of the dance style, such as the high or low impact movements and the number of actions performed per minute, characteristics previously mentioned to influence the onset of injury. This is most notably demonstrated in Ballet where the jump step (jete or assemble), plie (full knee flexion on toes) and demi plie (knee flexion with heels on the floor) reflect the traditional artistic movement pattern. Similarly the dominance of the step, toe-heel step and side step movement in African Caribbean dance highlight the 'flat footed' almost stamping nature of a ritual, tribal display. The relatively modern styles of Jazz and Contemporary dance tended to incorporate and develop movements based on the traditional aspects of Ballet movement to a greater or lesser extent. This is reflected with the occurrence of several actions common to these styles such as plie, demi plie and the jump step. Contemporary dance was shown to be the least demanding of the four styles due to the lower frequency of high impact actions such as the jump step (Table 4.1.3.5). In Contemporary dance the subjects were completing 65.3% fewer actions per minute at performance intensity (38.5 vs 109.8) and 87.5% fewer actions per minute at marking intensity (7.5 vs 62.5) when compared to Jazz. It would then seem that in terms of the factors relating to injury risk potential, actions per minute and impact nature, Contemporary dance would impose less stress on the musculoskeletal system than the styles of Jazz, Ballet and African Caribbean.

The percentage time spent at each recorded movement intensity also tended to develop certain patterns linked with each style. Although the present study did not identify significant differences in the percentage time spent at each movement intensity category between the styles, the suggested unique movement patterns of the styles may come from the order in which the movement intensity categories where choreographed (Figures 4.1.3.2 – 4.1.3.5). Previous research has concluded that the description of the dancers' activity could be labelled as "intermittent" in nature, that is periods of high intensity activity followed by similar periods of low or static activity. In the present study, as can be seen from Figure 4.1.3.2, a similar pattern of involvement in exercise intensity was established, although the measurement technique was based on movement classification. During class time a segment of dance was performed at either performance (high) intensity or marking (low) intensity followed by a rest period. Several of these choreographed exercise bouts occurred at various intensities during the class. However, as can be seen from Figures 4.1.3.2 through 4.1.3.5, the duration of the exercise bouts and rest periods varied as did the occurrence of the movement intensities. The occurrence of the rest periods may inhibit the body in terms of maintaining muscle temperature and joint suppleness and could lend itself as an injury risk.

It was noted that contemporary dance had the second highest percentage time spent at high intensity. If coupled, as previously mentioned, with its lower injury risk potential this would suggest that contemporary dance could elicit a physiological response, with a reduced physical stress compared to the other styles. Therefore it may be the preferred style from both a health and an injury safe perspective. A typical intensity profile for contemporary dance is shown in Figure 4.1.3.4.

This study was designed to quantify the movements within a typical dance class and attempted to categorise them in terms of intensity, through the number of actions per minute, following the adaptation of a hand notation method. The patterns of the styles were quantified in terms of the occurrence and timing of the action; nevertheless a certain degree of choreographic individuality may have been apparent in the classes due to the artistic individual interpretation of the style as seen by the teacher. No set guidelines for choreography are listed in the National Curriculum for Dance within the United Kingdom for the movements that need to be performed, only a general understanding of the nature of the dance movements that need to be undertaken. It then seems possible that teachers or choreographers may adjust the general style of the dance to suit their own interpretation and in doing so alter the intensity and timing of the actions and movements. This may then alter the physiological and physical stress on the musculoskeletal system. The usefulness of this system is therefore evident as an aid in choreographing rehearsals and classes in terms of a recording medium for the whole structure of the dance and as a measurement of attainment to a certain level of movement intensity through the frequency (actions per minute), pattern (sequencing of the movement intensity categories) and high or low impact nature of the movements.

4.1.5 Conclusion

The aim of the study was to quantify the intensity of dance movement in terms of the common actions performed and movement patterns. This was accomplished through the use of the hand notation system. The hand notation system was a reliable and objective method for recording dance movement in the four dance styles. The styles exhibited different movement patterns in terms of the occurrence of the four movement intensity categories, in the action frequency (number of actions performed per minute) and in the types of actions performed.

Jazz dance had a significantly higher occurrence of the performance and marking movement intensity categories and in the action frequency (actions per minute) in those categories than the other dance styles. This style would therefore be expected to induce a greater physiological stress on the student dancers. Therefore the greater occurrence of the high intensity movement category coupled with the increased action frequency (actions per minute) and high impact actions, most apparent in Jazz, would provide an increased injury risk potential than the other styles. Injury risk is effectively reduced during low impact activities predominantly found in Contemporary, Ballet and African Caribbean dance styles.

4.2 AN EVALUATION OF THE PHYSIOLOGICAL DEMANDS OF FOUR DANCE STYLES ON STUDENT DANCE TEACHERS.

A report of the initial findings of study 4.2 is published in Sport, Leisure and Ergonomics (edited by G. Atkinson and T. Reilly).

Doggart, L., Cable, N.T. and Lees, A. (1997) An Ergonomic Evaluation of the Physiological Stress of Four Dance Styles on Student Dance Teachers. In: G. Atkinson and T. Reilly (eds). Sport, Leisure and Ergonomics. London: E and F.N. Spon, pp176-181.

4.2.1 Introduction

In the U.K., dance is enjoying increasing popularity both as an exercise activity and in schools as part of a cultural education experience (Allen and Coley, 1995). This has led to the development of degree courses specialising in the teaching and health aspects of dance including various styles (Gray, 1998). Teachers of dance need to be skilled not only in each dance style, in terms of teaching awareness, but also in the health and exercise benefits particular to the activity.

In order for an exercise activity to elicit a cardiovascular training response, mean heart rate values must rise above 140 beats/min (with respect to the age of the subjects) for a 15-20 minute period as specified by the American College of Sports Medicine (1991). Several research teams have investigated the physiological responses of elite level performers in various dance styles (Bell and Bassey, 1994;

Blanksby and Reidy, 1988; Rimmer et al., 1994; Schantz and Astrand, 1984; Hawlet et al., 1990; Leiderbach et al., 1994). These authors dealt with certain profiling parameters, most notably muscular strength and oxygen consumption aspects. Mostardi et al. (1983) analysed cardiopulmonary data but limited the analysis to performances of professional ballet dancers. Chmelar et al., (1988b) attempted to quantify the physiological difference between the styles and level of participant but did not relate the intensity of activity, in terms of heart rate responses, to the standard of participation or dance style. The data reported is therefore limited in terms of the level of participation, the styles involved and the methods reported for analysis of dance intensity.

Cardiovascular fitness has been identified as an intrinsic risk factor in the onset of injury (Neely, 1998b). Heart rate has also been used an indicator of cardiovascular fitness in previous dance studies (Mostardi et al., 1983; Chmelar et al., 1998b). Student dance teachers must be fit to cope with the demands of dance activity in terms of movement intensity, movement intensity duration and sequencing and dance action frequency, i.e. number of actions performed per minute, as identified previously in Study 4.1. A relatively higher heart rate, when compared to other dancers performing similar dance movement patterns, may indicate a lower level of fitness (Astrand and Rodahl, 1990). If a student dance teacher is not able to cope with the demands of the dance activity in terms of the factors mentioned in Study 4.1 then they may be at a higher risk of musculoskeletal injury due to the inability of their bodies to cope with the physical demands. Establishing a benchmark of physical fitness, through heart rate monitoring, for student dance teachers on a dance degree programme may be an important factor in the prevention of injury by highlighting the demands of the activity prior to participation. Heart rate, in this case, may therefore be a relative but gross indicator of injury by highlighting the physical stress and demand placed on the body by the performance of dance actions. The link between heart rate and energy expenditure (Astrand and Rodahl, 1990) may also be an important factor in terms of the potential and kinetic energy expended during completion of dance actions and movement patterns and may be further used as a basis from which the physical stress and demands of the dance actions may be identified (Study 4.3).

The published results, although varying in data collection methods, have indicated that different dance styles may impose different physiological responses on the dancer based on heart rate and oxygen consumption data. Further, the data also implies that the participation levels may also induce specific physiological responses. It is therefore likely that student dance teachers participating in a number of dance styles would experience specific physiological responses depending on the participation style.

The aim of this study was to quantify the physiological demand of dancing, in terms of heart rate, across four dance styles as participated in by student dancers.

It was hypothesised that:-

Hypothesis 1: The four dance styles, common to student dance teacher participation, will differ in intensity as measured by heart rate.

4.2.2 Method

4.2.2.1 Subjects

Fifteen female student dance teachers (age = 22.1 ± 4.2 years) participated in the study following informed consent. All the subjects had been participating in dance on a regular basis (experience = 7.5 ± 4.6 years) and were currently participating in the four styles which included Contemporary, Ballet, African Caribbean and Jazz.

4.2.2.2 Procedure

The subjects were asked to wear a short range radio telemeter heart rate monitor (Polar Sports tester, Oy, Finland) before and during a dance class. Resting heart rate was recorded for twenty minutes prior to the start of each class and every 15 seconds during dance class. A total of 12 randomly selected dance classes (three classes from each of the four styles) were used for the data collection. Prior to the commencement of testing all subjects were familiarised with the use of the heart rate monitor. The female subjects were offered the option of wearing the transmitter on a chest strap or fitted to a specially designed sports bra for comfort. The duration of the class was recorded. After each class the heart rates were downloaded onto a computer for analysis.

4.2.2.3 Data Analysis

The variables recorded were heart rate profile and heart rate distribution. The results were analysed descriptively to establish the range of the heart rates, the mean and peak heart rate values. Differences in intensity between each style of dance were investigated using a one way analysis of variance. Post-hoc analysis using a Tukey test was used to highlight any difference between the styles. A probability of 0.05 was taken to indicate statistical significance.

4.2.3 Results

The mean and standard deviation for the duration of each class was 94 ± 6 min; 85 ± 4 min; 118 ± 9 min; 62 ± 5 min , for Jazz, Contemporary, African Caribbean and Ballet respectively. The average resting heart rate for the subjects was 62 ± 4 beats/min. The mean heart rates were averaged over each style for the fifteen subjects. An example of the heart rate profiles for the four styles, on one female subject, is displayed in Figure 4.2.4.1 a,b,c,d.. The mean heart rate values were 134 ± 13 beats/min; 119 ± 9 beats/min; 131 ± 10 beats/min; 116 ± 9 beats/min, for Jazz, Contemporary, African Caribbean and Ballet respectively as shown in Table 4.2.3.1. The mean heart rates were equivalent to 67%, 60%, 66% and 58% of the age predicted maximum (220-age) for the subjects for each of the four styles.

The mean peak heart rate and mean range between minimum and maximum heart rate across the four styles were 193 (range = 118) beats/min; 164 (range = 82) beats/min; 197 (range = 130) beats/min; 143 (range = 54) beats/min, for the styles of Jazz, Contemporary, African Caribbean and Ballet. When the peak heart rates were analysed with respect to the age predicted maximum they equated to 97.5%; 82.9%; 99.5% and 72.2% of the age predicted maximum for the four styles. The African Caribbean dance style produced the largest peak heart rate (197 beats/min) and was also found to have the greater range (130 beats). This style produced the lowest average recorded heart rate of 67 beats/min.

A summary of the heart rate responses is shown in Table 4.2.3.1. Following a one-way ANOVA a significant difference ($F_{(4,14)} = 27.65$: $p<0.05$) was found between the mean heart rate responses of the subjects across the four styles. Tukey post-hoc analysis revealed significant differences between Jazz and Contemporary ($p<0.05$); Jazz and Ballet ($p<0.05$); African Caribbean and Contemporary ($p<0.05$); and African Caribbean and Ballet ($p<0.05$). No significant differences were noted between the styles of Jazz and African Caribbean or Ballet and Contemporary.

Table 4.2.3.1 Mean and standard deviation heart rate (HR) responses to the dance styles for the subject group (n=15)

	Resting HR	Mean HR	Mean peak	Mean HR range
Jazz	62 ± 4	134 ± 13	193	118
Contemporary	62 ± 4	119 ± 9	164	82
Ballet	62 ± 4	116 ± 9	143	54
African Caribbean	62 ± 4	131± 10	197	130

Table 4.2.3.2 shows the percentage of class time spent within four heart rate intensity categories. These categories correspond to low intensity, low to moderate intensity, moderate to high intensity and high intensity as suggested by the American College of Sports Medicine (1991). The styles of Jazz and African Caribbean were the only styles to register heart rates in the high intensity category. Jazz also registered the highest percentage class time spent in the moderate to high intensity (131-160 beats/min) with a percentage of 61.9%. Ballet had the largest percentage class time

spent in the moderate to low and low intensity categories with percentage values of 64.9% and 16.7% respectively.

Table 4.2.3.2 Percentage of class time spent at Heart Rate Intensity

	Heart Rate (beats/min)			
	70-100	101-130	131-160	161-190
Jazz	8.5 ± 0.9	25.3 ± 1.9	61.9 ± 2.5	4.3 ± 0.7
Contemporary	11.5 ± 1.1	56.3 ± 2.4	32.2 ± 1.9	0
Ballet	16.7 ± 0.8	64.9 ± 2.3	18.5 ± 2.4	0
African Caribbean	3.2 ± 0.6	53.9 ± 1.7	36.7 ± 0.8	6.2 ± 1.1

4.2.4 Discussion

The monitoring of heart rate is one method for estimating training intensity (Thomson and Ballor, 1991; Bell and Bassey, 1994). This method has been used to monitor training intensity during dance activity (Koltyn and Morgan, 1992; Scharff-Olsen et al., 1992). A slow resting heart rate is indicative of a high level of cardiovascular fitness in trained subjects (Peterson et al., 1986). The average resting heart rate of the subjects in the present study was found to be 62 ± 4 beats/min.

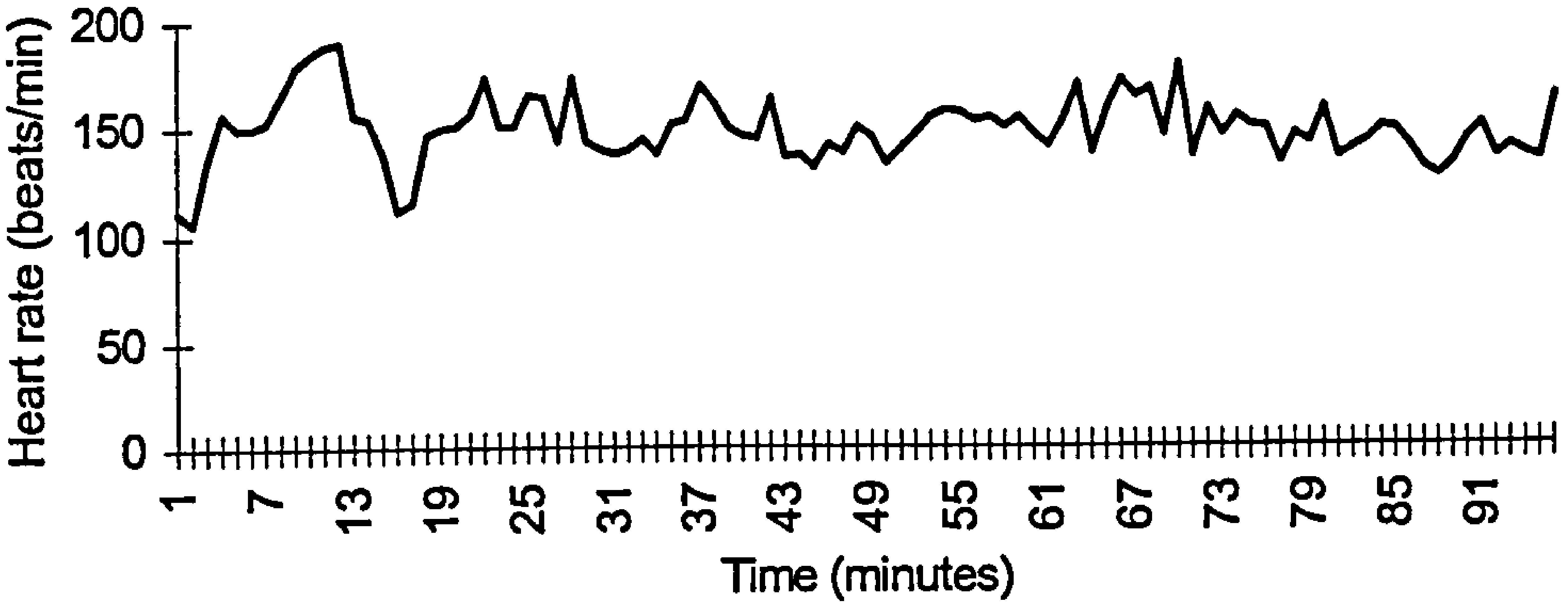

Figure 4.2.4.1a Jazz

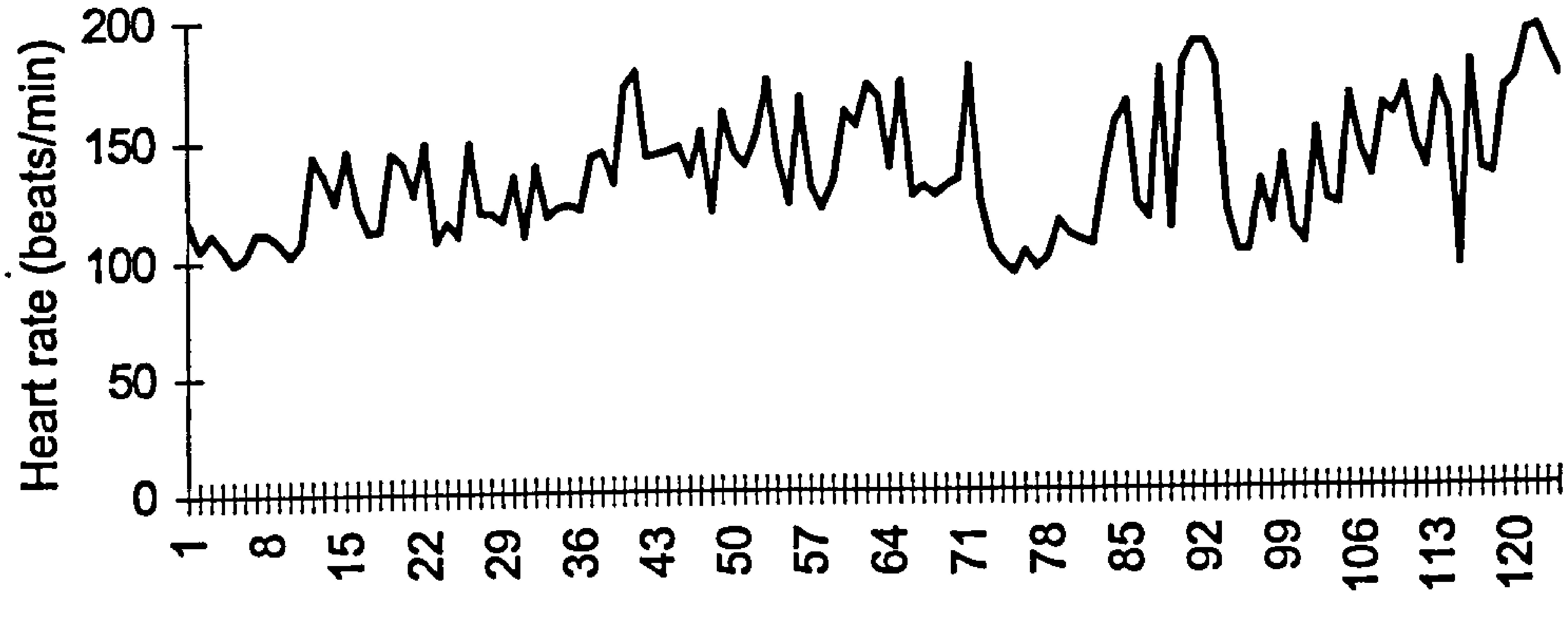

Figure 4.2.4.1b African Caribbean

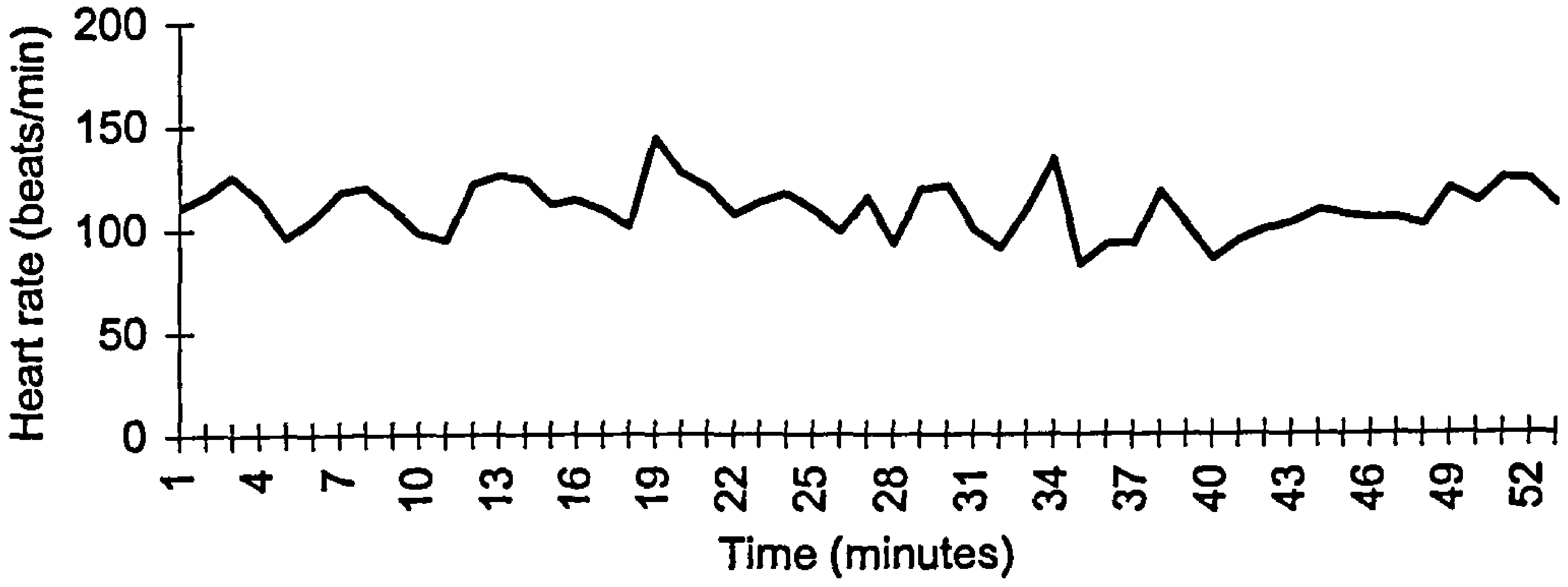

Figure 4.2.4.1c Contemporary

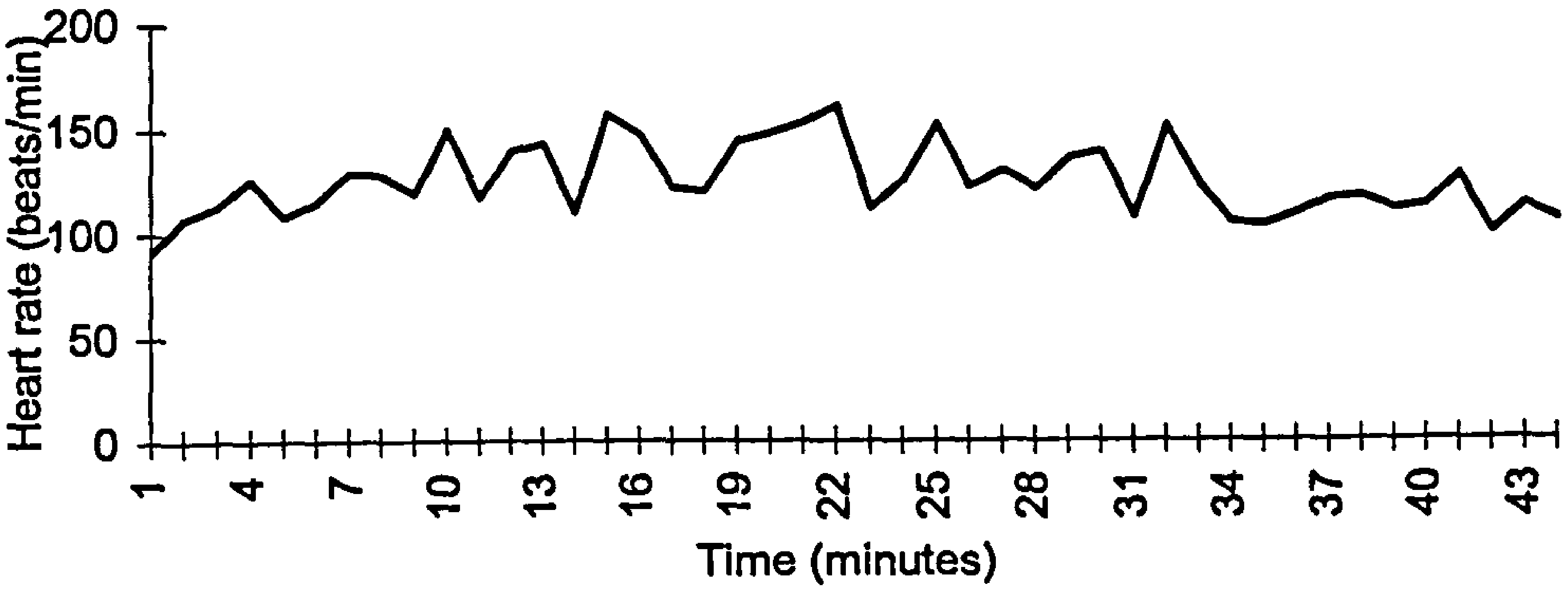

Figure 4.2.4.1d Ballet

This is comparable to other previous studies of dancers; 63 ± 8 beats/min, (Peterson et al., 1986); 68 ± 6 beats/min, (Mostardi et al., 1983); 63 ± 4 beats/min, (Blanksby and Reidy, 1988). This suggests that the dancers used in the present study were of a standard of fitness representative of trained dance performers.

As a general rule, aerobic capacity will improve if exercise is of sufficient intensity to increase heart rate to about 60-70% of maximum for four 20 minute periods a week (ACSM, 1991). The highest heart rates measured at any time during the classes equated to 97.5%; 82.9%; 99.5%; 72.2% of age predicted maximum for Jazz, Contemporary, African Caribbean and Ballet respectively. Kirkendall and Calabrese, (1983) recorded percentage maximum heart rates of 73% and 77% for females and males respectively in Ballet classes. They concluded that the intensity and duration were inadequate to bring about desired changes in cardiorespiratory fitness. A similar conclusion was also reached by Schantz and Astrand (1984). During composite dance performance they recorded percentage maximum heart rates of 46% of the subjects' maximum.

Exercise which results in sustained heart rate in excess of 150 beats/min has been classified as extremely heavy (Astrand and Rodahl, 1990). In this study the subjects recorded an overall mean heart rate of 134 beats/min for Jazz; 119 beats/min for Contemporary; 131 beats/min for African Caribbean and 116 beats/min for Ballet. According to the above definition, therefore, the four styles of dance are of moderate activity level requiring medium energy expenditure to match this physiological stress. The intermittent nature of all the dance classes is reflected in the heart rate profiles (Figure 4.2.4.1a, b, c, d). Although the peak heart rates recorded range from 72.2% to 99.5% of the age predicted maximum, these values were only recorded for short periods of time (2-3 minutes). This heavy work intensity level would then be interspersed with similar rest periods allowing sufficient time for the recovery. This high intensity 'burst' like quality of dance activity, because of its brief duration, would only moderately stimulate improvements in aerobic activity. However, if the rest periods were minimal then the heart rate may be maintained through the continued high intensity dance activity.

The difference in the intensity between the dance styles was highlighted from the post-hoc analysis. Significant differences were found between Contemporary and Jazz, Contemporary and African Caribbean, Ballet and Jazz, and Ballet and African Caribbean. This is a reflection on the nature of the dance activity. The musical timing and pace of contemporary choreography is often left to individual interpretation. The relaxed and flowing body movements do not lead to a pronounced physiological response, but more to artistic impression. The precise and aesthetic movements in ballet, although they may stress the musculoskeletal system in terms of body alignment and balance, are performed at a pace where they are controllable and accentuate the aesthetic line of the body. These styles are very different to the vigorous and aggressive movements of tribal dance rituals and the high tempo jazz rhythm.

Although the styles of dance monitored in this study were of a moderate intensity, consideration must be given to the context in which the analysis was performed. The high intensity periods of activity were restricted due to the duration of the class and the scheduling demands placed on the student dance teachers. Previous research (Kirkendall and Calabrese, 1983) has suggested that the duration of the class was inadequate to elicit a cardiovascular training response relative to the time the heart rate spent in the appropriate training zone. The longer duration of the African Caribbean dance class, and hence the increase in the frequency of the high intensity activity periods, may put more stress on physiological capacities and increase the cardiovascular training response. It should also be noted that the nature of the class depends on the individual interpretation with respect to the choreographer and timetabling of the student dancers. It may have been that more emphasis was placed on the teaching aspect of the class, the aesthetic quality of the movement and the choreography rather than the health and fitness response to the activity. The long rest periods will allow recovery but will increase the risk of injury due to the cooling down process associated with the rest periods. If the students are then asked to perform at a maximum intensity level after a long rest period this may make them more susceptible to muscle and joint injuries. The trade off between these two important criteria for the student dance teachers may prove to be an important factor when assessing dance activity and investigating relationships with injury.

4.2.5 Conclusion

The aim of the study was to quantify the physiological strain of four dance styles on student dance teachers as measured using heart rate responses. The study identified the heart rate responses, of the students, in the four styles and the heart rate patterns during the classes. Jazz and African Caribbean dance styles were of significantly greater intensity than Contemporary and Ballet dance and could elicit a greater cardiovascular training response. The physiological demands imposed by the four forms of dance exercise was of moderate intensity (indicated by heart rate), which fell below the suggested heart (140 beats/min: 70% of the dance subjects' predicted maximum heart rate) for eliciting a cardiovascular training response as specified by the American College of Sports Medicine (1991). Further, the intermittent nature of dance activity in terms of high intensity activity and long rest periods, the class duration and scheduling demands on student dance teachers would increase the injury risk potential due to the cooling down between the choreographed movements. The heart rate responses further highlighted the styles of Jazz and African Caribbean as being significantly more physiologically demanding than the styles of Ballet or Contemporary, in this respect the hypothesis was accepted.

4.3 FORCE CHARACTERISTCIS OF COMMON DANCE ACTIONS

4.3.1 Introduction

Injuries are a significant problem for dancers, affecting approximately 80% of them at some stage of their career (Bowling, 1989; Ryan and Stephens, 1987; Doggart, et al., 2000). Injury rates, as calculated by number of injuries per 100 participants, have been reported across different skill levels. Reid et al. (1987) reported an injury rate of 336.0 per 100 participants for ballet students aged between 10.4 to 18.8 years, and Clanin et al. (1984) reported an injury rate of 125.0 per 100 participants for students following a multidisciplinary collegiate dance programme. Whilst the difference in the methods employed for collecting the injury data as reported in the studies may limit an integrative analysis, it is clear that injury in dance is not restricted to the professional dancer or dance company.

Lower extremity injuries are common among dancers across a variety of styles (Hardaker et al., 1986; Silver, 1985), with the lower extremity accounting for 86% of reported injuries to ballet dancers alone (Ryan and Stephens, 1987). Silver's (1985) observation that injury rates may depend on a particular dance form suggests that performing specific movements may contribute to injury. To support this observation Solomon and Micheli (1986) recorded differences in injury patterns between two modern dance techniques as performed by professional dancers. This study recorded injuries to the knee and noted that 10.8% of all injuries reported for one of the techniques occurred at the knee, whereas 25.0% of injuries reported from the other technique was at the knee. It is therefore evident that the types of movements required of dancers may influence the incidence and site of injury.

A further factor that may be linked to injury predisposition is landing technique (Simpson et al., 1996). Chronic dance injuries have been thought to be linked to improper technique (Gans, 1985; Ryan and Stephens, 1987; Gantz, 1990). Both of the studies by Hardaker et al. (1986) and Sammarco and Miller (1982) on foot and ankle injuries in dancers suggested that the technique of individual dancers can influence injury risk potential. They found that the majority of injuries are chronic and related to the mechanisms in which the foot and ankle do not properly dissipate repetitive forces. The magnitude of excessive impact forces and the rate of their application has been suggested as an important factor in repetitive injury situations (Nigg, 1986; Dufek and Bates, 1990; Cavanagh and LaFortune, 1980).

The research published on force analysis of dance actions has concentrated on the impact forces in aerobic dance (Ricard and Veatch, 1990; 1994; Reeves et al., 1992; Elliott et al., 1991). Values for peak impact forces ranged from 1.0 BW to 2.62 BW, with loading rate values ranging from 14.4 BW/s to 73.12 BW/s for both low impact and high impact dance movements. Force data on traditional dance styles is limited. Simpson and Kanter (1997) reported impact forces from travelling jump steps in modern dancers. They recorded a range of values from 1.38 BW to 2.78 BW across three jump distances. No load rate data was reported. Dozzi (1988), in a similar type of study, using 3 ballet dancers, analysed ground reaction forces in one ballet jump. This study specifically looked at the technique of landing and the difference when landing with forced heel contact and normal landing techniques. No quantitative data was reported, however the author noted that larger forces were recorded when forced heel contact was observed.

The research published to date on force characteristics of dance actions has been limited. Of the data reported authors have focused on fitness dance idioms, such as aerobic dance or professional dancers trained in only one technique such as modern or ballet dance. Further, the actions that have been analysed have been limited in that they have only reported on landings from jumps. To date no research has been reported on the force and load rate characteristics of movements common to other more traditional dance styles, nor has there been data reported on student dance teachers performing a number of different actions across a number of different styles. Therefore the quantification of impact forces and load rates, specific to dance movements across a number of different dance styles, would aid in the understanding of the mechanisms that may contribute to injury in dance. It can be hypothesised that dance actions, common to a number of different styles, will record different force characteristics. The aim of this study was to determine peak impact forces and load rates, as a measure of physical stress, on actions common to four dance styles as participated in by student dance teachers.

Hypothesis 2: The dance actions, common to the four styles, will record different force characteristics in terms of peak ground reaction forces (Fx, Fy, Fz), free moment (Mz) and load rates.

4.3.2 Method

4.3.2.1 Subjects

Seventeen student dance teachers (age = 18.4 ± 2.4 years; mass = 56.3 ± 6.3 kg; height = 160.7 ± 4.8cms; dance experience = 11.9 ± 3.8 years) gave informed consent for participation in the study. The subjects were currently performing in a number of dance styles that regularly incorporated the dance movements to be analysed.

4.3.2.2 Procedure

Seven dance actions, as identified from the notation study, and common to the four dance styles were investigated. These included; (1) single limb landing from a backwards leap; (2) flat footed stamping step; (3) landing with hips, knees and feet abducted 90 degrees with ankles shoulder width apart (feet in open fourth position); (4) landing with hips, knees and feet abducted 90 degrees with the heels together (feet in second position); (5) single limb drive off action into a jog step; (6) single limb landing from a jog step; (7) exaggerated stamping step with a toe then a heel landing. The subjects were given as many practice attempts as required to consistently land on the force platform with the right foot. Once the subjects were familiar to the experimental requirements they were instructed to perform 5 trials of each dance action. The force data for each trial were recorded. All subjects performed the actions bare foot.

The force data were recorded using a force platform (Kistler, Type 9281. Winterthur, Switzerland), mounted flush with the floor surface. Data were sampled at 300Hz for three seconds. Data were recorded for vertical (Fz), anterio-posterio (Fy), medio-lateral (Fx) ground reaction force components and free moment (Mz). Instantaneous load rates were calculated using the software accompanying the force platform. The calculation is based on the ratio of the peak force and the time taken to peak force.

4.3.2.3 Data Analysis

Since the purpose of this study was to quantify the magnitude and rate of loading, the following dependent variables were calculated; peak ground reaction force (Fz); peak anterio-posterio force (Fy); peak lateral force (Fx); peak free moment about the vertical axis (Mz); load rate for vertical force component (Fz load rate). All force data were normalised by dividing by the subject's body weight in Newtons.

Initially the data were analysed descriptively. This was achieved through mean load rates and mean peak reaction forces in the three directions for all the subjects. Differences between the movements were investigated using a one-way ANOVA. A Tukey post-hoc analysis test highlighted the actions which differed significantly between one another. A probability of $p<0.05$ was taken to indicate statistical significance.

4.3.3 Results

Reliability of the Force Data Collection Method

An analysis of the reliability of the force data collected was completed using one student dancer. The student dancer gave informed consent to repeat the study on 2 occasions. A total of two data sets were recorded for the student dancer on each dance action and each measured force component for the dance actions. Each dance action was repeated five times to replicate the method used in the main study. The reliability study was completed on two separate days with a 7 day interval

An example of the mean data collected (Fz and load rate) for the test and re-test is shown in Table 4.3.3.1.

Table 4.3.3.1 Mean Peak Vertical Force (Fz) and Load Rate data for the test and re-test analysis for the seven dance actions. (All values in BW for Fz and BW/s for load rate)

	Test		Re-test	
	Fz	Load rate	Fz	Load rate
Dance Action				
1	1.86	79.2	1.89	80.1
2	2.29	401.5	2.20	405.7
3	1.89	186.1	1.82	189.6
4	2.30	139.3	2.42	141.8
5	1.47	267.1	1.49	251.1
6	1.56	200.9	1.50	211.7
7	2.34	179.3	2.44	184.9

The reliability of the force data collected, from the five trials during each testing session, were examined using limits of agreement (Bland and Altman, 1986). A dependent t test was used to determine if any large systematic bias existed between the 2 sets of data for each force and dance action variable. Results from the dependent t test indicated no significant differences ($p>0.05$) between the data sets for any of the force variables across the seven dance actions.

Table 4.3.3.2 Mean and Standard Deviation (SD) of the differences and Limits of Agreement for the reliability of the force variables for dance actions 1 and 2.

	Mean of Differences	SD of Differences	Limits of Agreement
Dance Action 1			
Fx	0.02	0.001	0.02 ± (0.002)
Fy	0.22	0.05	0.22 ± (0.09)
Fz	0.48	0.15	0.48 ± (0.29)
Mz	0.01	0.002	0.01 ± (0.004)
F z Load rate	15.8	10.6	15.8 ± (20.77)
Dance Action 2			
Fx	0.04	0.01	0.04 ± (0.02)
Fy	0.18	0.04	0.18 ± (0.08)
Fz	0.91	0.29	0.91 ± (0.57)
Mz	0.02	0.002	0.02 ± (0.004)
Fz Load rate	71.3	19.8	71.3 ± (38.81)

Table 4.3.3.2 shows an example of the limits of agreement for dance actions 1 (landing from a backwards leap) and 2 (flat footed stamp). The limits of agreement were calculated based on the normalised data obtained from the reliability study. The limits of agreement, for all variables and dance actions, ranged from ± 0.002 BW on

the Fx variable for dance action 1 to ± 0.57 BW on the Fz variable for dance action 2. This suggests that the 95% limits of agreement, for a force value of 0.35 BW measured in the Fx (medio-lateral plane), would range from 0.348 BW to 0.352 BW. Similarly a force value of 1.75 BW recorded in the Fz (vertical plane) would have 95% limits of agreement of 1.18 BW to 2.32 BW.

Dance Action Force Data

A description of the vertical force trace, for each action, is documented in Appendix 2. As an example, Figures 4.3.3.1 and 4.3.3.2 display the vertical (Fz) force traces for action 1(landing from a backwards leap) and action 2 (flat footed stamp).

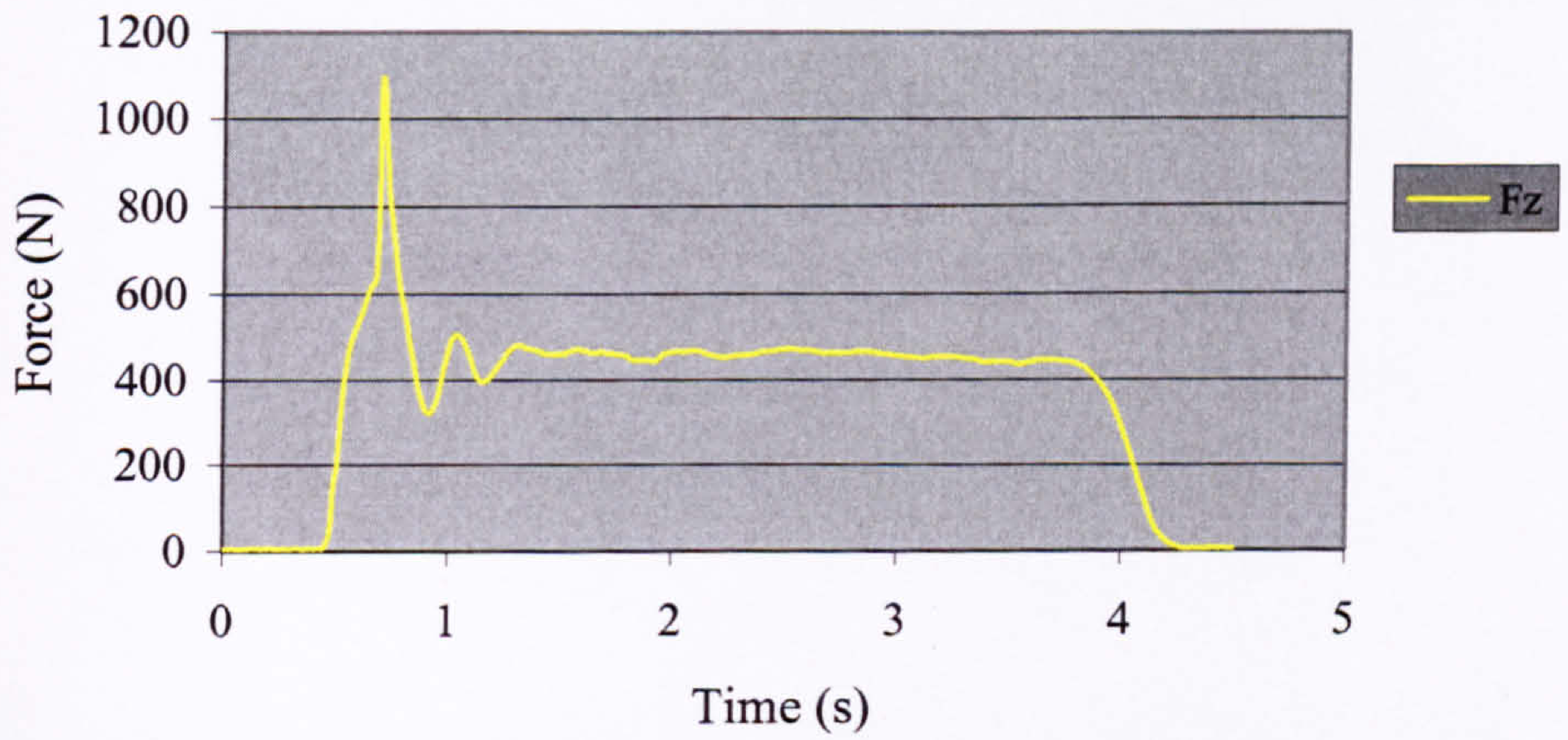

Figure 4.3.3.1 Typical Vertical Force Trace (Fz) for Dance Action 1, Landing from a Backwards Leap

Figure 4.3.3.1 displays a typical ground reaction force pattern representative of dance action 1. The figure illustrates the peak impact force, approximately 1100N, and the time frame over which the action was recorded approximately 4.5 seconds. The initial peak indicates the landing from the leap and then the absorption of the force, by the dancer, through the flexing of the knee before gaining balance and stability depicted by the horizontal constant line indicating body weight.

Similarly, Figure 4.3.3.2 displays the peak impact force (approximately 2100N) and the time frame (4 seconds) over which dance action 2 was recorded. The peak force is an indication of the initial impact due to the foot hitting the ground.

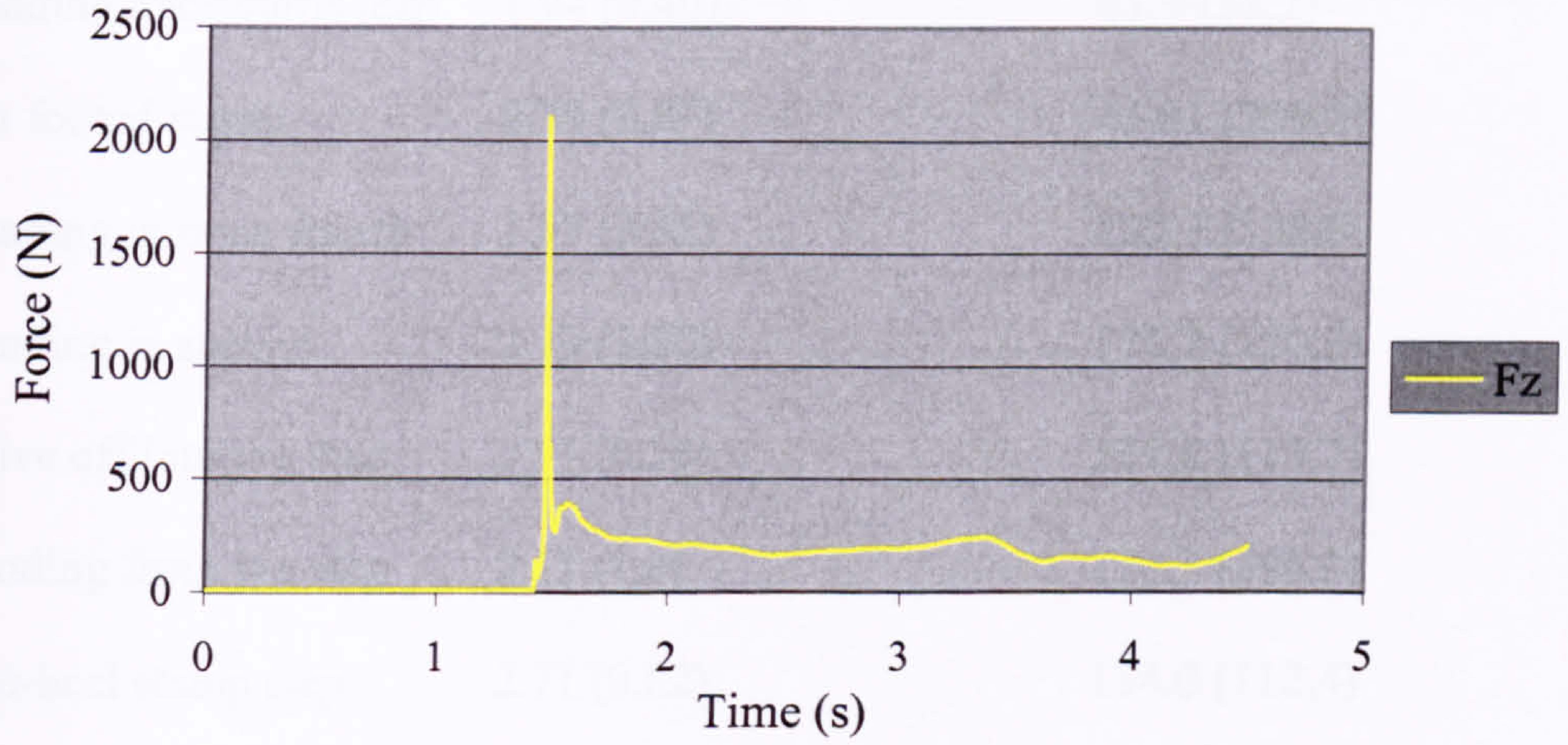

Figure 4.3.3.2 Typical Vertical Force Trace (Fz) for Dance Action 2, Flat Footed Stamp Step

Table 4.3.3.3 displays the mean peak vertical force (Fz) and load rate for the seventeen subjects across the seven dance actions. The raw force data was normalised across the subjects for body weight in Newtons (N). There was no significant difference between the actions for peak vertical force, $F_{(6,112)} = 2.04$; $p > 0.05$. The largest vertical forces were recorded for both 'stamp' steps, actions 2 and 7 with values of 2.39 BW and 2.71 BW respectively. The vertical force recorded from the landings associated with the jump steps, (actions 1,3,4 and 6), highlighted action 6 as recording the largest force with a value of 2.13 BW. It was further noted that the smallest vertical force was recorded for the drive off phase (action 5) into the jog step with a value of 1.51 BW.

Table 4.3.3.3 Mean and Standard Deviation values for the Peak Vertical Force and Load Rate for the Seven Dance Actions.

Action	Vertical Fz (BW)	Load Rate (BW/s)
1. Landing backwards leap	1.94 (0.40)	81.9 (53.2)
2.Flat footed stamp	2.39 (0.89)	454.1 (259.3)
3. Landing in open fourth	1.97 (0.65)	192.7 (138.6)
4. Landing in second	2.19 (2.26)	135.2 (120.3)
5. Drive off into jog step	1.51 (0.28)	251.8 (113.7)
6. Landing from jog step	2.13 (1.0)	174.7 (195.3)
7. Toe-heel stamp step	2.71 (0.82)	154.0 (112.4)

The analysis of the load rate data was undertaken using a one-way ANOVA. A significant difference was calculated for the load rates across the seven dance actions, $F_{(6,112)} = 10.41$; $p<0.05$. Tukey post-hoc analysis highlighted action 2 (flat footed stamp step) as having a significantly larger load rate (454.1 BW/s) than the other actions ($p<0.05$). It should also be noted that this action had a large standard deviation ($s = 259.3$ BW/sec) and hence variance between the subjects. Nevertheless this action was 55.5% larger than the second highest load rate value, that of action 5, which was the drive off phase into the jog step.

Table 4.3.3.4 displays the mean peak anterio-posterio force (Fy), lateral force (Fx) and free moment (Mz) components associated with the seven dance actions. Commensurate with previous published data and force platform construction the negative values indicate a reaction force opposite in direction to the positive set-up of the platform. During analysis of the data the research was predominantly concerned with the magnitude of the force or moment variable and in this respect analysis was performed on peak force data regardless of sign.

Table 4.3.3.4 Mean and Standard Deviation value for the Peak Anterio-Posterio Force (Fy), Lateral Force (Fx) and Free Moment (Mz) for the Seven Dance Actions.

Action	Anterio-Posterio Fy (BW)	Lateral Fx (BW)	Moment Mz (BW.m)
1. Landing backwards leap	-0.51 (0.28)	0.13 (0.03)	0.04 (0.15)
2. Flat footed stamp	0.33 (0.13)	0.33 (0.11)	0.05 (0.01)
3. Landing in open fourth	0.16 (0.06)	0.10 (0.04)	0.01 (0.03)
4. Landing in second	-0.19 (0.14)	0.14 (0.03)	0.03 (0.01)
5. Drive off into jog step	0.26 (0.13)	0.17 (0.05)	0.01 (0.03)
6. Landing from jog step	-0.33 (0.16)	-0.12 (0.05)	0.01 (0.01)
7. Toe-heel stamp step	0.19 (0.05)	0.19 (0.06)	0.03 (0.02)

Significant differences ($p<0.05$) were recorded across the three variables (Fy, Fx, Mz) following a one-way ANOVA statistical design with values of $F_{(6,112)} = 10.97$;

$p<0.05$; $F_{(6,112)} = 30.20$; $p<0.05$; $F_{(6,112)} = 2.3$; $p<0.05$, for Fy, Fx and Mz components respectively. Post-hoc analysis revealed action 1 as having a significantly larger peak force in the Fy component when compared to the other actions and action 2 as having a significantly larger peak lateral force (Fx) than the other actions. Post-hoc analysis failed to differentiate between the actions for the free moment (Mz). As shown in Table 4.3.3.4 all values in the Fy and Fx variables were below 1BW of force and below 1BW.m in the Mz variable.

Action 1 registered the largest force across the three components and the seven actions with a value of –0.51BW. The negative value indicates the subjects leaped in the positive set-up direction of the platform and therefore the reaction force recorded a measurement opposite to this. Action 2, the flat footed stamp step, recorded the largest lateral force (0.33BW) and free moment (0.05BW) across the dance actions.

4.3.4 Discussion

Magnitude of the force and the rate of the force application are two factors that describe the load imposed on the human body by an activity (Ricard and Veatch, 1994). Impact forces have been suggested to cause bionegative effects such as microtrauma in muscle, ligaments and bone (Nigg et al., 1995; 2000). However there is no conclusive evidence to substantiate the claim that the magnitude of an impact force, and the rate of loading of the impact force, cause injury.

The impact force (Fz) for the seven dance actions ranged from 1.51 BW (action 5) to 2.71 BW (action 7). When compared to the data reported by Simpson and Kanter (1997) and Simpson and Pettit (1997), for impact forces associated with travelling jump steps, the values are within their reported range of 1.38 BW to 2.78 BW. More specifically if jump actions 1,3,4 and 6, from the present study, are compared individually to the results of Simpson and Kanter (1997) then they are found to be more towards the top end of the published range with values of 1.94 BW to 2.62 BW. However, when compared to the data reported by Ricard and Veatch (1990, 1994) for aerobic dance actions, the forces recorded in this study were generally greater than those previously published (0.98 BW to 1.98 BW; 1.28 BW to 2.62 BW). These forces were based on high and low impact jump actions were either one foot or both feet would be airborne respectively. If collectively comparing only the jump actions in this study (actions 1,3,4,6) the mean impact forces were 1.94 BW; 1.97 BW; 2.19 BW and 2.13 BW respectively. It would seem that the jump actions being performed in the traditional dance forms were consistent, in terms of force magnitude, to the actions performed in dance fitness classes. However the flat footed 'stamping' steps (actions 2 and 7), which could be categorised as low impact movements, recorded similar impact force values and indeed a higher value for the 'toe-heel' (2.71 BW) step than the high impact actions previously mentioned. The 2.71 BW recorded for the 'toe-heel' flat footed step would equate to landing from an aerobic dance jump step of over 8cm according to the results reported by Ricard and Veatch (1994). It would further equate to running faster than 4 m/s in terms of the magnitude of the peak impact force as reported by the same authors. Similar comparisons and extrapolations can be made of the impact data for the results reported by Reeves et al. (1992) and Elliott et al. (1991).

No significant differences ($p>0.05$) were calculated for the peak vertical force across the seven dance actions. However actions 2 and 7 (flat footed stamp step and toe-heel stamp step) recorded a peak impact force of 2.39 BW and 2.71 BW respectively.

These two actions were 8% and 19% greater than the peak vertical force recorded for the largest impact force for a jump step (action 4) with a value of 2.19 BW. A possible explanation for this maybe the nature of the step action. The step must be flat footed to represent tribal or native dance style as in African Caribbean. In modern dance styles, such as jazz and contemporary, the flat footed step is used to change direction suddenly and quickly in preparation for further movements. In this way the students are not aware of the impact of such movements as the technique in stepping in such a manner is not taught in a dance class as perhaps it is not a recognised skill more as an intermediary precursory action. However it may be that the technique of jumping and more importantly landing are recognised as skilled actions that must be mastered in order to allow continual flowing movement throughout a choreographed dance piece. In this way the students are more aware of the importance of such actions and have been trained to correctly perform the technique and hence dissipate the impact throughout the body.

The loading rate for the seven actions ranged from 81.9 BW/s to 454.1 BW/s. When compared to the data reported by Ricard and Veatch (1994), for aerobic dance actions, the loading rates recorded ranged from 16.26 BW/s to 73.12 BW/s. Ricard and Veatch (1994) also reported loading rates for running for speeds between 2.4m/s and 4.0m/s which ranged from 65.06 BW/s to 112.55 BW/s. The loading rates from the present study are considerably larger than reported previously in dance action studies and this is possibly due to the nature of the software package. The analysis programme calculated instantaneous load rate, i.e. the maximum gradient of the vertical (Fz) force trace while the more common method of calculating and reporting load rate is to use the average gradient from first contact to peak vertical force. Woodward et al. (1999) suggested that there was a strong correlation between a number of methods for calculating load rate and reported that both instantaneous and average methods were acceptable. Although the method used for calculating load rate was not reported by Ricard and Veatch (1994) this may well explain the differences between the results.

Dance action 2, the flat footed stamp step, had the largest loading rate which was 4 times greater than that reported for a running speed of 4 m/s. The drive off phase into a high jump step, dance action 5, recorded a loading rate of 251.8 BW/s which was 2 times greater than that recorded for a running speed of 4 m/s. No other published studies on dance actions are available from which a comparison can be made. A possible explanation for this is the deliberate and almost explosive nature of the dance actions. The drive off phase into the jump step is aimed at getting height, that is, raising the centre of gravity for as long as possible to perform an airborne movement. In order to achieve this the dancer must push off quickly and although the corresponding vertical impact force is relatively small the time period over which this must be accomplished is greatly reduced so to allow the dancer to perform the airborne movement and be prepared to follow on into another movement. The drive off action must be relatively quick to incorporate the rhythm of the music and although the natural movement of the body would be to perform a counter movement jump to gain extra height this is not aesthetically acceptable in dance idioms as opposed to sports actions. This technique is a skilled movement and may be performed a number of times in repetition therefore preventing the dancer the time to incorporate a counter movement action.

A significant difference in loading rate was calculated across the seven dance actions ($p<0.05$) with post-hoc analysis highlighting dance action 2 (flat footed stamp) as significantly larger than the other actions ($p<0.05$). This dance action recorded a loading rate of 454.1 BW/s which was up to 3.5 times greater than the rates recorded on landing from the jump steps (actions1,3,4,6). Similar to the peak vertical force the technique of landing is a skill that the dancers must be able to perform and be prepared to follow on into another action. The step action is a deliberate movement, sometimes discrete, that may end a sequence within a choreographed performance, hence the importance as a symbol within a dance piece.

The seven actions analysed in this study were representative of the dance movements common to the four dance styles. These movements have been previously reported earlier in this chapter (section 4.1). The important aspects of the dance actions in conjunction with the peak force values are the frequency of the occurrence of the actions, the cumulative effect of the peak forces on the repetitive nature of each action and the technique of performing each action in a choreographed dance sequence.

As can be seen from the data previously reported in Table 4.1.4.5 there are a number of different actions. There are also a number of common actions across the four styles. The only dance action that was analysed for peak force values and did not occur in all styles was the jog step. The reason for its inclusion was the importance, in terms of frequency of occurrence, in the Jazz style. If this style was considered as a typical sequence, as reported in section 4.1.5, it would include 136 jog steps (including drive-off phase and landing), 59 jumps (including landing in open fourth position, second position and landing from backwards leaps) and 82 step actions. There are further actions included in this sequence over the 3 minute and 33 second period. However if these actions are related to the vertical peak force values this would equate to;

(136 drive off phases x 1.51 BW) + (136 jog step landings x 2.13) + (59 x 2.03*) + (82 steps x 2.39).

(* mean vertical peak force value for the three jumps)

This is a total of 810.79 BW units over a 3 minute and 33 second dance sequence. This value neglects the other actions involved in producing this sequence. If this is coupled with the corresponding load rate values for each action then the cumulative effect of both the dance action sequence and the impact forces imposed on the body is comparable to the repetitive nature of the stress imposed during fast running (this is based on approximately 400 steps over a 3 minute period, with an average of 2 BW units per stride). Further, this sequence is often repeated several times during a dance class in order to perfect the timing and coordination of the movements to the rhythm of the music. It is also continually added to, in terms of additional actions and refinements, to produce the aesthetically required movement pattern. Although the method illustrated is not a standard way of assessing accumulative load it does however provide an indication of the potential magnitude of the physical load experienced by the student dance teachers during a typical dance sequence

4.3.5 Conclusion

In addressing the aim of the study the analysis of the ground reaction forces have highlighted typical peak forces and their corresponding load rates associated with dance actions, common to four dance styles, as performed by student dance teachers. Due to the different movement patterns, the different frequency of the movements and the high or low impact nature of the actions, student dancers would be exposed to a variety of cumulative force states dependent on the participating style. However student dance teachers must be proficient at performing each different action in terms of technique and the movement sequences appropriate to each dance style. The students are therefore exposed to the peak forces and load rates as reported. It would then seem that in terms of the cumulative effects of factors relating to injury risk potential, peak vertical forces and load rates, the low impact actions of flat footed steps and toe-heel steps have a greater injury risk than the actions associated with landings from jumps.

Further, the force analysis revealed that only dance action 2 (flat footed step) was significantly different from the other actions in terms of the load rate characteristics but not in terms of peak vertical force, peak lateral force, peak anterior-posterio or free moment component. In this respect the hypothesis must be rejected.

4.4 SUMMARY

Three studies were reported in this chapter in an attempt to quantify the physiological and physical stress imposed on the body through dance. The physiological stress was reported through the use of conventional heart rate monitoring (section 4.2) and from a hand notation system (section 4.1) developed specifically for the recording of dance movements. Both methods reported the intermittent nature of dance classes with frequent periods of rest followed by corresponding frequent periods of high intensity activity. These periods were identified through heart rate and calculated as a percentage of age predicted maximum, and also reported as the number of actions per minute as established from the hand notation study. The results from these two studies suggest that Jazz dance was significantly different from the other styles in terms of the frequency of occurrence of the high intensity activity, the number of actions performed per minute and the heart rate response to the dance style. African Caribbean dance was also identified, from the heart rate profile, as having a significantly higher heart rate response when compared to the styles of Ballet and Contemporary, but not in terms of the actions per minute nor in the frequency of occurrence of high intensity activity. Therefore the styles of Jazz and African Caribbean would be expected to induce a greater physiological stress on the female student dancers.

Jazz dance was also noted as having predominantly high impact dance actions, such as jumps, leaps or jog steps, as opposed to the low impact actions of a flat footed step or demi plie, as recorded in the African Caribbean dance style. The inclusion of high impact actions in dance have been reported in the literature (Reeves et al., 1992; Ricard and Veatch, 1994) as increasing a performers risk or susceptibility to injury. The authors suggested that this was due to the increase in the impact forces as a result of the landing. Therefore the frequency of the high intensity categories, actions performed per minute and the high impact nature of the actions may increase the risk of injury. These factors are more apparent in jazz dance which was also reported as having the highest prevalence of injury (Chapter 3).

The physical stress of dance was reported through the use of an analysis of ground reaction forces as recorded on a force plate. Seven dance actions, common to the four styles, were analysed for their peak ground reaction forces and corresponding load rates. As expected the landing from a jump or leap, common in jazz dance, tended to have the greater peak impact force and load rates although not significant. However, the two actions recorded as having the highest peak impact forces were the flat footed stamp (2.39 BW), and the toe-heel step (2.71 BW) both more commonly found in the African Caribbean dance style. The flat footed stamp also recorded the largest load rate (454.1 BW/sec).

These actions are low impact but because of the nature of the dance style are performed in a deliberate and rigorous manner, hence the greater ground reaction forces and load rates. These actions are performed frequently in the dance class, an average of 731 times, which would place the dancer's body, and specifically the lower limb, under great physical stress with an average cumulative force of approximately 1747 BW units. Technique, in terms of lower limb and body alignment, strength and flexibility, is therefore important for every step.

Links between the physiological stress and physical load are difficult. The physiological stress, as measured by heart rate and dance actions per minute, provide reliable methods, and a basis, from which these two specific performance measures may be studied simultaneously. It could be suggested that in order to successfully complete a greater number of actions per minute the student dancer would have to work harder and in doing so elevate the heart rate. Therefore a higher heart rate would indicate more actions per minute, both of which have been suggested in the present study to reflect a greater physiological stress.

The force analysis provided specific information on the physical loads of the individual dance actions. However, because of the laboratory setting in which the force data was collected, the affect of the forces in conjunction with the physiological stresses as recorded in real time, would be difficult to delineate and make accurate associations between the performance measures tenuous. Nonetheless if the heart rate indicated a high intensity sequence of movements, supported by the notation system, as measured by a greater number of actions per minute, then in order for the student dancer to perform all the movements in the sequence this would require the student dancer to complete the dance actions quickly. If this was the case then the dancer would be completing the action in a shorter period of time. Because of the technical nature of the dance action this may not necessarily significantly increase the impact force, associated with the dance action, but would increase the load rate, i.e. a similar peak force experienced over a shorter time period. It could therefore be implied that the greater the actions per minute, the higher the heart rate and the greater the load rates experienced by the dancer, variables which have been forwarded as potential factors in the onset of injury. However unless the synchronisation of the measurement techniques could be achieved, with a common time frame, the accuracy of such an interpretation is questionable.

The physiological and physical stresses imposed upon the body of a student dance teacher are quantifiable and demonstrate the level at which the dancer is participating. Both stress characteristics are working simultaneously during dance and they themselves would have a cumulative effect on the onset of dance injury through fatigue. It is suggested that a dancer's body, in order to remain free from injury, must have functional and kinanthropometric characteristics capable of coping with the physiological and physical stresses as discussed.

5. BIOMECHANICAL AND KINANTHROPOMETRIC CHARACTERISTICS OF STUDENT DANCE TEACHERS

This chapter contains four studies that consist of the quantification of kinanthropometric and functional characteristics of student dance teachers. In the first study the orthopaedic alignment of the dancers is examined. The functional characteristics of strength and flexibility are examined in the 2nd and 3rd studies, and the body composition of the dancers is reported in the 4th study. These studies address objective 3 of the research.

5.1 INTRODUCTION TO THE FOUR STUDIES

The aim of the four studies was to develop a student dancer profile from an injured and non injured perspective. The profile was based on kinanthropometric and functional characteristics previously identified in the sports injury literature as potential predisposing factors in the onset of injury. The studies further set out to identify any statistical significant differences between the injured and non injured student dancer profiles.

The published sports medicine literature has suggested a number of factors predisposing to injury including intrinsic factors (physical, functional and psychological), extrinsic factors (exposure to the activity, training time and environmental), previous injury history and injury mechanisms (Caine et al., 1996; Kuhn et al., 1997; Bartlett, 1999). It has highlighted certain flexibility, strength, body composition and alignment factors that have been proposed to increase the risk of the onset of injury ((Kuhn et al., 1997). These factors have often been reported (Macera et al., 1989; Knapik et al., 1991; Jones, 1994; Kuno et al., 1996) separately on a specific sports population and inferences and models developed based on the one factor analysed. The literature, however, has not addressed the inter-related nature of these factors nor is there literature on a student dance population. The present studies address the specificity of a student dance population and also provide data on a cohort of injured and non injured dancers, across a number of factors, with a view to producing a model of an injured dancer.

5.2 ORTHOPAEDIC ALIGNMENT IN STUDENT DANCE TEACHERS

5.2.1 Introduction

Movement in all dance forms requires balance, co-ordination and aesthetic alignment. During dance movements it is imperative that the body is correctly positioned and aligned to adequately dissipate the forces involved in performing common movements. Injury to the musculoskeletal system can result from incorrect body positioning during the dance movements and from inherent skeletal malalignment (Howse and Hancock, 1992).

Biomechanical factors associated with malalignment have been reported including leg length discrepancies, large 'Q' angle and 'knock-kneed' or 'bow-legged' lower limbs (Whiting and Zernicke, 1998). Various researchers have examined and highlighted the importance of skeletal alignment in dancers (Lawson, 1986; Solomon et al., 1990) and its relationship to injury (Watkins et al. 1989; McNeal et al., 1990; Bennell et al., 1999). Of the studies reported most have concentrated on 'turn-out' and its effect on alignment in the ballet dancer. These studies have reported that lower limb alignment may predispose the individual to injury by promoting muscle fatigue (Bennell et al., 1999); altering joint load distribution (Riegger-Krugh and Keysor, 1996); or by introducing compensatory mechanisms, to counteract the alignment, and thereby placing stress on muscles and ligaments which are not capable of absorbing the forces involved in movement (Watkins et al., 1989).

The aims of this study were: (1) to quantify lower limb alignment characteristics in student dance teachers; and (2) compare the alignment characteristics between injured and non-injured dancers.

It was hypothesised that:-

Hypothesis 3: Orthopaedic alignment characteristics are different between injured and non-injured female student dance teachers.

5.2.2 Method

5.2.2.1 Subjects

A total of forty six female student dance teachers completed the study. Twenty eight student dance teachers had reported a dance related injury (age = 20.4 ± 4.2 years; mass 58.4 ± 8.8 kg; height = 161.1 ± 6.2 cm; dance experience 12.6 ± 4.9 years), and eighteen student dance teachers had no dance related injury (20.3 ± 3.6 years; 55.4 ± 6.4 kg; 158.8 ± 5.0 cm; 12.6 ± 3.8 years). All the dance students gave informed consent for participation in the study. The subjects were currently enrolled in a degree programme and were performing in a number of dance styles.

5.2.2.2 Procedure

The subjects were asked to stand on a 'foot template' (Baumann et al., 1982). The dimensions of the template enabled the subjects to stand with their heels 25 cm apart and their feet in 5 degrees of external rotation (Figure 5.2.2.2.1). The subjects were asked to stand in an upright, comfortable and relaxed manner and to look straight ahead during the taking of the measurements.

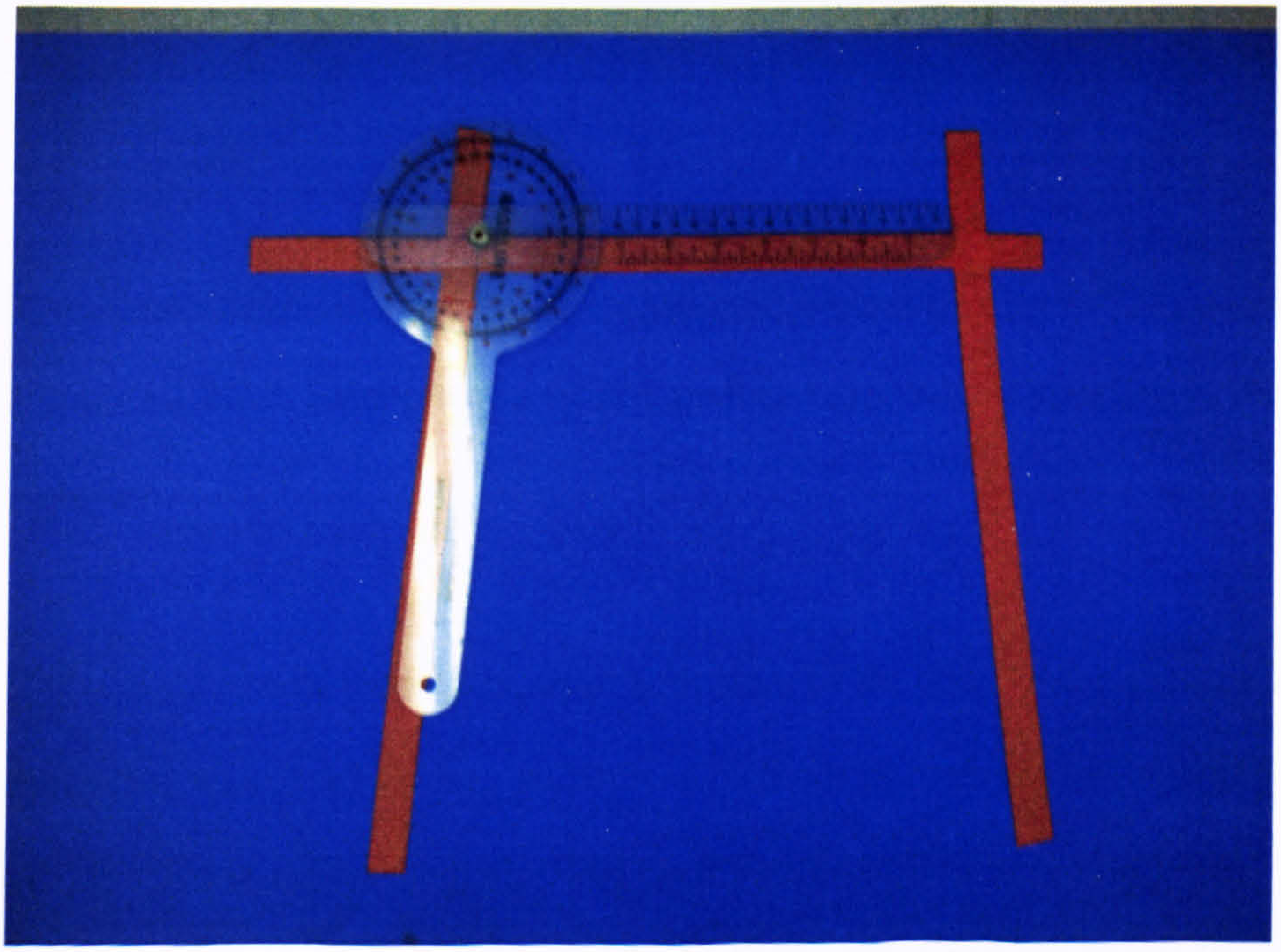

Figure 5.2.2.2.1 Orthopaedic Alignment Foot Template (Baumann et al., 1982)

An example of a subject positioned on the foot template is shown in Figure 5.2.2.2.2.

A total of ten measurements were taken with body length and width measurements recorded in centimetres and angular measurements recorded in degrees.

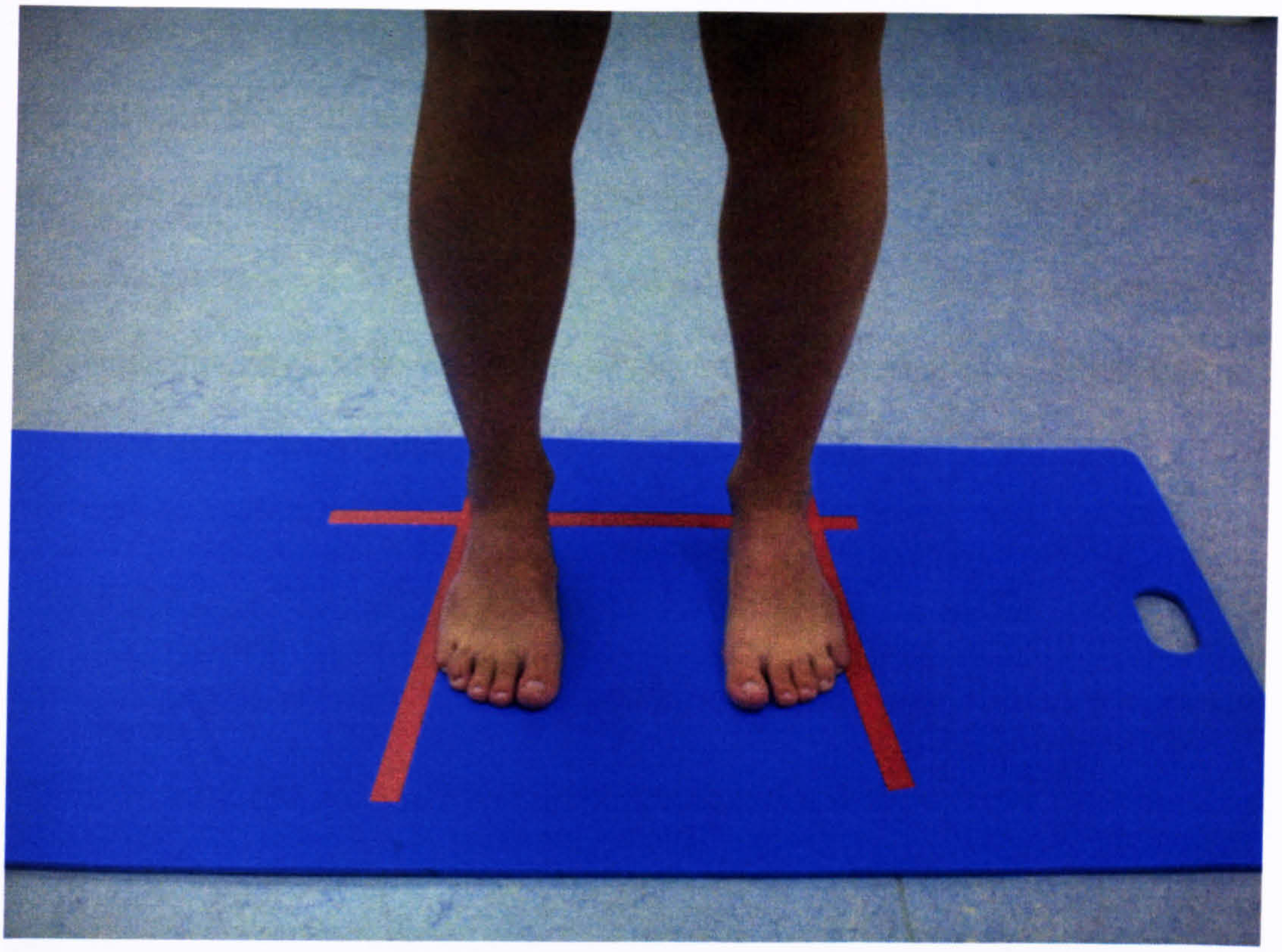

Figure 5.2.2.2.2 Example of a female student dance subject standing in the foot template.

The measurements were taken from both sides of the body where appropriate, this procedure was based on the standardised methods as reported by Enneking et al. (1979) cited in Baumann et al. (1982) and Percy and Strother (1985). The measurements included leg length (distance between anterior superior iliac spine to medial malleolus for left and right legs), Q-angle (angle between the vertical line of the tibial tuberosity and femur), ASIS distance (horizontal distance between the left and right anterior superior iliac spines), greater trochanter distance (horizontal distance between the left and right greater trochanters), outer and inner femoral condyle distance (horizontal distance between the left and right inner and outer femoral condyles) and medial malleoli distance (horizontal distance between the left and right inner medial malleoli) . Additional measurements included upper and lower leg lengths. These measurements were taken from the greater trochanter to the outer femoral condyle for the upper leg, and from the outer femoral condyle to the lateral malleolus for the lower leg. An example of the lower leg length and medial malleoli measures are shown in Figures 5.2.2.2.3 and 5.2.2.2.4 respectively. An example of the data collection sheet is shown in Appendix 3. A complete and detailed description of the protocols for the measurements are shown in Appendix 4.

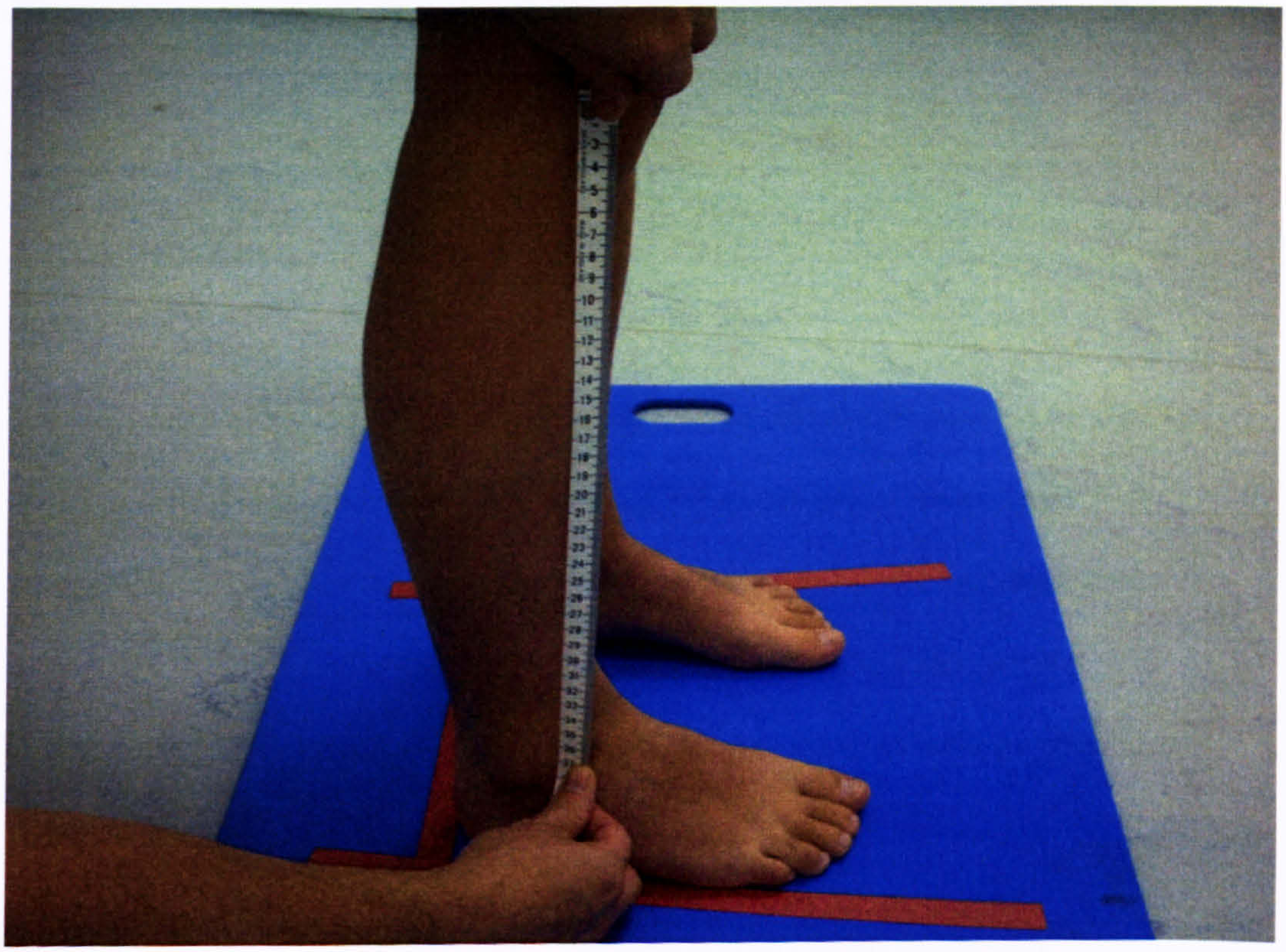

Figure 5.2.2.2.3 Lower leg length measurement.

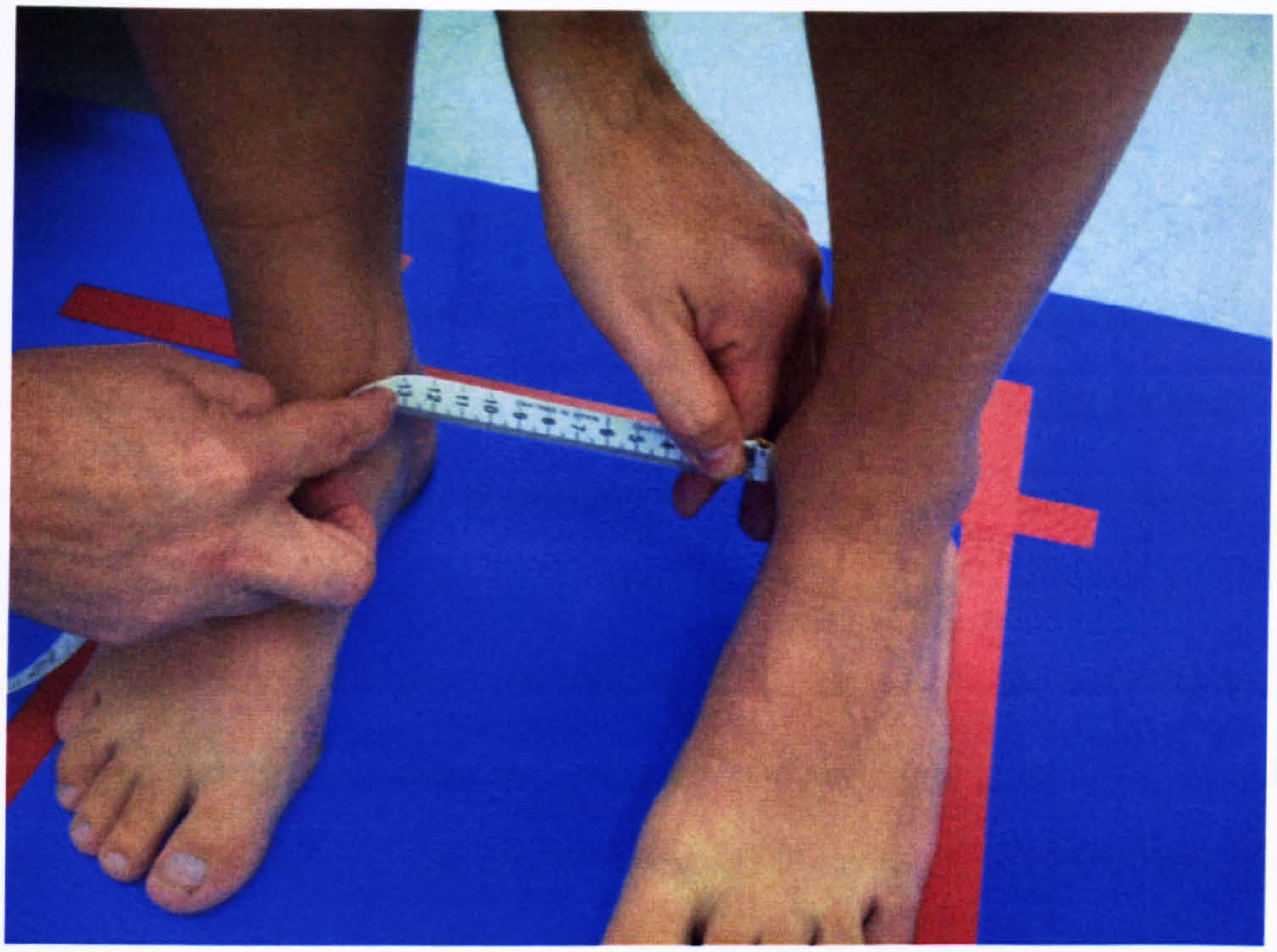

Figure 5.2.2.2.4 Medial malleoli orthopaedic measure.

5.2.2.3 Data Analysis

The data were analysed descriptively and an alignment model developed. Further analysis, using independent 't' tests enabled a comparison of lower alignment characteristics between the injured and non-injured subjects. A correlation matrix (Pearson's 'r') was also obtained for the alignment characteristics for both the injured and non injured groups. A probability of $p<0.05$ was taken to indicate statistical significance.

5.2.3 Results

Reliability of the Alignment Data

In order to establish the reliability of the data obtained from the orthopaedic alignment protocols a female student dance teacher volunteered to repeat the protocols for each measurement on two separate occasions. The student gave informed consent and a total of two complete data sets were recorded on the orthopaedic alignment for the dancer. The reliability data was collected on two separate days with a 7 day interval between the two testing sessions. Reliability analysis of the data were examined using limits of agreement (Bland and Altman, 1986). A dependent t test was used to determine if any large systematic bias existed between the data sets. Results from the dependent t test indicated no significant difference ($t= 1.24$; $p>0.05$) between the data sets. The limits of agreement were recorded as 2.76 ± 1.25 cms (mean of the differences ± (1.96 x SD of differences)). This suggests that an alignment measure for leg length of 86.9cms would have 95% limits of agreement ranging from 85.65cms to 88.15 or a Q angle measure of 18.1 degrees would have 95% limits of agreement ranging from 16.85 to 19.35 degrees.

Although this technique is recommended by Bland and Altman (1986) and Mullineaux et al. (2001) for this type of data set, comparison with other studies is difficult as this technique is not reported in the dance medicine or sports medicine literature. However, within the context of the study the protocols were accepted as being accurate and reliable.

The results of the orthopaedic alignment for the whole group and the injured and non-injured groups are presented in Table 5.2.3.1.

Table 5.2.3.1 Mean and standard deviation values for the Age, Mass, Height and Dance Experience characteristics for the whole data set and the injured and non-injured dancers.

Characteristic	All subjects (n=46)	Injured (n=28)	Non-injured (n=18)
Age (years)	20.4 (3.9)	20.4 (4.2)	20.3 (3.6)
Mass (kg)	57.2 (7.9)	58.4 (8.8)	55.4 (6.4)
Height (cms)	160.2 (5.8)	161.1 (6.2)	158.8 (5.0)
Dance Experience (yrs)	12.6 (4.4)	12.6 (4.9)	12.6 (3.8)

No significant differences (p>0.05) were obtained between the injured and non-injured group for the data displayed in Table 5.2.3.1. It was noted, however, that the injured group were both taller, 2.3 cm on average, and heavier, 3.0 kg on average, than the non-injured group. The variance, as depicted by the standard deviation, was also noted to be smaller for the non-injured group.

Table 5.2.3.2 details the mean and standard deviation of each of the alignment measures for the whole group and specifically for the injured and non-injured groups. It was noted from the data shown in Table 5.2.3.2 that, as a whole group, the dancers in the study had a 'knock-kneed' or genu valgum alignment. This is depicted as the inner femoral condyle distance being small (11.6 cms) relative to the medial malleoli distance (17.8cms) relative to the foot template. This gives the impression of a splayed lower leg and hence knock kneed effect.

Table 5.2.3.2 Comparison of the mean and standard deviation (s) values for the orthopaedic alignment measurements for the injured and non-injured student dance teachers

Alignment Characteristic		Injured (n=28)	Non-injured (n=18)	t value
Leg length (cms)	(R)	86.9 (5.0)	84.2 (3.8)	2.00
	(L)	86.9 (5.1)	84.3 (3.8)	1.88
Q-angle (degrees)	(R)	18.1 (2.3)	17.9 (2.4)	0.18
	(L)	18.1 (2.4)	17.3 (1.9)	1.20
ASIS distance (cms)		22.7 (4.4)	24.2 (2.1)	1.37
Greater trochanter distance (cms)		31.2 (2.6)	31.0 (1.3)	0.28
Outer femoral epicondyle distance (cms)		29.7 (2.6)	29.0 (2.5)	0.87
Inner femoral condyle distance (cms)		11.9 (2.8)	11.0 (2.9)	0.96
Medial malleoli distance (cms)		18.4 (3.9)	16.7 (3.2)	1.51
Greater trochanter to lateral malleolus (cms)	(R)	79.2 (4.4)	76.8 (4.3)	1.84
	(L)	79.4 (5.6)	76.7 (4.4)	1.67
Greater trochanter to outer femoral condyle (cms)	(R)	41.0 (2.8)	39.4 (4.6)	1.29
	(L)	40.8 (3.1)	39.5 (4.4)	0.85
Outer femoral condyle to lateral malleolus (cms)	(R)	38.2 (3.8)	37.4 (2.8)	0.80
	(L)	38.6 (3.9)	37.2 (2.9)	1.01

An independent ‘t’ test analysis found no significant differences ($p>0.05$) in any of the alignment characteristics between the two groups. All the measures were larger in the injured group with the exception of the anterior superior iliac spine (ASIS) distance. The variances also tended to show a similar pattern.

When comparing the data in Table 5.2.3.2 between the two groups the injured group tended to have a more pronounced knock kneed or genu valgum effect. This is demonstrated by a larger difference between the inner femoral condyle distance and medial malleoli distance with values of 6.5 cms and 5.6 cms for the injured and non-injured groups respectively. The larger difference indicates greater genu valgum in the injured group. However no significant difference was obtained between the injured and non injured groups for this measurement.

The 'Q' angle is also reported in the Table 5.2.3.2 for both legs and both groups relative to the foot template. The standard deviation of this angle was noted to be relatively large with values of 2.3 degrees, 2.4 degrees, 2.4 degrees and 1.9 degrees for left and right legs for the injured and non injured groups respectively. The equipment (goniometer and foot template) and measurement of Q angle is shown in Figure 5.2.3.3 (Baumann et al., 1982). A diagrammatical representation of the Q angle is shown in Figure 5.2.3.4.

Figure 5.2.3.3 Measurement of Q angle using a long arm goniometer with a subject standing on foot template (Baumann et al., 1982).

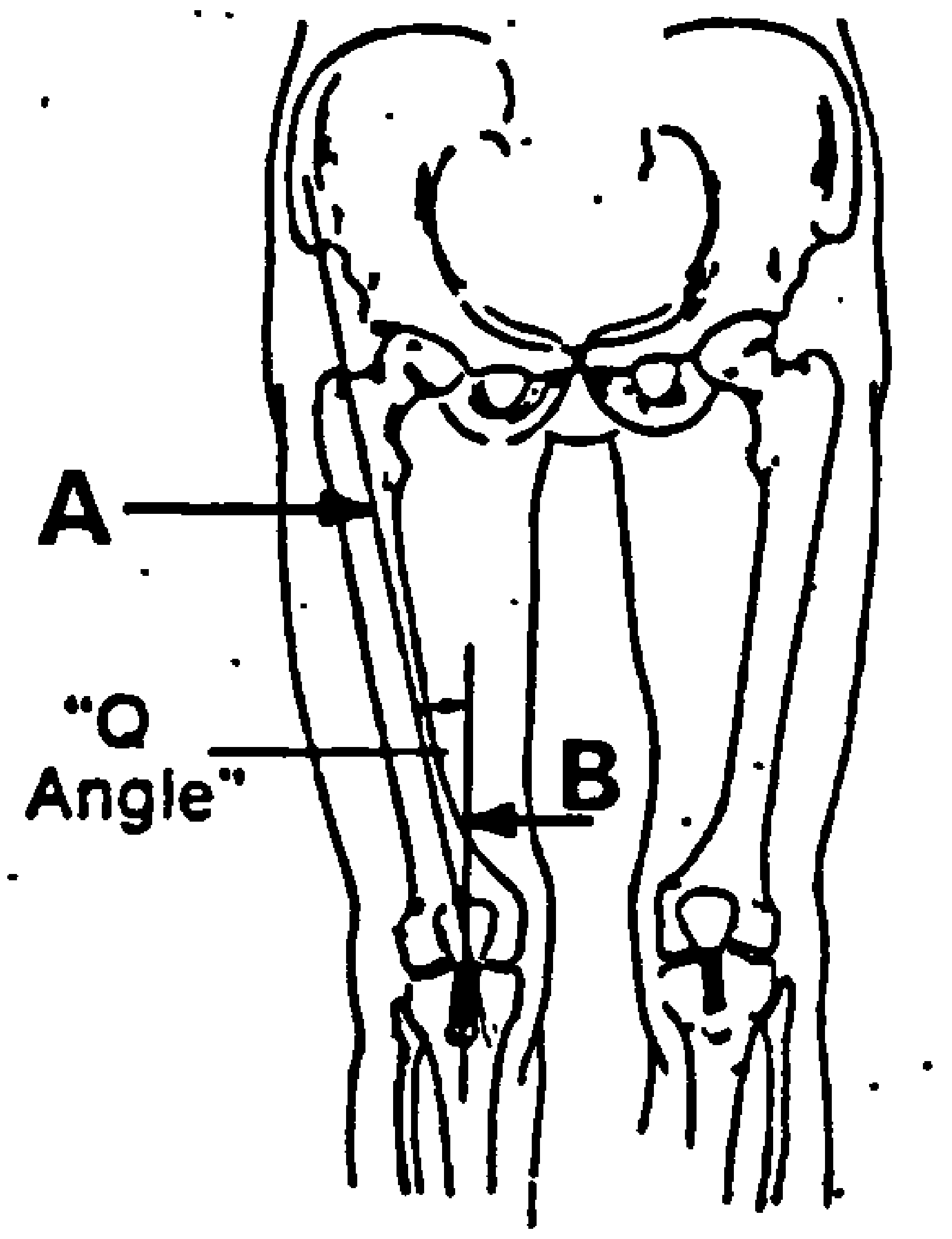

Figure 5.2.3.4 Diagrammatical representation of Q angle measurement (A = line of the femur; B = vertical line of the tibial tuberosity)

The correlation matrices for the fifteen alignment characteristics, as highlighted in Table 5.2.3.3, for the injured and non injured groups were obtained. A number of significant correlations were noted for both groups. These correlations were centered around the relationships between the lower leg measurements, on both sides of the body, and included significant correlation values for trochanter distance and leg length with significant values ranging from 0.49 to 0.52 ($p<0.05$); femur length and inner femoral condyle distance (significant r values ranging from 0.45 to 0.62; $p<0.05$); femur length and outer femoral condyle distance (significant r values ranging from 0.48 to 0.52; $p<0.05$); and femur length and medial malleolus distance (significant r values ranging from 0.53 to 0.57; $p<0.05$).

Differences between the groups for significant correlations was also noted. The differences between the groups are highlighted in Table 5.2.3.3.

Table 5.2.3.3 Correlation coefficients for the non-injured student dance group for different alignment characteristics as compared to the injured group.

Alignment Characteristics		r value
Outer femoral condyle distance and leg length	(R)	0.57*
	(L)	0.58*
Medial malleolus distance and leg length	(R)	0.58*
	(L)	0.57*
Inner femoral condyle distance and ASIS distance		-0.63*
Left trochanter to malleolus distance and outer femoral condyle distance		0.55*
Trochanter to lateral malleolus distance and	(L)	0.53*
Medial malleolus distance	(R)	0.56*
Right trochanter to femoral condyle distance and right femoral condyle to lateral malleolus distance		0.47*
Medial malleolus distance and Q angle	(L)	-0.39*
Medial malleolus distance and inner femoral condyle distance		0.76*
Trochanter to lateral malleolus distance and trochanter distance	(L)	0.54*
	(R)	0.60*
Left femoral condyle to lateral malleolus distance and trochanter to lateral malleolus distance	(L)	0.73*
	(R)	0.73*
Right femoral condyle to lateral malleolus distance and left trochanter to lateral malleolus distance		0.73*

* denotes significant correlation, $p<0.05$

Table 5.2.3.3 illustrates the significant correlation coefficients between the alignment characteristics for the non-injured group which were different to the injured group. From the table it can be seen that right and left leg length is positively related to the distance between the inner femoral condyles, so the distance between the outer femoral condyles are positively related ($r = 0.57$ and $r = 0.58$) as is the distance between the medial malleoli ($r = 0.58$ and $r = 0.57$). It was further noted that a negative relationship existed between the inner femoral condyle distance and the left and right anterior superior iliac spine (ASIS), $r = -0.63$. A similar negative relationship was shown to exist between lower leg length (right femoral condyle to right lateral malleolus) and the upper leg length (right greater trochanter to the right femoral condyle; $r = -0.47$).

Table 5.2.3.3 also illustrates the alignment characteristics for the injured group which produced different significant correlations when compared to the non-injured group. A significant negative correlation coefficient ($r = -0.39$; $p<0.05$) was obtained between the medial malleolus distance and the left Q angle which suggests that as the distance between the medial malleoli increased so the Q angle as measured on the left leg decreased. A positive correlation ($r = 0.76$) was noted between the medial malleolus distance and the distance between the inner femoral condyles. Additionally, significant positive correlations were also noted for the distance between the greater trochanters and the left and right trochanter to lateral malleolus distances, $r = 0.54$ and $r = 0.60$ for left and right respectively. This suggests that an increase in lower limb lengths will normally correspond with an increase in hip width.

5.2.4 Discussion

Correct body position and alignment are imperative for aesthetic appearance and for technical precision when performing in all forms of dance. Both of these factors are important components of dance and as a result student dance teachers are required to be competent in these components across a number of dance styles. An incorrect body position or a malalignment of the lower extremity may not only present an inadequate and unbalanced appearance and a technically poor completion of the movement, but can also lead to injury through over compensation of the malalignment by the musculo-skeletal system.

Genu valgum (knock kneed) and genu varum (bow-legged) have been reported as malalignments of the lower extremity and as such may predispose an individual to injury (Solomon et al., 1990; Whiting and Zernicke, 1998). In terms of orthopaedic alignment, as measured by the present study, genu valgum may be characterised by a wider pelvis (greater ASIS distance) and a small inner femoral condyle distance leading to a larger 'Q' angle. Conversely genu varum could be characterised by a smaller pelvis, a greater distance between the inner femoral condyles leading to a smaller 'Q' angle, and a greater distance between the medial malleoli. However, if this was the case, it is possible that significant differences would be apparent between the injured and non-injured groups. Although the injured group had a smaller pelvis, a greater distance between the inner femoral condyles and medial malleoli, the Q angle was slightly smaller. Additionally no significant differences were recorded for Q angle, ASIS distance, inner femoral condyle distance or medial malleoli distance between the groups.

the placement of the feet to the position of the head and arms. The ability to maintain the lines through the body is imperative for technical and aesthetic precision. The movements are preformed across a variety of musical rhythms and tempos which continually challenge the dancer to move smoothly from posture to posture.

The modern dance forms such as jazz and contemporary have taken many of the ballet actions and postures and relaxed them to provide a more fluid look to the movement. The body's torso is often not as rigid as a ballet posture and the styles are characterised by sharp quick movements and steps, in jazz, or slower more fluid movements in contemporary dance. These movements often revolve around a 'motif' or a set pattern or sequence of movement which is repeated regularly throughout the choreography (Rimmer et al., 1994). The choreography can also involve 'floor work' were the dancer falls to the dance floor and performs a choreographed sequence of movements. Similar to ballet these modern dance styles and their movements are performed across a wide variety of musical tempos and rhythms.

Traditional folk or ethnic dance styles have originated over hundreds of years reflecting the development of a culture within a country. One of these styles is that of African Caribbean which has its origins in south west Africa but was then influenced by the musical rhythms of the people of the West Indies following the movement of slaves around the world (Adshead-Lonsdale and Layson, 1994). This ethnic dance style has a strong rhythm and a tribal dance movement pattern reflecting the nature of hunting and war between tribes in west African culture. The movement is characterised with strong flat footed stamping steps with a low body posture similar to a squat position. Each movement is deliberate and represents assertive, aggressive and

Reigger-Krugh and Keysor (1996) reported that excessive genu valgum resulted in the quadriceps being less effective as a knee extensor. This was due to an alteration in the direction of pull of the quadriceps tendon on the patella. The patella would be pulled laterally rather than proximally causing patella subluxation and injury would result due to an alteration in joint loading dynamics and pressure distribution about the knee. Similarly genu varum is due to excessive lateral displacement of the tibia in the frontal plane and, although the inner femoral condyles would not necessarily be abnormally any further distance apart, the 'bowleggedness' of the tibia would produce excessive lateral displacement of the patella and lead to an alteration in joint load dynamics about the knee.

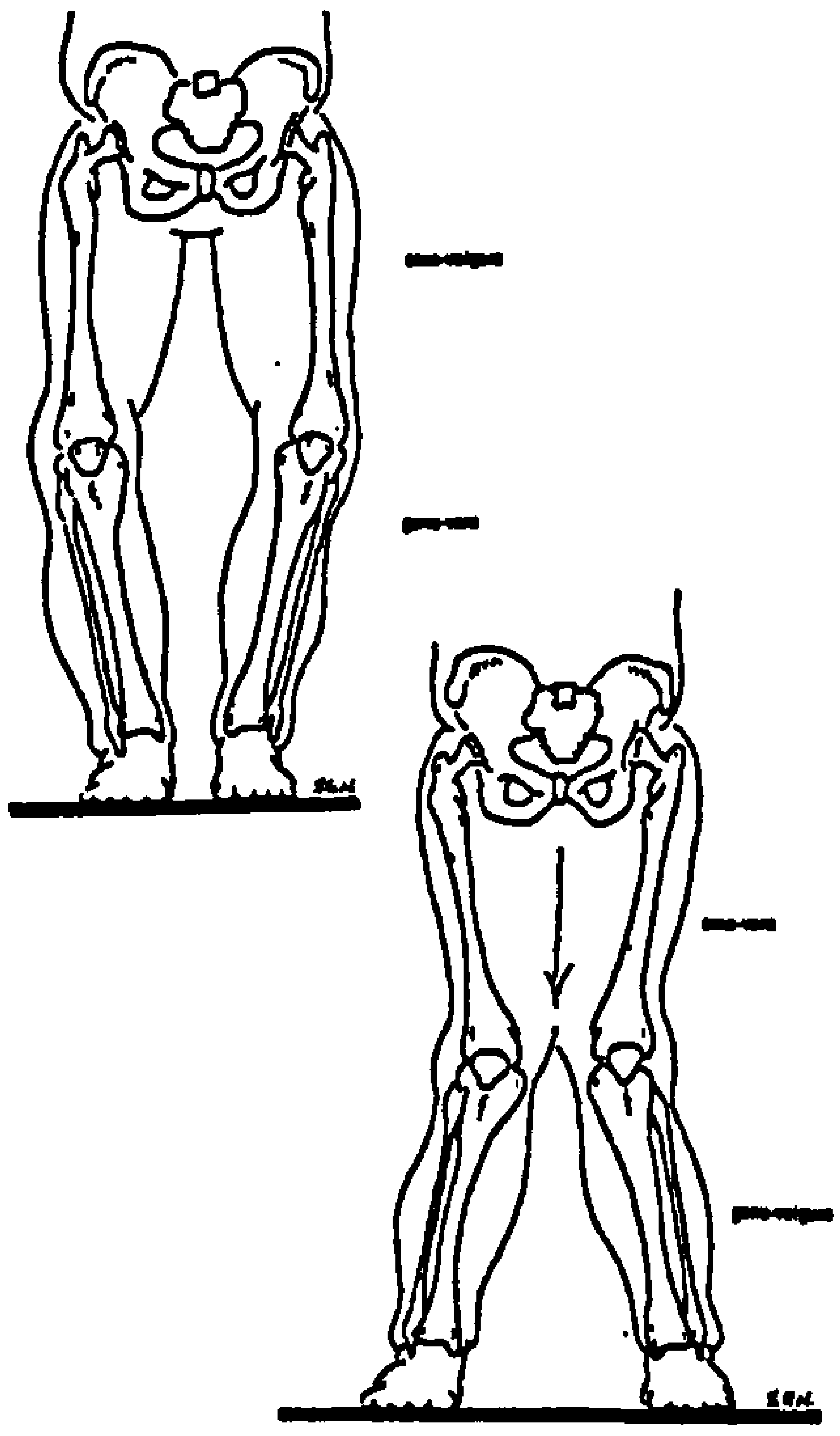

Figure 5.2.4.1 Diagrammatic representation of genu valgum (knock kneed) and genu varum (bow legged) (Palastanga et al., 1994).

The subluxation of the patella, due to these abnormalities, influences the magnitude of the 'Q' angle. The 'Q' angle is the angle between the line joining the anterior superior iliac spine to the insertion of the quadriceps tendon on the patella, and the line joining the distal end of the patella tendon to the tibial tuberosity (Baumann et al., 1982; Palastanga et al., 1994). This is shown diagrammatically in Figure 5.2.4.2. The lateral displacement of the distal end of the patella tendon, in both genu valgum and varum, increases the angle adjoining the line of the femur and hence a greater 'Q' angle. This larger angle can reduce the knee joint contact area and therefore the forces going through the knee joint have to be dissipated by a smaller area leading to a smaller margin of error in terms of injury prevention. Also, because of this smaller area for force dissipation, and the excessive joint contact pressures associated about the knee, it may be that the joint is incapable of absorbing shock or degenerates over time in its ability to do so (Nisonson et al., 1984; Macera et al., 1989; Hennig and LaFortune, 19911; Palastanga et al., 1994)

From the data in Table 5.2.3.2 the 'Q' angle of the injured dancers (18.1 degrees for left and right) is larger, but not significantly larger, than that of the non-injured group (17.9 and 17.3 degrees for right and left respectively). Bennell et al. (1999) reported that a 'Q'angle of greater than 15 degrees was associated with a 5.4 times greater risk factor of a stress fracture in the lower limb. However this 15 degree angle was only reported as an arbitrary value and specific to the sample from which it was recorded. The 'Q'angle may well be reflective of a wider ASIS distance (Neely, 1998a). However in this case the injured dancers have a smaller ASIS distance of 22.7cm when compared to the non-injured group with a distance of 24.2cm. Again the difference is not significant. It would therefore seem that the potential link between the 'Q'angle and ASIS distance is inaccurate for the female student dancers used in this study. A possible explanation for this, i.e., a larger 'Q' angle with a smaller ASIS distance, may be that the lateral subluxation of the patella is due to a pronounced bow-legged or knock-kneed lower limb alignment and therefore affects the 'Q' angle. Therefore the size of the 'Q' angle may not only be dependent on the ASIS distance but may also be dependent on the alignment of the lower aspect of the leg.

Riegger-Krugh and Keysor (1996) reported correlated postures and compensatory mechanisms associated with malalignments. In terms of the effect of genu valgum (knock knees), associated postures included excessive subtalar pronation and ipsilateral excessive hip internal rotation. For genu varum (bow-legged) the authors highlighted subtalar supination and ipsilateral hip external rotation as aspects associated with the alignment. From the data collected on the female student dance teachers the identification of excessive subtalar pronation or supination could be linked to the distance between the medial malleoli. The alignment characteristics were recorded whilst the subjects were standing on a template with the heels 25 cms apart and the feet at 5 degrees of external rotation. Pronation or supination could be identified as deviation from the 25 cm template. The data in Table 5.2.3.2 shows that the distance between the medial malleolli is 18.4 cm and 16.7 cm for the injured and non-injured groups respectively. This suggests that the injured group had a tendency to display subtalar supination. This associated posture is concomitant with genu varum (bow-leggedness) which is also linked to a larger 'Q'angle through the lateral subluxation of the patella. From the present data, the 'Q' angles of 18.1 and 17.3/17.9 degrees are greater than the arbitrary data reported by Bennell et al. (1999) for injury risk. However from the data (Table 5.2.3.2) the injured dancers have a more pronounced knock kneed effect. This is characterised by a large medial malleoli distance relative to the inner femoral condyle distance. The literature suggests that the associated postures with genu valgum are excessive subtalar pronation, lateral patella subluxation and excessive ipsilateral hip internal rotation. Therefore the dancers are displaying alignment characteristics representative of both types of malalignment. It is therefore difficult to draw precise and adequate explanations between the presented data and the explanations given in the literature. This limitation may be due to the method employed for collecting the data and specifically the template from which the student dancers were measured.

A tenuous explanation could be based around compensatory mechanisms reported by Riegger-Krugh and Keysor (1996). One of the compensatory motions associated with genu varum is that of subtalar pronation, i.e. forcing adduction of the medial malleoli. This permits the medial aspect of the heel to contact the ground. In the present study it could be argued that the non-injured group have managed to adopt this compensatory motion, represented by a smaller medial malleoli distance, and hence reduce the risk of injury, when compared to the injured group. If the injured subjects had malalignment defined as genu valgum then excessive subtalar pronation could be identified from the orthopaedic alignment measurements as a smaller medial malleolli distance than that recorded for the non-injured group. In the present study this is not the case. However Reigger-Krugh and Keysor (1996) have suggested that geun valgum may be compensated by excessive subtalar supination to allow the lateral aspect of the heel to contact the ground. In the present study it would seem that the injured group have adapted to this compensatory mechanism and hence may have influenced the reported alignment results. This may be a result of the injury (McNeal et al., 1990) and as such highlights the limitations of the use of cross-sectional data to study what may be a problem over time. At present no data exists on alignment characteristics for an athletic population or a female population, it is therefore difficult to assume cause-effect relationships without 'normal' alignment data.

A further alignment characteristic, not obviously apparent from the data presented in Table 5.2.3.2, is the horizontal distance between the vertical line drawn from the medial malleoli and the vertical line drawn from the inner femoral condyle. The average distance, between these two lines, for the injured group was 7.5 cm compared to 5.7 cm for the non-injured group. Although these differences were not significant, and are dependent on the height and standing position of the subject this may have implications for the dissipation of force during impact activities. A larger proportion of the vertical force associated with the impact is not actually dissipated through the bones of the lower leg but through the lateral ligaments of the ankle joint. This may predispose the dancer to ligamentous injury in the form of a sprain about the ankle. This alignment is possibly another indicator of a more pronounced genu valgum effect.

Although no significant differences between the injured and non injured dance groups were noted, significant correlations were found between a number of the alignment characteristics for both groups. Differences in the correlations were also noted between the two groups.

The similar significant correlations, between the groups, were predominantly related to lower leg lengths and specifically between total leg length and upper (femur) and lower leg (tibia) lengths. These results were not unexpected. Similar positive correlations were noted between femur length (greater trochanter to outer femoral condyle distance) and the distance between the inner and outer femoral condyles. This suggested that as the femur length increased then the distance between the left and right inner and outer femoral condyles increased.

A number of different significant correlations, between the groups, were also recorded. These have been highlighted in Table 5.2.3.3. The non injured dancers produced significant positive correlations between leg length and outer femoral condyle distance and medial malleoli distance. The increase in leg length would correspond with an increase in height of the dancer and therefore the increase in distance between the body landmarks could possibly represent proportional differences based on height differences. However this was not apparent in the injured group where no significant correlations were found between leg length and the femoral condyle or malleolus distances. If these distances did not increase proportionally then this would imply a greater Q angle in the injured dancers which has been reported in the literature as a contributing factor to the onset of injury. However in the present study both groups had similar Q angle values.

In the injured group the Q angle on the left side of the body produced a negative correlation with the distance between the medial malleoli ($r = -0.39$; $p<0.05$). This was interpreted as the distance between the medial malleoli increased so the left Q angle decreased. Based on the sports medicine literature if this was the case then by decreasing the Q angle this would decrease the chances of the onset of injury. Linked to that was the negative correlation found between the inner femoral condyle distance and ASIS distance for the non injured group of dancers (r = -0.63). This suggests that as the distance between the inner femoral condyle increases so the dancer has a potentially smaller pelvis as measured between the anterior superior iliac spines. It could be interpreted as a dancer, smaller in stature, would have a correspondingly smaller pelvis and so reduce the Q angle and reduce the risk of the onset of injury. Smaller dancers could therefore display better orthopaedic alignment in terms of lower limb alignment. However it could also be interpreted that the foot template is better suited to the smaller dancer in that it is a more natural or normal standing position. No normative data, or reported data in other sport or exercise disciplines exist, it is therefore difficult to compare the present results and the suitability of the template.

The above points have highlighted the potential relationship between malalignment and injury in female student dance teachers. As mentioned previously no normative data presently exists to draw a conclusive cause effect relationship and it is therefore impossible to comment, via comparison, on the degree to which the injured dancers were poorly aligned. Furthermore the reported data is not consistent with the interpretation of alignment reported in the literature. This may also be a limitation reflective of the interpretation for alignment in student dancers based on the measurements taken using the foot template and the foot template itself. Although Baumann et al., (1982) advocates the use of the template, specific to female subjects, there is limited evidence of the template being reported elsewhere (Percy and Strother, 1985).

The template ensures that all subjects, irrespective of height, stand in a similar manner with heels 25 cm apart and feet in 5 degrees of external rotation. This may not be reflective of normal stance for an individual dancer and adjustments may have had to be made in order to remain within the parameters of the template. It is possible that these adjustments may have influenced the measurements in terms of the dancer compensating for a potentially awkward standing position. These adjustments could have influenced the distance between the medial malleoli and the inner femoral condyles and either magnified or hidden an alignment variation, inherent in the dancer, noticeable only from a normal relaxed standing position. If this was the case then any potential explanations highlighting links between orthopaedic alignment and injury would be erroneous. Additionally the lack of any significant differences between the groups could also be as a result of the template not reflecting a normal standing position for the dancers. It may be that the present method, adhered to through the use of the template, is inadequate and not specific to individual variations in height and normal standing posture. Therefore it is important to stipulate that the results obtained are relative to the foot template reported and in doing so may provide a limitation to the degree to which the data could be interpreted

The protocol for orthopaedic alignment has enabled data to be obtained on the lower limb for female student dance teachers. An injured student dancer tends to demonstrate characteristics reflective towards malalignment. These factors include a larger Q angle, a smaller ASIS distance but a correspondingly larger trochanter distance. The model further highlights a greater distance between the medial malleoli and a larger inner femoral condyle and outer femoral condyle distance. Although the orthopaedic measures were not significantly different between the injured and non-injured groups of student dancers, it is the relative distance of the anatomical landmarks to each other that contribute to malailgnment. That is, the Q angle relative to ASIS distance and the medial malleoli distance relative to the inner femoral condyle distance. These factors contribute to alignment and the onset of injury and have been highlighted in the model.

5.2.5 Conclusion

The aims of the study were to quantify lower limb alignment characteristics in student dance teachers and identify significantly different alignment characteristics between injured and non-injured student dancers. The data suggest that student dancers are knock kneed (genu valgum) which is characterised by a small inner femoral condyle distance, large ASIS distance and a correspondingly large Q angle. The literature also reports that excessive pronation is a characteristic of genu valgum but this was not found in the present study.

Although no significant differences were recorded between the alignment characteristics for injured and non-injured dancers, the injured dancers tended to demonstrate a larger Q angle, longer lower limbs, smaller ASIS distance and a larger inner femoral condyle distance, the later alignment characteristics of which contradict the published literature. It was suggested that these differences could be the result of a compensatory mechanism but where more likely to be due to adjustments made whilst standing on the foot template. The correlation analysis between the alignment characteristics provided data suggesting that the non injured student dance group were more in proportion in terms of the corresponding increases and decreases of lower limb lengths and their relationship with outer femoral condyle distance, medial malleoli distance and ASIS distance. These characteristics where not apparent in the injured group. Based on this, the hypothesis was rejected as there were no significant differences between the injured and non injured student dancers.

5.3 STRENGTH CHARACTERISTICS OF STUDENT DANCE TEACHERS

5.3.1 Introduction

In a dance performance, dancers have to execute the same movements over the course of a 2-3 hour period, with short rest intervals. Dynamic movements, such as jumping and leaping, must be performed as effectively and accurately at the end of the performance as at the beginning. Therefore dance movements require a high level of muscular strength of the lower extremities as well as muscular endurance.

Skeletal muscle has two main functions. Firstly to attenuate and dissipate forces applied to the body during movements, and secondly, to generate force, via concentric and eccentric muscle actions, in order to perform movement (Bennell et al., 1999). Therefore muscle weakness could predispose the performer to injury as a direct result of impact or inadequate technical ability. It has been suggested that dance injuries are a result of faulty technique (Howse and Hancock, 1992).

Reported measurement of strength in dancers is limited to pre-professional and professional specialist dancers. Mostardi et al. (1983), Kirkendall et al., (1984) and Micheli et al. (1984) reported values for lower extremity strength measures, whilst Kuno et al. (1996) reported values for upper extremity strength measures. These authors reported the values from isokinetic dynamometry. This method is reported as being both effective and accurate for highlighting strength imbalances between and across muscle groups, however it is expensive and requires a period of familiarisation to obtain reliable results (Coldwells et al., 1994). The ability to reliably measure leg and back strength in a familiar setting with minimum equipment training required on behalf of the dancer would be beneficial. The use of a portable leg and back strength dynamometer has been suggested as a reliable method for strength measurement (Coldwells et al., 1994). The use of a grip strength dynamometer has also been suggested as a method of assessing strength and as an indicator of overall body strength (Spijkerman et al. 1991). This type of measurement tool and procedure records the isometric strength of the individual. Although dance movement requires eccentric and concentric muscular contractions, in the context of dance, isometric strength is also important as this demonstrates the ability of the dancer to control a posture or hold a movement in the technical manner required within a dance movement pattern. A measure of isometric strength would therefore provide an adequate estimation of muscular strength specific to a dancer and the movements required within a student dance teacher environment.

The aims of this study were: (1) to quantify leg, back and grip strength as a measure of overall body strength, in student dance teachers; and (2) compare the strength measurements between injured and non-injured dancers.

Hypothesis 4: The strength profiles of the injured dancers will be smaller than the non-injured group in the three strength measures.

5.3.2 Method

5.3.2.1 Subjects

A total of forty six female student dance teachers volunteered for the study. Twenty eight student dance teachers had a history of dance related injury (age = 20.4 ± 4.2 years; mass 58.4 ± 8.8 kg; height = 161.1 ± 6.2 cm; dance experience 12.6 ± 4.9 years), and eighteen student dance teachers had no history of dance related injury (20.3 ± 3.6 years; 55.4 ± 6.4 kg; 158.8 ± 5.0 cm; 12.6 ± 3.8 years). All the dance students gave informed consent for participation in the study. The subjects were currently performing in a number of dance styles and were not undergoing any specific strength conditioning programme.

5.3.2.2 Procedure

The subjects were asked to warm-up and stretch prior to undergoing the strength tests. The warm-up involved a fifteen minute cycle, on a cycle ergometer, at a pace determined by the subjects. During this time the subjects were informed of the exact procedure. Following the warm-up the subjects then followed a series of stretches similar in nature to those undertaken prior to a dance class. Three strength measures were then taken, which included grip strength, back strength and leg strength. Grip strength was measured, on both hands, using a Takei grip dynamometer, with both leg and back strength being measured using a portable Takei dynamometer. Protocols for the measurement of the strength components were based on Coldwells et al. (1994) and Spijkerman (1991) for the back and leg strength and grip strength respectively.

Leg and back strength were assessed using a Takei dynamometer. Subjects stood on the foot plate, which was 15 cm from a wall, with the scapulae and buttocks positioned flat against the wall. For leg strength a fluid filled goniometer was placed 10 cm above the patella and zeroed. Subjects flexed the legs, sliding down the wall until the leg extension angle equalled 135 degrees. Subjects then reached down with the elbows fully extended. The pull-bar of the dynamometer was placed in the hands and the chain length was adjusted appropriately. Subjects were instructed to extend the legs with maximal effort, pulling the bar simultaneously without 'jerking'. The highest score from three pulls was recorded (Figure 5.3.2.2.1).

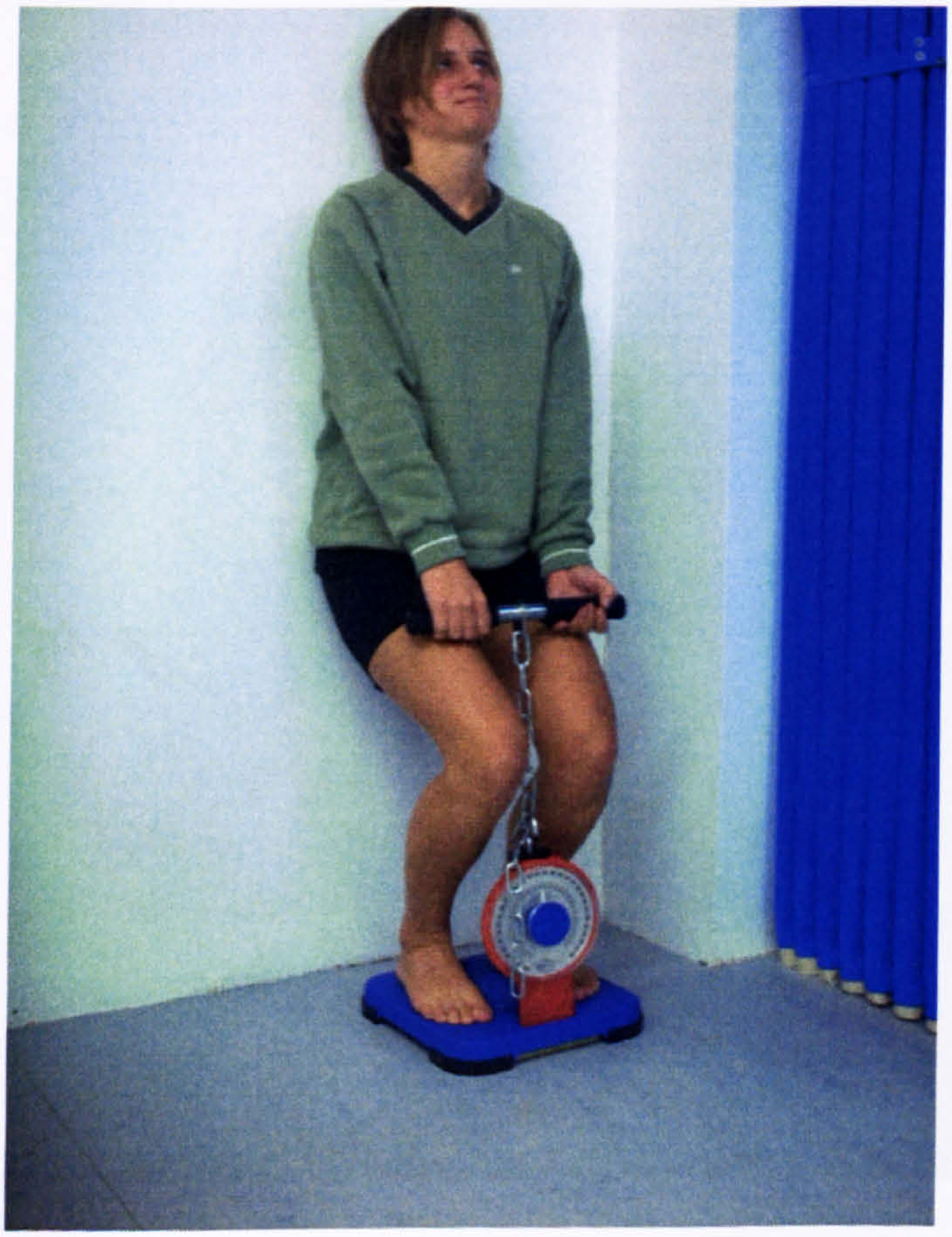

Figure 5.3.2.2.1 Measuring leg strength using the leg and back dynamometer

For back strength the same starting position was required as in the leg strength, with the legs straight and the scapulae and buttocks pressing against a flat wall. The legs were, this time, kept straight and the back was flexed. Flexion continued until, with fully extended elbows, the tips of the index fingers reached the patellae. The pull bar was then placed in the hands and the chain length adjusted. A reverse grip was adopted for the measurement to deter the use of shoulder muscles during the 'pull' (Coldwells et al., 1994). Subjects were also instructed to keep the head up during measurement. The highest score from three pulls was recorded (Figure 5.3.2.2.2).

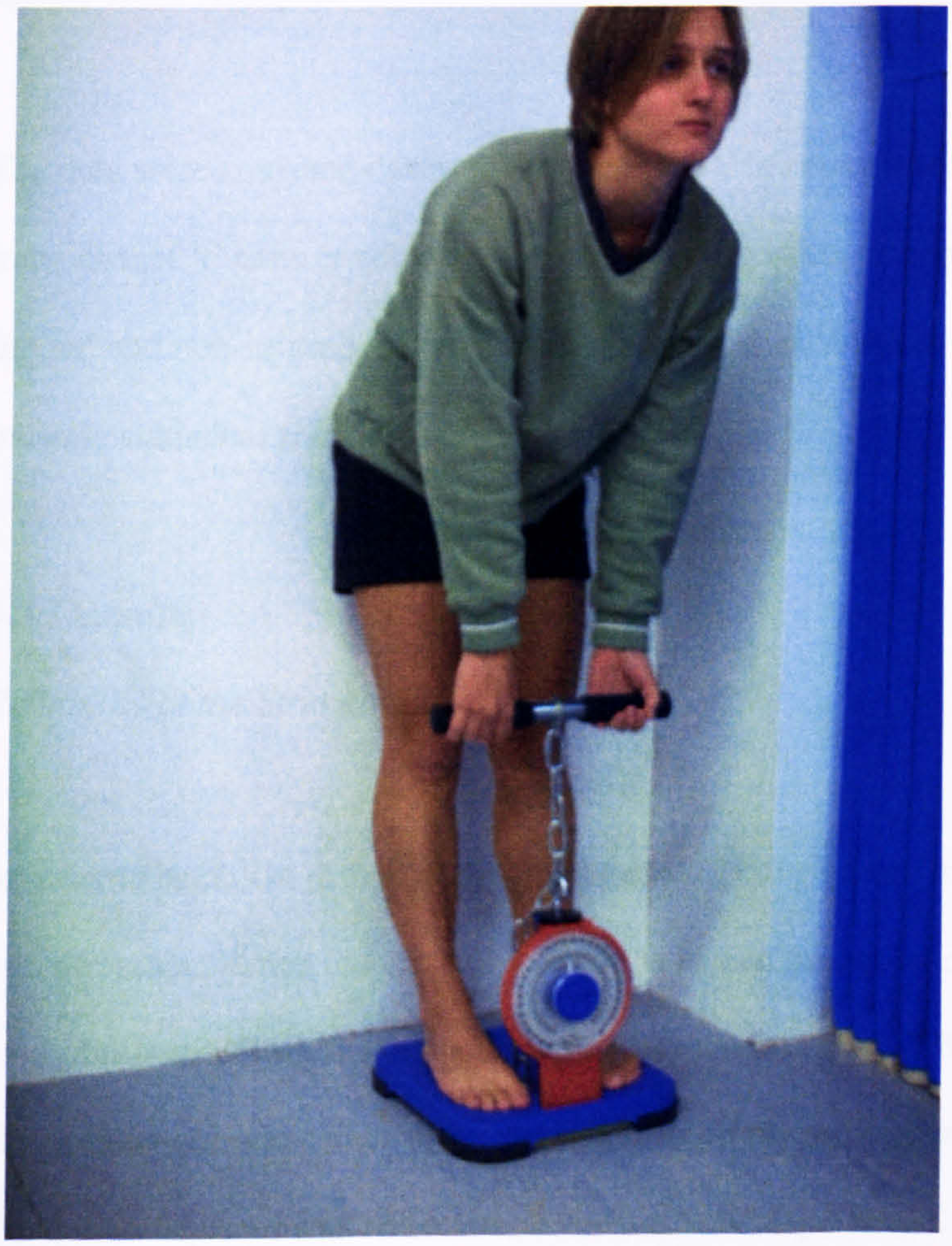

Figure 5.3.2.2.2 Back strength measurement using the leg and back dynamometer

Grip strength was assessed using a hand dynamometer. The subjects were instructed to sit in a comfortable but upright manner. The hand grip was adjusted for comfort by the subject, an acceptable method as suggested by Bohannon (1991). The subjects were then asked to flex their arm to 90 degrees and then gradually squeeze the grip up to a maximum effort. The highest score from three grips was recorded. The method was then repeated for the other hand. An example of the data collection sheet, for all strength and kinanthropometric measures, is shown in Appendix 3.

5.3.2.3 Data Analysis

The data were analysed descriptively and a profile constructed. Further analysis, using independent 't' tests enabled a comparison of the strength components between the injured and non-injured subjects to be obtained. A probability of $p<0.05$ was taken to indicate statistical significance.

5.3.3 Results

Reliability of the Strength Data

In order to establish the reliability of the data obtained from the strength protocols a female student dance teacher volunteered to repeat the protocols for each measurement on two separate occasions. The student gave informed consent and a total of two complete data sets were recorded on the strength measures for the dancer. The reliability data was collected on two separate days with a 7 day interval between the two testing sessions. Reliability analysis of the data were examined using limits of agreement (Bland and Altman, 1986). A dependent t test was used to determine if any large systematic bias existed between the data sets. Results from the dependent t test indicated no significant difference (t= 1.56; p>0.05) between the data sets. The limits of agreement were recorded as 4.67 ± 4.7 N (mean of the differences ± (1.96 x SD of differences)). This suggests that a leg strength measure of 646.9 N would have 95% limits of agreement ranging from 642.2 N to 651.6 N.

Although this statistical reliability technique is recommended for this type of data (Bland and Altman, 1986) there are no published reliability data from which comparisons can be made. In the context of female student dance teachers it was suggested that the method employed for estimating leg, back and grip strength was reliable.

Table 5.3.3.1 shows the data collected on the strength characteristics (Newtons), displayed as a whole data set and as separate injured and non-injured groups. The non-injured subjects displayed higher back strength values than the injured subjects, however this trend was reversed in the leg strength. A large standard deviation between the subjects can be seen for both groups for leg and back strength. It was noted that the standard deviation was greater for the non-injured dancers across the leg and back strength measurements. This trend was reversed for the grip strength measures.

The independent 't' test revealed no significant differences (p>0.05) between the strength characteristics of the injured and non-injured groups. A similar test was then performed on the normalised data. This data was corrected for bodyweight and height and produced strength to weight (N kg^{-1}) and strength to height (N m^{-1}) ratio values.

The ratio values are shown in Tables 5.3.3.2 and 5.3.3.3. No significant differences were noted between the injured and non-injured groups for the normalised data.

Table 5.3.3.1 Mean and standard deviation (s) of the strength components for the student dance teachers.

Strength component		All subjects (n=46)	Injured (n=28)	Non-injured (n=18)	t value
Back (N)		519.2 (163.3)	506.4 (145.0)	539.0 (191.2)	0.67
Leg (N)		646.9 (198.0)	684.1 (187.3)	589.1 (205.6)	1.60
Grip (N)	(R)	241.2 (38.2)	247.5 (39.3)	231.4 (35.3)	1.41
	(L)	229.5 (42.8)	235.4 (46.3)	220.4 (36.0)	1.17

Table 5.3.3.2 Strength to weight ratio ($N\ kg^{-1}$), for the strength measures, for the student dance teachers

Strength ratio component		All subjects (n=46)	Injured (n=28)	Non-injured (n=18)
Back ($N\ kg^{-1}$)		9.1 (3.0)	8.7 (2.3)	9.9 (3.9)
Leg ($N\ kg^{-1}$)		11.4 (3.7)	11.8 (3.3)	10.8 (4.1)
Grip ($N\ kg^{-1}$)	(R)	4.1 (0.8)	4.3 (0.8)	4.0 (0.7)
	(L)	4.3 (0.8)	4.1 (0.8)	4.2 (0.7)

Although the data reported in the tables was non significant, in terms of the differences between the injured and non-injured group, it is interesting to note how the individual group measures compared to the whole sample group (n=46). For the back and leg strength measures the injured group recorded scores less than the whole sample mean for back strength but greater than the whole sample mean for the leg strength. This trend was not apparent for the grip strength scores. The non-normalised data collected on grip strength (Table 5.3.3.1) produced strength measures greater than the whole sample mean for the injured dancers, both left and right, whereas the non-injured group scores were less than the whole sample mean. This suggests that in terms of a strength profile the injured group had weaker back musculature than the non injured group, but consistently greater leg strength musculature than the non injured group.

Table 5.3.3.3 Strength to height ratio (N m^{-1}) for the student dance teachers

Strength ratio component	All subjects (n=46)	Injured (n=28)	Non-injured (n=18)
Back (N m^{-1})	324.2 (101.8)	313.4 (85.1)	341.0 (124.3)
Leg (N m^{-1})	404.3 (123.3)	424.4 (114.6)	372.2 (132.7)

5.3.4 Discussion

Dynamic movements, common in many sports and dance, require a high level of muscular strength, particularly in the lower extremities. This level of muscular strength has two functions, firstly to dissipate the forces associated with impacts and also to generate force for movement. If there is muscle weakness around any joint, of a dancer, then the execution of a movement may be inadequate resulting in faulty technique and injury. Therefore muscle weakness could predispose the dancer to injury.

Little data is available on the use of the portable leg-back dynamometer for recording leg and back strength. Bale et al. (1985) reported values of 329.6 N, 297.2 N and 764.2 N for right grip, left grip and back strength respectively. These values are up to 32% larger (back strength) than the scores reported in Table 5.3.3.1. This difference may have been due to the nature of the class, i.e. strength and conditioning programme in that the subjects used were enrolled in a total body fitness class.

Creagh (1996) reported grip and leg strength values using similar methods and equipment for three groups of female athletes. These groups were successful orienteers (n=12), less successful orienteers (n=13) and a control group (n=20) of female student sports participants. Grip strength values were reported in the range 266.8 N – 312.9 N for the successful orienteers to the control group respectively. Leg strength values were in the range 1027.1 N –1293.9 N for the control group and the less successful orienteers respectively. These values are considerably higher than the strength measures reported in Table 5.3.3.1, however this may be due the body mass and height characteristics of the orienteers who were on average taller (166.7 cm) and heavier (63.4 kg) than the dancers in the present study.

In a similar study Doggart et al. (1996) compared a number of characteristics, including leg, back and grip strength, between a group of female student dancers (n=13) and a group of female student sports participants (n=19). The equipment used and methods employed were similar to those used in the present study. The mean reported strength measures, for the female student dancers, for grip, back and leg strength were 237 N, 536.5 N and 602.2 N respectively. These values compare favourably to the present study although the whole sample group (n=46) had a reduced back strength measure (3.2%) and an increased leg strength measure (6.9%). The authors further reported that when the data was normalised for body weight and height significant differences ($p<0.05$) in all strength measures was noted between the dancers and non-dancers with the non-dancers being significantly stronger in all strength measures.

Based on the above studies it would seem that the female student dancers, as a whole, are weaker than their female sports participant counterparts. As was described in Chapter 4, the intensity, duration, frequency and associated mechanical stress of the actions involved in dance could be comparable to those present in common sports. Nicholas (1975) and Hamilton et al. (1992) suggested that the physical demands of classical dance was equal to that of a professional American footballer in terms of the level of exercise intensity and the intermittent nature of the physiological profile. The intermittent physiological profile, for student dancers, was illustrated in Chapter 4. Therefore it could be assumed that the relative strength patterns (strength/weight ratios) of dancers would reflect the physical endeavour. In the present study this does not seem to be the case. Therefore the dancers could be predisposing their bodies to injury through inadequate muscular strength. The musculature of the body not only generates force to perform actions but also attenuates impact forces. If the dancer does not have an adequate strength to weight profile then they not only put themselves at risk of injury through inadequate technique, based on imprecise completion of the action, but also through inadequate musculature to absorb the forces associated with the impact of the actions. Therefore an inadequate strength to weight muscular profile could be a predisposing factor to injury.

Although the strength results do not necessarily demonstrate inadequate musculature, the injured dancers profile, when compared to the non injured dancers, suggests that there may be an imbalance between back and leg strength measures and the height of the dancers. The height of the injured group were, on average, 2.3 cm taller than the non injured group. The strength to height ratio ($N\ m^{-1}$) for the injured group, for back strength, was 313.4 $N\ m^{-1}$ compared top 341.0 $N\ m^{-1}$ for the non injured group. It may be that the strength of the back musculature of the injured group may not be in proportion to the height of the subjects and may impact on the occurrence of injury. This may lead to a greater lower leg musculature to absorb forces on impact rather than dissipate them through the musculature of the whole body. This compensatory mechanism would develop a larger lower limb musculature and hence a larger strength to height ratio for leg strength, a characteristic illustrated by the injured dancers. This imbalance between strength to height ratio of the back and leg may predispose the dancer to injury.

There are two possible reasons why dancers may have inadequate strength characteristics. Firstly it may be that the dance degree programme does not incorporate a specific resistance training regimen in the dance class. Due to time constraints and the demands of the degree programme it may be that the tutors do not have time to develop this component and therefore rely on the involvement and intensity of the dance class to provide the necessary muscular development. Secondly there is the importance of the aesthetic line and dancer appearance during performance. It may be that muscle bulk is not aesthetically pleasing during dance performance and as such the tutors have been reluctant to develop or promote the importance of this.

5.3.5 Conclusion

The aims of this study were twofold. The first aim was to quantify strength characteristics in student dance teachers. This was achieved through the measurement of grip, back and leg strength. The student dancers recorded strength measures were less, in magnitude, than those values previously reported on a female sporting population (Creagh, 1996, Doggart et al. 1996). It was therefore concluded that student dance teachers had a strength profile specific to dance and smaller in magnitude to other female sports populations.

The second aim of the study was to compare the strength profiles of injured and non-injured dancers. It was concluded that there were no significant differences between injured and non-injured dancers in terms of their strength profile. It was further concluded that the strength to height ratio profiles of the injured dancers were smaller for back strength and larger for leg strength suggesting weaker back musculature than the non injured dancers. In view of the data collected the hypothesis was rejected.

5.4 FLEXIBILITY IN STUDENT DANCE TEACHERS

5.4.1 Introduction

Dance is an aesthetic endeavour which utilises the human body as its prime instrument of expression. Therefore competent aesthetic performance requires support from enhanced physiological capabilities including flexibility. Flexibility can be defined as the range or degree of movement in a joint or in several joints (Bloomfield et al., 1994; Watkins, 1999). In this respect flexibility can be both static and dynamic.

An individual dancer is a composite of many joints with potentially varying ranges of motion therefore flexibility is specific and depends on a number of factors. These factors include joint range of motion (Clippinger-Robertson, 1985), ligamentous laxity (Gannon and Bird, 1999), tightness of muscles, tendons and joint capsules (Bloomfield et al., 1994) and muscle length (Bennell et al., 1999). Therefore the precise role of flexibility in the epidemiology of injury is not definitive. However Gleim and McHugh (1997) suggested that many medical experts believe that flexibility is an important factor, to a greater or lesser extent, in the onset of injury. Alter (1988, 1996) reported that a stretching programme may decrease the incidence, intensity and duration of musculotendinous and joint injury and noted that flexibility training was currently seen as a way of avoiding injuries.

The published research into flexibility and its relationship to injury is inconclusive. The mechanisms reported to account for the relationship are based on the effect of flexibility on the range of motion about a joint and the relationship between flexibility and the elasticity of the musculotendinous units (Bloomfield et al., 1994). Studies on similar samples from the same population have reported conflicting results. Ekstrand and Gillquist (1982) and Ekstrand et al. (1983) in two separate studies on soccer players reported no significant relationship between flexibility and all injury types in 1982, however a year later (Ekstrand et al.,1983) the authors reported a significant relationship between muscle tightness and groin and tendinitis injuries. Research published on dance injuries and flexibility are not quite as conflicting. Knapik et al. (1991) and Reid et al. (1987) reported a significant relationship between hip flexibility, adduction and extension, and injury in that a greater range of motion was positively related to a reduced risk of injury. However Wiesler et al. (1996) found no significant relationships between any type of injury and lower limb flexibility.

As reported by Bennell et al. (1999), studies do not seem to exist linking significant differences in flexibility with reductions in injury. It may be that flexibility alone is not linked to injury but that a combination of flexibility and strength, in the form of a weakness or imbalance of both factors, or specific joint flexibility may predispose the athlete or dancer to injury. There are also differences in the published studies in terms of the type of study used, i.e. prospective, retrospective, the number of subjects used and in the type of flexibility measurements recorded, i.e. dynamic or static. These differences, particularly in the type of flexibility measurements, can greatly affect the results recorded for any joint range of motion. The use of dynamic flexibility incorporates the use of muscular strength to help in the movement of the joint and can therefore influence the joint range of motion either positively or negatively depending on the effectiveness of the muscles involved. However static flexibility isolates the genuine component of elasticity of the muscle/tendon during motion without the aid of the muscular force component. Further, the nature of the flexibility tests in isolating the specific muscle/tendon group, about the joint, are also important in terms of reporting on the specificity of the flexibility test.

There is no universal agreement on the most reliable test protocol or type of measurement (static or dynamic) of flexibility associated with dance (Koutedakis and Sharp, 1999). Dynamic measurement of flexibility involves the assessment of the joint angle during dynamic activity. This may give the best representation of flexibility during a dance movement but relies on the strength of the dancer to control and hold the movement and is often a measure associated with the resistance to the movement being performed (Alter, 1996). Further, this type of measurement is difficult to accurately obtain due to the nature of the protocol required and little research has been published using this type of assessment (Heyward, 1998).

Static flexibility is a measure of the total range of motion at a joint and may be assessed reliably and easily in a field or clinical setting (Jackson and Lanford, 1989; Worrell et al., 1994). Studies on dancers have utilised this technique and protocol as it represents the type of stretching performed pre and post a dance class or performance (Micheli et al., 1984; Ryan and Stephens, 1987; Hamilton et al., 1992). This flexibility technique may permit not only an accurate and valid value for the range of motion of a joint based on the definition of flexibility but may also provide data that is reliable and reflective of the dancer's ability due to its familiarity.

The aims of this study were: (1) to quantify specific flexibility around the joints of the lower extremity in female student dance teachers; and (2) compare the flexibility measurements between injured and non-injured female dancers.

Hypothesis 5: The flexibility profiles of the lower extremities will be different between the injured dancers and non-injured dance groups.

5.4.2 Method

5.4.2.1 Subjects

A total of forty six female student dance teachers volunteered for the study. Twenty eight student dance teachers had a history of dance related injury (age = 20.4 ± 4.2 years; mass 58.4 ± 8.8 kg; height = 161.1 ± 6.2 cm; dance experience 12.6 ± 4.9 years), and eighteen student dance teachers had no history of dance related injury (20.3 ± 3.6 years; 55.4 ± 6.4 kg; 158.8 ± 5.0 cm; 12.6 ± 3.8 years). All the dance students gave informed consent for participation in the study. The subjects were currently performing in a number of dance styles and were not undergoing any specific flexibility conditioning programme.

5.4.2.2 Procedure

A series of static flexibility tests were performed on all subjects. They included the standard back and hip 'stand and reach' test and muscle specific flexibility tests. A total of seven flexibility tests were administered including hamstrings, adductor, quadriceps, hip extension, gastrocnemius, soleus and hip rotation. The flexibility of the muscle groups were measured on both sides of the body. An example of the hamstring and gastrocnemius flexibility test is shown in Figures 5.4.2.2.1 and 5.4.2.2.2 respectively. The tests were carried out following a fifteen minute warm-up on a cycle ergometer and general stretching which was commensurate with stretches as would be performed prior to a dance class.

Figure 5.4.2.2.1 Hamstring flexibility measured with a long arm goniometer.

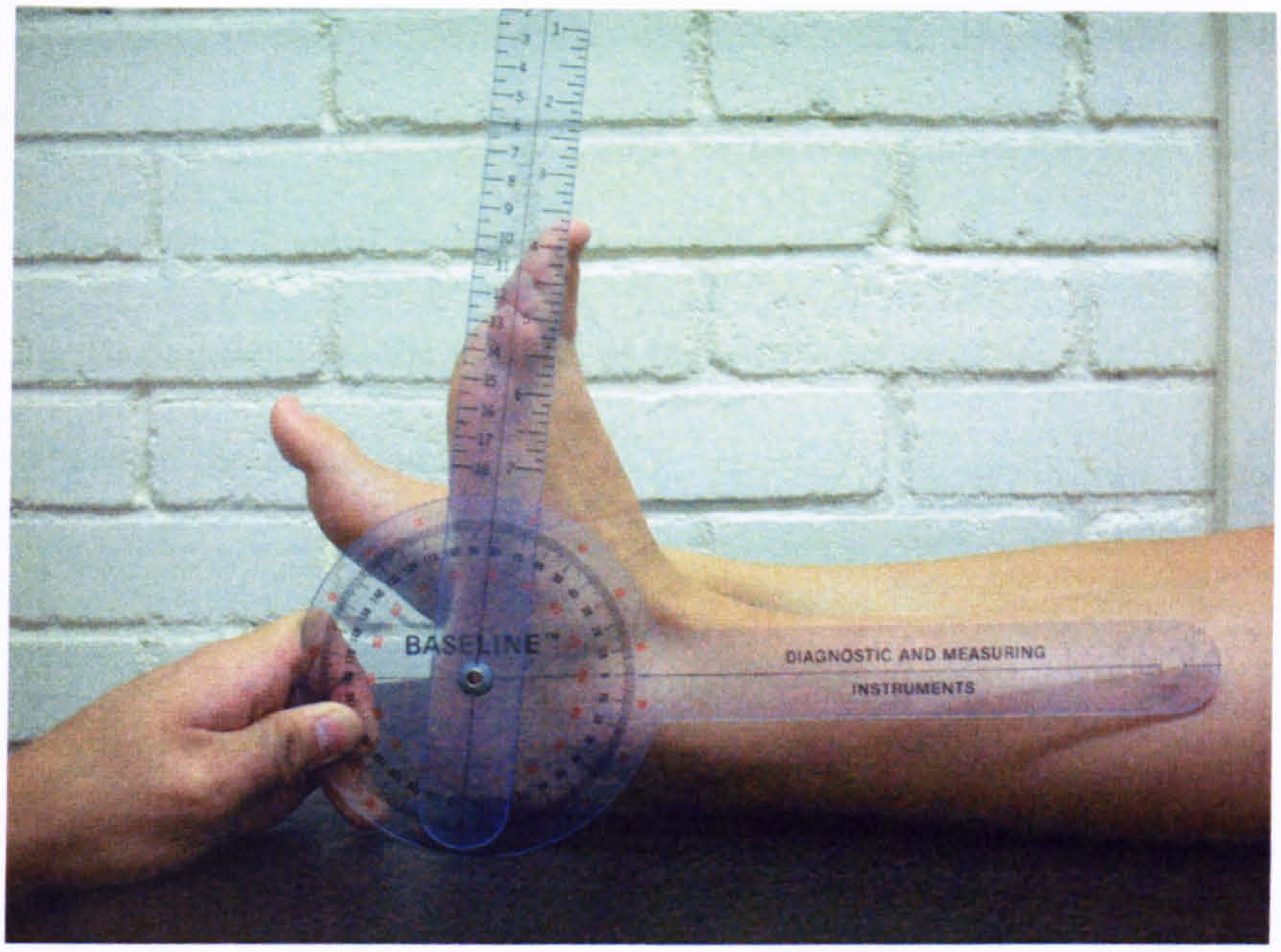

Figure 5.4.2.2.2 Gastrocnemius flexibility measured in the long sitting position

The stand and reach test required the subject to stand on a platform which was raised off the ground, barefoot, and keeping both legs straight bend forward and push the digital 'touch' meter as far as possible below the level of the platform. Three attempts were performed with the highest reading being recorded.

The muscle specific flexibility tests, performed on both lower limbs, included hip extension, flexion and rotation, and hamstring, quadricep, adductor, calf and soleus stretching. The protocols, for each stretch, were based on the standardised method as reported by Baumann et al. (1982). A detailed description of each flexibility test is given in Appendix 5. Further examples of hip extension, hip rotation and quadricep flexibility are shown in Figures 5.4.2.2.3, 5.4.2.2.4 and 5.4.2.2.5 respectively. An example of the data collection sheet is shown in Appendix 3.

Flexibility of each muscle group was measured in degrees with zero degrees representing the horizontal position of the limb on the flat table surface. For example a hamstring flexibility of 100 degrees would represent the dancer being able to lift her leg 10 degrees past the vertical as measured between the horizontal surface of the table and the extended limb.

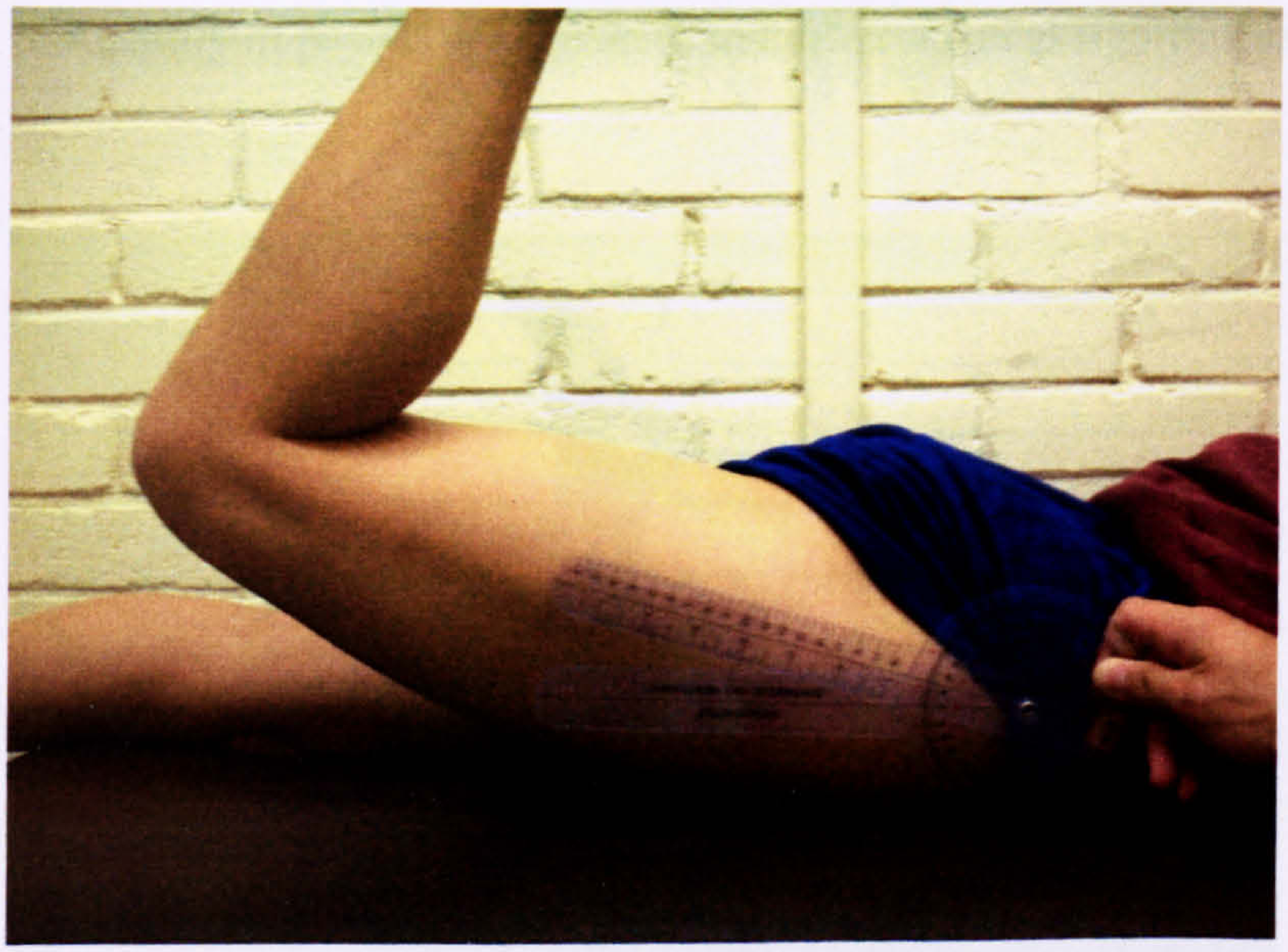

Figure 5.4.2.2.3 Hip extension flexibility measurement.

Figure 5.4.2.2.4 Hip rotation flexibility measurement

5.4.2.3 Data Analysis

The data were analysed descriptively and a profile constructed. Further analysis, using independent and dependent 't' tests, enabled a comparison of the flexibility of muscle groups between (injured vs non-injured) and within subjects respectively. A probability of $p<0.05$ was taken to indicate statistical significance.

Figure 5.4.2.2.5 Quadricep flexibility measurement

5.4.3 Results

Reliability of the Flexibility Data

In order to establish the reliability of the data obtained from the flexibility protocols a female student dance teacher volunteered to repeat the protocols for each measurement on two separate occasions. The student gave informed consent and a total of two complete data sets were recorded on the flexibility measures for the dancer. The reliability data was collected on two separate days with a 7 day interval between the two testing sessions. Reliability analysis of the data were examined using limits of agreement (Bland and Altman, 1986). A dependent t test was used to determine if any large systematic bias existed between the data sets. Results from the dependent t test indicated no significant difference ($t= 1.97$; $p>0.05$) between the data sets. The limits of agreement were recorded as 2.97 ± 2.04 degrees (mean of the differences ± (1.96 x SD of differences)). This suggests that a hamstring flexibility measure of 105.1 degrees would have 95% limits of agreement ranging from 103.06 degrees to 107.14 degrees.

Although this statistical reliability technique is recommended for this type of data (Bland and Altman, 1986) there are no published reliability data from which comparisons can be made. In the context of female student dance teachers it was suggested that the method employed for estimating lower extremity flexibility was reliable.

The flexibility data for the dancers is shown in Table 5.4.3.1. The independent 't' test revealed significant differences ($p<0.05$) between the injured and non-injured groups for both left and right hamstring measures. The hamstring flexibility, in both legs, for the injured group was significantly greater than that for the non-injured group. The mean hamstring flexibility difference for both legs between the injured and non-injured groups was 8.8 degrees (8.4%) and 8.1 degrees (7.7%) for the left and right sides respectively. No other significant differences between the groups were noted.

Significant differences ($p<0.05$) between the groups were noted for hamstring flexibility for left and right muscle groups. In this case there was significantly greater flexibility in the left and right legs for injured group. No other significant differences were observed.

Table 5.4.3.1 Mean and standard deviation flexibility measurements for student dance teachers. (All measurements in degrees except where indicated)

Flexibility Site		All subjects (n=46)	Injured (n=28)	Non-injured (n=18)	t value
Stand & Reach (cm)		13.1 (7.7)	14.8 (7.4)	10.4 (7.7)	1.94
Hamstring	(L)	101.6 (13.7)	105.1 (12.8)	96.3 (13.6)	2.21*
	(R)	101.4 (12.8)	104.6 (12.6)	96.5 (11.9)	2.19*
Adductor	(L)	39.7 (10.4)	40.8 (10.3)	37.9 (10.6)	0.90
	(R)	39.5 (9.8)	40.1 (9.6)	38.4 (10.4)	0.58
Quadriceps	(L)	121.6 (12.2)	119.8 (13.9)	124.3 (8.6)	1.22
	(R)	122.7 (8.8)	122.3 (9.2)	123.4 (8.3)	0.43
Hip extension	(L)	30.8 (11.2)	31.5 (10.0)	29.6 (13.0)	0.54
	(R)	31.2 (10.9)	32.0 (10.1)	30.0 (12.1)	0.59
Hip rotation	(L)	39.0 (6.7)	38.8 (7.0)	39.4 (6.5)	0.32
	(R)	39.2 (6.3)	38.9 (6.0)	39.7 (7.0)	0.45
Gastrocnemius	(L)	15.5 (3.2)	15.6 (3.5)	15.3 (2.8)	0.37
	(R)	16.4 (3.5)	16.6 (4.1)	16.2 (2.4)	0.41
Soleus	(L)	12.2 (2.6)	12.3 (2.7)	12.0 (2.4)	0.36
	(R)	12.6 (2.7)	12.8 (3.0)	12.3 (2.4)	0.57

* denotes significant difference ($p<0.05$)

It is of interest to note that the injured group recorded greater flexibility scores on 11 of the 15 tests when compared to the non-injured group. The non-injured group produced larger scores in only the quadriceps and hip rotation tests.

5.4.4 Discussion

The precise role of flexibility in the epidemiology of injury is unknown. Medical experts believe that flexibility is an important factor, however, quantification of its importance is difficult (Gleim and McHugh, 1997). This is further exacerbated by the conflicting results published in the literature (Ekstrand and Gillquist, 1982; Ekstrand et al., 1983; Knapik et al., 1991; Wiesler et al., 1996)

The data presented in Table 5.3.3.1 suggest that increased hamstring flexibility, in dancers, is a possible indicator of injury. However it must be noted that the difference in flexibility may be a result of the injury and may not be a causal factor. The literature has reported on diametrically opposite findings in that increased flexibility can predispose an individual as much as decreased flexibility (Heyward, 1998; Alter, 1996). Baumann et al. (1982) designed a musculoskeletal profiling system for women and reported that flexibility below a certain level was suspected to predispose a muscle to injury when stressed. However the authors did not report the flexibility level nor suggest reasons for this but did provide clear protocols for obtaining specific joint range of motion data from which comparisons could be made in future research.

Gannon and Bird (1999) proposed that ligamentous laxity could predispose an individual to injury. Laxity in the ligaments is more related to joint stability and not necessarily associated with the elastic component of the muscle. The problems with the definition of flexibility, 'normal' flexibility scores and measurement techniques make comparison and interpretation of data difficult between studies.

Of the data reported on flexibility and its links to injury, the main hypothesis proposed by Bennell et al. (1999), was that flexibility would directly influence injury by altering the forces applied to the bone. Optimal flexibility would enable the correct alignment of the skeleton and joints to absorb the reaction forces associated with movement. Flexibility outside of an optimal range may result in malalignment of the skeleton therefore reducing the joint contact area for maximum force dissipation. Further the malalignment may then place undue stress on the weaker structures around the joint, such as the ligaments, which may lead to injury.

Hamilton et al. (1992) reported data on elite professional ballet dancers. The authors recorded hip rotation range of motion as 81 degrees. However the authors also recorded the internal and external rotation range of motion with values of 29 degrees and 52 degrees respectively. When this data is compared to the data reported in Table 5.3.3.1 the hip rotation values (external) ranged from 38.8 degrees to 39.7 degrees suggesting that the internal rotation of the dancers in the present study was greater than the elite professional ballet dancers. Hamilton et al. (1992) reported norm range of motion values for internal rotation as approximately 34 degrees. This further suggests that the dancers in the present study have greater internal hip flexibility when compared to a normal population and elite professional ballet dancers. However Reid et al. (1987) reported internal hip rotation range of motion as 49 degrees in classical ballet dancers, somewhat greater than both the present study and Hamilton et al.

(1992). This may illustrate the lack of a regimented definition and measurement technique. It is interesting to note that left and right hip rotation were two of the four flexibility tests where the non-injured dancers in the present study recorded higher values. It is therefore possible that a reduced flexibility in internal hip rotation may contribute to injury.

The injured dancers recorded a significantly greater flexibility in both hamstring muscle groups when compared to the non-injured group. The hamstring muscle group is a two joint muscle in that it influences flexibility about the knee and the hip. Therefore a variation in the flexibility of the hamstrings may influence the distribution of the forces experienced at the two joints. Based on the data reported in Chapter 3 the combined incidence of injuries about the hip and knee was 38.7%, of which 31.2% were muscle strains or pulls. It could therefore be suggested that the demand on the dancers to achieve greater flexibility of the hamstring muscle group, in order to perform the extremes of motion required in dance, may be a contributing factor to injury in that the dancers over stretch this muscle group too quickly resulting in injury. Bennell et al. (1999) suggested that increased flexibility may be linked to injury via the inadequate strength of the musculature in its ability to stabilise, control and perform the range of motion. This inadequate strength would then lead to injury of the muscle group. The importance of muscular strength was mentioned in Section 5.2 as imperative, not only to dissipate impact forces but also to generate force to complete the dance movements. If the musculature is not strong enough to cope with the technical demands of the movement then this results in an adjusted or faulty technique which leads to injury (Howse and Hancock, 1992). Therefore increased flexibility of the hamstring muscle groups could lead the dancer into a false sense of security in that the flexibility of the muscle group is available to perform the dance movements but the strength component is not. An optimal balance between flexibility and strength may therefore be required and that dynamic flexibility may also be a more accurate measurement factor in links with injury.

5.4.5 Conclusion

The aims of this study were to quantify and compare muscle flexibility of the lower limb musculature between injured and non injured student dancers. The data presented in Table 5.4.3.1 illustrates the mean flexibility measures for both injured and non injured dance groups. The table further indicates that injured dancers have significantly increased flexibility in the hamstring muscle groups when compared to the non dancers.

The profile of the flexibility measures, for the injured dancers, also suggest that the injured dancer has larger adductor and hip extension flexibility and a smaller hip rotation and quadriceps flexibility. It was proposed that the differences in flexibility may affect the alignment of the skeleton, in terms of contact areas between joints, and thus alter the distribution of the loading forces across the joints. Further, knowing that dance requires extreme flexibility to perform and enhance the aesthetic line, the muscles, although flexible enough to achieve this, may not be strong enough to stabilise and control the movement. Although the profile of the injured and non injured dancers differed it was not significant across all flexibility measurements, the hypothesis was therefore rejected.

5.5 BODY COMPOSITION OF STUDENT DANCE TEACHERS

5.5.1 Introduction

The physical appearance required in dance, in terms of body weight and fat, is often a demand for success (Clarkson et al., 1985; Chmelar et al., 1988b; Koutedakis and Sharp, 1999). This is necessary because of the nature of dance performance in that the aesthetic component runs parallel, in importance, with technical ability (Howse and Hancock, 1992). However not all dancers possess, nor dance styles require, the lean body shape and aesthetic line as portrayed in classical ballerinas.

Body composition is defined as the ratio of fat to fat-free weight and is often expressed in percentage body weight, %BF (Koutedakis and Sharp, 1999). This definition is based on a two-compartment or component model where body weight is taken to be the sum of fat weight plus fat-free weight. Numerous methods for estimating %BF have been reported including computer tomography, densitometry and bioelectrical impedance (Heyward, 1998; Koutedakis and Sharp, 1999), however the use of the field based skinfold method has been reported in a number of studies as being a more practical method of estimating %BF (Heyward, 1998).

The skinfold method indirectly measures the thickness of subcutaneous adipose tissue and the use of this method is based on the premise that areas of the body where adipose tissue tends to be deposited will be larger than average in persons with greater amounts of body fat (Lohman 1981 cited in Heyward, 1998). The calculation of %BF from the skinfolds is then estimated based on population specific prediction equations used to estimate body density and hence percentage body fat. Therefore the calculation of %BF is a two stage process with a number of equations available to estimate body density and %BF (Behnke and Wilmore, 1974; Sinning, 1978; Carter, 1982; Jackson and Pollack, 1978 & 1985 cited in Heyward 1998; Brozek et al., 1963 cited in Koutedakis and Sharp, 1999).

The estimation of %BF in dancers has been well reported (Novak et al., 1978; Dolgener et al., 1980; Calabrese et al., 1983; Chmelar et al., 1988a; Clarkson et al., 1989; Hamilton et al., 1992; Koutedakis and Sharp, 1999). Percentage body fat values have ranged from 12.9% in professional dancers based on the Carter and Heath equation (1982) to 22.1% in university dancers using the Behnke and Wilmore equation (1974). These differences may be explained on the basis of the number and the site of the skinfold measurements. In the female population the main sites on the body for fat deposits are the thigh, suprailiac and abdominal. Some equations used for estimating %BF do not incorporate these sites eg. Brozek et al., 1963 (cited in Koutedakis and Sharp, 1999) and may therefore not provide a true estimation of female percentage body fat. Further, some equations only use three sites (triceps, biceps, subscapularis) for estimating %BF (Jackson et al., 1980). However the Carter and Heath equation (Carter, 1982) incorporates the main sites for fat deposits, representative of a female population, and also incorporates three additional sites to including two from the upper body (triceps and subscapularis) and an additional one from the lower leg (calf). Therefore comparison of reported data on body composition needs to take these aspects into consideration. However it is now more common to report the sum of the skinfolds when estimating body composition to permit comparisons (Heyward, 1998). No published studies have attempted to link body composition, based on skinfold measurements, to injury in dance.

In order to obtain a complete structural basis from which athletic or dance performance may be considered, it is has been postulated that kinanthropometric measurements can provide additional data on the shape and size of the body. This information permits the development of a comprehensive structural model from which problems with performance may be explored (MacDougall et al., 1991) and provides a link between the structure and function of the human body. Kinanthropometric measurements include muscle girths (gluteal girth or thigh girth), limb widths (humerus and femur widths) and body circumferences (waist and chest). This information supplements the measurements of body composition to provide the quantification of differential training influences or movement limitations and to potentially help describe the relationship between the structure and function of the human body particularly in the context of movement (Eston and Reilly, 2001). Although the techniques associated with this type of measurement are well documented (Eston and Reilly, 2001) their application and interpretation in relation to injury has yet to be explored within a dance environment.

The aims of this study were: (1) to quantify body composition and kinanthropometric measurements of female student dance teachers; and (2) to compare body composition and kinanthropometric characteristics between injured and non-injured student dancers.

Hypothesis 6: Body composition and kinanthropometric profiles will differ between the injured and non-injured dancers.

5.5.2 Method

5.5.2.1 Subjects

A total of forty six female student dance teachers volunteered for the study. Twenty eight student dance teachers had reported a dance related injury (age = 20.4 ± 4.2 years; mass 58.4 ± 8.8 kg; height = 161.1 ± 6.2 cm; dance experience 12.6 ± 4.9 years), and eighteen student dance teachers had no dance related injury (20.3 ± 3.6 years; 55.4 ± 6.4 kg; 158.8 ± 5.0 cm; 12.6 ± 3.8 years). All the dance students gave informed consent for participation in the study. The subjects were currently performing in a number of dance styles and were not undergoing any specific conditioning nor dietary programme.

5.5.2.2 Procedure

A total of 17 body girth and circumference measures were recorded, along with 10 skinfold site measures. All measures were based on the protocol as reported by Ward et al. (1989) as part of an advanced physique assessment system. The girth measures included upper arm (flexed and relaxed), wrist, forearm, gluteal, thigh, calf and ankle. These measures were recorded using a flexible tape measure. Examples of ankle girth and calf girth measurement techniques are shown in Figures 5.5.2.2.1 and 5.5.2.2.2 respectively.

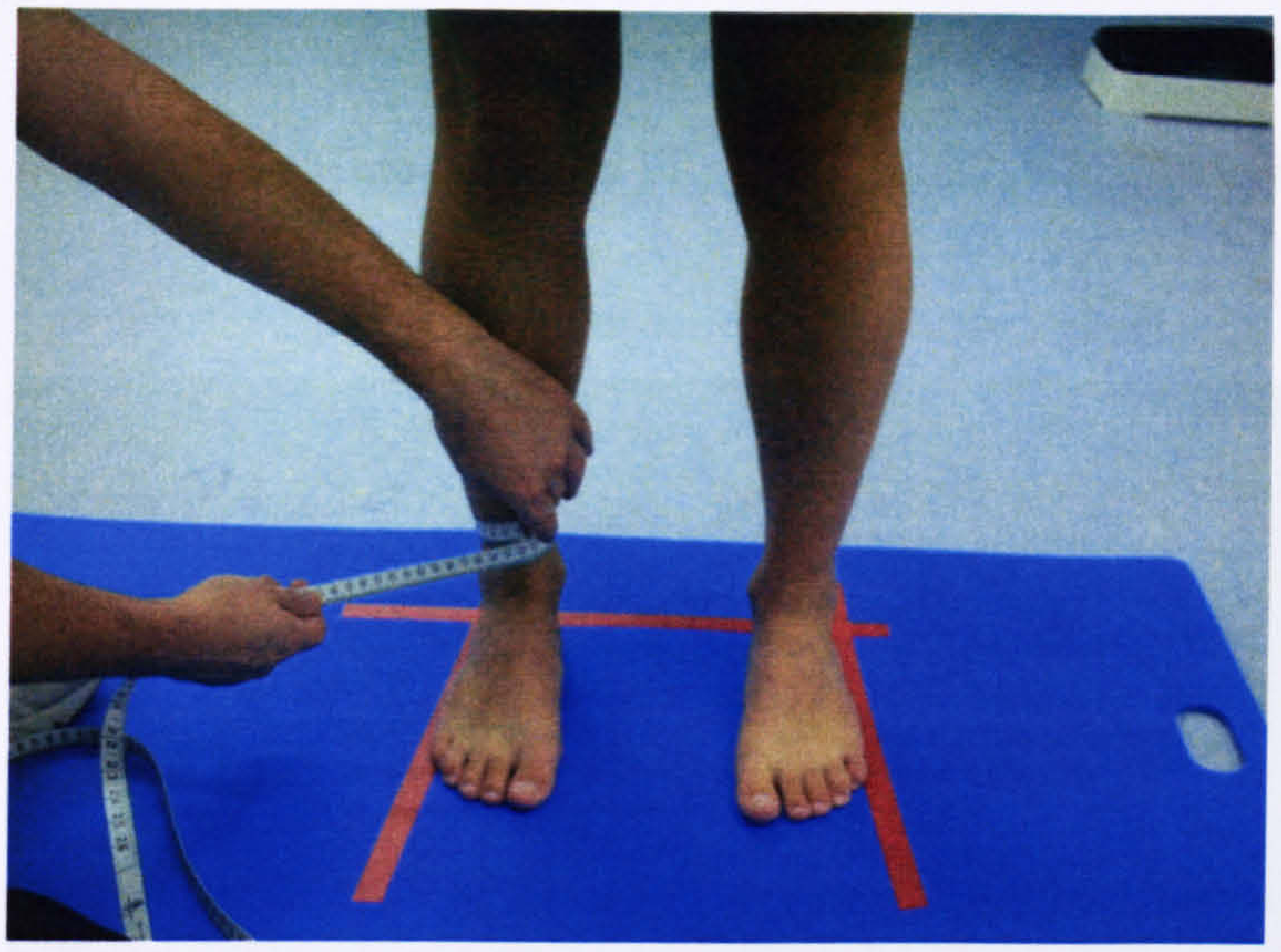

Figure 5.5.2.2.1 Ankle girth measurement.

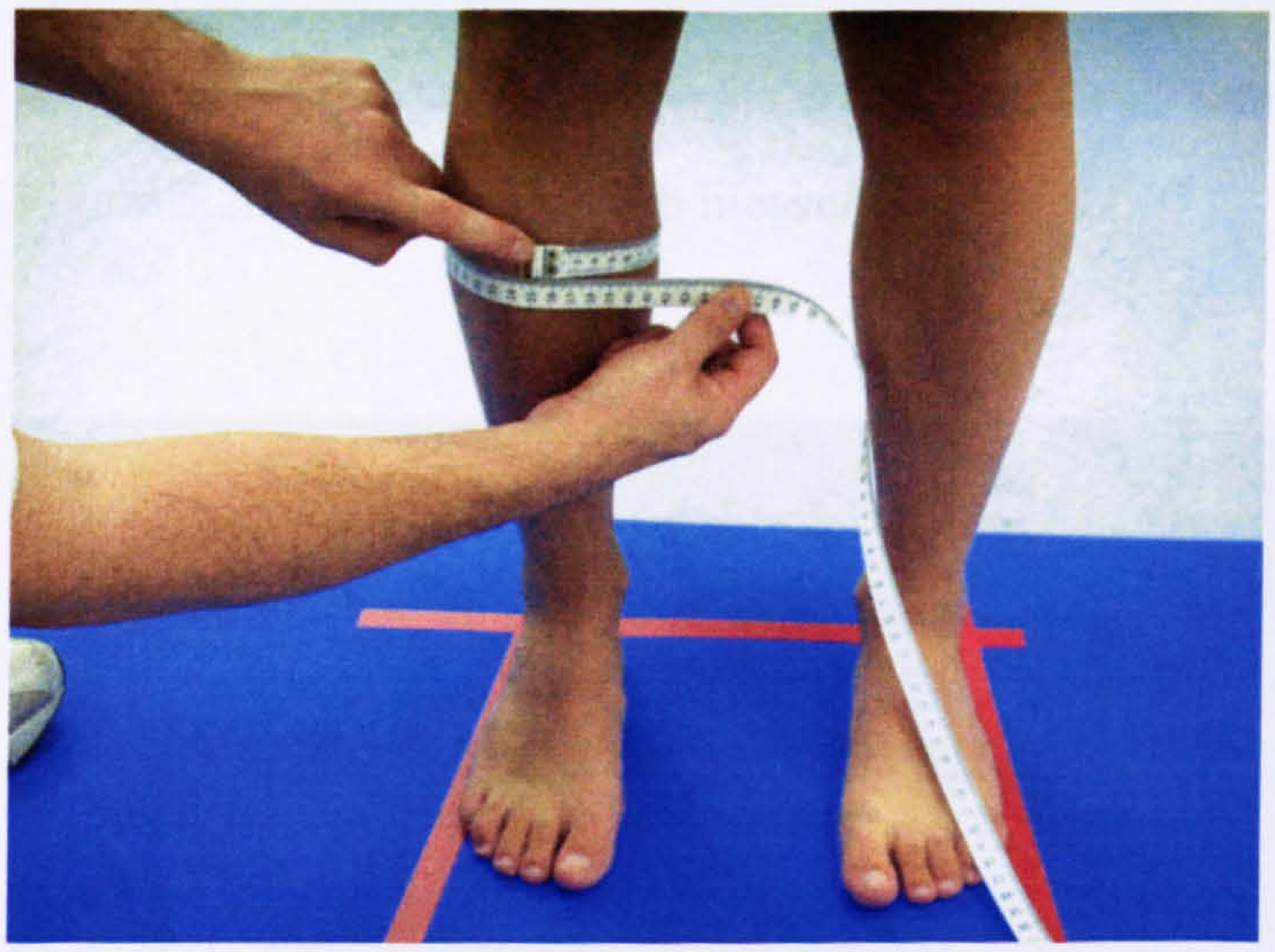

Figure 5.2.2.2.2 Calf girth measurement

The circumference measures included chest and waist with the further measurements including upper arm length, humerus and femur width, tibiale sitting height and normal sitting height. The humerus and femur widths, tibiale sitting height and normal sitting height were recorded using an anthropometer. Full details on the measurement protocols are shown in Appendix 6. Further examples of forearm girth, thigh girth and humerus width are shown in Figures 5.2.2.2.3, 5.2.2.2.4 and 5.2.2.2.5.

Figure 5.2.2.2.3 Forearm girth measurement

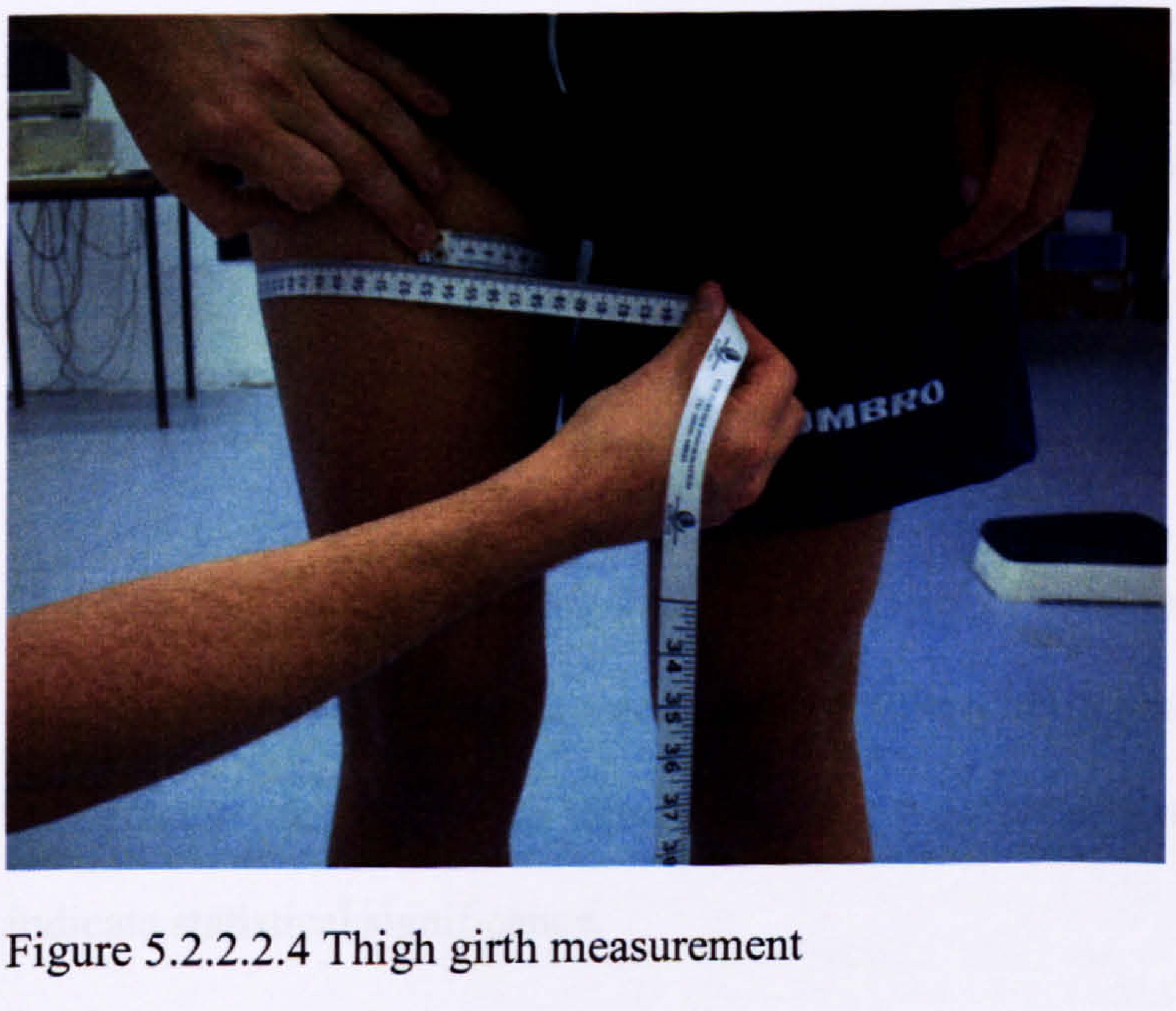

Figure 5.2.2.2.4 Thigh girth measurement

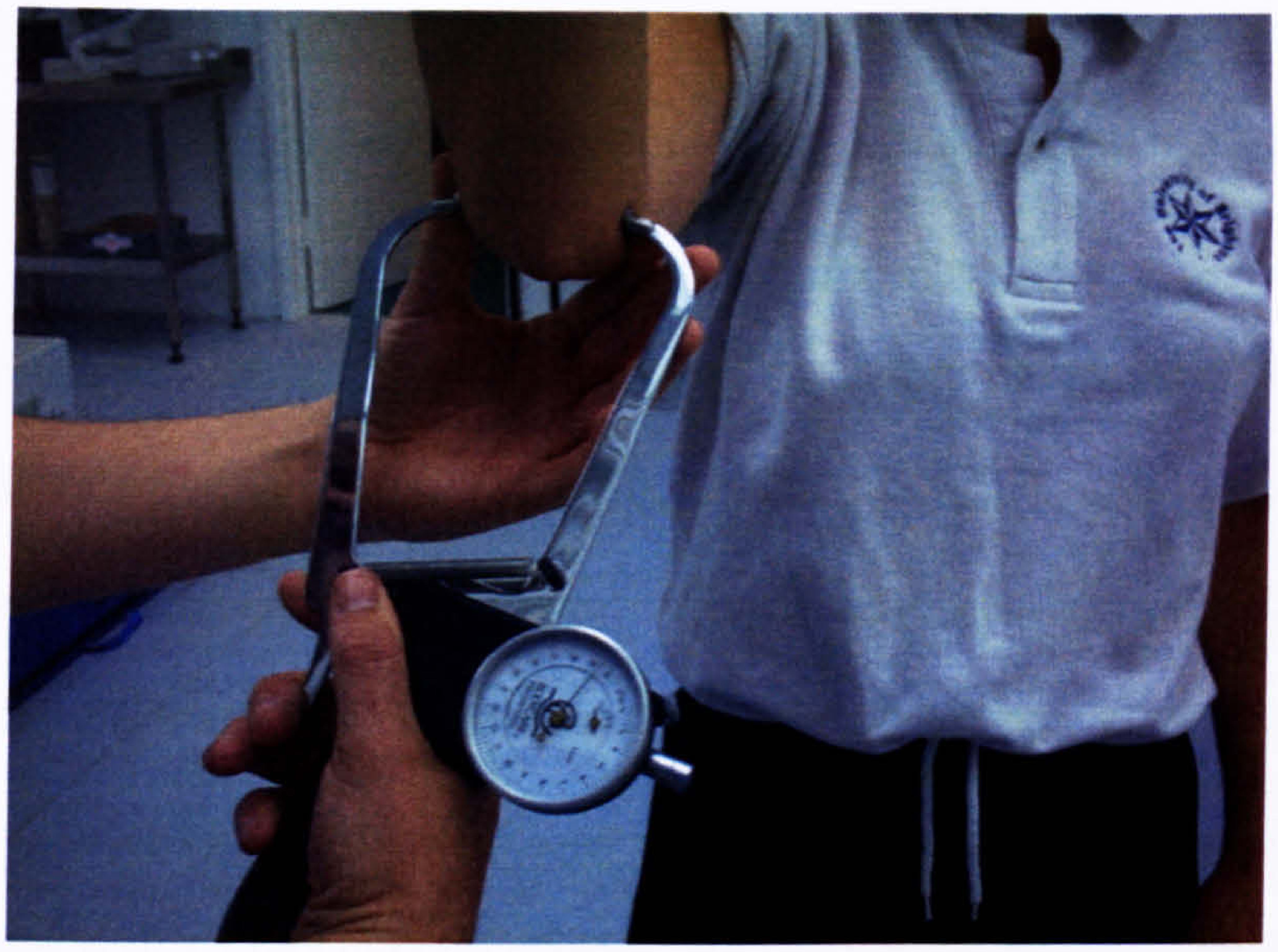

Figure 5.2.2.2.5 Humerus width measurement

A total of 9 skinfold site measurememts were also recorded using skinfold calipers. These included triceps, biceps, iliac crest, subscapularis, supraspinale, abdominal, axilla, thigh and calf. Percentage body fat was calculated using the method reported by Carter (1982). Body mass index was also calculated using the equation (weight / height^2). Full details on the measurement protocols are shown in Appendix 6.

5.5.2.3 Data Analysis

The data were analysed descriptively and a profile constructed. Further analysis, using independent 't' tests, enabled a comparison of the anthropometric characteristics between the injured and non-injured subjects. A probability of $p<0.05$ was taken to indicate statistical significance.

5.5.3 Results

Reliability of the Body Composition and Kinanthropometric Data

In order to establish the reliability of the data obtained from the body composition and kinanthropometric protocols a female student dance teacher volunteered to repeat the protocols for each measurement on two separate occasions. The student gave informed consent and a total of two complete data sets were recorded on the flexibility measures for the dancer. The reliability data was collected on two separate days with a 7 day interval between the two testing sessions. Reliability analysis of the data were examined using limits of agreement (Bland and Altman, 1986). A dependent t test was used to determine if any large systematic bias existed between the data sets.

Results from the dependent t test indicated no significant difference ($t= 1.16$; $p>0.05$) between the data sets for the 9 body composition measures (skinfolds). The limits of agreement were recorded as 0.96 ± 2.07 mm (mean of the differences ± (1.96 x SD of differences)). This suggests that a triceps skinfold measure of 19.3 mm would have 95% limits of agreement ranging from 17.23 mm to 21.37 mm.

The kinanthropometric measures were divided into widths ($n=2$), girths ($n=10$) and lengths ($n=4$). Table 5.5.3.1 highlights the limits of agreement for the three categories. Results from the dependent t tests indicated no significant difference ($p>0.05$) between the data sets for the width, girth or length measures. The limits of agreement were recorded as 0.61 ± 0.84 cms, 0.53 ± 0.96 cms and 0.74 ± 0.73 cms for the girths, lengths and widths respectively.

Table 5.5.3.1 Limits of Agreement for the Kinanthropometric Reliability Measures. (All measurements in cms)

	T value	Mean of Differences	SD of Differences	Limits of Agreement
Girths	0.94	0.61	0.43	0.61 ± 0.84
Lengths	1.28	0.53	0.49	0.53 ± 0.96
Widths	2.00	0.74	0.37	0.74 ± 0.73

This suggests that a gluteal girth measure of 94.4 cms would have 95% limits of agreement ranging from 93.56 cms to 95.24cms, a tibial sitting height measure of 37 cms would have 95% limits of agreement ranging from 36.04 cms to 37.96 cms and a humerus width measure of 5.5 cms would have 95% limits of agreement ranging from 4.77 cms to 6.23 cms.

Although this statistical reliability technique is recommended for this type of data (Bland and Altman, 1986) there are no published reliability data from which comparisons can be made. In the context of female student dance teachers it was suggested that the methods employed for estimating percentage body fat using skinfold measures and kinanthropometric measures was reliable.

The results for the anthropometric and skinfold and body fat measures are shown in Tables 5.5.3.2 and 5.5.3.3 respectively. Percentage body fat was calculated using the Carter (1982) equation. This equation incorporated the sum of six skinfolds and two constants in the form;

% body fat = 0.1548 x (sum of skinfolds, triceps, subscapularis, suprailiac, abdominal, thigh, calf) + 3.58.

No significant differences ($p>0.05$) were noted between the injured and non-injured groups for the measures shown. However, it is interesting to note that the injured group recorded higher average scores in 12 out of the seventeen anthropometric measures. This included height, body mass, and a larger gluteal, thigh and ankle girth measure. Of the 5 other measurements the non-injured group recorded a larger mean femur width of 8.2 cm compared to 7.7 cm for the injured group, whilst the other measures of humerus width, ankle girth, waist circumference and forearm width recorded smaller differences between the means. Ratios of sitting height to standing height and tibiale sitting height to sitting height were also calculated and compared using an independent 't' test. No significant differences were noted between the two groups for the two ratios.

For the mean skinfold measures the injured group recorded higher values for the triceps, subscapularis, iliac crest, axilla, thigh and calf sites. The biggest difference was noted in the calf skinfold with the injured group having a 8.8% (1.9mm) increase in skinfold thickness.

Table 5.5.3.2 Mean and standard deviation values for the anthropometric characteristics for student dancers. (All measurements in cms unless stated)

Anthropometric Characteristic	All subjects (n=46)	Injured (n=28)	Non-injured (n=18)	t value
Mass (kg)	57.2 (7.9)	58.4 (8.8)	55.4 (6.4)	1.23
Height	160.2 (5.8)	161.1 (6.2)	158.8 (5.0)	1.38
Arm girth	25.1 (2.6)	25.4 (2.7)	24.8 (2.5)	0.72
Arm girth (flexed)	26.5 (2.5)	26.9 (2.6)	25.9 (2.2)	1.35
Upper arm length	28.8 (3.0)	29.4 (2.9)	27.9 (2.9)	1.66
Forearm girth	23.2 (1.4)	23.3 (1.5)	23.1 (1.1)	0.46
Wrist girth	15.0 (0.9)	15.1 (1.0)	14.9 (0.7)	0.87
Chest circumference	84.7 (6.5)	85.1 (7.0)	84.1 (5.9)	0.47
Waist circumference	66.7 (6.1)	66.9 (5.6)	66.3 (7.0)	0.29
Gluteal girth	94.4 (5.8)	95.1 (6.2)	93.3 (5.1)	1.01
Thigh girth	53.1 (6.2)	54.2 (5.6)	51.2 (6.8)	1.63
Calf girth	34.7 (2.2)	35.1 (2.2)	34.2 (2.2)	1.23
Ankle girth	22.3 (1.1)	22.3 (1.2)	22.3 (1.0)	0.17
Humerus width	5.4 (0.6)	5.5 (0.6)	5.3 (0.6)	0.79
Femur width	7.9 (1.7)	7.7 (2.1)	8.2 (0.6)	0.99
Tibial sitting height	36.7 (3.4)	37.0 (3.8)	36.2 (2.8)	0.73
Sitting height	85.3 (4.0)	86.2 (3.9)	83.9 (3.8)	1.99

The non-injured group had larger skinfold thicknesses at the suprailiac and abdominal sites with values of 18.6mm and 20.1mm respectively. The sum of respective skinfolds were also calculated. These calculations were based on the equations from previous literature (Behnke and Wilmore, 1974; Evans et al. 1985; Clarkson et al. 1989; Chatfield et al. 1990).

Table 5.5.3.3 Mean and standard deviation values for the skinfold measurements and percentage body fat scores of student dancers. (All measurements in millimetres (mm) unless stated)

Skinfold Site	All subjects (n=46)	Injured (n=28)	Non-injured (n=18)
(1) Triceps	19.0 (6.6)	19.3 (7.2)	18.5 (5.6)
(2) Subscapularis	16.8 (6.4)	16.9 (7.3)	16.6 (4.9)
(3) Biceps	10.0 (4.2)	10.0 (4.1)	10.1 (4.3)
(4) Iliac crest	17.9 (6.5)	18.4 (6.7)	17.0 (6.2)
(5) Supraspinale	17.8 (6.4)	17.3 (6.2)	18.6 (6.9)
(6) Abdominal	19.2 (6.4)	18.7 (6.8)	20.1 (5.9)
(7) Axilla	13.0 (5.1)	13.6 (5.7)	12.2 (4.1)
(8) Thigh	24.9 (7.0)	25.1 (7.7)	24.7 (6.0)
(9) Calf	20.4 (8.3)	21.5 (9.0)	18.6 (6.9)
Sum of SF (1,4,8)	55.0 (17.9)	62.9 (18.4)	60.2 (14.0)
Sum of SF (1,2,3,5)	63.6 (20.3)	63.5 (21.6)	63.8 (18.7)
Sum of SF (1,2,5,6,8)	97.8 (26.6)	97.3 (29.8)	98.5 (21.6)
Sum of SF (1,2,5,6,8,9)	118.1 (33.6)	118.8 (37.8)	117.1 (26.7)
% body fat (Carter, 1982)	21.9 (5.2)	22.0 (5.9)	21.7 (4.1)
BMI (wt/ht^2)	22.3 (2.6)	22.5 (2.9)	22.0 (1.9)

By calculating the sum of skinfolds it removes the errors associated with percentage body fat calculations using equations based on body density, age and gender. It also provides scope to compare and contrast the data with a wider range of previous studies. However percentage body fat was calculated using an equation which incorporated 9 skinfolds from the sites where the deposition of fat is common in the female population.

5.5.4 Discussion

Body size and soft tissue composition have been suggested, in theory, to directly affect injury by altering the forces applied to the bones (Bennell et al. 1999). During the gait cycle, for both running and walking, bodyweight is alternatively supported on each leg and as the speed increases the muscles must contract with greater force in order to propel the body. As the propulsive and supportive stresses on the muscles and bone are positively related to bodyweight, individuals with a high BMI (mass / height ^{2}) or percentage body fat may have excessive biomechanical stresses on the musculoskeletal system because of the extra weight (Neely, 1998b).

The body mass and height of the dancers shown in Table 5.5.3.3 are similar to the values reported by other authors. Chatfield et al. (1990) recorded height and body mass for 4 skill levels of dancer ranging from the non dancer through to the advanced dancer. Body mass ranged from 51.5 kg for the advanced dancer to 55.7 for the non-dancer and height values in the range of 159.8 cm to 163.4 cm for the advanced dancer and non-dancer respectively. The data presented in Table 5.5.3.3 suggests that the dancers involved in the present study were similar in height as the advanced dancer but up to 5.7 kg (9.9%) heavier.

Body mass index (BMI) has been linked with injury in both a dance and a military population (Benson et al. 1989; Neely et al. 1998b). The ratio of body mass/height^2

(BMI) has been used as an anthropometric marker to compensate for the variations in body type. The studies by Clarkson et al. (1989), Chatfield et al. (1990), Novak et al. (1978) and Evans et al. (1985) reported mean body mass and height scores for a number of dancers from beginner to professional level. The respective mean BMI scores were 18.6, 20.4, 19.5 and 20.4. Therefore the BMI of the dancers in the present study would seem to be slightly higher than the published literature with a mean whole sample BMI score of 22.3. This difference may be due to the sample of dancers used. In the reported studies the dancers were mainly pre-professional or professional. However even the non-dancer group reported by Chatfield et al. (1990) recorded a smaller BMI of 21.7. Although Chatfield et al. (1990) did not report BMI a simple calculation from the height and weight data demonstrated that even the non-dancer group had a smaller BMI when compared to the present dancers.

Ross and Woodward (1994) cited in Neely (1998a), reported that army recruits with a BMI of greater than 26.9 were at a greater risk of injury than those with a BMI of less than 20. However the study reported by Benson et al. (1989) concluded that a BMI of less than 19 prolonged the rehabilitation process in ballet dancers. The mean BMI recorded in Table 5.4.3.2 for the dancers in the present study ranged from 22.0 in the non-injured group to 22.5 in the injured group. It would then seem that both the injured and non-injured dancers were not necessarily at risk from injury when compared to the BMI measurement as reported on a military population. When compared to a dance population, however, it would seem that the BMI scores for the injured group are slightly higher than that reported by Chatfield et al. (1990) and may pose an injury risk.

Percentage body fat of the dancers was calculated using the Carter (1982) equation. This was based on the sum of 6 skinfolds as mentioned in Section 5.4.3. The skinfold measurements were taken at sites that reflected the most common areas for fat deposits for females. These sites included the abdominals, thigh and suprailiac as well as the more common sites such as the triceps and subscapularis. The Carter equation was used because of the sites involved in the calculation and that it best represented the areas of likelihood of fat deposit. However, because of the variety of techniques involved in calculating percent body fat, both mathematically and directly (hydrostatic weighing), it was felt that the inclusion of the exact skinfold measures would enable a more accurate comparison between the published and present data.

Percentage body fat for the whole sample group was 21.8% (5.3), with an average percent measure of 22.0% and 21.5% for the injured and non-injured groups respectively. This data compares favourably with that of Novak et al. (1978) and Evans et al. (1985) who reported values of 20.5% and 22.4% respectively. Chmelar et al. (1988a) reported ranges of percentage body fat for university and professional ballet and modern dancers. The authors calculation was based on the Sinning equation for density and the Siri equation for percent fat from density (Chmelar et al. 1988a). The percentage body fat values ranged from 9.6% - 20.5%, 10.9% – 23.6%, 11.2% – 17.6% and 9.6% – 16.1% for university ballet and modern and professional ballet and modern dancers respectively. These range of values are quite large but based on values for the university dancers it would seem fair to suggest that the dancers used in the present study were representative of a student dance population. Chatfield et al. (1990) reported similar percentages for the intermediate and beginner dancers but reported an average percent body fat of 18.1% for the advanced dancers in their study.

This study calculated body fat using an underwater weighing system which is widely respected as being the most accurate method, therefore the calculation of body fat, using the 6 skinfold sites, in the present study seem to be an accurate reflection of percentage body fat in a dance population.

The individual skinfold site measures are also useful in terms of identifying the distribution of fat around the body. Calabrese et al. (1983), Evans et al. (1985) and Clarkson et al. (1989) reported skinfold measures for classical ballet dancers, dance majors and student classical ballet dancers respectively. Clarkson et al. (1989) also reported skinfolds for professional classical ballet dancers. The skinfolds that were common to these studies and the present study were the triceps, suprailiac, subscapular, abdominal and the thigh. These five measures are perhaps the most commonly cited skinfold measures for females as they represent the main sites for fat deposit.

The skinfold data presented by Calabrese et al. (1983) on classical ballet dancers are up to 50% lower than the skinfold data reported in Table 5.4.3.3 with the largest difference being in the measurement of the triceps with 9.69 compared to 19.3 and 18.5 for the injured and non-injured group respectively. Similar differences in findings are also apparent when compared to the data reported by Evans et al. (1985) and Clarkson et al. (1989). It would therefore seem that for the student dance teachers the skinfold thickness at the sites of the body reflect a higher level of body fat and injury risk as suggested by Neely (1998b). As was shown in Chapter 3 the injuries being reported are representative of a dance population in terms of their incidence and type. Therefore if there is a relationship between body fat and injury, as suggested by

Neely (1998a) and Rayson et al. (1996) cited in Neely (1998), and the professional dancers are having a similar pattern of injuries, with a lower body fat, it would then seem that the students dancers would be exposed to a higher risk of injury based on this measurement. Additionally, based on the fact that the student dancers must perform in a number of different styles, the cumulative effect of the demands of the different dance styles may increase the risk potential further. A possible explanation for the student dance teachers having more body fat may be due to the nature of the degree programme. Students being taught how to teach spend more time in the theory of teaching rather than dancing. However when required to dance the intensity and physical demands are similar to the pre-professional and professional dancer (Chapter 4). The class time is not therefore seen as producing fit and healthy dancers but dancers who are good teachers. The fitness required for dancing or participating in the dance class is left to the responsibility of the student. It may be that in order to reduce the risk of injury a specific dance fitness class may be required to keep the student dancers at a level of fitness, and hence a reduced level of body fat, to reduce the risk of injury .

Table 5.5.3.2 includes data relating to a number of anthropometric measures. This data includes girths (8), circumferences (2), widths (2) and heights (3). Clarkson et al. (1989) and Dolgener et al. (1980) have reported on similar anthropometric measures for three levels of adolescent dancer and professional ballet and modern dancers respectively. For the humerus width and femur width Clarkson et al. (1989) reported mean values of 6.1cm and 7.8cm respectively. These values changed to 5.8cm and 7.9cm for elbow and knee width respectively as the level of the dancer increased. These values are similar to the student dance teachers in the present study with mean whole sample widths of 5.4 cm and 7.9 cm for the elbow and knee respectively. Dolenger et al (1980) reported mean width values of 9 cm for the knee and 6.4 cm for the elbow in both ballet and modern professional groups. It was noted from the data presented in Table 5.5.3.1 that the injured student dance teachers had a larger humerus width (5.5 cm v 5.3 cm) and a smaller femur width (7.7cm v 8.2 cm) than the non-injured group. It may be therefore that the non-injured group had a larger surface area, at the knee joint, to dissipate the repetitive forces associated with dance movement.

Muscle girths have been used as indicators of muscle size (Kuno et al.,1996) in dancers. However it may also be representative of body fat which has been suggested as a risk factor in injury. The injured student dance teachers had larger gluteal, thigh and calf girths when compared to the non-injured group. The gluteal area and thigh area are two of the sites where fat is readily deposited on the body. When compared to the data reported by Clarkson et al. (1989) the adolescent dancers had a range of gluteal girths from 85.2 cm to 85.7 cm. This compares to values of 95.1 cm and 93.3 cm for the injured and non-injured dance teachers respectively. Kuno et al. (1996) and Dolgener et al. (1980) reported thigh girths of 46.5 cm for Japanese ballet dancers, and 50.1 cm and 50.5 cm for professional ballet and modern dancers respectively. The thigh girths of 54.2 cm and 51.2 cm for the injured and non-injured student dancer teachers are somewhat greater and may certainly reflect the thigh skinfold size and hence body fat measurement. A similar pattern of measurement difference was also apparent in waist circumference with the previous literature reporting values in the range 59.3 cm to 63.0 cm (Clarkson et al. 1989; Dolgener et al. 1980), as compared to 66.9 cm and 66.3cm in the injured and non-injured student dancer's. It may therefore be, in the present case, that the increased girths reflect higher fat deposits, than muscle size, and in doing so contribute to injury predisposition.

5.5.5 Conclusion

The quantification, and comparison, of the injured and non-injured dancer profiles fulfil the two aims of this study. To conclude, the student dance teachers, based on the anthropometric characteristics, are representative of a dance population. These characteristics are not significantly different between the injured and non-injured groups and based on this the hypothesis was rejected.

5.6 SUMMARY

The aims of this chapter were twofold. The first aim was to quantify the anthropometric and functional characteristics of student dance teacher population, with a view to producing a dancer profile. The second aim was to compare these characteristics between the injured and non injured student dance teachers in an attempt to identify characteristics that may predispose a dancer to injury. Four studies were completed with data collected for orthopaedic alignment, strength, flexibility and anthropometric characteristics.

The data collected provided information from which a student dance teacher profile could be quantified. The profile suggested that, on average, the student dance teachers were 20.4 years old, 160 cm in height, had a mass of 57.2 kg and had had 12.6 years of dance experience. The lower limb alignment characteristics highlighted the student dancers as having a leg length of 86.9 cm, Q angle of 18 degrees, an ASIS distance of 22 cm, outer and inner femoral condyle distances of 29 cm and 12 cm respectively and a medial malleoli distance of 17.6 cm. This data suggested that student dance teachers were of a 'knock kneed' or genu valgum lower limb alignment. This alignment characteristic is illustrated by a small inner femoral condyle distance in relation to the ASIS and medial malleoli distances.

The recording of muscle strength data provided estimates of grip, back and leg strength. The student dancer tended to be slightly weaker than other corresponding female sports participants for all strength measurements with absolute mean values of 519.2 N, 646.9 N, 241.2 N and 229.5 N for back, leg and right and left grip strength respectively.

Data was also reported on specific muscle group flexibility. Due to the specific nature of the flexibility tests comparison with other female sports participants was difficult, nevertheless, of the published data that was available the student dancers tended to be more flexible. Flexibility values of 101 degrees, 122 degrees, 39 degrees and 12.6 degrees were recorded for hamstrings, quadriceps, hip rotation and soleus muscle groups respectively.

Data on the estimation of percentage body fat and kinanthropometric measurements were also recorded. The mean percentage body fat of 21.8%, of the whole dance group, compared favourably to other studies of dancers (Novak et al., 1978; Evans et al., 1985; Chmelar et al., 1988a). Kinanthropometric measures of humerus width (5.4 cm) and femur width (7.9 cm) also compared favourably with studies on similar dance populations (Dolgener et al., 1980). However the girth measures, often used as indicators of muscle size (Kuno et al., 1996) and body fat (Clarkson et al., 1989), and waist circumference in the present study were notably larger when compared to previous research. Mean values of 94.4 cm and 66.7 cm for gluteal and waist girth respectively were larger than the values reported by Clarkson et al. (1989) of 85.2 cm and Kuno et al. (1996) 46.5 cm for gluteal and waist girths respectively. It would therefore seem that the body composition profile of the present student dance teachers is larger than the published student dancer profile.

No significant differences were noted for the alignment, strength or anthropometric data between the injured and non-injured groups. However the injured group had a more pronounced genu valgum or knock-kneed effect of the lower limbs reflective of a larger 'Q' angle but not reflective of a smaller anterior superior iliac spine. It was suggested that this may be due to a greater subluxation of the patella which would increase the risk of injury due to poor lower limb alignment. The injured dancers also had a lower back strength but greater leg strength than the non-injured group.

Further to these functional characteristics the kinanthropometric characteristics of the injured group highlighted a larger BMI and percent body fat value. It was suggested that the larger girths, in the injured group, especially the gluteal and thigh girth, reflected fat deposits rather than a greater musculature. This could substantiate the relatively poor strength measures when compared to other female sports participants.

The flexibility data produced the only significant differences ($p<0.05$) between the injured and non-injured groups. These differences were noted for both left and right hamstring flexibility. It was suggested that too much flexibility in the hamstrings could predispose the dancer to injury by altering the forces applied to the bone. Bennell et al. (1999) suggested that optimal flexibility would enable the correct alignment of the skeleton and joints to absorb the reaction forces associated with dance movement. Flexibility outside of an optimal range may result in malalignment of the skeleton therefore reducing the joint contact area for maximum force dissipation and placing undue stress on the weaker structures around the joint.

Based on the data collected a profile for an injured student dance teacher would have the following characteristics; supinated feet, pronounced knock-knees, small pelvis width (ASIS), large 'Q' angle, reduced back strength, large gluteal and thigh girth and extreme flexibility in both hamstring muscles.

The limitations of the data collection methods have been highlighted in each of the four studies within the chapter. However an additional limitation may be the use and interpretation of multiple t tests and the respective outcomes when attempting to highlight the differences between the injured and non injured female student dance teachers. A number of authors have reported the potential of occurrence of type I and type II errors when using multiple t tests (Bland and Altman, 1986; Altman, 1991; Vincent, 1999). A type I error occurs when the significance value or 'p' value is set too high, i.e. $p<0.1$ and a significant difference is detected when in reality a significant difference does not exist, i.e. rejection of null hypothesis. A type II error occurs when the 'p' value is set too low, i.e. $p<0.01$ and no significant differences are detected when in reality a significant difference does exist, i.e. accept null hypothesis. Vincent (1999) recommends that any statistical analysis must be protected against such errors and suggests that the researcher must be aware of the consequence of being wrong if errors exist. In the four studies reported in this chapter only two significant differences were detected using the independent t tests, that of the left and right hamstring flexibility. The potential limitation of this analysis may be the occurrence of type II errors in that significant differences may exist in reality. If this was the case then the consumers of the research, i.e. potential female student dance teachers or existing dance teachers, will never be able to take advantage of the knowledge that may be helpful in preventing the further occurrence of injury (Vincent, 1999). This may well have implications in the conclusions across the four studies in that predisposing factors, based on the data from the variables collected, may exist that could be predetermining injury in female student dance teachers.

The reasons for the occurrence of this type of error may be related to a number of factors including measurement error in the protocols, a small sample size or a conservative 'p' or significance value (Bland and Altman, 1986; Atkinson and Nevill, 1998). The use of a reliability analysis may help to alleviate the potential errors associated with measurement error. Although the statistical techniques employed in the reliability analysis are recommended (Altman, 1991; Bland, 1991; Atkinson and Nevill, 1998) and the results were accepted as being reliable there were no other published data on this type of reliability analysis with which to compare so it may be that the reliability of the protocols and their implementation may contribute to the error. The setting of the significance value of 0.05 may also have been conservative. However this value is widely used across the sports science and sports medicine literature (Atkinson and Nevill, 1998) as being an acceptable level of error. It may therefore be that a more liberal probability value between 0.05 and 0.1 may be better suited to detect significant differences based on the context of the study i.e the occurrence of injury. It is therefore possible that the main limitation on the present studies could be the number of students used, i.e. sample size. The sample size (n=46), although reflective of a female student dance population, may have been too small to detect significant differences based on the injury nature of the study. It is therefore possible that certain variables across the four studies, between the injured and non injured female student dance teachers, may be significantly different and could predispose the individual to injury which were not previously detected using the current analysis and sample size.

Although characteristics have been identified, from the injured group, as possible contributors to injury, it is noted that all of the data, recorded across the four studies, may be interrelated. The interaction and role of strength and flexibility is well documented (Barton et al. 1986; Whiting and Zernicke, 1998; Watkins, 1999), the effect of flexibility on alignment and force dissipation was forwarded by Bennell et al. (1999) as a possible factor in the onset of injury, and the role of BMI, percent body fat, body mass and force generation are all possible causative factors in injury (Neely, 1998a; 1998b). However the links and interactions between all characteristics, identified by the literature to affect the onset of injury, have yet to be explored as a whole data set.

6. MODELLING INJURY IN FEMALE STUDENT DANCE TEACHERS

An integrative analysis of the epidemiological data collected in Chapters 3 and 5 is carried out in this chapter. These chapters attempted to identify the potential risk factors leading to the prediction of injury in student dance teachers. The data collated included information pertaining to the questionnaire (injury history and demographic data), orthopaedic alignment, flexibility, strength and body composition of the student dancers. Logistic regression statistical procedures were utilised to identify variables that were significantly associated with predicting injury in female student dance teachers meeting objective 4 of this research.

6.1 Introduction

The understanding of the cause of injury is imperative in advancing knowledge towards its prevention. Injuries, associated with physical activity, usually result from a complex interaction of several independent risk factors (Lysens et al. 1984). Identifying the way in which these risk factors interact with one another may lead to the development of effective preventative intervention.

Fletcher et al. (1982) cited in Meeuwisse (1991) defined risk as 'the likelihood that people who are without a disease, but exposed to certain factors (risk factors), will acquire the disease'. Risk factors, in exercise activity, can be generally classified into extrinsic (environmental conditions, and equipment) or intrinsic (individual physical or physiological characteristics) categories (Caine et al., 1996). Often the extrinsic factors cannot be controlled such as environmental conditions and equipment and therefore make their contribution to the injury process irrespective of the individual. However the intrinsic factors are adaptive and manageable in nature, for example strength, flexibility and body composition, and in this respect may be identifiable. A number of intrinsic factors have been identified to affect the onset of injury in sport, exercise and dance. These factors have included the age of the participant and the length of time in participation (Caine and Garrick, 1996), body composition (Benson et al., 1989), flexibility (Gleim and McHugh, 1997), strength (Bennell et al., 1999) and lower limb alignment characteristics (Neely, 1998b). By identifying controllable risk factors it is then possible to predict injury, via a statistical or mathematical model, and ultimately prevent injury in an individual (Kuhn et al., 1997). Preventative measures can be either specific training regimes or by steering potential participants towards a more suitable activity.

The use of multifactorial statistical analysis to predict disease is well documented in the medical literature (Vollmer, 1995; Selker et al., 1995; Dunn et al., 1997; Shann et al., 1997; Matthews et al., 1998; Wallenstein et al., 1998). These analyses have used linear regression, discriminant factor analysis and multiple regression to obtain variables that may predict the onset of a particular disease or indices of mortality. By incorporating such techniques the authors have attempted to establish cause-effect relationships between the associated variables and the disease. Meeuwise (1994) has postulated that such a technique may work in a sports context, in terms of injury prediction, and cited a number of authors including Blair et al. (1987), Giladi et al. (1991) and Macera et al. (1989) who had used similar techniques. These authors used a variety of statistical techniques including multiple regression to predict the onset of injury in runners (Blair et al., 1987), the onset of stress fractures in army personnel

(Giladi et al., 1991) and orthopaedic problems in active males and females, from age and body composition characteristics (Macera et al., 1989). The accuracy of the predictions ranged from 75% for predicting running injuries (Blair et al., 1987) to 84% for predicting stress fractures in army personnel (Giladi et al., 1991). However these studies, although incorporating a multifactorial statistical design, analysed injury from only one parameter, i.e. body composition or flexibility and often employed a univariate or single risk factor approach to assessing causation. As stipulated by Meeuwise (1994), injuries in sport and exercise are likely to be multifactorial in aetiology and examining each risk factor separately without controlling other risk factors would not give a true picture of the nature of the injury. Further it would not determine the factors or combinations of factors that may be truly causal, i.e. flexibility and strength, flexibility and body composition, strength and lower limb alignment.

Of the injury data analysed in this manner in sport and exercise most of the studies have focused on team sports or running (Ross and Schuster, 1983; Tropp et al., 1984; Blair et al., 1987). Little reported data exists on injury prediction in individual sports or exercise activity, such as dance. However, a study by Steele and White (1986) reported on the use of multiple regression in predicting injury-proness in gymnasts. The study was retrospective in nature and analysed flexibility and posture scores. The authors reported a multiple correlation coefficient of $r = 0.840$ ($p<0.05$) for 9 significant independent variables. This coefficient accounted for over 70% of the variance between the injury-proness categories. As was noted by Meeuwise (1991) the authors did not report data on non-injured gymnasts which would affect the ability to predict injury in healthy gymnasts.

The studies reported have highlighted the possibility of studying injury, or disease, from a multifactorial research design. Data exists to support the theory that injury can be predicted, albeit from a single factor. However, no reported information exists on injury predictive equations incorporating more than two intrinsic parameters that have been speculated to contribute to the onset of injury, nor is there evidence to suggest that this type of analysis has been applied to a cohort of dancers.

The aim of this study was to analyse the epidemiological data, reported in Chapters 3 and 5, with a view to developing an injury predictive statistical relationship for female student dance teachers. It was therefore hypothesised that:-

Hypothesis 7: A statistical predictive model of injury, specific to female student dance teachers, can be obtained from the selection of measured variables.

6.2 Method

6.2.1 Subjects

Forty six practicing female student dance teachers, from three college degree programmes, volunteered for the study. All subjects were participating or had participated in similar dance styles. The mean (SD) for age, mass, height and dance experience were 20.4 (3.9) years, 57.2 (7.9) kg, 160.2 (5.8) cm and 12.6 (4.4) years respectively. Of these subjects 28 had reported being injured, as a direct result of dance, at some stage of their dancing career, (age = 20.4 ± 4.2 years; mass 58.4 ± 8.8 kg; height = 161.1 ± 6.2 cm; dance experience 12.6 ± 4.9 years), and eighteen student dance teachers had no history of dance related injury (20.3 ± 3.6 years; 55.4 ± 6.4 kg; 158.8 ± 5.0 cm; 12.6 ± 3.8 years). All the dance students gave informed consent for their data to be used in the study. The subjects were currently enrolled in a degree programme and were performing in a number of dance styles.

6.2.2 Procedure

Data was collected using a number of laboratory based techniques as reported in Chapters 3 and 5. This included flexibility, strength, orthopaedic alignment, body composition and anthropometry (Chapter 5), and a self reporting injury questionnaire (Chapter 3). Dance injury was defined as, any physical ailment that prevented participation in at least one dance class, and was caused as a direct result of dancing. Detailed protocols are reported in Chapters 3 and 5 and in appendices 4 and 5. All data was collected at the same stage of term time over a period of 2 years.

A total of 67 variables were recorded for analysis. This included, 25 kinanthropometric variables, 15 flexibility measures, 4 strength measures, 16 alignment variables and 7 variables as identified from the questionnaire. A further 24 variables were calculated including the strength variables normalised for body weight, a number of whole body and limb length related ratio characteristics, eg. sitting height to body height ratio, Q angle to ASIS distance and femur length to tibial length, and further kinanthropometric values including percentage body fat (%BF) and body mass index (BMI). A total of 91 measured or calculated variables were available for analysis. The data was statistically analysed using the SPSS package. A full list of the variables entered is shown in Appendix 7.

6.2.3 Data analysis

Analysis of the data was performed using a multiple linear logistic regression technique on the SPSS (version 8) statistical software package. This was used because of the nature of the data in that the explanatory variables were predominantly on a continuous scale, whereas the response variable, i.e. injury, was dichotomous (0 = not injured, 1 = injured). This type of analysis, a generalised linear modelling technique, allows predictions to be made as well as an indication of the importance of the variables in relation to the accuracy of the model (Hutcheson and Sofroniou, 1999).

Three logistic regression analyses were performed in order to identify a best fitting model for injury prediction. These included:

1. A software driven forward stepwise logistic analysis as would be automatically performed using all available data by the statistical package;
2. A backward stepwise regression analysis on pre-selected variables based on theoretical concepts, as highlighted in the literature, that have been suggested to influence the onset of injury, and;
3. A backward stepwise regression analysis on the variables that were highlighted on the previous two models.

The explanatory variable coefficients, odds ratios (OR) and their corresponding 95% confidence intervals were calculated for the three predictive models. A probability of $p<0.05$ was taken to indicate statistical significance.

6.3 Results

6.3.1 Model One

In forward stepwise logistic regression the first stage is the calculation of a model containing only a constant value. The constant can be simply interpreted as the intercept on the 'y' axis if all other variable values were equal to zero, i.e. the constant corresponds to the injury status when the predictor variables are zero. The goodness of fit of the model, that is, how well the model with the constant can predict the data, is then assessed using the Chi square distribution and the –2 log likelihood (-2LL). The model with the constant is then compared to a hypothetical model, containing no variables or constants, and analysed for significance. If the difference ($-2LL_{diff}$) between the –2LL for the model with the constant, and the hypothetical model, is significant then the introduction of the constant has had a significant influence on the predictive capacity of the model. A detailed example of logistic regression is given in Appendix 8.

Following this initial analysis of a regression model containing only the constant, the available variables are entered one at a time and a new model recalculated and compared to the previous model in terms of how it fits the data, that is, using the $-2LL_{diff}$. The criteria for selection for the order in which the variables are entered into the model is dependent on the significance of a score statistic as calculated by, and specific to, the SPSS software. Therefore in this type of logistic regression analysis all 91 variables were available for selection into the model.

The most significant explanatory variable is selected first, assuming it meets the selection criteria ($p<0.05$), and the model is then recalculated. The new model containing the constant and explanatory variable is then compared to the previous model, containing the constant only, and analysed for significant difference and fit of the data. The goodness of fit of the model, to the data, is established using the Chi square distribution and -2 log likelihood (-2LL). If the difference ($-2LL_{diff}$) between the initial log likelihood value, which contains only the constant in the model, and the -2 log likelihood value, from the model with the constant and one explanatory variable, is significant then the introduction of the variable into the model has a significant influence on the predictive capacity of the model. An example of this is shown in Table 6.3.1.1.

The information shown in Table 6.3.1.1 displays the data on the assessment of the goodness of fit of the variables, and the model, when compared to the model without the variables. The -2 log likelihood (-2LL) is the statistic used to provide a measure of deviance for the logistic regression model, that is, a measure of the difference between the observed values and those predicted from the model. The change in –2LL represents the effect the explanatory variable(s) have on the deviance of the model. This can be evaluated for significance using the Chi-squared distribution. The degrees of freedom, in this situation, is equal to the difference in the number of terms between the models. The smaller the value of -2LL (chi square statistic) then the better the model fit.

Table 6.3.1.1 Forward Stepwise Selection Model for Predicting Injury

Explanatory Variable	-2LL	$-2LL_{diff}$	df	P
Initial Model Function	61.58			
Left Hamstring Flexibility	56.84	4.74	1	0.03
Sitting height	49.79	7.05	1	0.01
ASIS distance	41.13	8.66	1	0.003

In the forward stepwise selection the first model contains only the constant value. As can be seen in Table 6.3.1.1 the –2LL (a measure of the difference between the observed values and those predicted by the first model) is equal to 61.58. The other variables are then calculated, using a score statistic with corresponding significance value, to test its significance if added to the model. In SPSS the null hypothesis, for variables entered into the model, is that the coefficient is equal to 0, i.e., the variable has no significant effect on the predictive assessment of the model. The software then selects the variable with the lowest significance level, providing it fulfils the entry criteria, $p<0.05$, and recalculates the model and the score statistics for the remaining variables. This selection process is repeated with the model being recalculated at each iteration. The degrees of freedom correspond to the number of variables added to the model at any one stage. Therefore for this type of logistic analysis this value is equal to one as only one variable at a time is added to the model. Table 6.3.1.1 illustrates the outcome of this process. When the constant was used as the only value in the model a –2LL was calculated equal to 61.58. The software package then calculated the significance of the remaining variables on the basis of how influential the variables would be if included into the model with the constant. For entry into the model the variable must have a significant influence on the predictive capacity of the model at $p<0.05$. In the present model the flexibility of the left hamstrings fulfilled the criteria. This variable was then added to the model and the –2LL recalculated for the constant and left hamstring flexibility as the proposed model. The difference between the initial model –2LL (61.58) and the new model –2LL (56.48) is then obtained (4.74) and the significance of this value is compared to the Chi square statistical tables with 1 degree of freedom at $p<0.05$. For this model the inclusion of the flexibility of the hamstrings proved to have a significant influence on the predictability of injury from the data set. This process is repeated, with additional variables being added to the model, if they fulfil the criteria, until no other variables fulfil the criteria and hence would not influence the accuracy of the predictability of the model. Additionally each new model is assessed in terms of the removal of a variable from the model. The Wald statistic is used in SPSS for this procedure (Norussis, 1994). The Wald statistic is calculated for each variable in the model.

If the significance of the Wald statistic for the variable is greater than 0.1 then the variable is removed from the model. If no variables meet the removal criteria then the next eligible variable is entered into the model. The process stops when a variable, selected for removal, results in a model that has already been considered, or when no more variables meet the entry criteria.

From Table 6.3.1.1 there was a significant effect on the predictive accuracy of the model when the three variables were introduced. The forward stepwise regression terminated at this stage suggesting that this was the best fit model and that the introduction or removal of any further variables would significantly reduce the goodness of fit of the model. It should be noted that the introduction of the ASIS distance into the model had a highly significant ($p=0.003$) effect on the model.

Table 6.3.1.2 displays the coefficients for the explanatory variables and the constant along with their respective standard errors (S.E.) and 95% confidence intervals (95%CI). The coefficients of the model represent the change in the log odds of an injury occurring for a unit change in the explanatory variable. For example the coefficient for sitting height is 0.39, therefore a 1cm increase in sitting height, with all other variables constant, will increase the log odds ($e^{0.39}$) of an injury occurring on average by 0.39, i.e. the odds of an injury occurring increases by 1.47. The confidence intervals for sitting height are 0.12 ($e^{0.12}$) and 0.66 ($e^{0.66}$) therefore there is a 95% certainty that for every 1cm increase in sitting height, with all other variables remaining constant, the log odds of an injury occurring will increase by at least 0.12 (1.13) and at the most by 0.66 (1.93).

Table 6.3.1.2 Standardised regression coefficients (and 95% confidence intervals) of significant variables as identified from the forward stepwise logistic regression analyses.

Variable	Coefficient	S.E.	95%CI
Constant	-34.99	14.04	
Sitting Height	0.39	0.14	0.12, 0.66
Left Hamstring Flex	0.12	0.04	0.04, 0.20
ASIS distance	-0.04	0.22	-0.47, 0.39

In order to obtain a final model, based on the forward stepwise regression technique, the log probability of the constant and variables in the model must be obtained. For logistic regression this is known as the logit(p). Logit(p), or log of the odds, is the *ratio* of the probability of an event occurring to the probability of the event not occurring,

$\text{Logit}(p) = \log_e [p / (1-p)]$ (equation 1)

In terms of the reported model it refers to the log probability of an injury occurring based on the explanatory variables. An easier interpretation of the logit (p) is to take the inverse of the natural log of logit (p), e^p. Therefore, rearranging equation 1, the probability of the event occurring i.e. an injury occurring, will be:-

$p = 1 / 1 + e^{-p}$ (equation 2; adapted from Altman, 1991)

This will give the probability of injury occurring based on the values of the three variables. The final model, based on the forward stepwise regression technique, was calculated as:-

logit (p) = -34.66 + 0.39 * (sitting height) + 0.12 * (left hamstring flexibility) – 0.04 * (ASIS distance).

The constant, calculated for this model was –34.66 and the logistic regression coefficients were 0.39, 0.12 and –0.04 for sitting height, left hamstring flexibility and ASIS distance respectively. In order to illustrate, and fully explain, how the model works it is useful to input data obtained from one of the subjects. As an example subject 3 recorded measured scores of 83 cm, 120 degrees, and 24.3 cm for sitting height, hamstring flexibility and ASIS distance respectively. When substituted into the model the logit(p) value is calculated as 2.39. Using equation 2 the probability of subject 3 acquiring an injury, due to dancing, is 0.92, i.e. there is a high probability that an injury would occur. This high probability is based on Norussis (1994) who suggested that if the estimated probability of the event (injury) was greater than 0.5 then it is predicted that the event (injury) would occur. Similarly if the estimated probability was 0.5 it would be predicted that the event would not occur. Subject 3 in this case did have a history of dance related injury.

Chi-square for the model was $X^2_{(3)} = 20.45, p<0.05$. The model was significantly different, in that it was a better fit, than the initial model function with no variables in the model, i.e. a better fit than the model with the constant only. This was the best fitting model as calculated by the forward stepwise logistic regression analysis on the

SPSS software and reported as the log probability (logit (p)). The predictive accuracy of the model was 78.26% based on the classification table. The classification table assesses how well the model fits its predictions to the observed data (Norussis, 1994). This is a measure of how successfully the model predicts the categories of injured and non-injured dancers, from the model, based on the values of the explanatory variables within the model.

A further way of reporting the data and the probability of injury occurring is that of odds ratio (OR) as shown in Table 6.3.1.3.

Table 6.3.1.3 Odds ratios (and 95% confidence intervals) for the significant variables as identified from the forward stepwise logistic regression analyses

Variable	Odds Ratio (OR)	95% CI
Sitting Height	1.47	(1.11, 1.95)
Left Hamstring Flex	1.12	(1.03, 1.22)
ASIS distance	0.96	(0.92, 1.00)

The odds ratio represents the change in the odds of p associated with a unit change in the explanatory variable (Hutcheson and Sofroniou, 1999). It is calculated by taking the inverse of the natural log of the coefficient. From Table 6.3.1.2 the coefficient for sitting height was 0.39 which equates to an odds ratio of 1.47 ($= e^{0.39}$). This indicates that for each unit increase in sitting height, with all other variables held constant, the odds of p change to 147% of its previous value, an increase of 47%. The confidence intervals suggest that this increase will be at least 11% and at the most 95%. As both of these confidence intervals predict an increase in the odds ratio it can be concluded that at the 95% two-tailed level of significance sitting height does have an affect on the occurrence of injury.

A similar conclusion can be drawn on the flexibility of the left hamstring. The confidence intervals suggest that in 95% of cases a unit increase in left hamstring flexibility will result in at least a 3% and at the most a 22% increase in the odds of injury occurring. Both intervals predict an increase therefore it can be concluded that the flexibility of the left hamstring does have a significant affect on the occurrence of injury. However the odds ratio for anterior superior iliac spine distance (ASIS) suggests a decrease in the odds of injury occurring (4%) for every unit increase in ASIS distance. In 95% of cases, each unit increase in ASIS distance results in the odds of p, and hence injury, decreasing by up to 8% (0.92) and having no change at all (1.00).

6.3.2 Model Two

The second model was calculated using a backward stepwise regression analysis. The starting model in this case is one where all, pre selected, explanatory variables are entered and terms are then removed from the model sequentially. At each step in the process the term which, if removed, results in the smallest change in the predictive capacity of the model, is removed from the model provided it has reached the removal criterion, $p>0.1$ (Hutcheson and Sofroniou, 1999). In SPSS the Wald statistic is used for this purpose. After each term is removed the regression equation is recalculated and the terms left in the model are re-examined to see if any contribute less than the criterion level. This process continues until all terms are removed from the model or until none of the remaining terms reach the criterion for removal.

A total of 16 variables were entered into the starting model. These variables included; age, percentage body fat, body mass index (BMI), back strength in body weight units, left and right hamstring flexibility, left and right hip flexibility, the whole body stand and reach flexibility score, left and right Q angles, ASIS distance, the distance between the left and right inner femoral condyles, the distance between the left and right medial malleoli, time spent in dance practice and the years spent dancing regularly. The criteria for selection of these variables was predominantly based on data reported in the literature identifying the selected variables as possible contributors to the onset of injury. Further reasons for including the variables focused around the predictor variables from Model 1 and also associated, or secondary variables, that could influence the role of the dominant variables reported in the literature and mentioned throughout the present study. For example, the inclusion of ASIS distance as a secondary variable related to Q angle and inner femoral condyle distance and medial malleoli distance as indicators of genu valum or varum discussed in Chapter 5.

Table 6.3.2.1 displays the information on $-2LL_{diff}$ and significance levels for the explanatory variables in the final model. In this case, for backward stepwise regression, the $-2LL_{diff}$ and corresponding significance level, refers to the effect that the removal of the explanatory variable would have on the overall goodness of fit of the model. For the final model therefore, removal of any of the explanatory variables would have a significant effect on the fit of the model, $p<0.05$.

The explanatory variable that, if removed, would have the greatest effect on the fit of the model was the flexibility of the right hamstring ($p=0.002$). That is, if this explanatory variable was removed from the regression equation it would reduce the accuracy of the fit of the model to the data, effectively reducing the power of the equation to accurately predict injury. The distance between the medial malleoli and the Q angle, as measured on the left leg, would also have a highly significant effect on the fit of the model with p values of 0.006 and 0.002 respectively.

Table 6.3.2.1 Backward Stepwise Selection Model for Predicting Injury

Explanatory Variable	$-2LL_{diff}$	df	P
Right hamstring flexibility	9.96	1	0.002
Left Q angle	5.56	1	0.02
Right Q angle	3.69	1	0.05
ASIS distance	3.51	1	0.05
Medial malleoli distance	7.54	1	0.006
Hours in practice	3.74	1	0.05

Table 6.2.3.2 displays the regression coefficients, standard errors and corresponding 95% confidence intervals for the explanatory variables in the backward stepwise regression model. The final model, based on the selected explanatory variables, was:

Logit(p) = -19.98 + 0.14 * (right hamstring flexibility) + 1.17 * (left Q angle) – 0.90 * (right Q angle) – 0.03 * (ASIS) + 0.04 * (medial malleoli distance) + 0.24 * (practice hours)

The overall predictive accuracy of the model was 82.61%, i.e. the model identified the injured and non-injured dancers, from the explanatory variables in the model, correctly 82.61% of the time. Chi-square for the model was $X^2_{(6)} = 23.76$, $p<0.05$. The model was significantly different, in that it was a better fit, than the initial model function with no variables in the model. This was the best fitting model as calculated by the backward stepwise logistic regression analysis on the SPSS software and reported as the log probability (logit (p)).

Table 6.3.2.2 Standardised regression coefficients (and 95% confidence intervals) of significant variables as identified from the backward stepwise logistic regression analyses.

Variable	Coefficient	S.E.	95%CI
Constant	-19.98	10.13	
Right Hamstring Flexibility	0.14	0.06	(0.02, 0.26)
Left Q angle	1.17	0.59	(0.02, 2.33)
Right Q angle	-0.90	0.54	(-1.96, 0.16)
ASIS distance	-0.03	0.02	(-0.06, 0.01)
Medial malleolos distance	0.04	0.02	(0.01, 0.08)
Hours in dance practice	0.24	0.14	(-0.03, 0.51)

The odds ratios (OR), representing the change in the odds of p associated with a unit change in the explanatory variable are shown in Table 6.3.2.3. The explanatory variables, right hamstring flexibility, left Q angle, medial malleoli distance and hours spent in dance practice had odds ratios greater than one. This indicates that a unit change in these variables, providing the other variables were held constant, would have a corresponding increase in the odds of p. For this model the left Q angle would have an average increase in the odds of p equivalent to 223% for a every unit increase in Q angle, i.e one degree.

Table 6.3.2.3 Odds ratios (and 95% confidence intervals) for the significant variables as identified from the backward stepwise logistic regression analyses

Variable	Odds Ratio (OR)	95%CI
Right Hamstring Flexibility	1.15	(1.02, 1.29)
Left Q angle	3.23	(1.02, 10.28)
Right Q angle	0.41	(0.14, 1.17)
ASIS distance	0.98	(0.94, 1.01)
Medial malleoli distance	1.04	(1.00, 1.07)
Hours in dance practice	1.28	(0.96, 1.69)

The odds ratio (OR) for right Q angle and ASIS distance, however, were less than one. This indicates that for every unit increase in these variables, one degree or one centimetre, there would be a corresponding decrease in the odds of p. This decrease would be, on average, equivalent to 59% and 2% for a unit increase in right Q angle and ASIS distance respectively.

The confidence intervals for the odds ratio for each explanatory variable are also shown in Table 6.3.2.3. The intervals for both right hamstring flexibility and left Q angle predict increases ranging from 2% to 29% and 2% to 928% for the variables respectively. As the confidence intervals, for both variables, predict an increase in the odds ratio it can be concluded that at the 95% level of significance right hamstring flexibility and left Q angle have a significant affect on the occurrence of injury from this model.

The 95% CI's for the other explanatory variables, however, include the value of 1 in their interval range. This suggests that these variables do not have a significant influence on the model, in that, a value of 1 indicates that for every unit increase in the explanatory variable there will be no change in the odds ratio of the occurrence of injury. Indeed the right Q angle variable has a confidence interval range from an 86 % decrease in the odds of injury occurrence to a 17% increase in the odds of injury occurrence.

6.3.3 Model Three

The final model considered was based upon a backward stepwise logistic regression incorporating the variables as identified from the previous two models. This combination of eight explanatory variables included sitting height, left hamstring flexibility and ASIS distance from Model One, and the remaining variables of right hamstring flexibility, left and right Q angles, medial malleoli distance and hours spent in dance practice from Model Two. The significance of the combined model explanatory variables are shown in Table 6.3.3.1.

The explanatory variables that, if removed, would have the greatest significant effect on the fit of the model were the flexibility of the right hamstring (p=0.001) and sitting height (p=0.003). Removal of these variables would have a significant effect on the fit of the model based on the data set (p<0.05). However, as with the previous backward regression model (Model Two), removal of any of the variables would have a significant effect on the fit of the model.

Table 6.3.3.1 Backward Stepwise Selection Combined Model for Predicting Injury

Explanatory Variable	$-2LL_{diff}$	df	P
Sitting height	8.96	1	0.003
Right hamstring flexibility	12.2	1	0.001
Left Q angle	4.34	1	0.04
Right Q angle	3.75	1	0.05
ASIS distance	6.98	1	0.01
Medial malleoli distance	3.61	1	0.05
Hours in practice	4.89	1	0.03

Table 6.3.3.2 displays the regression coefficients, standard errors and corresponding 95% confidence intervals for the explanatory variables in the backward stepwise

regression model. The final model, based on the combined explanatory variables from the previous two models, was:

Logit (p) = -56.79 + 0.47 * (sitting height) + 0.18 * (right hamstring flexibility) + 1.15 * (left Q angle) – 1.04 * (right Q angle) – 0.05 * (ASIS) + 0.04 * (medial malleoli distance) + 0.33 * (practice hours in dance)

The overall predictive accuracy of the combined model was 89.13%, i.e. the model identified the injured and non-injured dancers, from the data set, correctly 89.13% of the time. Chi-square for the model was $X^2_{(7)} = 32.72$, $p<0.05$. The model was significantly different, in that it was a better fit, than the initial model function with no variables in the model. This was the best fitting model as calculated by the backward stepwise logistic regression analysis on the SPSS software and reported as the log probability (logit (p)).

The odds ratios, representing the change in the odds of p associated with a unit change in the explanatory variable are shown in Table 6.3.3.3. The explanatory variables, sitting height, right hamstring flexibility, left Q angle, medial malleoli distance and hours spent in dance practice had odds ratios greater than one. This indicates that a unit change in these variables, providing the other variables were held constant, would have a corresponding increase in the odds of p. For this model the left Q angle would have an average increase in the odds of p equivalent to 216% for every unit increase in Q angle, i.e a one degree increase in left Q angle would increase the odds of injury occurring by 216%. Similarly a one centimetre increase in sitting height would increase the odds of injury occurring by 59%.

Table 6.3.3.2 Standardised regression coefficients (and 95% confidence intervals) of significant variables as identified from the backward stepwise logistic regression analyses for the combined models.

Variable	Coefficient	S.E.	95%CI
Constant	-56.79	22.26	
Sitting Height	0.47	0.20	(0.08, 0.86)
Right Hamstring Flexibility	0.18	0.07	(0.04, 0.32)
Left Q angle	1.15	0.66	(-0.14, 2.44)
Right Q angle	-1.04	0.65	(-2.31, 0.23)
ASIS distance	-0.05	0.03	(-0.11, 0.01)
Medial malleolus distance	0.04	0.02	(0.001, 0.08)
Hours in dance practice	0.33	0.19	(-0.04, 0.7)

The OR for right Q angle and ASIS distance were less than one, a finding similar to model two, Table 6.3.2.3. This indicates that for every one unit increase in either of these variables, providing the other variables remain constant, the odds of injury occurring will decrease. For example, a one unit increase in ASIS distance would decrease the odds of injury, on average, by 4%.

Table 6.3.3.3 Odds ratios (and 95% confidence intervals) for the significant variables as identified from the backward stepwise logistic regression analyses for the combined models.

Variable	Odds Ratio (OR)	95%CI
Sitting Height	1.59	(1.08, 2.36)
Right Hamstring Flexibility	1.20	(1.04, 1.39)
Left Q angle	3.16	(0.87, 11.52)
Right Q angle	0.36	(0.10, 1.26)
ASIS distance	0.96	(0.91, 1.01)
Medial malleolus distance	1.04	(0.99, 1.08)
Hours in dance practice	1.39	(0.96, 2.02)

The 95% confidence intervals for the OR for each explanatory variable in the model are also shown in Table 6.3.3.3. Only two variables, sitting height and right hamstring flexibility, do not include the value of 1 in their corresponding intervals. As both interval values, for both variables, predict an increase in the odds ratio it can be concluded that at the 95% level of significance right hamstring flexibility and sitting height have an affect on the occurrence of injury from this model. For the other explanatory variables their corresponding 95% confidence intervals include the value of 1 and are therefore non-significant ($p>0.05$).

6.3.4 Summary

Ninety one variables, as measured or calculated from each of the 46 participants, were used in the logistic regression analysis. Three models were calculated from the logistic regression techniques of forward stepwise regression (model 1) and backward stepwise regression (models 2 and 3). All 91 variables were made available for model 1 in the forward regression analysis which calculated the regression model:

$$\text{Logit}(p) = -34.99 + 0.39 * (\text{sitting height}) + 0.12 * (\text{left hamstring flexibility}) - 0.04 * (\text{ASIS distance})$$

The odds ratio's for the variables were 1.47, 1.12 and 0.96 for the three variables respectively. The overall predictive accuracy of model one was 78.26%

Model two contained 16 variables as identified by the literature and the previous studies (Chapters 3 and 5). These variables were entered into a backward stepwise regression analysis. This analysis calculated the model:

$$\text{Logit}(p) = -19.98 + 0.14 * (\text{right hamstring flexibility}) + 1.17 * (\text{left Q angle}) - 0.9 * (\text{right Q angle}) - 0.03 * (\text{ASIS distance}) + 0.04 * (\text{medial malleoli distance}) + 0.24 * (\text{practice hours})$$

The odds ratios for the variables were also calculated. The right Q angle and ASIS distance predicted a decrease in the odds of injury occurring for every unit increase in their respective variable while the other explanatory variables predicted increases in the odds of injury occurrence. The 95% confidence intervals indicated that only the explanatory variables, left Q angle and right hamstring flexibility, were significant in their influence on the occurrence of injury. The overall predictive accuracy of the model was 82.61%.

The third model commenced with the 8 different variables identified from the previous two models. These variables were input into a backward stepwise regression analysis and calculated the model:

Logit(p) = -56.79 + 0.47 * (sitting height) + 0.18 * (right hamstring flexibility) + 1.15 * (left Q angle) – 1.04 * (right Q angle) – 0.05 * (ASIS distance) + 0.04 * (medial malleoli distance) + 0.33 * (practice hours)

The right Q angle and ASIS distance were identified, from the odds ratios, as having an increase in the odds of injury occurrence for every unit decrease in their values. The other variables were calculated as having an increasing effect on the odds of injury occurrence for every unit increase in their respective values. The values for the 95% confidence intervals indicated that the explanatory variables of sitting height and right hamstring flexibility were the only variables to have a significant influence on the occurrence of injury. The predictive accuracy of the model was 89.13%.

6.4 Discussion

Three models and two logistic regression techniques were used to identify the variables, and their combinations, in predicting injury in student dance teachers. The three models had overall predictive accuracies of 78.26%, 82.61% and 89.13% respectively. The results of each of these models show that there are important relationships between injury in dance, kinanthropometric measures, flexibility, body alignment and time spent in dance participation.

Injuries are influenced by many factors (Lysens et al., 1984). In order to gain an insight the individual and joint contributions of each of the factors need to be evaluated. Logistic regression deals with, and incorporates the effect of, explanatory variables on a categorical outcome such as injured or non-injured. This statistical technique has been utilised for this purpose for a wide range of medical problems and outcomes (Vollmer, 1995; Selker et al., 1995; Matthews et al., 1998; Golding et al., 1992 cited in Hall and Pound, 1994).

As with other statistical analysis, the chance of the outcome being favourable would depend on the findings and this is represented by probability (Hall and Pound, 1994). The chance of an event, or injury, occurring would then lie between 0 (not injured) and 1 (injured). In logistic regression the probability is usually represented by the odds of an event occurring and this is defined as the ratio of the probability of the event occurring to the probability of the event not occurring.

There are two common methods of variable selection in logistic regression, a forward stepwise regression and a backward stepwise regression, both of which were utilised in the present study. However the process by which the variables were selected and then entered into the analysis was controlled and based on the calculations performed for entering data into a logistic regression model, outcomes of analyses in Chapters 3 and 5, and on the published sports medicine and dance medicine literature.

Model One was calculated using a forward stepwise regression analysis with 91 variables available for inclusion. However, forward regression enters one variable at a time on the basis of relative importance (a detailed description of this calculation is illustrated in Appendix 8). In Model Two a backward regression technique was utilised. In this case 16 variables were made available for analysis. These variables were specifically selected based on the literature which repeatedly reported on them and also on the variables identified from the data analysis performed in the previous chapters. Therefore the analysis was restricted to variables that were theoretically linked or singularly evidenced as influencing injury specific to dance.

The literature has reported the use of both types of logistic regression analysis without clearly justifying a rationale for their use. Several authors have suggested that method selection should be guided by the rationale for selecting the variables to be used as predictors, i.e. variables previously reported in the literature (Blair et al., 1987; Matthews et al., 1998). This rationale would favour the use of a backward regression as all variables would be considered from the outset both individually and in an interactive capacity. However the backward regression method relies heavily on the accuracy of the previously reported literature and its specificity to the population being studied. If this had been the only method considered then sitting height would not have been forwarded as it has not been previously reported as a significant influencing factor in the onset of injury. Therefore in order to identify the individual variables, specific to a dance population, a forward regression technique was utilised first (Model One).

Previous research has suggested that there are a number of intrinsic factors which appear to influence the onset of injury during sport and exercise participation including anthropometry and body composition (Benson et al., 1989); flexibility (Gleim and McHugh, 1997); strength (Kirkendall et al., 1984; Micheli et al., 1984); kinanthropometry and previous injury history (Clanin et al., 1984); body alignment (Solomon et al., 1990; McNeal et al., 1990); and length of time practising (Clanin et al., 1984; Caine et al., 1996). However these authors have only postulated with the criteria for one intrinsic factor on a specific population. They have also noted the limitations of this method and the importance of the combination of intrinsic factors, activity and population in the onset of injury. Based on this rationale all 91 variables were made available for the first model. Forward regression introduces significantly influencing variables one at a time, with the impact of the variable being assessed with and without other variables in the existing model. In this way the relationship and interaction of the explanatory variables under consideration, and their overall influence in the prediction equation, is effectively and fully assessed.

A similar backward regression technique, as utilised in Model Two, was employed for analysis in producing Model Three. This incorporated the variables from both prediction equations in Models One and Two. The rationale for using these variables was to produce a realistic, population specific, practiceable working model involving the significant variables identified from an automated selection process, as utilised by Satterthwaite et al. (1999), and a theoretical process (Blair et al., 1987; Matthews et al., 1998). The third model was considered because it not only incorporated the significant aspects identified in the previous two models, i.e. the variables theoretically reported to be linked to the onset of injury, but also included functional variable characteristics reflective of, and specific to, the requirements of a potential student dance teacher, i.e. population and activity specific. These variables have been reported previously in the dance medicine literature but as yet have not been considered in a statistical injury predictive model. This therefore has the potential of making the third model more realistic in terms of the functional and kinanthropometric characteristics representative of a practicing student dance teacher. Therefore the three model approach considers the data from; (1) an individual variable approach, in an attempt to identify any activity specific predictors, i.e. sitting height; (2) a research based approach in terms of the variable being previously reported in the sport and/or dance medicine literature, and combines the outcomes to produce a; (3) comprehensive predictive analysis of the variables responsible for influencing the onset of injury in female student dance teachers.

From model one sitting height was calculated as having a 47% higher risk of injury, for a unit increase in sitting height, with all other variables remaining constant based on this equation. Therefore if the odds ratio for injury of a dancer was calculated as 0.35 (a low possibility of injury, Appendix 8) a similar dancer, with a one unit increase in sitting height, i.e. 1 cm, with all other variables remaining constant, would have an odds ratio for injury of 0.51, i.e. a 50% chance of injury occurring. This explanatory variable may be related to the ratio of sitting height to standing height, but although available for selection in the third model, did not appear in the final equation. Therefore it is the absolute value of sitting height which may contribute to the onset of injury. A possible explanation for this maybe the role of the increased load on the lumbar spine, due to larger bony structures of the upper body, and the subsequent strength and flexibility requirements of the supporting structures. Biomechanically there is an increased moment and torque about the lumbar spine when performing twisting, turning or arching movements of the back, with a longer spine (Palastanga et al., 1994; Nigg et al., 2000). These movements were identified in Chapter 3 as movements preceding the onset of injury to the back.

The flexibility of the left hamstring was also identified from Model 1 as having a significant influence on the onset of injury. Increased flexibility has been highlighted by many authors as a possible predisposing factor to injury (Mechelen, 1992; Mechelen et al., 1992; Neely, 1998b; Bennell et al., 1999). These authors suggested that the cause of this may be down to the instability and lack of strength control at the optimal range of motion. Unless there is sufficient muscular strength and stimulation, at the optimal point of the muscle stretch, then there is a potential risk of injury at this range of flexibility. Direct comparison of the hamstring flexibility data (Section 5.4.3) with published data is difficult because of the different protocols reported. However, authors reporting on dancer flexibility generally conclude that dancers demonstrate high levels of flexibility, when compared to other sport and exercise performers, and suggest that this, combined with inadequate muscular strength, contributes to the onset of injury (Gannon and Bird, 1999; Hamilton et al. 1992; Reid et al. 1987). Conversely, hamstring flexibility that is too tight will prevent the dancer from achieving the correct posture and prevent the demonstration of correct dance technique, the latter of which has been suggested to lead to injury in dancers (Howse and Hancock, 1992).The present model, however, did not contain a strength variable. This may be due to the fact that leg strength, of the student dance teachers, was not measured at the extreme ranges of motion. It should also be noted that the measurement of muscle strength was performed using a portable leg dynamometer which does not isolate specific muscle groups nor left or right legs of the body. This may have limited a detailed explanation and interpretation of the model in relation to specific muscle group strength characteristics.

The final variable identified from Model One was the anterior superior iliac spine distance (ASIS) with the risk of injury increasing as the ASIS distance decreases. This contradicts the existing sports medicine literature (Neely, 1998a) which associates an increase in the ASIS distance with an increase in the angle of the femur in relation to the line of the tibia, with a corresponding increase in Q angle. This is a somewhat simple concept as it does not take into account the angulation of the femoral condyles on the tibial plateau, i.e. the effect of knock knees. It may be that this angulation has a greater influence on the Q angle. A possible further explanation for this contradiction would be the influence of the inner femoral condyle distance. If the ASIS distance was increasing with a corresponding increase in inner femoral condyle distance then the Q angle would effectively remain constant. However the statistical model did not include this variable and therefore makes a detailed interpretation difficult. The Q angle has been reported in the literature as having an influence in the occurrence of injury, predominantly in females, in that an increase in Q angle will increase the risk of injury by inducing poor lower limb alignment (Riegger-Krugh and Keysor, 1996;

Bennell et al., 1999). This in turn prevents the adequate attenuation of impact forces through the skeleton and relies more on the weaker ligamentous and tissue structures around the joints.

Model Two identified 6 explanatory variables from the starting 16 that were made available for the analysis. This model included two variables from model one, ASIS distance and hamstring flexibility, and also included the right hamstring flexibility as a significant influencing factor on this occasion.

The difference between Model One and Model Two, in terms of left and right hamstring inclusion, can be explained by the type of regression analysis employed. Model One used a forward regression analyses where variables are added based on their influence on the previous model, i.e in order for the variable to be included it must have a significant ($p<0.05$) influence on the predictive capacity of the model (in SPSS this is the Wald statistic). The analysis terminates when there are no more variables that meet the entry criteria, i.e.Wald statistic is greater than 0.05. Model Two used a backward regression analysis in that all variables are included in the initial model and are sequentially removed based on their predictive power within the model in that if removed they did not decrease the power of the model to accurately predict the outcome. The inclusion of all variables (parsimony) would increase the predictive accuracy of the model, however, the backward regression attempts to obtain the most succinct and simplest model to describe and predict the outcome. Therefore the inclusion of the left hamstring flexibility would be acceptable in the model, for parsimony, but not necessarily increase the predictive accuracy of the model and so would be sequentially removed from the model based on the analysis programme. Similarly the inclusion of the right hamstring flexibility would be acceptable in Model One, for parsimony, but would not increase the statistical predictive power of the model. It is therefore not included in Model One. It is therefore possible to argue that inclusion of the variables could be based on the order in which they are entered into the statistical programme. Nevertheless, in Model Two, both variables (left hamstring flexibility and ASIS distance) influenced the model as reported in Model One, with an increased flexibility score increasing the injury risk potential of the dancer. The model contained the further variables of medial malleoli distance and left and right Q angles as explanatory factors in the prediction of injury.

Both left and right Q angles were present in the model. However both left and right sides influenced the predictive equation from different perspectives in that an increase in the right Q angle would decrease the risk of injury, whereas an increase in the left Q angle would increase the risk of injury. A clear explanation or interpretation for this anomaly is not apparent and has not been previously reported in the literature. An average Q value was calculated as one of the additional variables available for selection in Model One, however it proved to be non significant. The inclusion of the two Q angles were based on potential structural imbalance about the pelvic region, and maybe related to leg length discrepancies (ASIS to medial malleolus distance). However it was anticipated that an increase in both Q angles would increase the risk of injury. From the 95% confidence intervals for the odds ratios only the left Q angle proved significant in that it did not include the value of one and indeed for every one degree increase in the left Q angle the odds of injury would increase on average by 223%. An increase in Q angle has been reported by a number of authors as a possible predisposing factor in the susceptibility to injury predominantly in females. The increase in right Q angle was not significant suggesting that this may be an anomaly in the predictive equation. However it is possible that a leg length discrepancy and muscular imbalance, around the pelvic region, could affect pelvic tilt and influence bilateral Q angle. It is therefore suggested that reporting the Q angle from one side of the body is not specific as a measure in its relation and explanation to injury for student dance teachers. However, no literature has been published to support such a theory which makes a comparison, and a clear understanding for this outcome, difficult to establish.

The other factor possibly related to the ASIS distance and Q angle, and influencing injury, is that of the medial malleoli distance. The equation suggested that an increase in this distance would have an increase in the odds of injury by 4%. During measurement of this distance the subjects were asked to stand on a template with heels a set distance apart and the feet externally rotated a set angle. Each subject therefore stood in the same position. An increase in the distance between the medial malleoli may suggest that the feet are in a supinated or inverted position. Genu varum (bowleggedness) is normally associated with this foot characteristic (Kendall et al., 1993) which increases the angle of the patella tendon and tibia to the femur and quadriceps tendon, through lateral subluxation of the patella, and hence effectively increases the Q angle. This may well help to further explain the role, and importance, of the ASIS distance in the equation in that although an increase in medial malleoli distance increases the likelihood of injury a corresponding increase in ASIS distance decreases the likelihood of injury in female student dance teachers. It therefore seems that predisposing factors to injury are inverted feet and a small pelvis. The inverted foot could also suggest a degree of over pronation, during the gait cycle, a factor further associated with the onset of injury (Cavanagh, 1990).

The final variable present in the model was the hours spent in practice. The model suggests that as the time spent practicing increases so the risk of injury increases. That is, for every one hour increase in practice time the risk of injury increases, on average, by 24%. This is a phenomenon widely reported in the literature for many exercise activities (Powell et al., 1986; Hoeberigs, 1992; Macera, 1992; Mechelen et al., 1992; Neely, 1998b; Satterthwaite et al., 1999). Dance in this case is no exception, however it can be further exacerbated by the continual practising of inaccurate technique as the dancers tend to practice unsupervised.

The final model considered incorporated the 8 variables present in the previous models. It was assumed that by selecting the significant variables identified from the automated variable selection and the theoretical variable selection a comprehensive and practical model may be developed which would lend itself to a realistic prediction of injury. The analysis produced a model containing 7 of the 8 explanatory variables submitted.

The explanation for each of the variables in the model has been interpreted in the previous models, with the magnitude and direction of the coefficients similar to both previous models. The coefficient for sitting height was slightly higher (0.47) when compared to Model One (0.39) emphasising the importance of sitting height as a predisposing factor in the onset of injury. The inclusion of the ASIS distance and the medial malleoli distance with similar coefficients as in Model Two, may reiterate the role that both play in the importance of Q angle for female dance teachers. Both Q angles have also been included in the final model suggesting the predictive capacity of both is essential in the possible relationship to leg length discrepancy and muscular compensation. The flexibility of the hamstrings, albeit the right side as opposed to the left side in Model One, emphasises the role of over flexibility and the potential inadequacies of muscular co-ordination at extreme ranges of joint and muscular motion. The further importance of over training or practising is also evident in the model with a higher coefficient than that of Model Two.

In order to highlight the relative importance of each of the explanatory variables it was useful to consider the 95% confidence intervals for the odds ratios of the final model. It is noted that sitting height and right hamstring flexibility were the only two variables which did not include the value of one in the intervals. This suggests that these variables are significant in 95% of the cases for explaining or predicting injury from the model. This was also the case in Model One, although it was the left hamstring flexibility that was reported. Further, in Model Two, hamstring flexibility (right) was also identified has having a significant influence on the predictive capacity of the model with this variable being significant in predicting injury 95% of the time from the reported model. However, in Model 2, sitting height was not submitted for selection in the model as no literature had suggested its importance as an influencing factor in the onset of injury. As it appears in both models, and both times significant, it may be that this upper body measurement has a significant importance in predicting injury in female student dance teachers. This may be further supported with the data reported in Chapter 3 which highlighted the back as the second most reported site of injury. It may well be that the structures supporting the longer spine, from both a torsional and moment force production, and also from increased stress due to extra loading of the spine on the lumbo-sacral junction, may have significant impact for injury in the lower back. This may also be exacerbated by inverted feet and an associated genu varum affecting the Q angle. This in turn affects body alignment, for force dissipation, during repetitive high impact actions common in the dance styles reported in Chapter 4. It was therefore suggested that Model Three was the more realistic and applicable model for the prediction of injury in female student dance teachers.

Although the three models considered have been interpreted qualitatively, and in respect of evidence in the reported literature, a number of precautions have been reported in the use of logistic regression (Hall and Pound, 1994; Hutcheson and Sofroniou, 1999). These precautions have been predominantly centered around the selection of the variables, their independence and the multiplicative nature of the models.

The precaution in the rationale for selection of the variables has been addressed in terms of the order and use of the regression techniques. It was preferred to start with a forward stepwise regression technique which introduced one variable at a time, to the initial model, based on the statistical significance of the independent variable. Although all variables could have an influence in the onset of injury, based on reported literature, and that statistical efficiency dictates the use of a parsimonious model, this first method of automated variable selection was thought to be of more value. It was assumed that the rationale for inclusion into the model was more scientific in its approach in terms of producing a predictive equation based on statistical modelling. This was opposed to starting with all possible variables and then removing them one at a time, as in backward regression. That is, starting with the most significant variable and building a model on this premise, as opposed to reducing a model based on least significant influence. Further, the inclusion of all variables in a model (parsimony), although statistically the most accurate and efficient, would prove unrealistic to control in a real situation, and difficult to interpret in terms of the multitude of interactions available through the model. In this respect, it could be argued that Model Three provided the best overall fit (89.13%) because of this degree of parsimony. However, if this was the case, then the final model would have included all 8 starting variables. This was not noted in the predictive model.

Hall and Pound (1994) have suggested that the lack of independence of the variables, their interaction and the multiplicative nature of the model may lead to inaccurate interpretation of the regression model. The authors note that although the equation assumes independence of the predictor variables this may not reflect the actual situation in terms of the practicality of the model in a real situation, in that variables in a real situation are usually correlated to some extent. They further suggest that to exclude interactions may promote type II errors. However although interaction may be evident in real situations and should be included for selection into the model, in practice many interactions prove to be non-significant in a logistic regression model (Lewis-Beck, 1993 cited in Hutcheson and Sofroniou, 1999). In the case of the models presented, specifically in Model One, an additional 15 composite variables were available for inclusion in the model. However none were found to be significant enough to be included in the initial model (Model One).

Bland (1991) and Altman (1991) suggested two further factors to be considered when interpreting a logistic regression model, those of mulitcollinearity and over or under dispersion. To some extent multicollinearity had been addressed in terms of the interactions of the predictor variables. This term is used to describe a situation where an explanatory variable is related to one or more of the other explanatory variables in the model. However, as stated by the authors, the consequences of multicollinearity depend on the objectives of the analysis. If the main aim of the analysis is to provide a predictive equation then multicollineraity may not be such a problem as it is primarily associated with the calculated importance of the explanatory variables.

A second factor is dispersion. Under or overdispersion is associated with the binomial errors apparent in a logistic regression model constrained by the variance being a fixed function of the mean (Altman, 1991). Therefore if the variance is greater than would be expected for the assumed distribution then the data is overdispersed. Hutcheson and Sofroniou (1999) suggest a simple correction for over or underdispersion involving the adjustment of the standard errors from the original model. As a method for checking the dispersion of the models considered, a correction factor was calculated and compared to the standard value reported by Hutcheson and Sofroniou (1999). The constant value calculated for the models was 0.98, suggesting underdispersion, i.e. the distances between the grouped data are larger than the simple probability would predict. However when the adjusted standard error was recalculated from the correction factor and used in the calculation of the confidence intervals for the fitted model, differences only occurred after the second decimal place. It was therefore suggested that although the data was underdispersed it was not felt that the level of underdispersion was significantly sufficient to affect the confidence intervals of the fitted model.

A final limitation that was also mentioned in Chapter 5.6 is that of sample size in respect of the models proposed. The data for the three models were collected on 46 female student dance teachers. The previous studies that have been reported have obtained data on 116 sedentary men (Dunn et al., 1997), 438 male and female runners (Blair et al., 1987) and 5582 male and female patients attending an orthopaedic clinic (Macera et al., 1989). In comparison to these studies the total number of subjects used in the present study is relatively small. However as a sample of a female student dance teacher population the number of subjects used was representative and reflective a female student dance teacher based on the University curriculum aiming to fulfil the requirements recommended in the National Curriculum for England and Wales (Gray, 1998). Further to this the 32 publicised and specialist dance teacher degree programmes in the UK (www.ucas.co.uk, accessed October, 2002) with an estimated 35 students per programme provide an approximate total of 1120 student dance teachers. A sample size of 46 equates to 4.1% of the total student dance teacher population in the UK. When this relative value is compared to that of the percentage of sedentary males in the UK or the percentage of male and female runners in the UK the sample size in the present study was considered to be very favourable.

A number of precautions and limitations pertaining to the models have been forwarded based predominantly on the rationale for variable selection and the type of logistic regression analysis performed. This has produced statistical models which have included variables for which it has been difficult to provide a detailed interpretation because of their contradiction of existing sports medicine literature. Further, variables have been postulated, i.e. sitting height, which have yet to be reported in the literature as a predisposing factor to the onset of injury. In an attempt to address this future investigations may which to include a number of additional measurements or adjustments to the testing protocols. This would include the use of isokinetic dynamometry to clearly establish contra-lateral and ipsi-lateral muscle group strength, the use of dynamic and static flexibility measures, a foot template sensitive to variations in height and a medically orientated self reporting questionnaire which may highlight a detailed diagnosis of the injury. These additional measures could enhance the sensitivity, and specificity, of the data collected.

6.5 Summary and Conclusion

Three models were considered for the prediction of injury in female student dance teachers. The explanatory variables used in the models were based on intrinsic factors identified from the sports medicine literature as possible predisposing factors to the onset of injury. These factors were recorded from 46 female student dance teachers, 28 of which had reported an injury as a direct result of dance. The factors included data on kinanthropometric measurements, strength and flexibility functional characteristics, past injury history data and data on orthopaedic body alignment.

Of the three models considered, the third model was suggested as the best fitting model from both a statistical perspective and from the perspective of practicality and its specificity to a real dance situation. The overall goodness of fit of the model was 89.13%, suggesting that based on the available data set, the model predicted injured and non-injured female student dancers correctly in 89.13% of the cases submitted. The logistic regression equation was:

log odds of injury = -56.79 + 0.47 (sitting height) + 0.18 (right hamstring flexibility) + 1.15 (left Q angle) - 1.04 (right Q angle) - 0.05 (ASIS distance) + 0.04 (medial malleoli distance) + 0.33 (hours in dance practice)

The 95% odds ratio confidence intervals identified sitting height and left hamstring flexibility as significant predictors of injury in that 95% of the time unit increases in the variables would elicit corresponding log odds increases in the occurrence of injury. It was therefore concluded that increases in the flexibility of the hamstring muscles and increased sitting height would predispose a female student dance teacher to injury in conjunction with a smaller pelvis and right Q angle, and increased practice hours, left Q angle and medial malleoli distance.

By producing the above statistical model the aim of the study was achieved in that an injury predictive equation was developed, based on the epidemiological data reported in Chapters 3 and 5. The hypothesis was therefore accepted in that a predictive model of injury, in female student dance teachers, was obtained based on the available variables. However it should be noted that the techniques employed, and the theoretical concepts published in the sports medicine literature, for factors predisposing to sports injury, may not be specific enough in their application for fully interpreting injury in student dance teachers.

7. SYNTHESIS OF FINDINGS

The purpose of this chapter is to interpret and integrate the results obtained within this thesis. The possible applications and limitations will be discussed. The realisation of the objectives and overarching aim of the thesis will be confirmed prior to reviewing the original hypotheses. Within the general discussion and conclusions which follow, the results of the separate studies will be interpreted with respect to the statistical model for predicting injury in female student dance teachers.

7.1 FULFILMENT OF OBJECTIVES

The experimental sections of this thesis have fulfilled all the objectives stated in Chapter 1. The prevalence of injury in female student dance teachers was established using a self reporting questionnaire (Objective 1). Ninety three, out of the 178 students completing the questionnaire (52.2%) reported an injury as a direct result of dancing.

The questionnaire further enabled the identification of the common sites of injury, and types of injury, the preceding dance movement and the dance style in which the injury occurred (Objective 1). Specific site and injury type prevalence ratios were calculated highlighting the knee (35:178) and muscle strains or tears (39:178) as the most prevalent site and injury type respectively.

Quantification of movement patterns and the physiological and physical stresses of dance were reported (Objective 2). The use of a hand notation system established the pattern of movement across, and between, four dance styles. The notation system identified four levels of intensity, and common dance movements, within the styles, and also established the frequency of their occurrence. The monitoring of heart rate established the intermittent nature of a dance class concomitant with the intensity levels as identified from the notation system. Force analysis of the common actions, identified from the notation system, established the physical stress on the dancer.

Measurement of kinanthropometric and functional characteristics of the student dancers provided a comprehensive profile specific to the female student dance teacher (Objective 3). Flexibility, strength, body composition and orthopaedic alignment contributed to the profile. Injured student dancers were found to have flexibility imbalances between hamstring muscle groups, were smaller in stature and had larger Q angles.

The final objective (4) was accomplished through the use of a multivariate logistic regression technique. The analysis produced three models for the prediction of injury from the available data set. Model Three was postulated as the best fitting model for the prediction of injury with an overall goodness of fit of 89.13%. Significant explanatory variables included sitting height and left hamstring flexibility which increased the odds of injury with respective unit increases in the variables.

7.2 REALISATION OF AIM

The overarching aim of the research was to develop a statistical model for predicting injury in female student dance teachers based on musculoskeletal, kinanthropometric and functional profiling. The fulfilment of objectives 1, 2 and 3 provided the profiling data on the functional and kinanthropometric characteristics for the dancers. The use of multivariate logistic regression analysis, in the fulfilment of objective 4, identified a number of explanatory variables across three models. The model postulated as having the best fit to the data contained 7 explanatory variables including sitting height, left hamstring flexibility, left and right Q angles, anterior superior iliac spine distance, medial malleoli distance and time spent in dance practise. This model predicted injury accurately in 89.13% of the cases as available from the data set.

7.3 REVIEW OF HYPOTHESES

A series of hypotheses were formulated throughout the thesis. It is appropriate to examine whether the findings have led to the accepting or rejecting of the hypotheses proposed.

Hypothesis 1: *The four dance styles, common to student dance teacher participation, will elicit different physiological responses, as measured by heart rate.*

This hypothesis was accepted. The average heart rate, recorded from the same dance students, during participation in the four dance styles, produced significant differences across the four styles. Jazz dance and African Caribbean were significantly different from the other two styles but not significantly different from each other.

Hypothesis 2: *The dance actions, common to the four styles, will record different force characteristics in terms of peak ground reaction forces (Fx, Fy, Fz), free moment (Mz) and load rates.*

This hypothesis was rejected. Peak impact forces recorded for the seven common dance actions did not differ significantly from each other. However load rates, anterior-posterior and lateral forces and moment torques differed significantly between the dance actions.

Hypothesis 3: *Orthopaedic alignment characteristics are different between injured and non-injured female student dance teachers.*

This hypothesis was rejected. No significant differences were reported for the 15 alignment characteristics measured on the injured and non-injured dancers. The injured group tended to be slightly taller in stature and heavier in body weight.

Hypothesis 4: *The strength profiles of the injured dancers will be smaller than the non-injured group in the three strength measures.*

This hypothesis was rejected. There were no significant differences between the injured and non-injured across the three strength measures. These measures included back, leg and grip strength.

Hypothesis 5: *The flexibility profiles of the lower extremities will be different between the injured and non-injured dance groups.*

This hypothesis was rejected. Significant differences in left and right hamstring flexibility were noted between the groups. No other flexibility profile differences were noted.

Hypothesis 6: *Kinanthropometric profiles will differ between the injured and non-injured dancers.*

This hypothesis was rejected. No differences in the 28 kinanthropometric variables were noted between the injured and non-injured groups.

Hypothesis 7: *A statistical predictive model of injury, specific to female student dance teachers, can be obtained from the selection of measured variables.*

This hypothesis was accepted. A model of injury based on sitting height, right hamstring flexibility, left and right Q angle, ASIS distance, medial malleoli distance and hours spent in dance practice was obtained.

7.4 GENERAL DISCUSSION

A multidisciplinary approach was adopted to investigate intrinsic factors associated with the onset of injury in female student dance teachers. The prevalence of injury, physiological and physical demands of dance and the kinanthropometric and functional profiles of dancers will be discussed. This will be followed by a reflection on the findings related to the modelling of an injured dancer and in the prediction of injury using statistical procedures.

The self reporting questionnaire provided the basis from which demographic and injury information could be recorded. The prevalence of injury (52.2%), in the student dancers, suggests that the styles, techniques and dance schedules are demanding, not only in terms of timetabling, but also in the training of the technique. The specific prevalance ratios for injury site and type were also calculated. Comparisons cannot be drawn for the data as similar ratios have not been reported in the literature. However, a muscular injury at the knee joint, occurring once in every fifth dancer, tends to indicate a high prevalence of injury in student dance teachers.

The students dancers, in order to become dance teachers, must be technically proficient in every style. The content and progression through each style must be maintained and that may well place a burden on the class teacher to progress quickly through an allocated time slot. This perhaps puts the emphasis on the student to practise outside class time. During this time the student is unsupervised and if the technique has not been adequately mastered during the class time then poor technique will be practised and may result in injury. This was highlighted from the questionnaire in that over 70% of the students practised for 5 hours or more outside normal class hours. The questionnaire, however, did not specify if the injury occurred during supervised class time or unsupervised practice time.

The timetabling of the classes, in that a student can participate in up to three different dance styles in any one day, may also affect the prevalence of injury. This is predominantly based on the cumulative effect of participation specifically; (a) inadequate warm-ups and cool downs; (b) the fatigue effect as a result of the demands placed on the body through the previous dance styles; (c) the different teaching methods and technical demands of the styles; and (d) the speed at which the curriculum is covered in the time allocated. The most important of these factors is fatigue and the effects this physiological condition has on the physical and technical demands of participation. There are no dance specific training classes, incorporated in the timetable, for aerobic endurance, flexibility or strength. It may be that the dance class is considered as adequate training for that technique and that the concept of training to dance is irrelevant. If this was addressed then the prevalence of injury may be reduced.

The effect of the scheduling on fatigue may also be reflected in the types of injury, and the preceding dance movements, reported. Technically demanding movements requiring skilful co-ordination and balance, such as landing from jumps, maybe affected by fatigue in that obtaining the correct posture and alignment on landing, from both an aesthetic and safety perspective, maybe inhibited through the physiological influence of fatigue. This may then place greater stresses on the musculo-skeletal structures not normally activated in the control of alignment from a jump and lead to injury in these structures such as ankle sprains or knee pain. Similarly a fatigued muscle has a reduced capacity to absorb impact forces which is exacerbated at the limits of joint range of motion and muscle flexibility. It is therefore possible, in a fatigued state, that coupled with a reduction in co-ordination and balance, two aspects of any dance movement that are imperative for optimisation in technical performance, and reduced force absorption capacity, muscle tears or pulls can result. It may therefore be suggested that a specific dance training programme would be of benefit, in the degree curriculum, for student dance teachers.

Injury specific and site specific prevalence rates were also calculated and recorded. These calculations were based on the ratio of the number of specific injuries recorded to the sample at risk (n=178). This calculation was reported for specific injuries and injury sites and was shown in Chapter 3. Data of this description or specificity had not previously been reported in the dance medicine literature and so direct comparison was difficult in terms of injury specific and injury site prevalence rates. Nonetheless injury site prevalence ratios of 1:5.1 and 1:7.4 were recorded for the knee and back respectively, whilst ratios of 1:4.6 and 1:16.2 were recorded for muscular specific injuries and shin splint specific injuries respectively. These ratios are interpreted as one in every 5 injuries are recorded at the knee and are muscular in nature.

Having accounted for the prevalence of injury in student dancers, and justifying to some extent an explanation for the rate, it was then necessary to quantify the physical and physiological demands of dance. In doing so this would substantiate the claims of the link between a fatigued state and the importance of co-ordination and balance in the performance of dance from an injury prevention perspective. This was achieved through a three tiered approach, notation, heart rate and force analysis. This was the first experimental chapter (Chapter 4).

The conventional monitoring of heart rate was supported with a hand notation system recording movement patterns and levels of performance intensity as calculated by the number of actions recorded per minute. The results of the two methods employed tended to support the fatigue theory. It further added support for the importance of dance style specific warm-up, and strength and flexibility training for dance. Although dance class and performance was intermittent in nature (Chapter 4.2), with many stationary periods, there was a corresponding high frequency of high intensity categories, with heart rates recorded up to 98% of age predicted maximum and incorporating up to 109 separate lower limb movements (dance actions) per minute. These lower limb movements were a combination of high and low impact actions which require precise technical execution in order to add momentum and transfer of energy into the completion of the choreographed sequence. The ability to land correctly, and safely, from a jump movement and immediately progress into a further movement, to a rhythmic beat, requires technical precision, strength, flexibility and a high level of aerobic endurance. The aesthetic and accurate completion of the movement sequence will be affected by fatigue. It may also be further exacerbated by the degree to which the musculo-skeletal system has to work in order to effectively dissipate the impact forces and loading rates of the actions.

The hand notation system recorded seven actions common to the four dance styles. The frequency of these actions varied across the four styles but where nevertheless present in each dance class (with the exception of the jog step). A force analysis of these actions revealed that the magnitude of the ground reaction forces ranged from 1.5 BW to 2.71 BW, and loading rates ranged from 81.8 BW/s to 454.1 BW/s. The average frequency of each action, per dance class, ranged from 6 to 718, and coupled with the average actions per minute reinforced dance, and dance movement, as a physically demanding and physiologically demanding activity at the student dance level. The impact of ground reaction forces and loading rates further highlighted the importance of adequate musculature and skeletal alignment to successfully dissipate the forces experienced but also the time available, in terms of loading rates, to correct alignment through limb position. This emphasised the need for technical precision in attempting to protect the weaker tissues from injury, as a result of fatigue, and the physical stress and demands of the dance movements. This research gives substance to previous speculations about the specific demands of the activity.

In order to cope with the physical and physiological demands of dance, the dancers' body needs to possess a certain balance between musculo-skeletal functional characteristics and anthropometric characteristics. The ability to do so will not only establish that the dancer is safe from injury but also maintain the aesthetic component in dance performance. Hence the role and importance of body posture and alignment, strength and flexibility, and body composition profiles in identifying possible weaknesses or risk factors in the onset of injury. The simultaneous balancing of these factors will not only produce the desired movements, during dance choreography, but also act and aid in the attenuation and dissipation of impact forces associated with the common movements. This provides the dancer with a sound structure and platform from which to perform the aesthetic dance movements and choreography.

A comprehensive functional and kinanthropometric profile, of both injured and non-injured dancers, was undertaken in Chapter 5. The profile failed to identify any significant differences between the injured and non-injured group for alignment, strength and body composition data. Of the flexibility characteristics considered only the hamstring flexibility provided significant differences with the injured group having a higher degree of flexibility in both left and right hamstring muscle groups.

However, the objective of the chapter was not only to identify differences but to also establish student dancer profiles. A typical profile of an injured dancer, based on the data collected, would have the following characteristics; larger body height; heavier in body weight; supinated feet; pronounced knock-knees (genu valgum); a smaller pelvic width (ASIS); larger Q angle; lower back strength; larger gluteal and thigh girth and higher flexibility in both hamstring muscle groups when compared to the profile of a non-injured dancer.

The importance of lower limb alignment has been emphasised in terms of the dissipation of ground reaction forces from the common dance actions. Therefore the pronounced genu valgum, although not significantly different from the non-injured group, would prevent the skeleton from maximising force dissipation through the stronger bones of the lower limb due to the reduced surface contact area between the bones at the ankle and knee joint. This would then place the weaker surrounding structures at the knee and ankle at risk due the greater residual physical load. This may also emphasise the inadequacy of the muscular compensatory mechanisms, in their role as shock absorbers, in attempting to correct posture to maintain the aesthetic line required in dance performance. However this compensation may place the junction of the tendon insertion, and the tendons themselves, at higher stress levels in terms of their flexibility. Therefore, although the joint range of motion may be maintained, the muscular and tendinous structures maybe inadequate to control the posture at optimal joint ranges of motion and injury may result. This could possibly explain how an increased level of flexibility, in the muscle, could predispose an individual to injury. The hamstring muscle group is therefore at a greater risk of injury in that it is a two joint muscle. It influences movement at two joints with a greater degree of motion. The flexibility of the hip joint may also impinge on the movement at the lumbo-scaral junction of the lower back. Therefore the hamstring muscle group may have a powerful influence on the onset of injury at the two sites on the body that were reported as having the main occurrence of injury, the knee joint and lower back. With an increased moment and torque this would place the musculature and attaching tendons and ligamentous structures under a greater stress and possibly contribute to lower back muscle strains or muscular tears if the structures were not strong enough to cope with this. The centre of rotation or twisting movement of the trunk is the lumbo-sacral junction of the spine. The muscles controlling twisting or rotation of the trunk are the multifidus, rotatores, semispinalis and internal and external obliques (Palastanga et al., 1994). Rotation of the trunk is produced by a simultaneous contraction of the ipsilateral internal oblique and the contralateral external oblique. The remaining muscle groups predominantly act as stabilisers of the vertebral column, where they act as extensible ligaments, adjusting their length to stabilise adjacent vertebrae.

Lateral flexion of the trunk, to either side, is initiated by the ipsilateral rectus abdominis, the external and internal oblique muscles, quadratus lumborum, erector spinae and the intertransversarii. Contraction of the quadratus lumborum produces lateral flexion of the trunk and when acting in conjunction with the intertransversaii help extend the lumbar vertebral column and also give it stability (Palasatanga et al., 1994). However the main function of the intertransversaii is again to act as an extensible ligament stabilising adjacent vertebrae. In terms of trunk extension the erector spinae is the major muscle responsible for the initiation of the action. It acts in conjunction with the interspinales to initiate extension but also to provide stability for the vertebral column.

The important technical aspects associated with rotation, flexion or extension of the trunk, especially in dance, is to maintain a stable 'core', that is, it is important to isolate only the portion of the trunk in the movement whilst keeping the pelvis in a stable or neutral (stationary) position. As noted by Palastanga et al. (1994) and Whiting and Zernicke (1998) many of the deeper muscles, involved in trunk extension, rotation and lateral flexion, act as synergists or stabilisers. For this they need to be extensible, similar to ligamentous structures. However the biomechanical properties and composition of these structures are based on muscle physiology and therefore may not be as extensible as required. Further, with an increased sitting height, suggesting a longer vertebral column, the muscles may be under additional stress and not capable of the level of stability required especially in an advanced dance movement requiring optimal range of motion and stability at a point of lateral flexion, extension or rotation.

Often in dance choreography one or more of these movements are required at any one time and this adds further pressure, and hence importance, on the stabilising structures. It could therefore be suggested that due to the increased loads on the spine (from a longer vertebral column) and an increased moment or torque, due to a longer lever (vertebral column), muscle strains or tears may result due to the stabilising structures being insufficient to maintain a controlled body position at an optimal degree of flexion, extension or lateral movement. Therefore an increased sitting height may be a significant explanatory variable, or predisposing factor, in the onset of injury in student dance teachers. It is therefore suggested that as part of a training for dance programme, specific core strength exercises form an integral part.

As the functional characteristics had therefore been delineated, albeit retrospectively, an overall model of the injured student dance teacher had been established. However, in order to complete the research, and provide a guide for prevention of injury a mathematical model, originating from analytical statistical procedures was explored. As indicated by the literature, the onset of injury is multi-factorial in nature. The simplistic statistical comparison of injured and non-injured dancers, from a single factor approach, would not enhance the knowledge base nor identify the potentially integrative aspects of the functional and kinanthropometric characteristics. Therefore a multivariate approach to statistical modelling was introduced with the purpose of identifying risk factors associated with the onset of injury in student dance teachers.

The use of an advanced statistical procedure permitted the potential analysis of all the functional and kinanthropometric variables from both an independent and integrated perspective. The analysis further enabled comparisons between models with a view to identifying the 'real' and specific explanatory variables related to the onset of injury in student dancers.

Logistic regression analysis has been predominantly used by the medical profession in an attempt to identify risk factors associated with disease. A similar method was employed to identify predisposing factors to the onset of dance injury. Of the three models compared a balance had to be established between the parsimony of the model, in terms of the number of accountable variables that could be readily selected for the model, the theoretical variables prescribed by the literature to predispose an individual to injury and the practiceable or real variables that could be altered or addressed by way of injury prevention.

The model postulated as being the best indicator of the onset of injury in student dance teachers, based on the data set available, contained 7 explanatory variables following a backward stepwise logistic regression analysis. Of the two significant variables, based on the 95% confidence intervals of their corresponding odds ratios, the role of the flexibility of the hamstring muscle group had been, to a certain extent predicted, via the functional characteristics identified in Chapter 5. However the second significant explanatory variable, that of sitting height, had not been previously identified as a potential risk factor by the literature, nor during the analysis of the experimental procedures in Chapters 4 or 5.

The explanation for the inclusion of this variable in the model has been addressed in Chapter 6. The importance of the spinal column from both a structural and neural protective capacity has been well documented. However the influence of the role of the spine, in terms of its identification as a predisposing factor in dance injury prediction has not been reported. Although the aesthetic line of the body, an important consideration in dance performance, is extensively referenced it maybe that an elongated spine or a disproportionate upper to lower body ratio may inhibit dance performance and predispose the student dance teacher to injury.

Based on this data analysis, and the predictive equation, it is evident that in order to prevent injury in female student dancers a comprehensive dance training programme is required to prepare the prospective dance teachers for the demands of a student dance teacher degree programme. Dancers have traditionally gone straight into dance performances or classes without any form of strength, flexibility or endurance training. Any aerobic endurance has been achieved through constant dance classes or performance or dance choreography. Little attention has been given to the physical, physiological or functional requirements of the dancer prior to participation. This has often resulted in injury and then further exacerbated through a cumulative effect from continued involvement resulting in strength, flexibility or alignment inadequacy and finally a completely debilitating condition preventing further participation in dance. The predictive equations have highlighted that the functional inadequacies, or intrinsic risk factors, are a significant influence in the onset of injury (hamstring flexibility). The models have further highlighted that there is also a predominance of lower limb alignment factors, which if identified early may be compensated for through specific strength or flexibility training. It therefore seems advisable for a dance degree programme to incorporate a specific dance fitness, strength and flexibility training programme for prospective students. This programme would focus on the complete body of the dancer to provide a solid aerobic, strength and flexibility basis from which optimisation of dance could be achieved. The programme could focus on strength training of muscle groups to adequately control the high levels of flexibility required of a dancer, it could also incorporate full body flexibility in that all muscle groups would be in proportion and reflect the cumulative demands of the various dance styles. Further, because of the demands of the degree programme, it would seem useful to develop a dance specific aerobic training programme to prepare the dancers for the physiological demands of the activity over the duration of their degree programme. This programme could include general aerobic exercises such as cycling or jogging but may also be dance specific. An example would be aerobic dance sessions which would be appropriate for increasing the physiological capacity of the body but also involve specific dance style steps, coordination, timing and choreography that could prepare the students for specific dance style classes. Additionally it would also seem pertinent to screen potential students for inadequate lower limb alignment, flexibility and strength with a view to providing an adapted training programme in preparation for dance participation. This screening programme would reflect the variables postulated in the predictive model, i.e. hamstring flexibility, Q angle, sitting height and ASIS distance but could also include isokinetic strength measures for lower limb muscle groups. This technique could potentially identify flexibility or strength weaknesses that maybe reflective of an alignment condition. It is therefore possible that a specific flexibility or strength training programme could be adapted to increase or decrease these functional characteristics based on the malalignment.

7.5 CONCLUSIONS

The prevalence of injury in student dance teachers may reflect the nature of a degree course due to the demands required of the student to complete the frequency and variety of dance classes and styles incorporated in a programme. The technical, physical and physiological loads placed on the body, across a number of dance styles, fatigues the dancers body and may place a cumulative stress on the musculo-skeletal system resulting in injury. The lack of a specific dance training programme may exacerbate any weaknesses in a dance students physical, technical or physiological framework. This, however, could be addressed at a pre-participation stage through a strength, flexibility and aerobic endurance training regimen.

The statistical modelling of functional and kinanthropometric characteristics can provide a basis for predicting injury risk and may even provide a starting point from which a pre-participation screening technique for prospective students may be developed. This could be coupled with a dance specific training programme to help reduce the risk of injury in female student dance teachers.

8. RECOMMENDATIONS FOR FUTURE RESEARCH

The studies completed within this thesis provided an overview of the functional and kinanthropometric characteristics of student dance teachers. The thesis also provided profiles of both an injured and non-injured dancer and postulated a statistical model for identifying predisposing factors in the onset of injury. In achieving this some issues have arisen and certain findings have prompted the formulation of recommendations for further research.

Suggestions arising from Chapter 3:

(1) Significant differences were observed across the injury sites, injury type and dance movements preceding the onset of injury. Certain categories of the injury sites and injury types had to be grouped in fulfilment of the criteria for Chi-square analysis. Further research would be useful in determining if such differences occurred when all categories for injury site and type fulfilled the analysis criteria. This may be achieved through the recruitment of a larger cohort of student dance teachers. The data may provide greater detail into the types of injury in dance, and the preceding movements, and may provide further implications for specific dance training programmes.

(2) The reporting of injury focused on student dance teachers. The students reported injury prevalence rates similar to professional dancers. Research into adolescent dancers or children involved in dancing may provide information specific to the age group and level of dancing and may have implications for specific training programmes prior to regular or full time involvement in dance.

(3) The structure of the dance class was suggested has having an influence on the onset of injury. Research into this aspect of a dance class in terms of warm up and cool downs, specific flexibility and strength, at differing age groups and ability and participation levels, may provide further information on the reasons for the duplication of this type of structure in a degree programme. This may have implications in suggesting changes in dance class structure to best prevent or reduce the prevalence of injury at student level.

(4) The reporting of injury was restricted to four dance styles. Information recorded on the self reporting questionnaire suggested that student dancers had been or were presently dancing in a variety of other styles. These students were omitted from the present research, however further research incorporating a wider range of dance styles may provide a more indepth profile of injury in student dancers.

Research proposals in response to the findings in Chapter 4:

(5) Fatigue was suggested as an important contributor in the onset of injury. An investigation involving portable gas analysis and heart rate monitoring may permit identification of the levels of fatigue and energy expenditure, specific to the actions and choreographed sequences which have the greater physiological demands on the student. This would have implications for the development of dance style and movement pattern specific training programmes at all levels of dance participation.

Research proposals in response to the findings in Chapter 5:

(6) The functional characteristics reported in Chapter 5 included strength. No significant differences were noted between the injured and non-injured groups in the present study. The protocol for the recording of back and leg strength relied on the use of a portable leg and back strength dynamometer. Although a reliable piece of equipment, it does not isolate specific muscle groups of the lower limb. An investigation incorporating isokinetic dynamometry, in the measurement of lower limb muscle group strength, may provide detailed information on specific muscle group strength characteristics that may impinge upon the onset of injury.

Research proposals in response to the findings in Chapter 6:

(7) The objective of Chapter 6 was to develop a statistical model with a view to identifying significant variables influencing the onset of injury in student dance teachers. A predictive equation was postulated, however in order to accurately test the equation a follow up study is required on a different sample of the student dance population. It would be of interest to test the predictive equation on a cohort of student dancers embarking on a dance degree programme. The extent of the success of the outcome of such a study would substantiate the present research and support the use of the explanatory variables in the development of an accurate, dance specific pre-participation screening technique.

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Appendix 1

Self-reporting Injury Questionnaire

Liverpool J.M. University

Biomechanics Laboratory

DANCE INJURY QUESTIONNAIRE

Please answer the following questions as accurately as possible. Please ask for assistance if you are unsure about any question. All information given in this questionnaire will be treated with the strictest of confidence. Thank you for your help.

1. ID Number: (completed by researcher)

2a. Date of Birth: 2b. Age:

3. Sex: ___ Male ___ Female (please tick)

4. At what age did you first start attending a dance class(es) regularly, i.e. at least once a week ?

5. How long have you been a regular dance participant ?

6. Please indicate the dance styles that you have participated in on a regular basis, i.e. at least once per week for at least three months.

___ ballet ___contemporary ___jazz ___modern ___ tap

___ African Caribbean ___ Indian ___Other (please specify) __________

7. What is your preferred / favourite dance style ?

8. What styles of dance do you participate in at present (please list them all) ?

9. What styles have you participated in since being a student dance teacher (please list them all) ?

10. How many hours per week do you spend in dance classes for your degree programme ?

11. How many hours per week do you spend practicing/rehearsing out side normal class time ?

12. Have you ever suffered an injury as a direct result of dance, i.e. the injury occurred in a dance class and prevented you from dancing for at least a week ?

___ Yes ___ No

If 'YES', please give details. If you are unsure please ask the researcher.

How old were you when you got injured ? ____________________

What style were you participating in when the injury occurred ? __________

Where on your body did the injury occur ? ________________________

What dance movement preceded the injury ? ________________________

What type of injury was it, i.e. sprain, strain, muscle pull, dislocation, fracture ?

____

Did you receive any medical treatment, doctor, hospital, physiotherapy ? Please indicate the help you received.

____

How long did the injury prevent you from dancing ? __________________

Please give any additional information you think is relevant. If you are unsure please ask the researcher. For example did the injury re-occur, or where you injured more than once?

Thank you for your help.

Appendix 2

Vertical Force Traces (Fz)

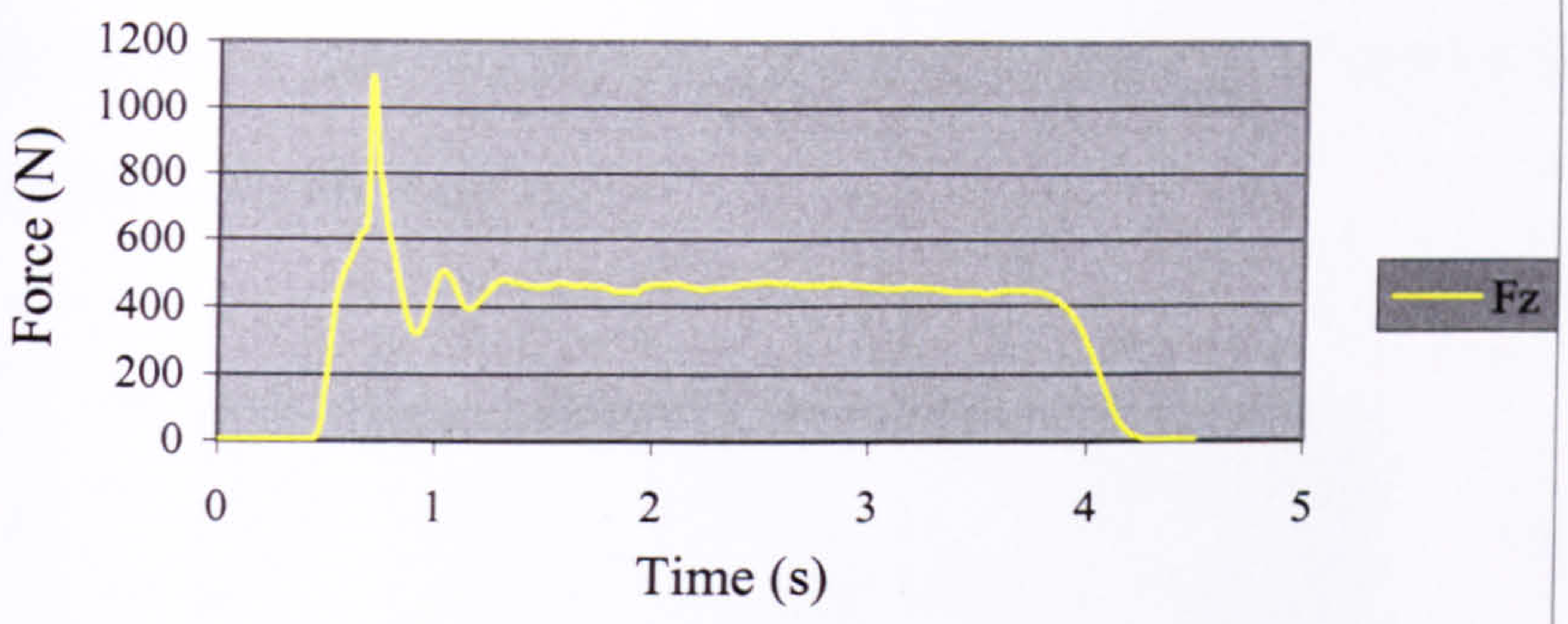


Figure A2.1 Fz Force Trace for Dance Action 1, Landing from a Backwards Leap

Figure A2.1 represents a typical vertical force trace for dance action 1. This dance action requires the student to leap backwards and land on one foot in a balanced position. The peak impact force represents the initial maximum vertical load which is then followed by the lowering of the center of gravity, through knee flexion, before maintaining a balanced position. The balanced position is represented by the horizontal trace from approximately 1.5 s through to the foot leaving the platform at approximately 4 seconds.

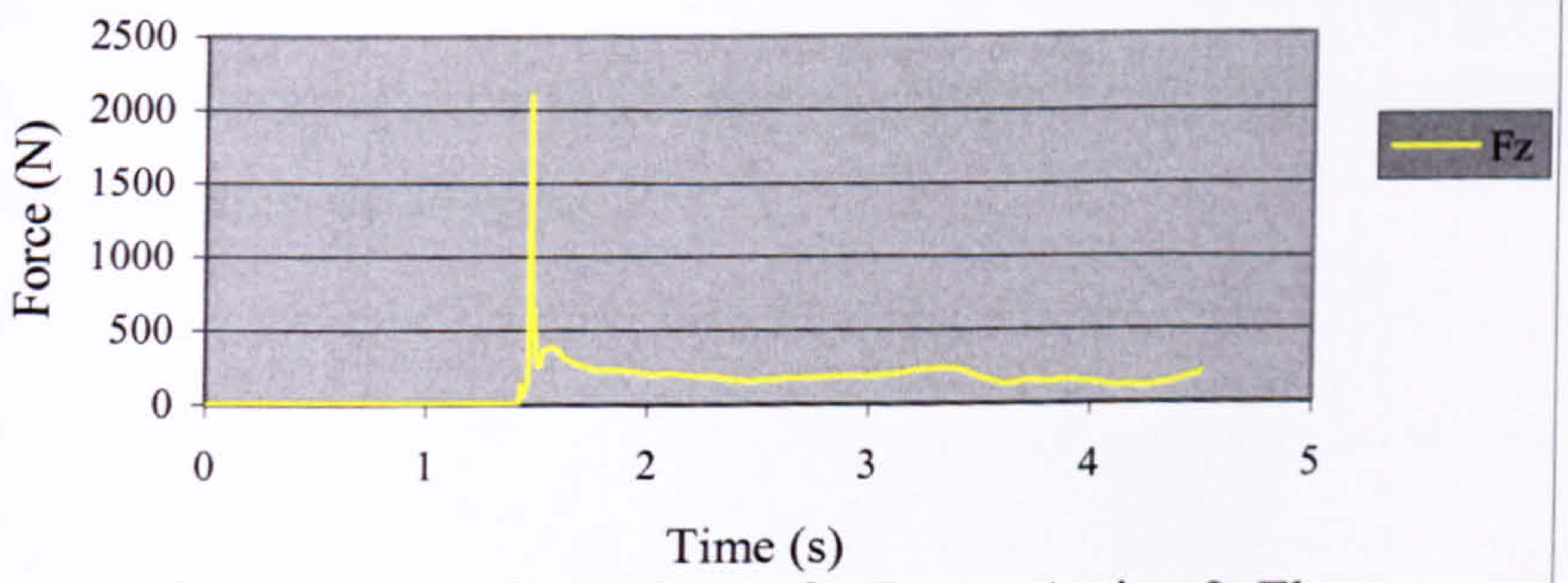


Figure A2.2 Fz Force Trace for Dance Action 2, Flat Footed Stamp Step

Figure A2.2 represents a typical vertical force pattern for dance action 2. This dance action is the flat footed stamp and requires the student to step firmly onto the ground and emphasise the aggressive nature of the movement. The peak vertical impact force represents this initial stamp on the ground. This dance action is normally performed in a series of 6-8 steps hence the sharp drop in the trace as the foot leaves the platform in preparation for the next step.

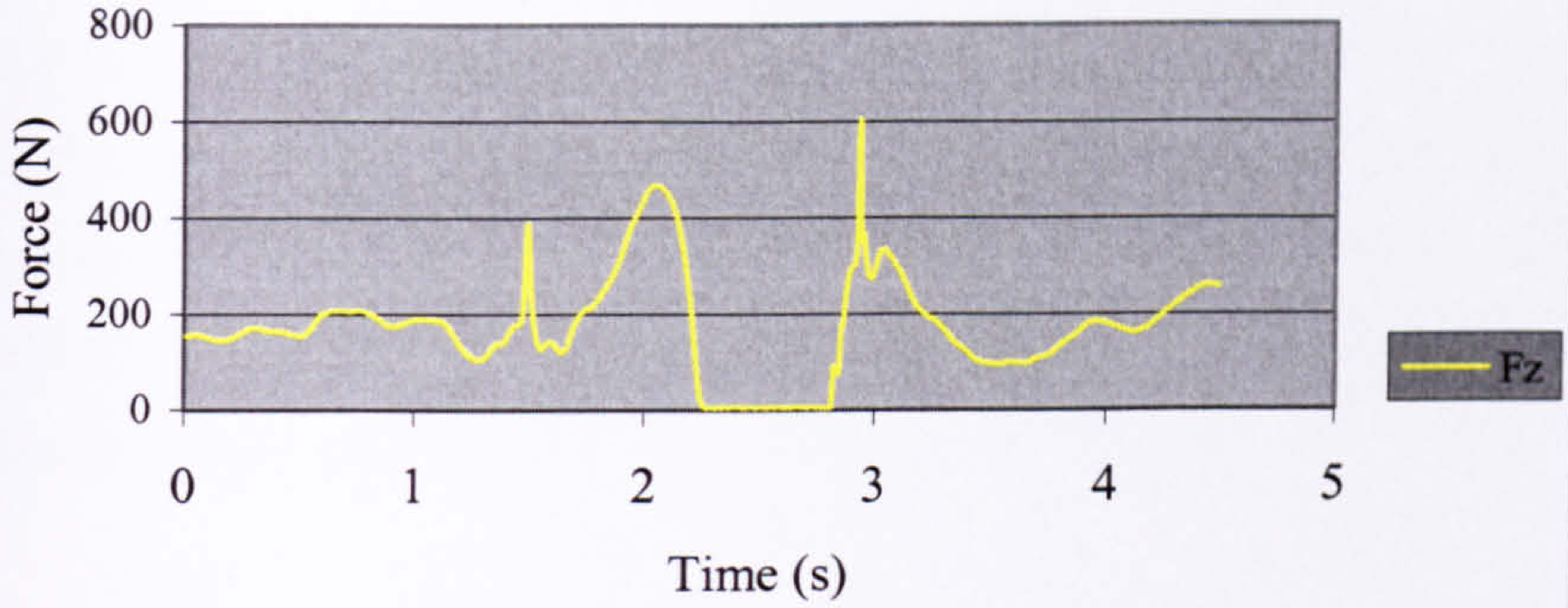


Figure A2.3 Fz Force Trace for Dance Action 3, Jump and Landing with feet in Fourth

Figure A2.3 illustrates a typical vertical force trace for dance action 3. This action involves the student dancer leaping vertically into the air with the feet externally rotated and approximately a shoulder width apart. The student must take off and land in this position. The trace illustrates the downward force (lowering of the center of gravity) in preparation for jumping into the air. The impact peak (approximately 600N in the above example) represents the landing from the jump firstly with the toes and then gently with the heels. The knees then flex slightly to absorb the impact and the student returns to a normal standing position. This action is normally performed several times in succession.

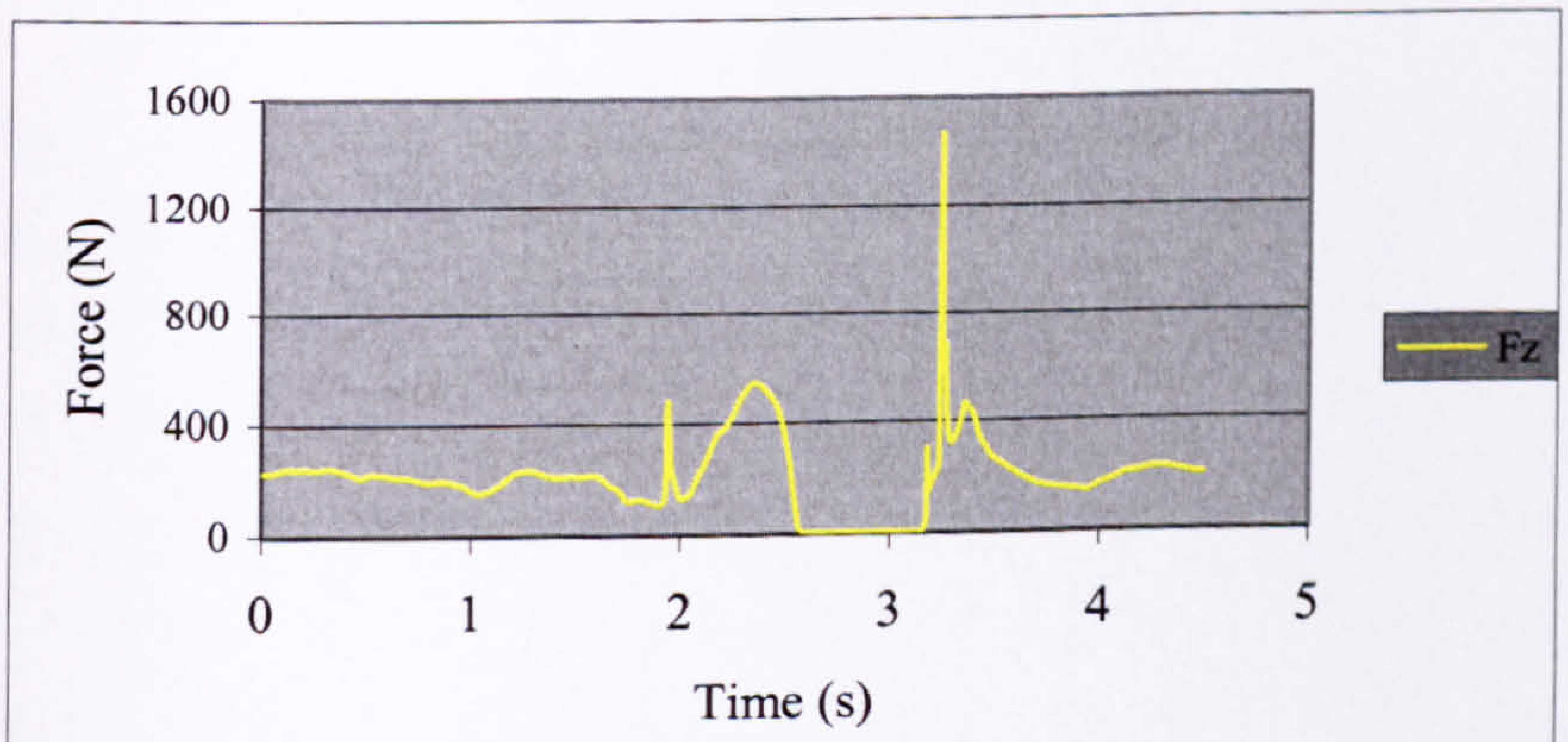


Figure A2.4 Fz Force Trace for Dance Action 4, Jump and Landing with Feet in Second

Figure A2.4 represents a typical vertical force trace for dance action 4. This dance action is similar to that illustrated in Figure A2.3 however the starting position, feet in second, requires the student dancer to have the lateral border of the right foot externally rotated and placed just in front of the arch of the left foot which is also externally rotated. The leap is then performed and the student must return to the ground with the feet in this position. In this dance action it is imperative that the student achieves maximum height hence the increased impact force (approximately 1500 N) on landing. As in dance action 3 this movement is normally performed several times in succession.

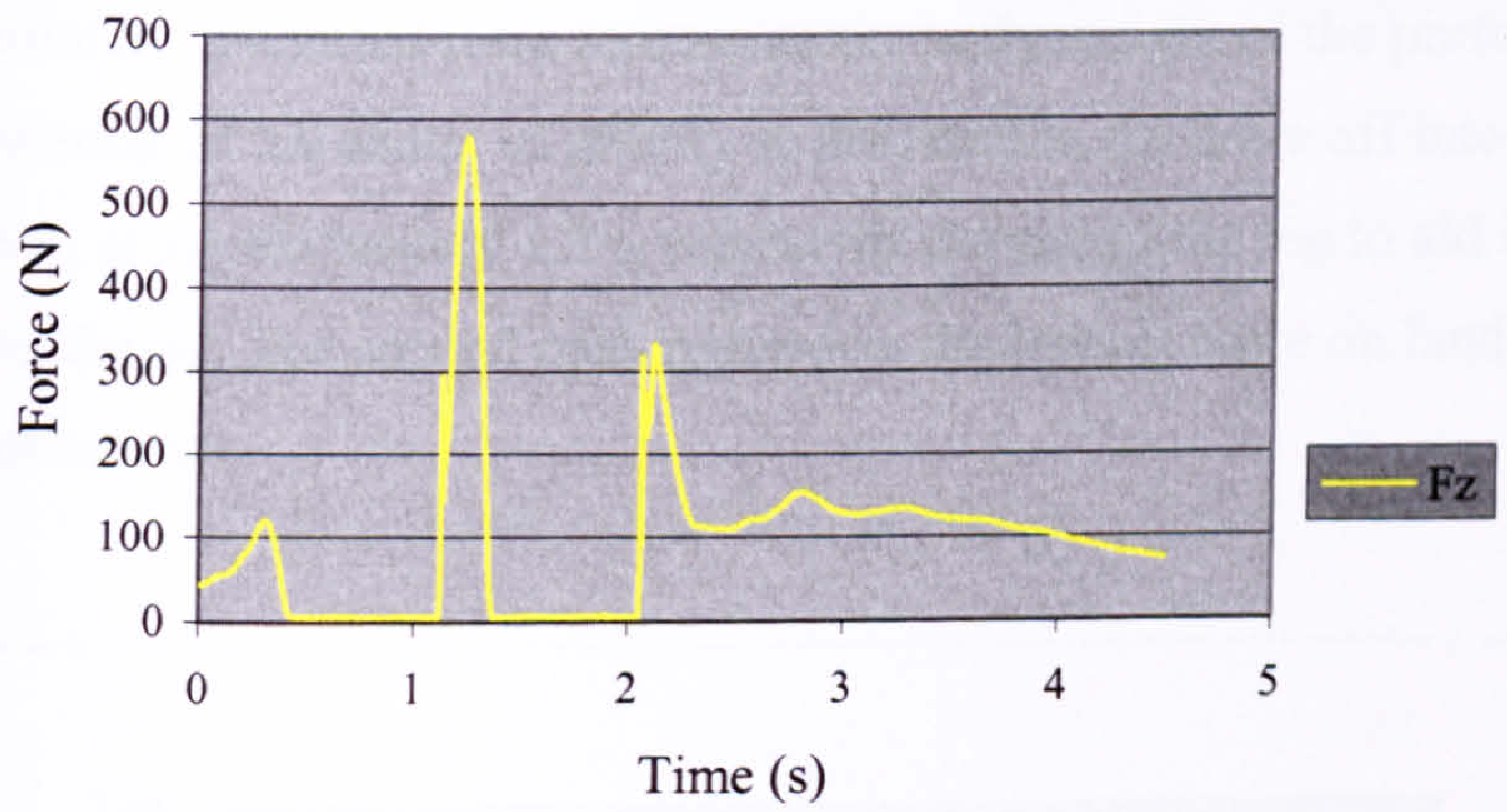


Figure A2.5 Fz Force Trace for Dance Action 5, Drive Off Action into Jog Step

Figure A2.5 illustrates a typical force trace pattern for dance action 5. This dance action requires the student performer to stand on one foot and use the other foot to propel themselves into the air. The trace therefore depicts the downward force of the drive off foot. The small initial peak, at approximately 0.4 s, is the toe of the drive off leg gently resting on the platform. This foot then leaves the platform in preparation for the downward thrust to drive the body into the air. This is illustrated by the second and largest peak (approximately 600 N). The final peak is the cushioned use of the drive off leg to stabilize the body and help absorb the impact when landing from the jump.

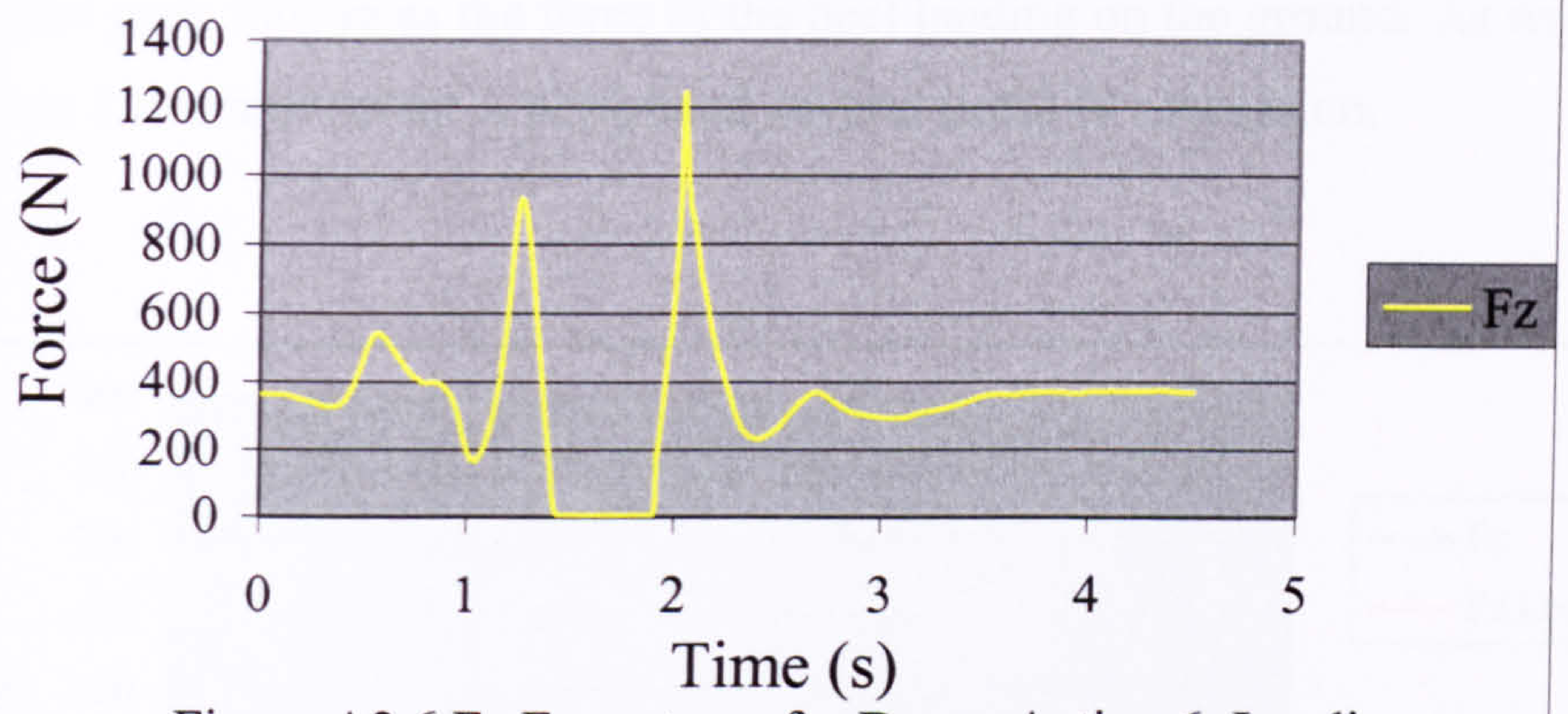


Figure A2.6 Fz Force trace for Dance Action 6, Landing from Jog Step

The above figure, Figure A2.6, is a typical force trace for the landing leg from dance action 5. The initial trace represents the body weight of the performer followed by the lowering of the center of gravity in preparation for drive off into the air. The first peak, at approximately 1.3 s, represents the use of the leg to aid in propelling the body into the air. The second peak represents the impact force on landing from the dance movement.

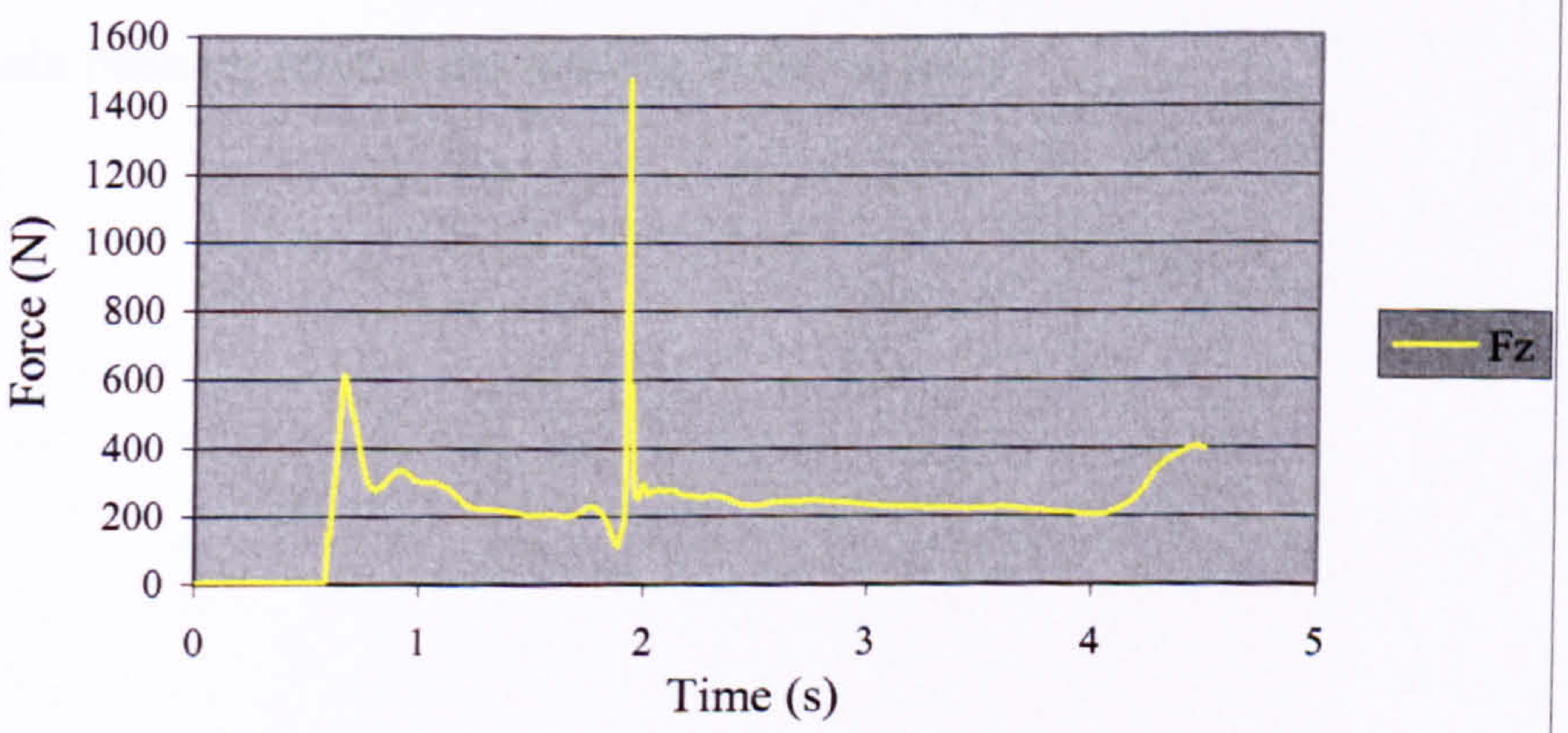


Figure A2.7 Fz Force Trace for Dance Action 7, Toe Heel Stamp Step

Figure A2.7 illustrates a typical vertical force trace for dance action 7. This dance action is a deliberate exaggeration of the flat footed stamp. In this case the first peak at approximately 0.8 s represents the toes landing on the ground. The toes are dorsi-flexed to approximately 90 degrees (demi pointe) at the tarsal metatarsal joint. The second peak illustrates the force of the heel landing on the ground. As with dance action 1 this movement is performed several times in succession.

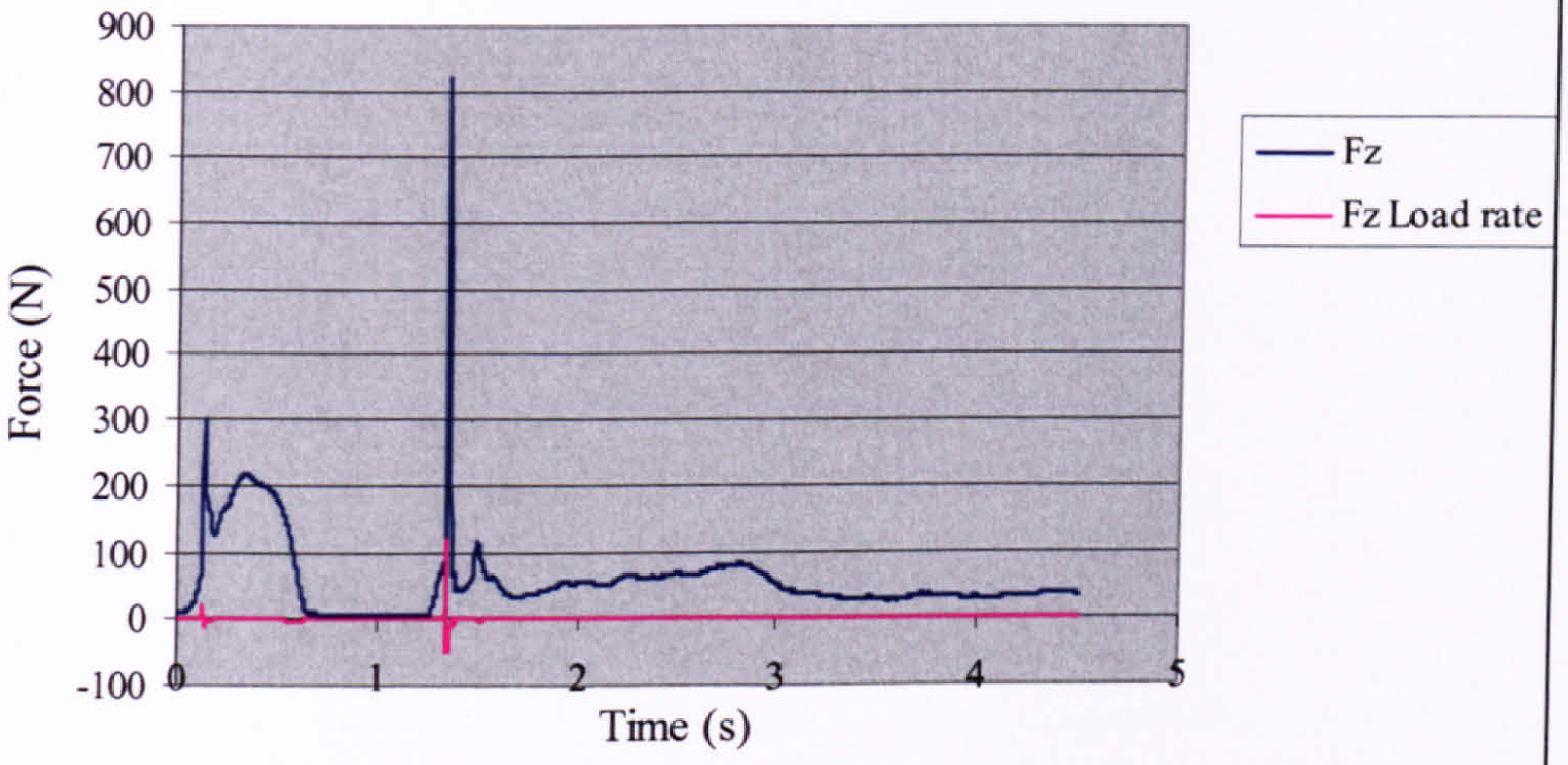


Figure A2.8 Fz Force Trace and Loading Rate for Dance Action 3, Landing from a Jump with Feet in Fourth

The above figure, Figure A2.8, illustrates a typical vertical force trace for dance action 3 with the load rate trace superimposed upon it. The first part of the peak represents the student stepping onto the platform and driving off into the jump. The main peak represents the landing from the jump.

Appendix 3

Kinanthropometric proforma

Liverpool J.M. University

Biomechanics Laboratory

KINANTHROPOMETRIC PROFORMA

Test Date: **Test Time:** **ID number:**

Age: **DOB:**

MEASUREMENT	**TRIAL**			**MEAN**
	1	2	3	
Mass (kg)				
Height (cm)				

SKINFOLD MEASURES

Triceps sf (mm)				
Subscap				
Biceps				
Iliac creast				
Supraspinale				
Abdominal				
Axilla				
Front thigh				
Medial calf				
(right side of body)				

MEASUREMENT (cm)	TRIAL			MEAN
	1	2	3	
Arm girth relaxed				
Arm girth flex&tense				
Forearm girth				
Wrist girth				
Chest girth				
Waist girth				
Gluteal girth				
Thigh girth				
Calf girth				
Ankle girth				

(measurements on both sides of the body, record largest)

MEASUREMENT (mm)	TRIAL			MEAN
	1	2	3	
Humerus width (mm)				
Femur width				
Tibiale sitting height				
Sitting height				
Upper arm length				

STRENGTH MEASURES

MEASUREMENT (kg force)		TRIAL			MEAN
		1	2	3	
Grip strength	L				
	R				
Back strength					
Leg strength					

FLEXIBILITY MEASURES

MEASUREMENT (degrees)		TRIAL			MEAN
		1	2	3	
Hamstring	L				
	R				
Adductor	L				
	R				
Quads	L				
	R				
Hip ext.	L				
	R				
Gastroc	L				
	R				
Soleus	L				
	R				
Stand and reach test					

ALIGNMENT MEASURES

MEASUREMENT (cm)		TRIAL			MEAN
		1	2	3	
Leg length	L				
	R				
Q angle	L				
	R				
ASIS dist.					
Troch dist					
Outer fem cond.					
Inner fem cond.					
Medial malleoli					
Troc-lat mal	L				
	R				
Troc-outfemcond	L				
	R				
Outfem – lat mal	L				
	R				

Appendix 4

Orthopaedic Alignment Protocol

The following orthopaedic alignment protocol was adapted from Bauman et al., (1982) in accordance with Enneking et al., (1979), cited in Baumann et al., (1982).

For the following measurements subjects were measured while standing on a foot template with their feet in 5 degrees of external rotation and their heels 25 centimetres apart. Angular measurements were recorded in degrees while the body length and width measures were recorded in centimetres or millimetres.

Test 1 – Leg length

The anterior superior iliac spine (ASIS) was identified and designated with a marking implement. Leg length was determined by measuring each leg from the ASIS to the medial malleolus.

Test 2 – Q angle

The Q angle was measured with a long arm goniometer. The axis of the goniometer was centered on the midpatella, and the arms were aligned with the ASIS and the centre of the tibial tuberosity.

Test 3 – Anterior superior iliac spine (ASIS)

An anthropometer was used to measure the distance between the right and left ASIS.

Test 4 – Greater trochanter

An anthropometer was used to compress the adipose tissue and measure the distance between the right and left greater trochanters.

Test 5 – Outer femoral condyle

An anthropometer was placed between the left and right outer femoral condyles and the distance measured and recorded.

Test 6 – Inner femoral condyle

An anthropometer was placed between the left and right inner femoral condyles and the distance measured and recorded.

Test 7 – Medial malleoli

An anthropometer was placed between the left and right medial malleoli and the distance measured and recorded.

Test 8 – Greater trochanter to lateral malleolus

The distance was measured, using a flexible measuring tape, from the greater trochanter to the lateral malleolus on both sides of the body.

Test 9 – Greater trochanter to outer femoral condyle

The distance was measured, using a flexible measuring tape, from the greater trochanter to the outer femoral condyle on both sides of the body.

Test 10 – Outer femoral condyle to lateral malleolus

The distance was measured from the outer femoral condyle to the lateral malleolus, using a flexible measuring tape, on both sides of the body.

Appendix 5

Flexibility Protocols

The following flexibility tests were adapted from Baumann et al. (1982).

Flexibility Test 1 – Hamstring

Hamstring flexibility was measured with the subject lying in a supine position with legs extended. The leg being tested was actively flexed at the hip with the knee locked. The axis of the goniometer was placed on the greter trochanter, with one arm aligned with the lateral midline of the thigh (parallel to the femur) and the other arm parallel to the measuring surface.

Flexibility Test 2 – Adductor

Adductor flexibility was measured with the subject lying supine with the tested leg extended and the nontested leg flexed and hanging over the side of the table to stabilise the pelvis. One arm of the goniometer was placed on a line across the right and left ASIS, and the other arm was placed on the anterior midline of the thigh. The leg was then actively abducted with the toes and knees pointing up to avoid lateral rotation of the hip.

Flexibility Test 3 – Quadricep

Quadricep flexibility was measured with the subject in a prone position with leg extended. The knee was actively flexed and measured with one goniometer arm aligned with the greater trochanter and the other arm aligned with the lateral malleolus (parallel to the crest of the tibia).

Flexibility Test 4 – Hip Extension

Hip extension flexibility was measured with the subject in a prone position with the knee flexed at 90 degrees. The thigh was actively extended, with the goniometer arms aligned with the lateral midline of the thigh and an imaginary line which paralleled the table surface.

Flexibility Test 5 – Hip Rotation

Hip rotation was measured with the subject in a prone position with the knee flexed to 90 degrees and the midpatella resting against the axis of the protractor of the goniometer. As the lower leg externally rotated hip rotation took place and the angle of the lower leg to the starting position was recorded.

Flexibility Test 6 – Gastrocnemius

Gastrocnemius flexibility was measured with the subject in a long sitting position with knees extended. The foot was actively dorsiflexed, with one goniometer arm placed parallel to the fifth metatarsal and the other arm aligned with the lateral midline of the leg (parallel to the shaft of the tibia).

Flexibility Test 7 – Soleus

Soleus flexibility was measured with the subject in a long sitting position with the knee flexed at 90 degrees. The foot was actively dorsiflexed, with the goniometer arms aligned parallel to the fifth metatarsal and the lateral midline of the leg (parallel to the shaft of the tibia).

Appendix 6

Kinanthropometric Protocols

Adapted from Ward et al., (1989) and Heyward (1991).

APPENDIX D.3 STANDARDIZED SITES FOR SKINFOLD MEASUREMENTS

Site	Direction of fold	Anatomical reference	Measurement
Chest	Diagonal	Axilla and nipple	Fold is taken between axilla and nipple as high as possible on anterior axillary fold with measurement taken 1 cm below fingers.
Subscapular	Diagonal	Inferior angle of scapula	Fold is along natural cleavage line of skin just inferior to inferior angle of scapula, with caliper applied 1 cm below fingers.
Midaxillary	Horizontal	Xiphisternal junction (point where costal cartilage of ribs 5-6 articulate with sternum, slightly above inferior tip of xiphoid process)	Fold is taken on midaxillary line at level of xiphisternal junction.
Suprailiac	Oblique	Iliac crest	Fold is grasped posteriorly to midaxillary line and superiorly to iliac crest along natural cleavage of skin with caliper applied 1 cm below fingers.
Abdominal	Horizontal	Umbilicus	Fold is taken 3 cm lateral and 1 cm inferior to center of the umbilicus.
Triceps	Vertical (midline)	Acromial process of scapula and olecranon process of ulna	Distance between lateral projection of acromial process and inferior margin of olecranon process is measured on lateral aspect of arm with elbow flexed 90° using a tape measure. Midpoint is marked on lateral side of arm. Fold is lifted 1 cm above marked line on posterior aspect of arm. Caliper is applied at marked level.
Biceps	Vertical (midline)	Biceps brachii	Fold is lifted over belly of the biceps brachii at the level marked for the triceps and on line with anterior border of the acromial process and the antecubital fossa. Caliper is applied 1 cm below fingers.
Thigh	Vertical (midline)	Inguinal crease and patella	Fold is lifted on anterior aspect of thigh midway between inguinal crease and proximal border of patella. Body weight is shifted to left foot and caliper is applied 1 cm below fingers.
Calf	Vertical (medial aspect)	Maximal calf circumference	Fold is lifted at level of maximal calf circumference on medial aspect of calf with knee and hip flexed to 90°.

Adapted from Harrison et al. (1988, pp. 55-70)

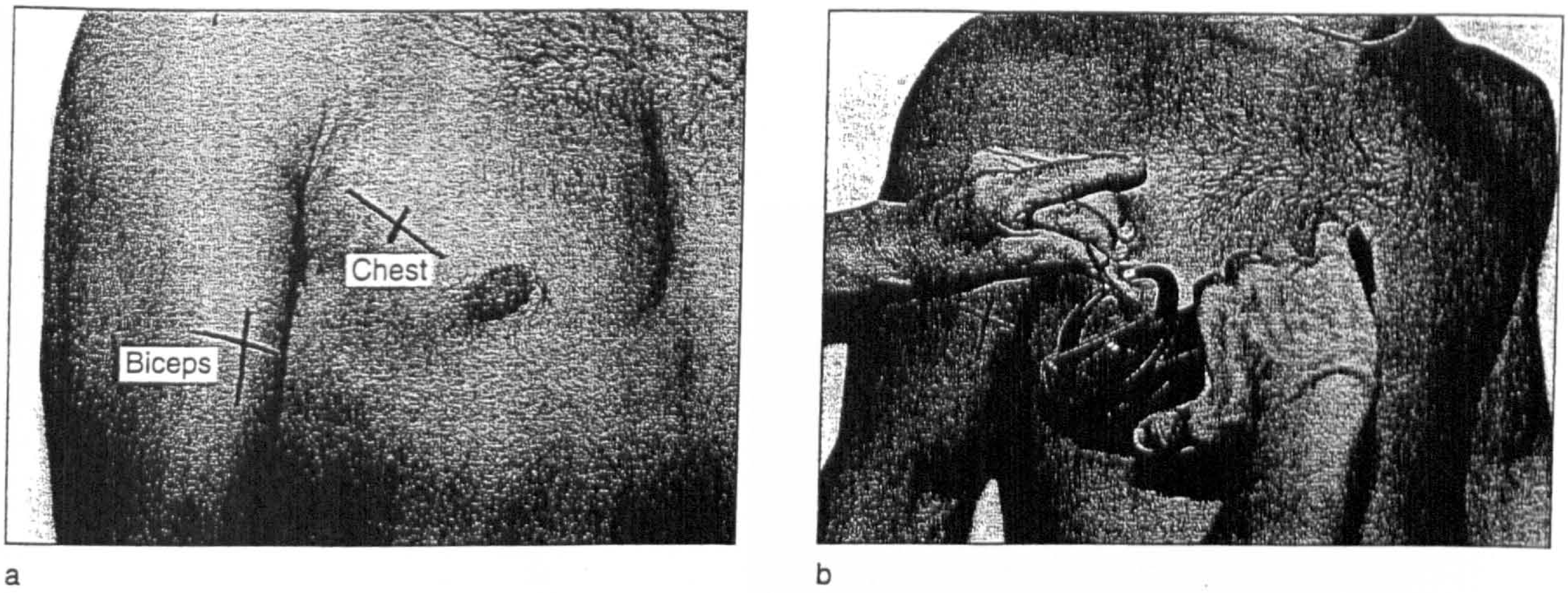


Figure D.3.1 (a) Site and (b) measurement of the chest skinfold. Photos courtesy of Linda K. Gilkey.

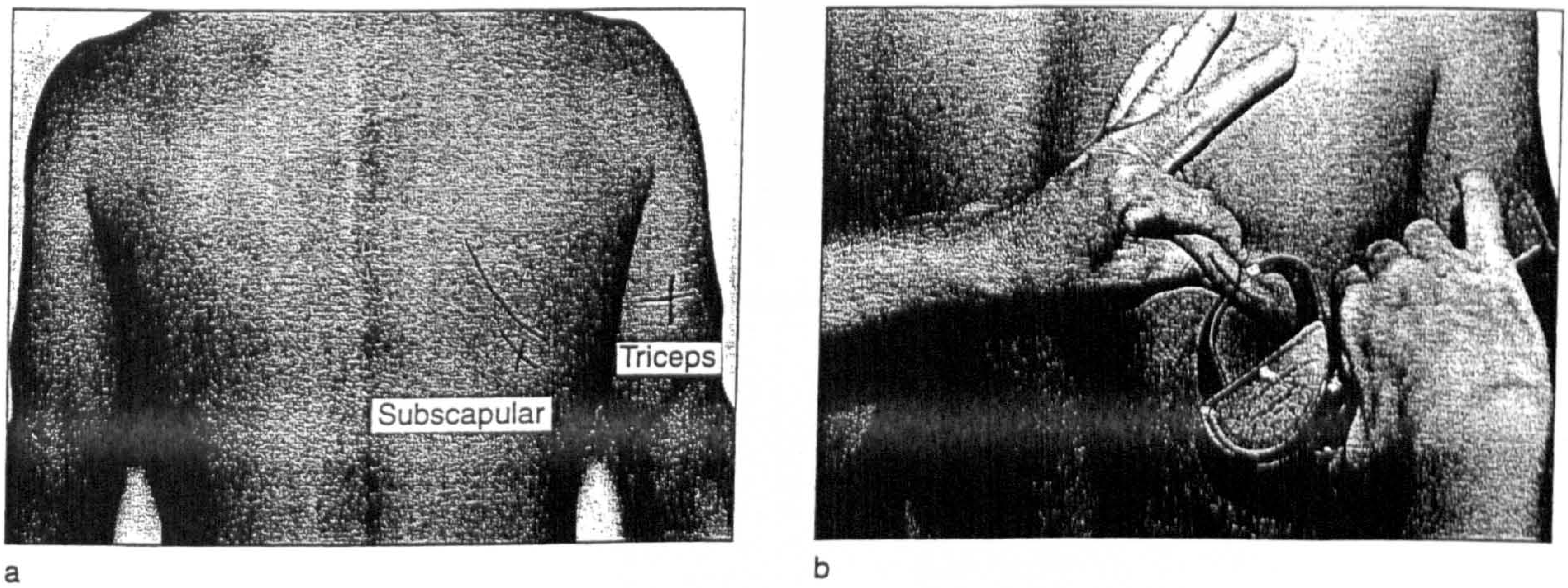


Figure D.3.2 (a) Site and (b) measurement of subscapular skinfold. Photos courtesy of Linda K. Gilkey.

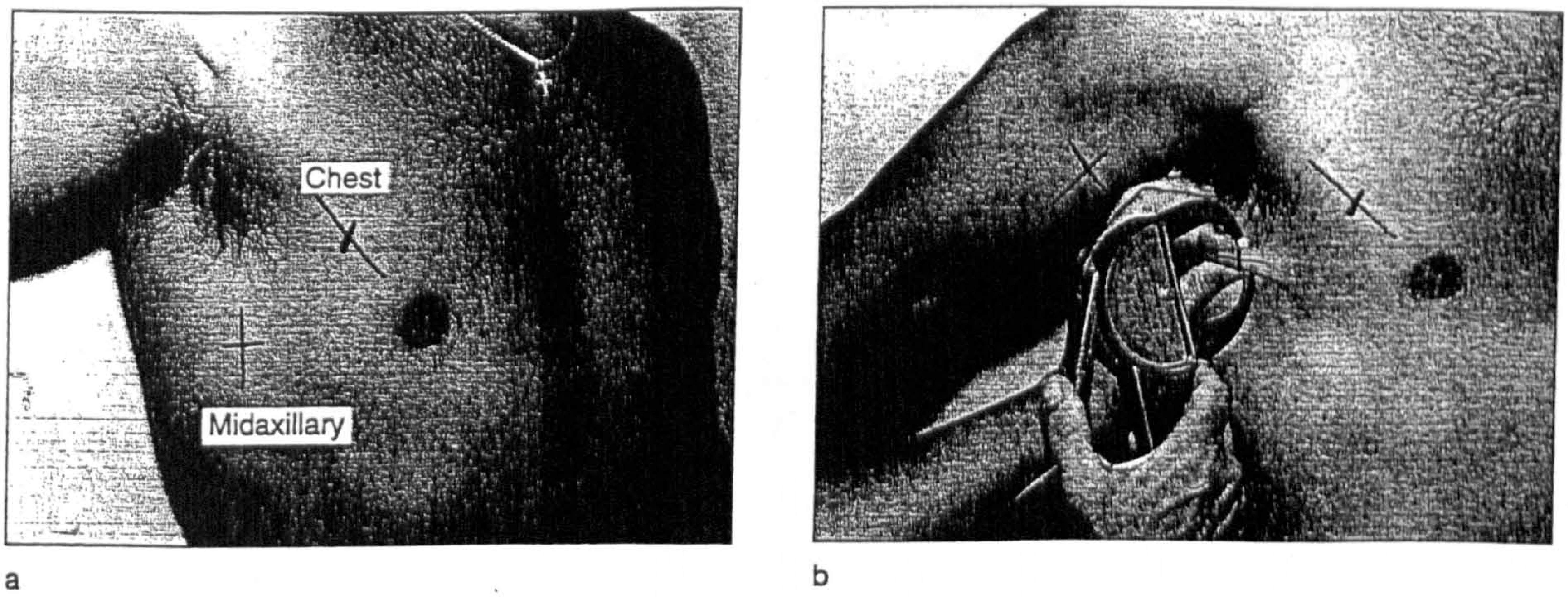


Figure D.3.3 (a) Site and (b) measurement of the midaxillary skinfold. Photos courtesy of Linda K. Gilkey.

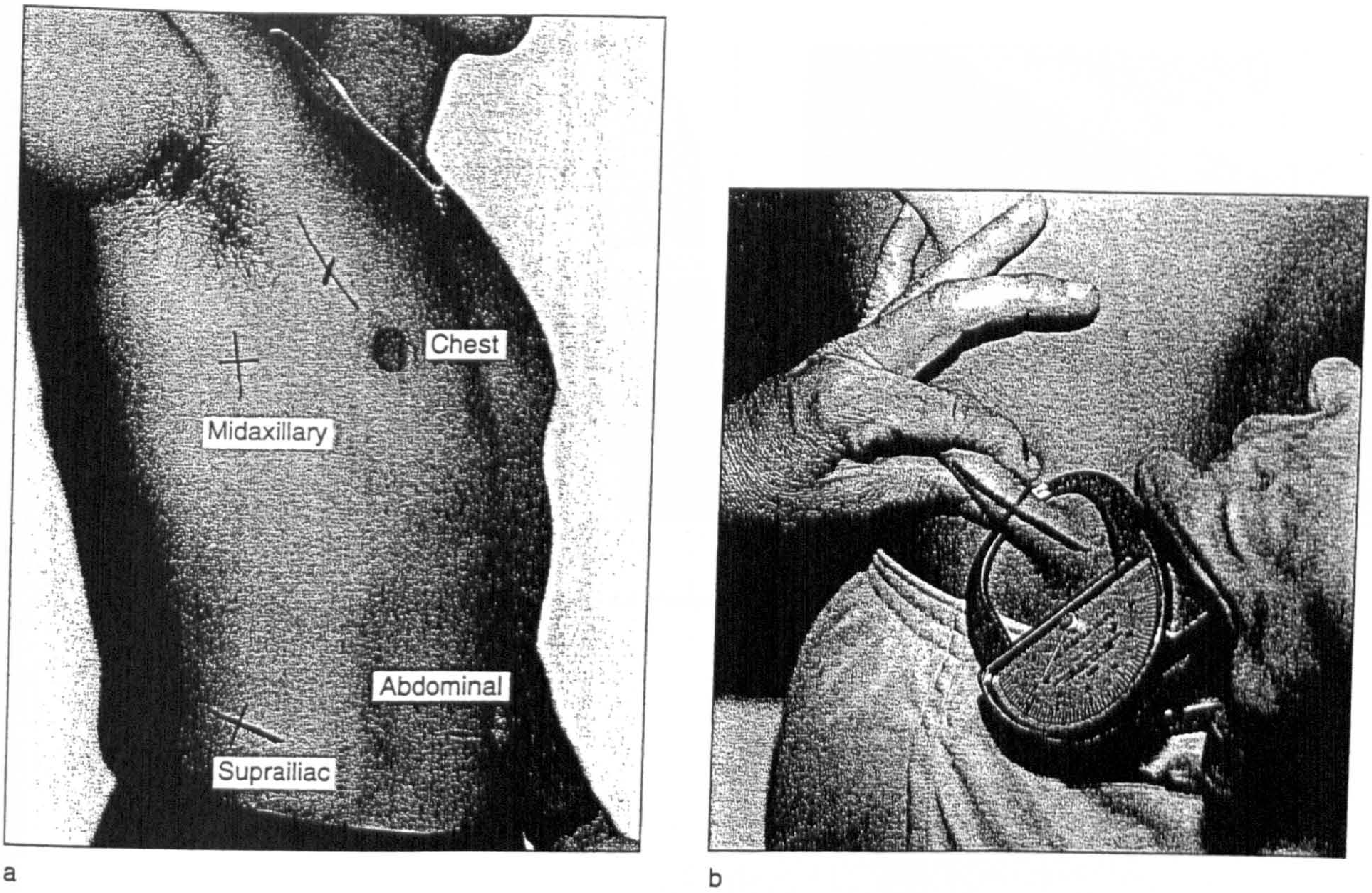


Figure D.3.4 (a) Site and (b) measurement of the suprailiac skinfold. Photos courtesy of Linda K. Gilkey.

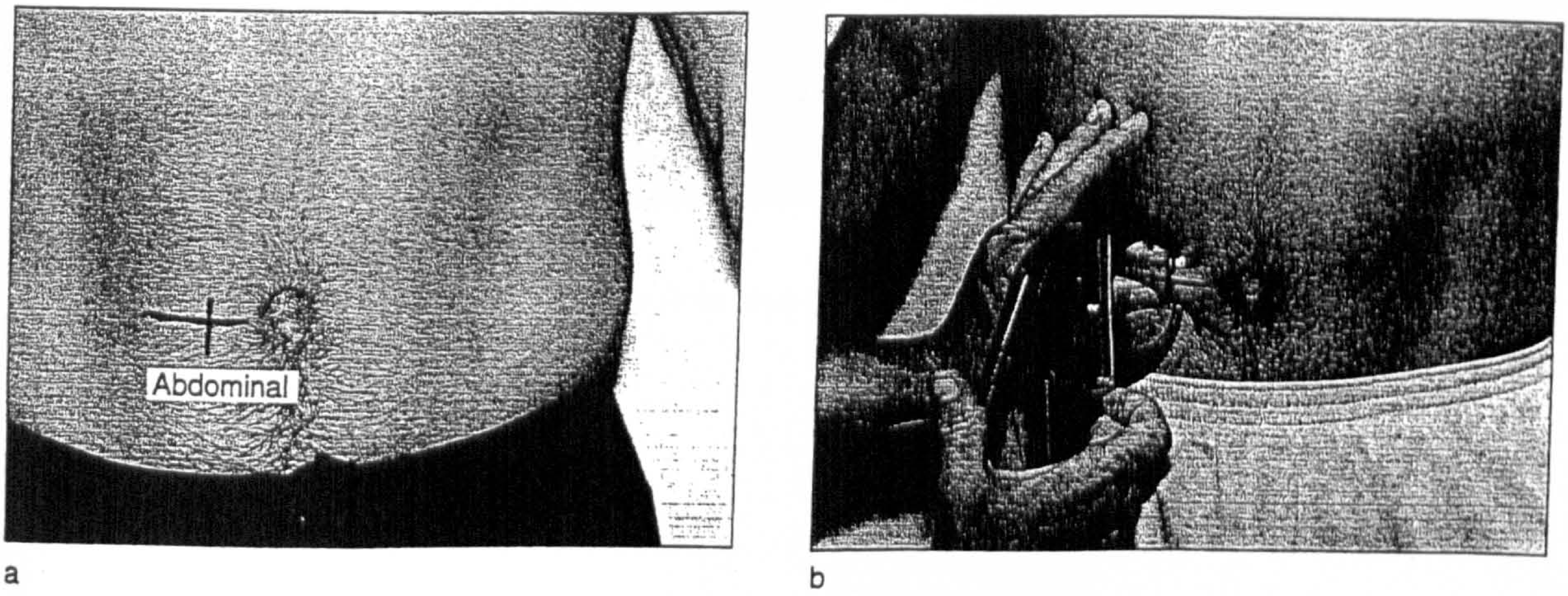


Figure D.3.5 (a) Site and (b) measurement of the abdominal skinfold. Photos courtesy of Linda K. Gilkey.

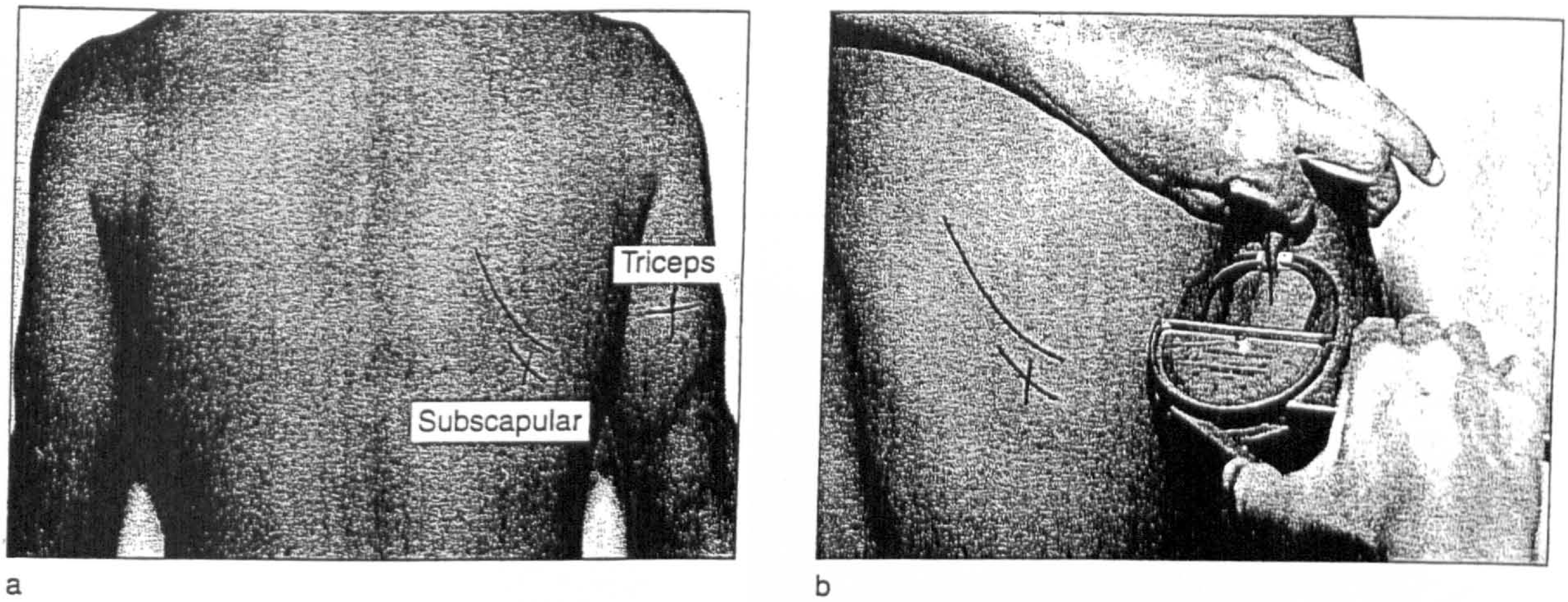


Figure D.3.6 (a) Site and (b) measurement of the triceps skinfold. Photos courtesy of Linda K. Gilkey.

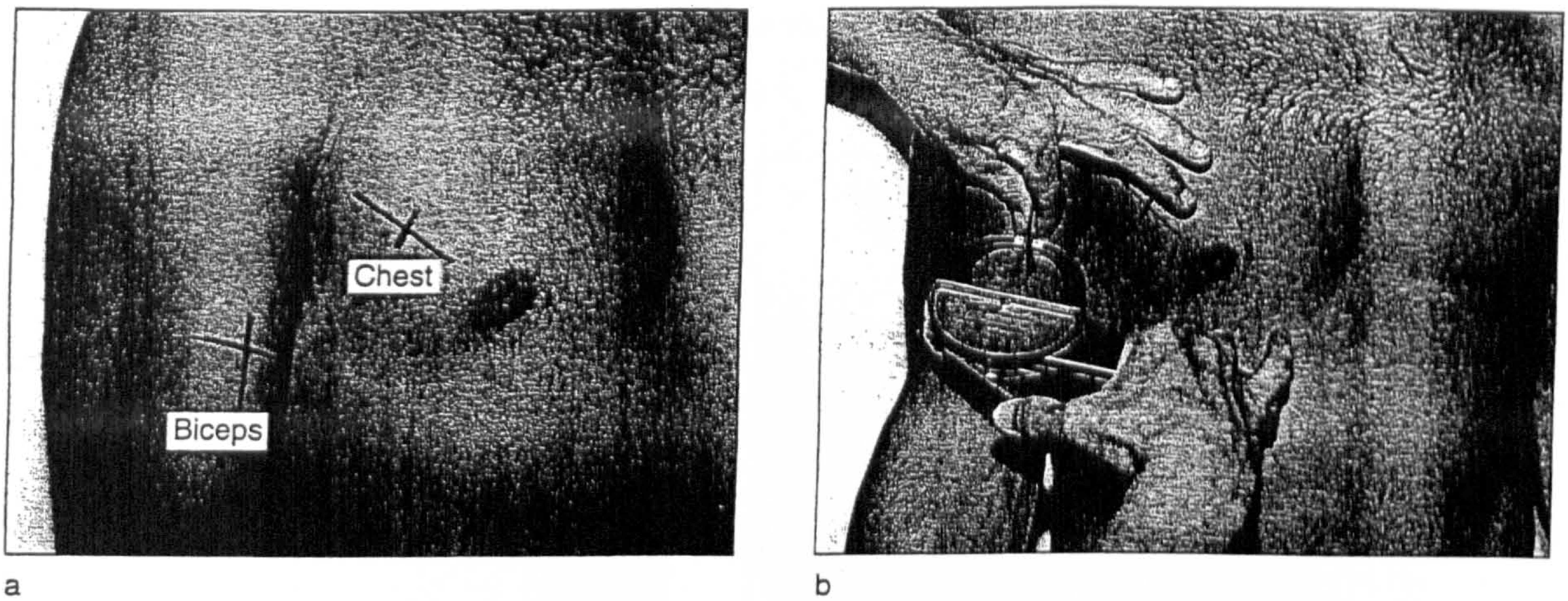


Figure D.3.7 (a) Site and (b) measurement of the biceps skinfold. Photos courtesy of Linda K. Gilkey.

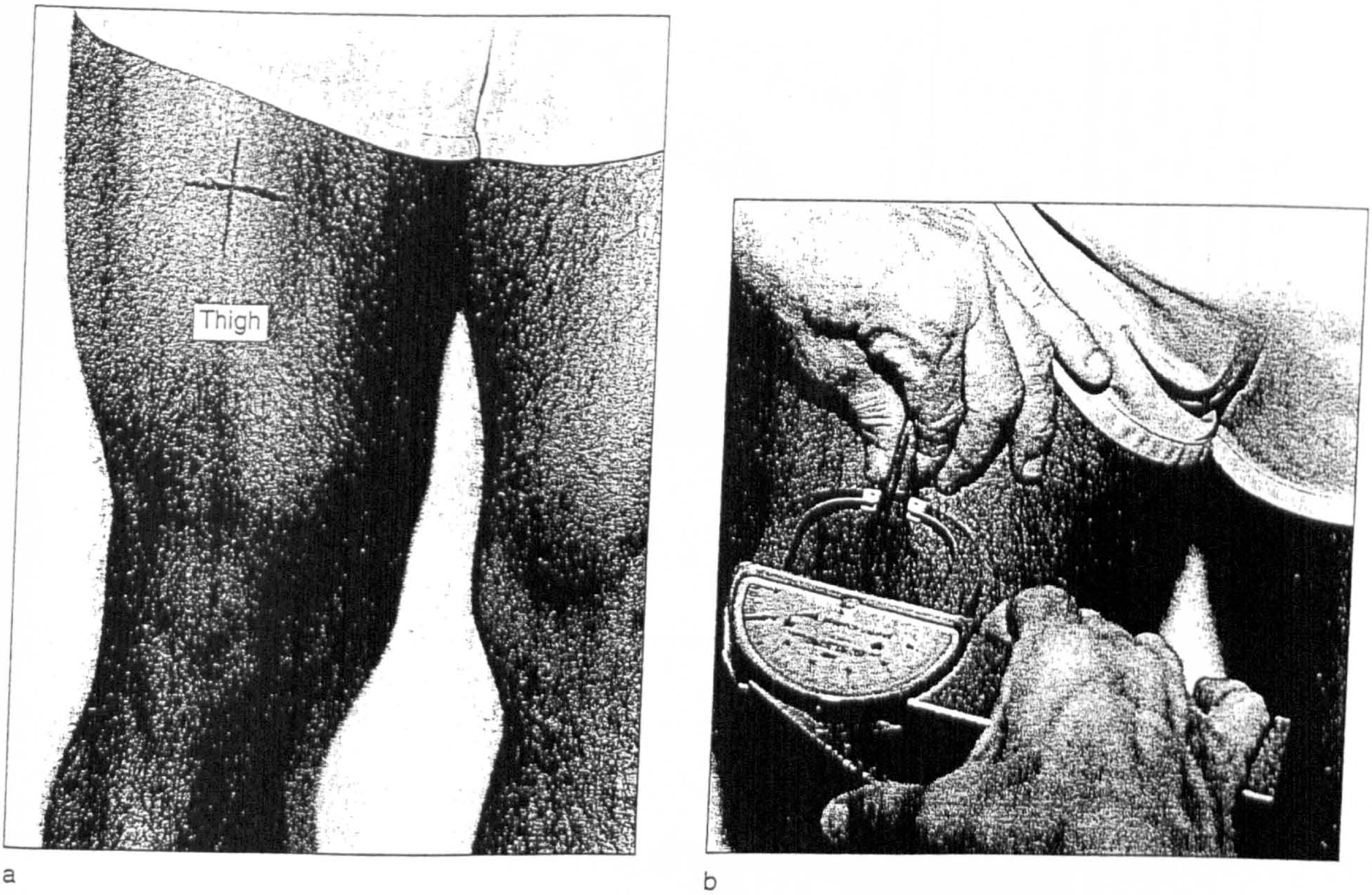


Figure D.3.8 (a) Site and (b) measurement of the thigh skinfold. Photos courtesy of Linda K. Gilkey.

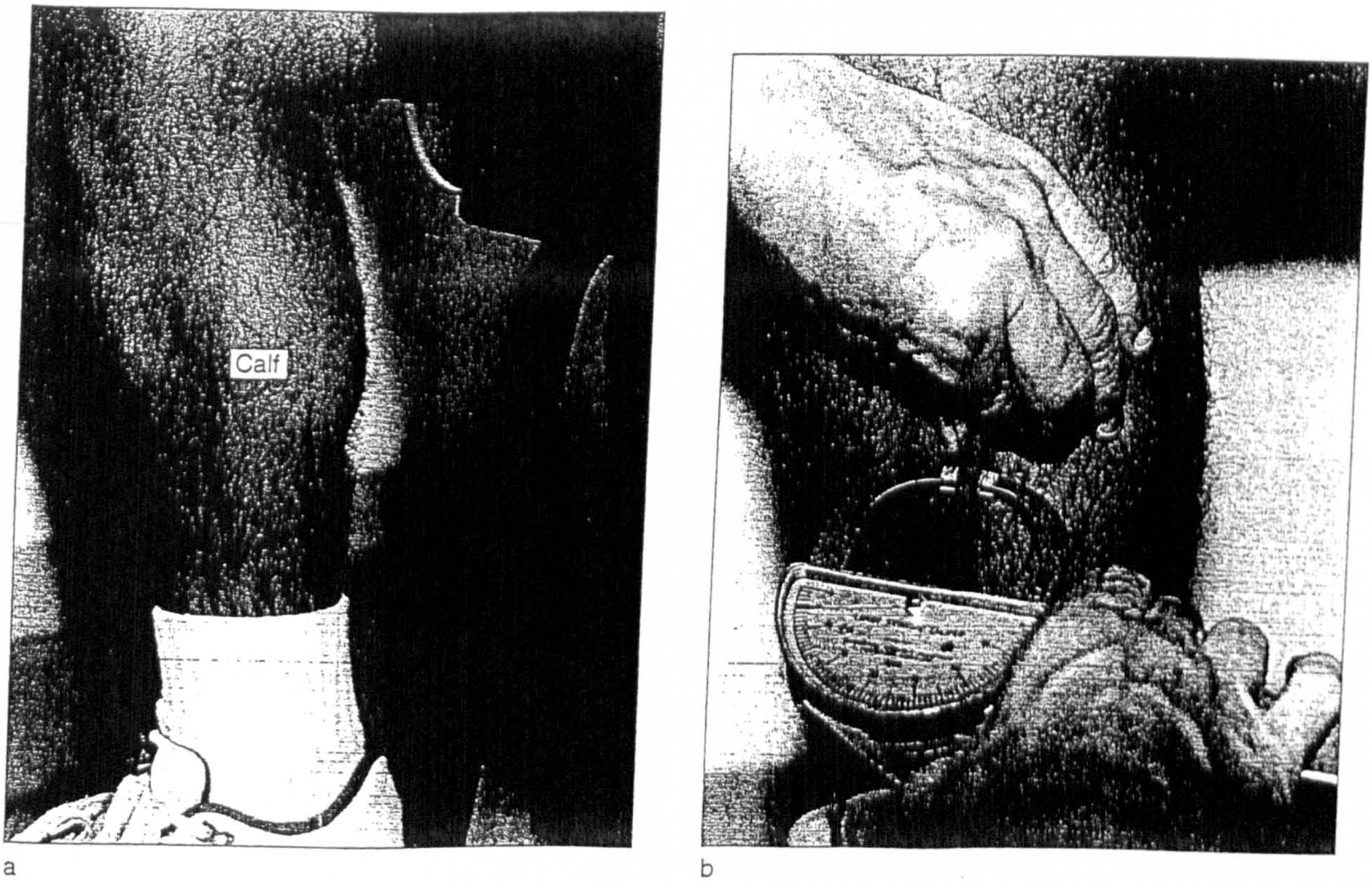


Figure D.3.9 (a) Site and (b) measurement of the calf skinfold. Photos courtesy of Linda K. Gilkey.

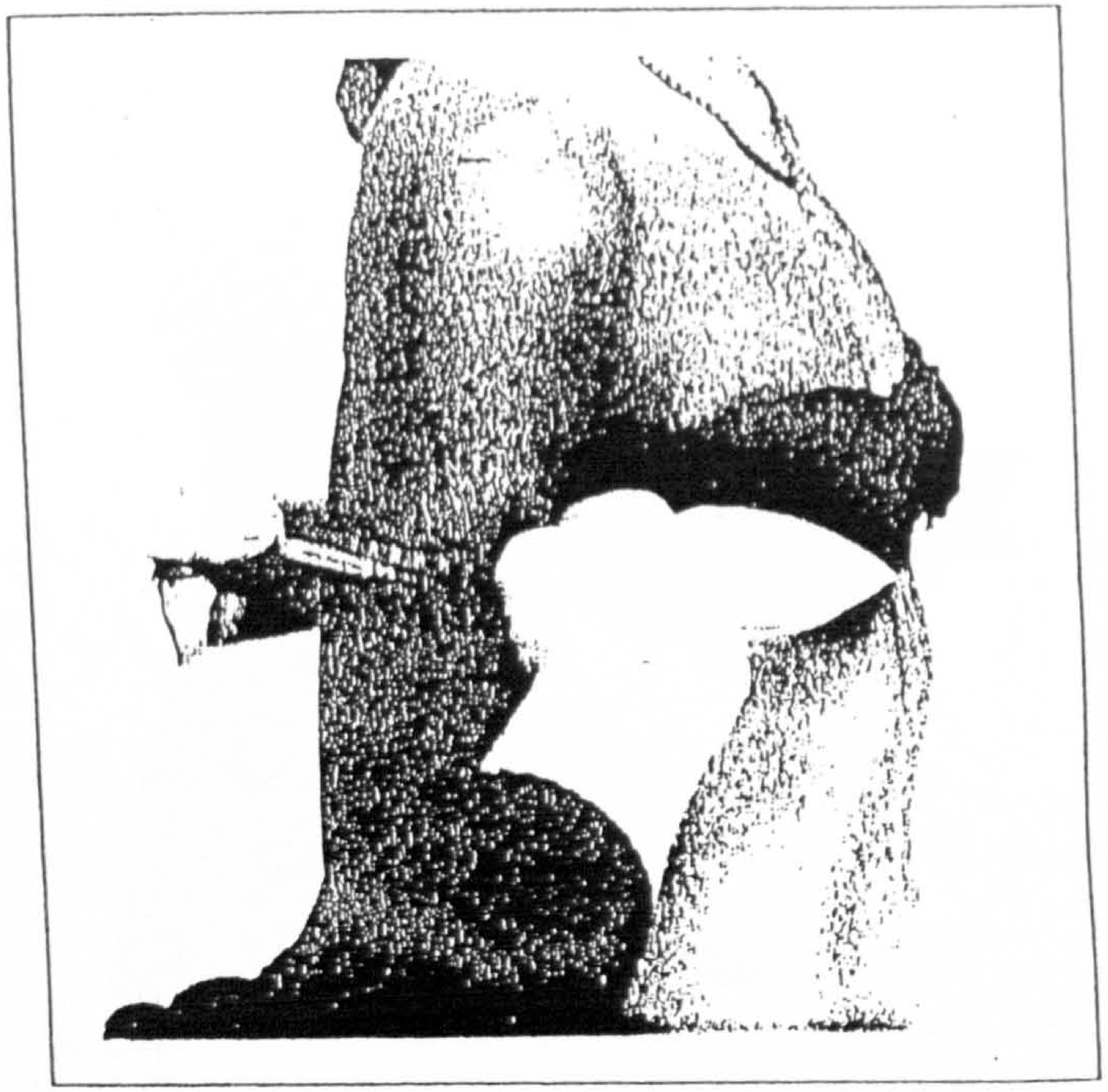
GIRTH MEASUREMENT TECHNIQUES

Ten girth measurements are recommended although these are optional measurements in the O-SCALE system. Relaxed arm, chest, thigh and standing calf girths are used to derive muscularity indicators in the associated computer programs.

Girths are measured with an anthropometric tape. Although this is a very simple piece of equipment it takes considerable practice to use efficiently. The anthropometric tape is narrow, 7mm (1/4 inch) wide. There is a preference for white-faced, flexible, retractable steel tapes with a clearly visible centimeter scale. However, a plastic tape can be used if desired. A 1.5m long tape is adequate for the O-SCALE system.

Anthropometrists always hold the tape in their right hand and extend it with the left passing it to the right hand after encircling the body part. It is important that the girth (circumference) reading is taken at right angles to the long axis of the limb. A light touch is required so that there is no indentation of the skin, since the aim is to measure the body segment's perimeter with the tape in contact with, but not depressing, the fleshy contour. Do not use an anthropometric tape with a spring device to ensure constant tape tension. This tension is usually too great and causes indentation of tissues, particularly in children and elderly. Ten girth measurements are made in the following order: relaxed arm, flexed arm, forearm, wrist, chest, waist, gluteal, thigh, calf, ankle.

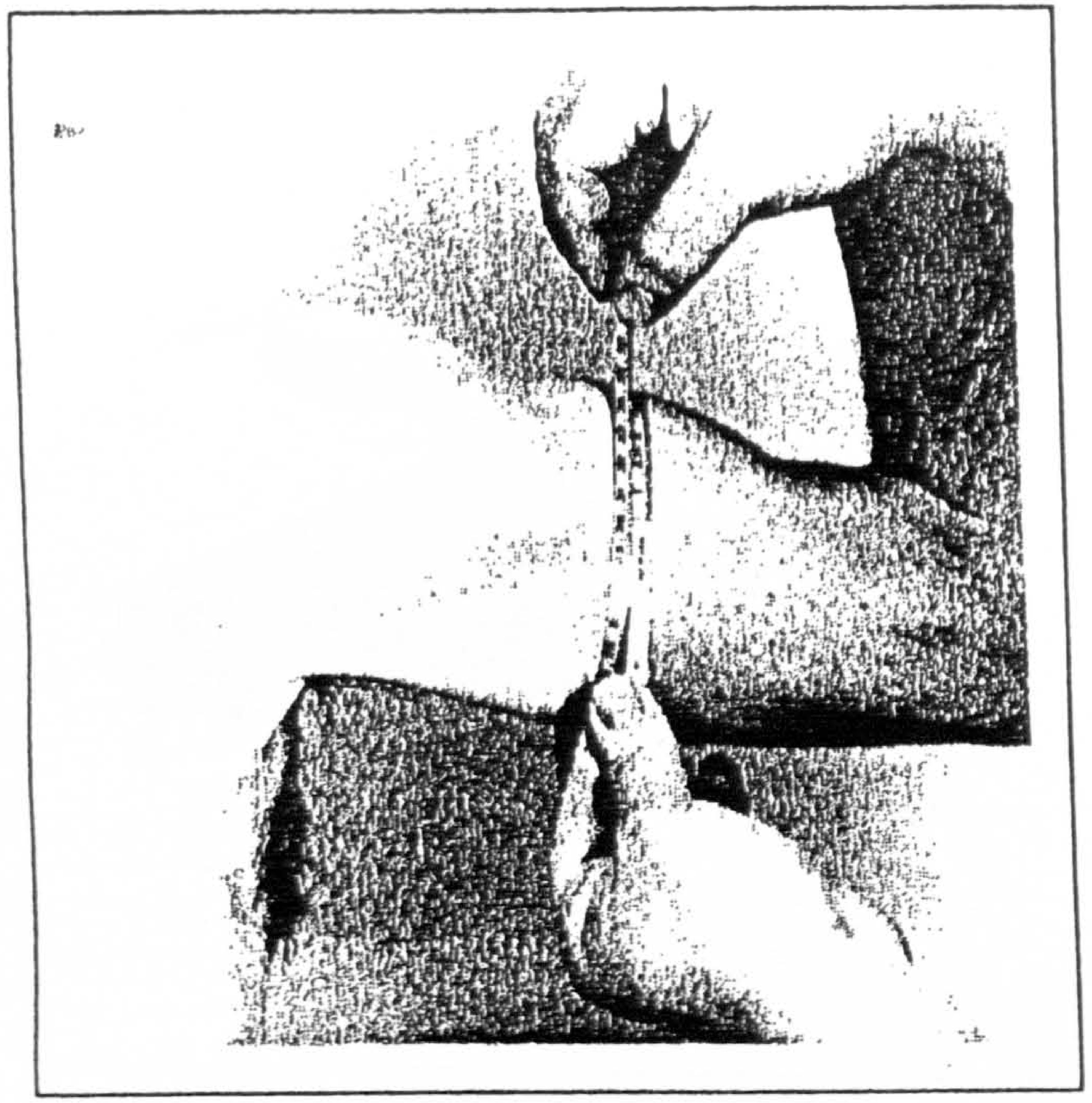
RELAXED ARM GIRTH



TECHNIQUE

The subject stands erect with the arm hanging relaxed, by their side. Relaxed arm girth is the perimeter distance at a right angle to the long axis of the humerus (mid acromiale radiale level). This is the same level as the triceps skinfold, if this position was marked accurately it is not necessary to reevaluate. Measurement is to the nearest 0.1cm.

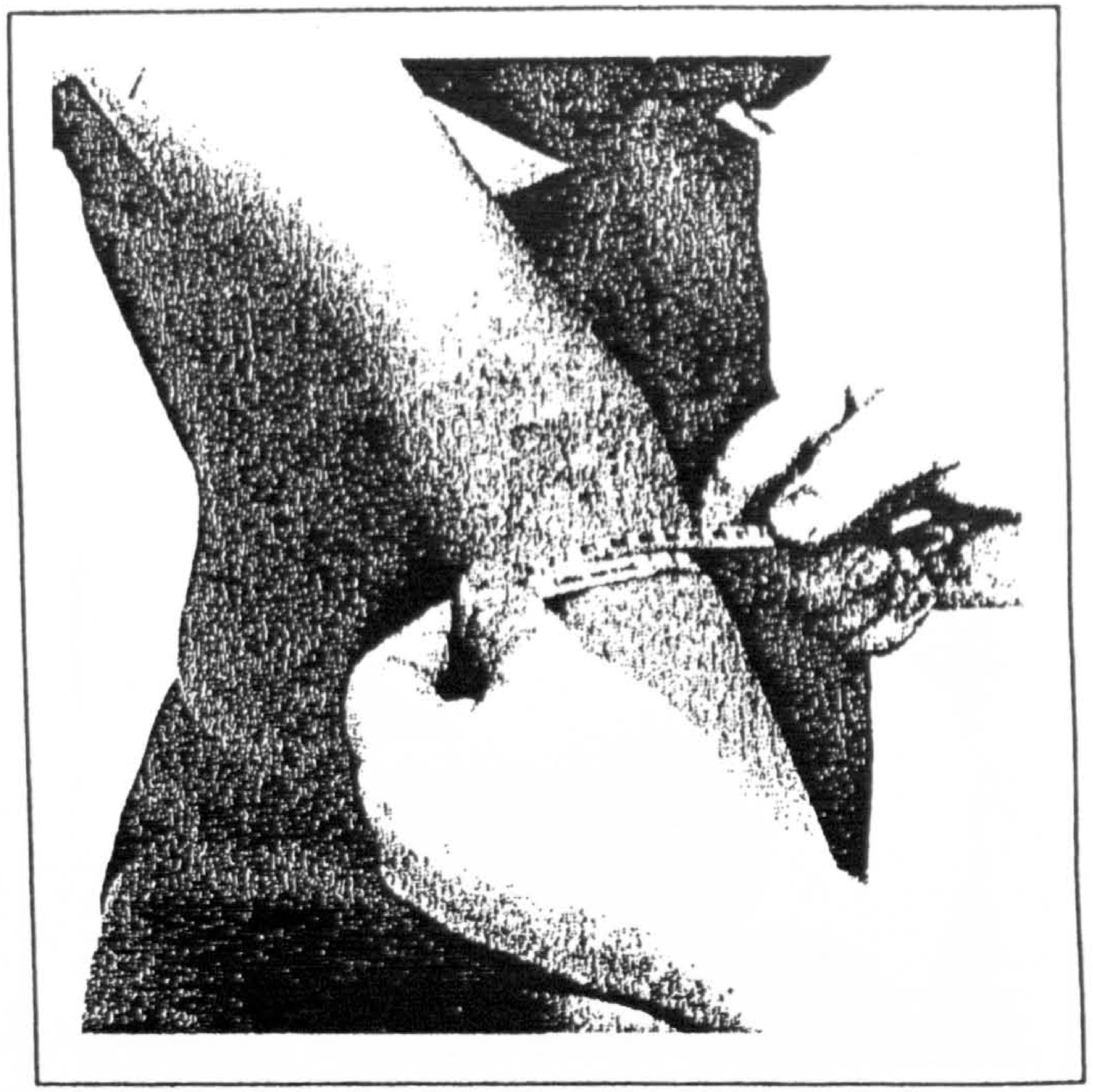
FLEXED ARM GIRTH



TECHNIQUE

This is defined as the maximum circumference of the right arm raised to the horizontal position. The subject is encouraged to "make a muscle" by tensing while fully flexing his elbow joint. Measurement is to the nearest 0.1cm.

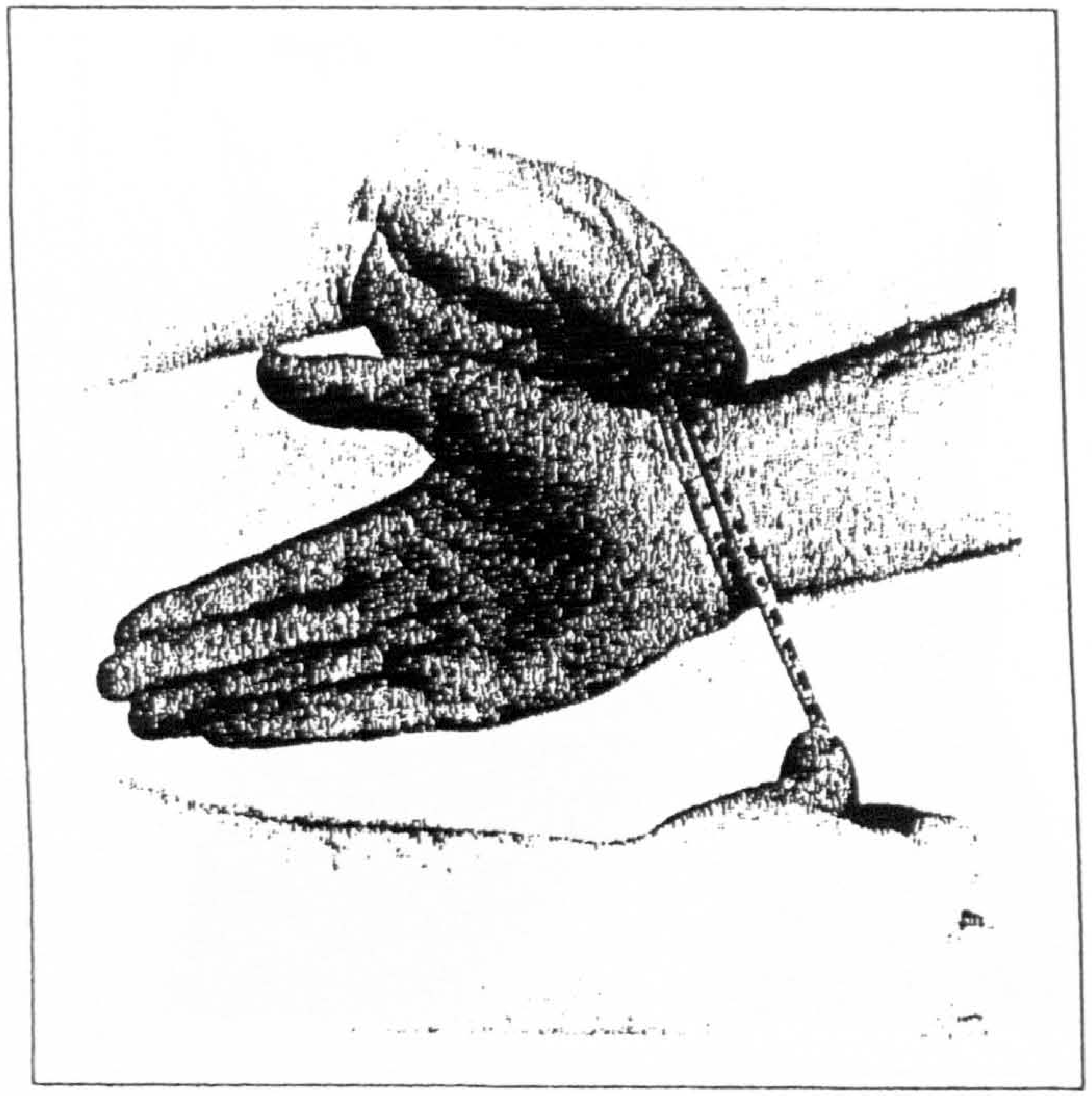
FOREARM GIRTH



TECHNIQUE

The tape is lowered to encircle the relaxed forearm, elbow extended with palm facing forwards and upwards. The tape is manipulated by loosening and snugging with the thumb and index fingers, while adjusting the level with the third finger, to obtain the maximum girth at a right angle to the long axis of the radius. Measurement is to the nearest 0.1cm.

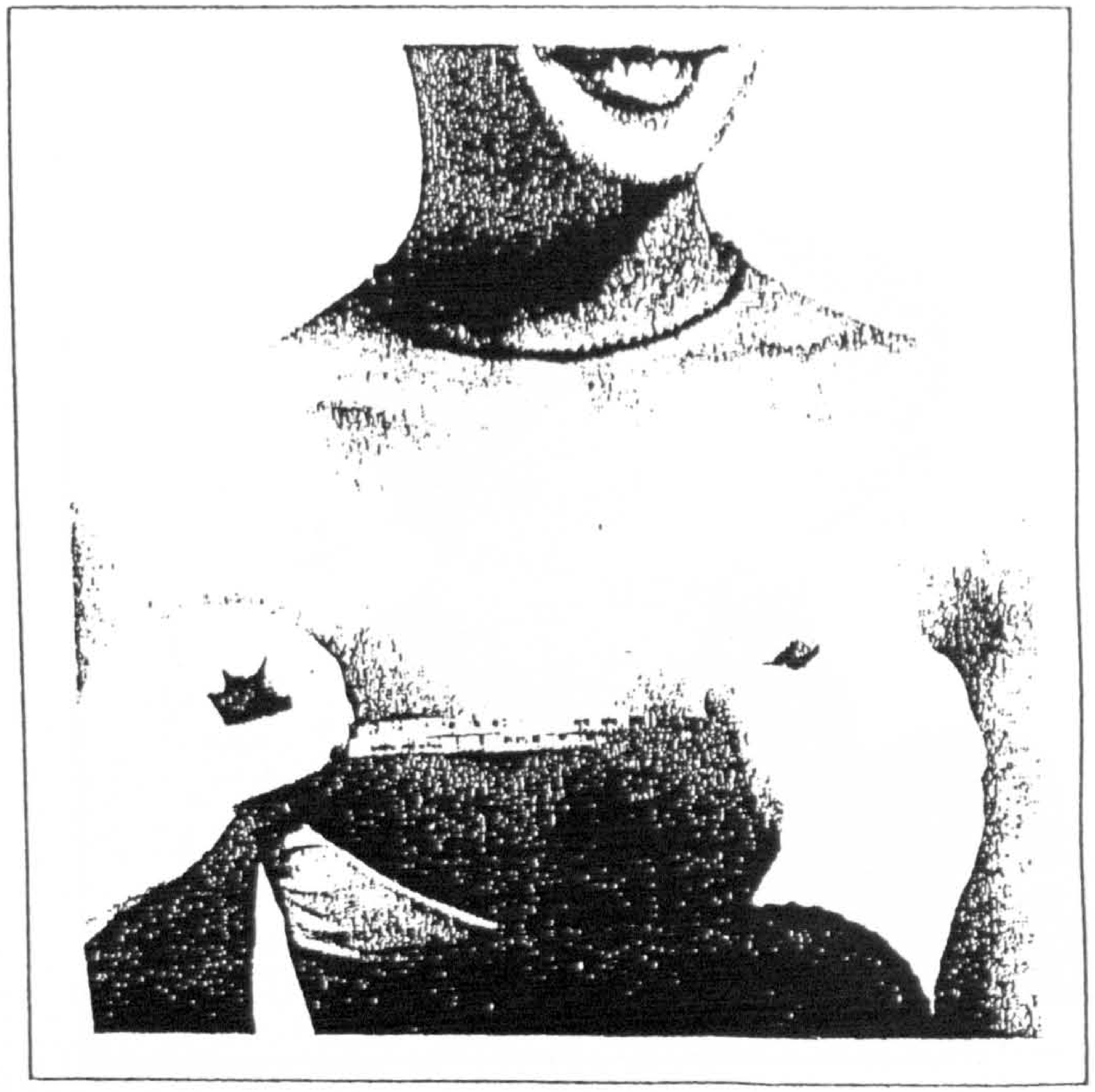
WRIST GIRTH



TECHNIQUE

The perimeter of the right wrist, distal to the styloid processes (close to the base of the hand) is measured with arm extended in a relaxed position with palm facing forwards. Measurement is to the nearest 0.1cn.

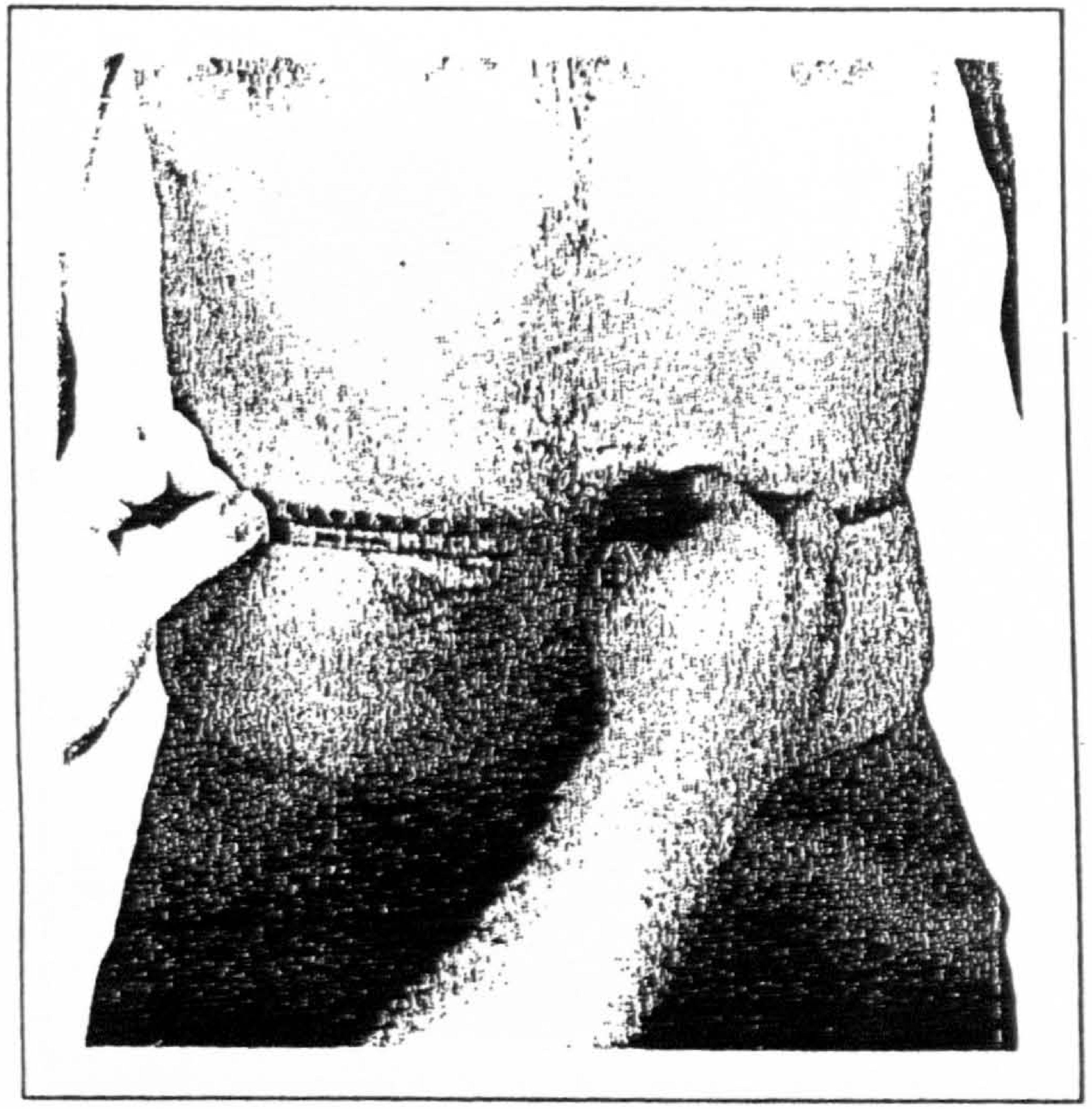
CHEST GIRTH



TECHNIQUE

The perimeter distance of the chest is taken horizontally at the level of the mesosternale. The measurement is taken with the subject standing erect and arms at the sides. The reading is taken at the end of a normal expiration. Measurement is to the nearest 0.1cm. For instructional purposes the mesosternale mark has been made visible in the photograph. During actual measurement the tape would lay directly over the mark.

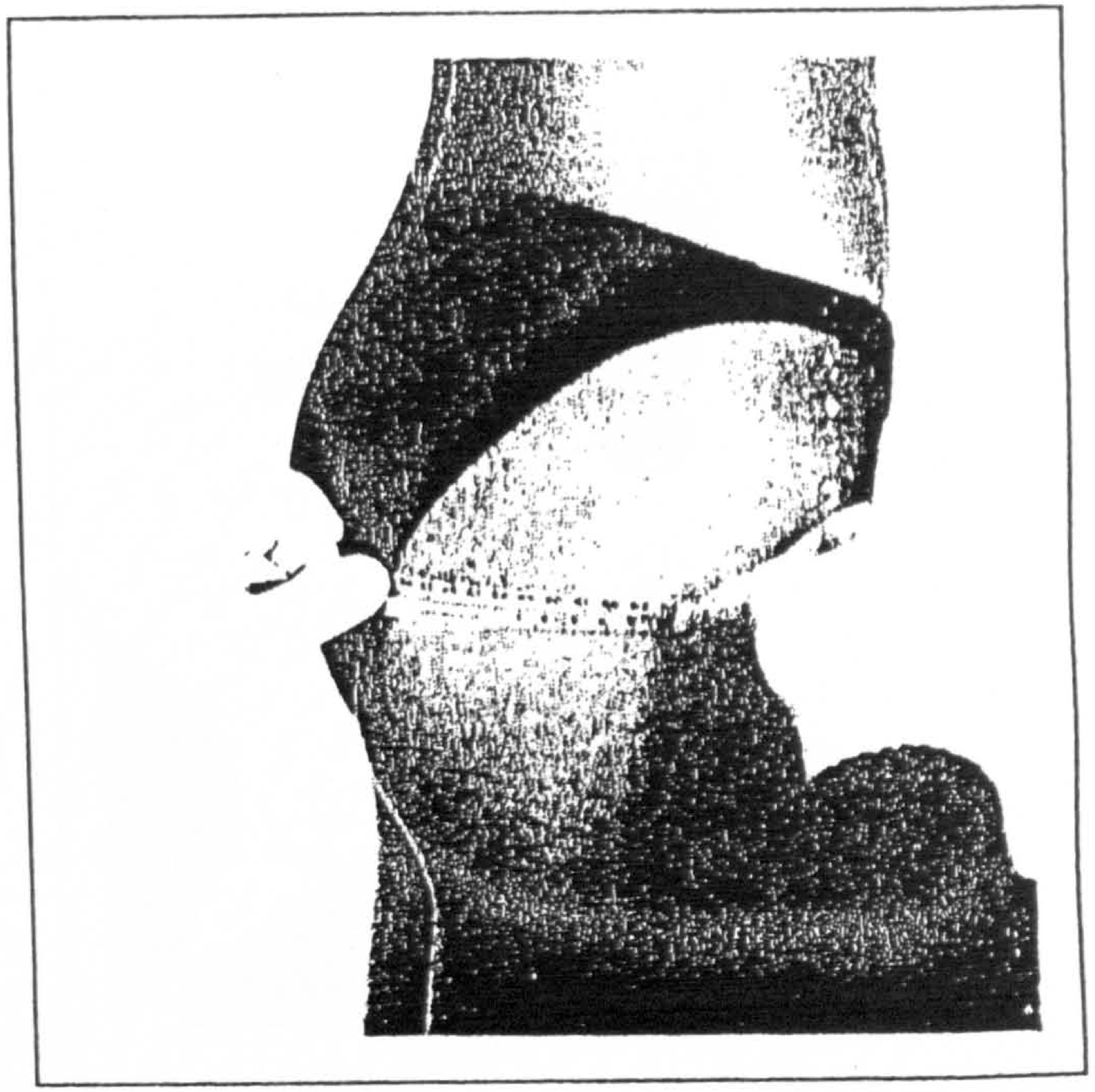
WAIST GIRTH



TECHNIQUE

The horizontal perimeter at the level of the noticeable waist narrowing is located approximately half way between the lower edge of the rib cage and the iliac crest. In subjects where the waist is not apparent an arbitrary waist measurement is made at this level. Measurement is to the nearest 0.1cm.

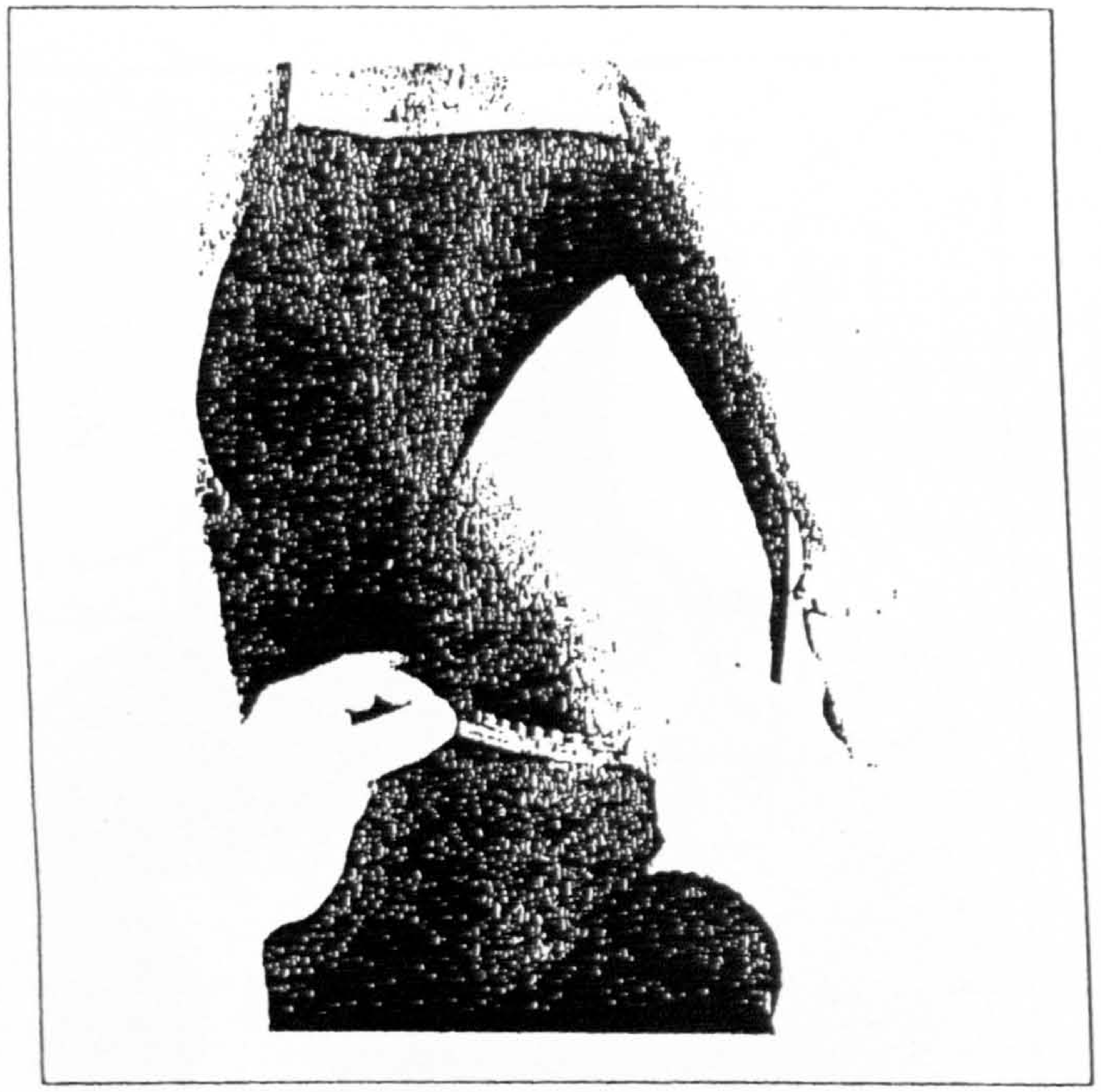
GLUTEAL GIRTH



TECHNIQUE

This is the horizontal perimeter at the level of the greatest posterior protuberance, (that is, where the bottom sticks out the most) and at approximately the symphysis pubis level anteriorly. The subject must stand erect with feet together. Measurement is to the nearest 0.1cm.

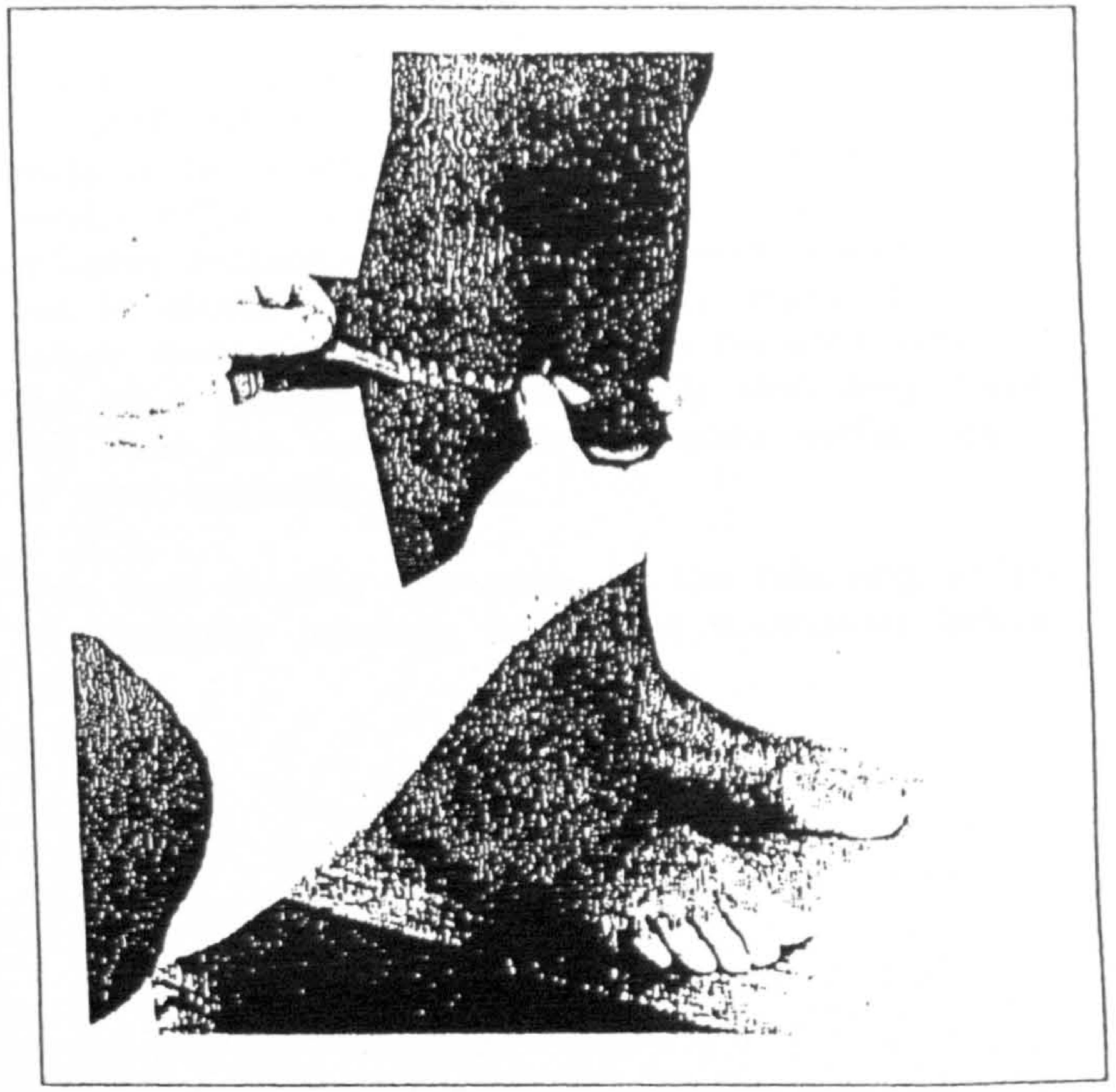
THIGH GIRTH



TECHNIQUE

The horizontal perimeter of the right thigh is measured when the subject stands erect, legs slightly parted, weight equally distributed on both feet. The tape is raised to a level two centimeters below the gluteal line (horizontal crease at the top of the thigh). Measurement is to the nearest 0.1cm.

CALF GIRTH



TECHNIQUE

The subject stands with weight distributed equally on each foot. A series of perimeter measures are obtained by manipulation of the tape as for the forearm. The maximum calf girth is the largest measure obtained with the tape at right angles to the long axis of the tibia. Measurement is to the nearest 0.1cm.

ANKLE GIRTH

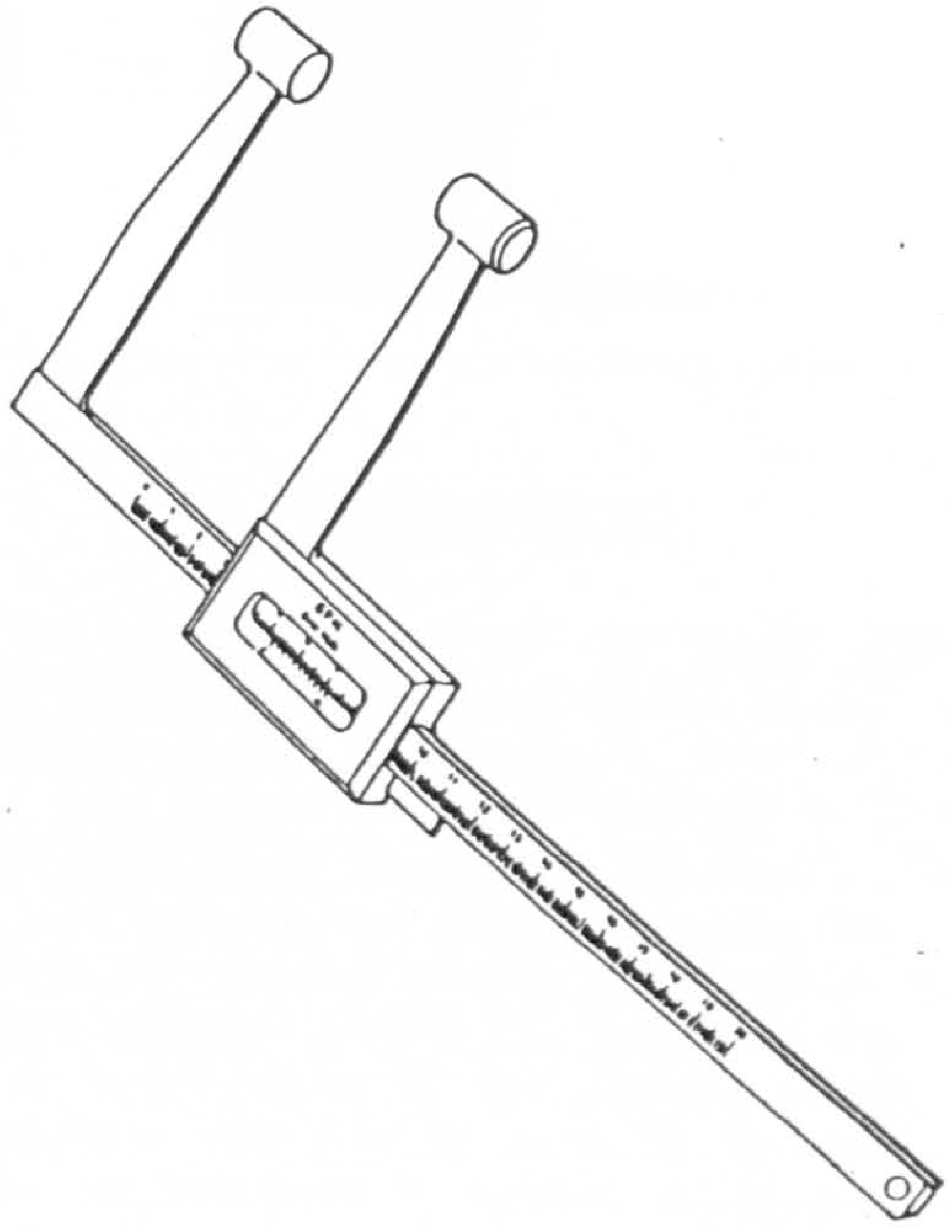
TECHNIQUE

The perimeter of the narrowest part of the lower leg superior to the malleoli of the ankle (protruding bones of the ankle) defines the position of measurement. Measurement is to the nearest 0.1cm.

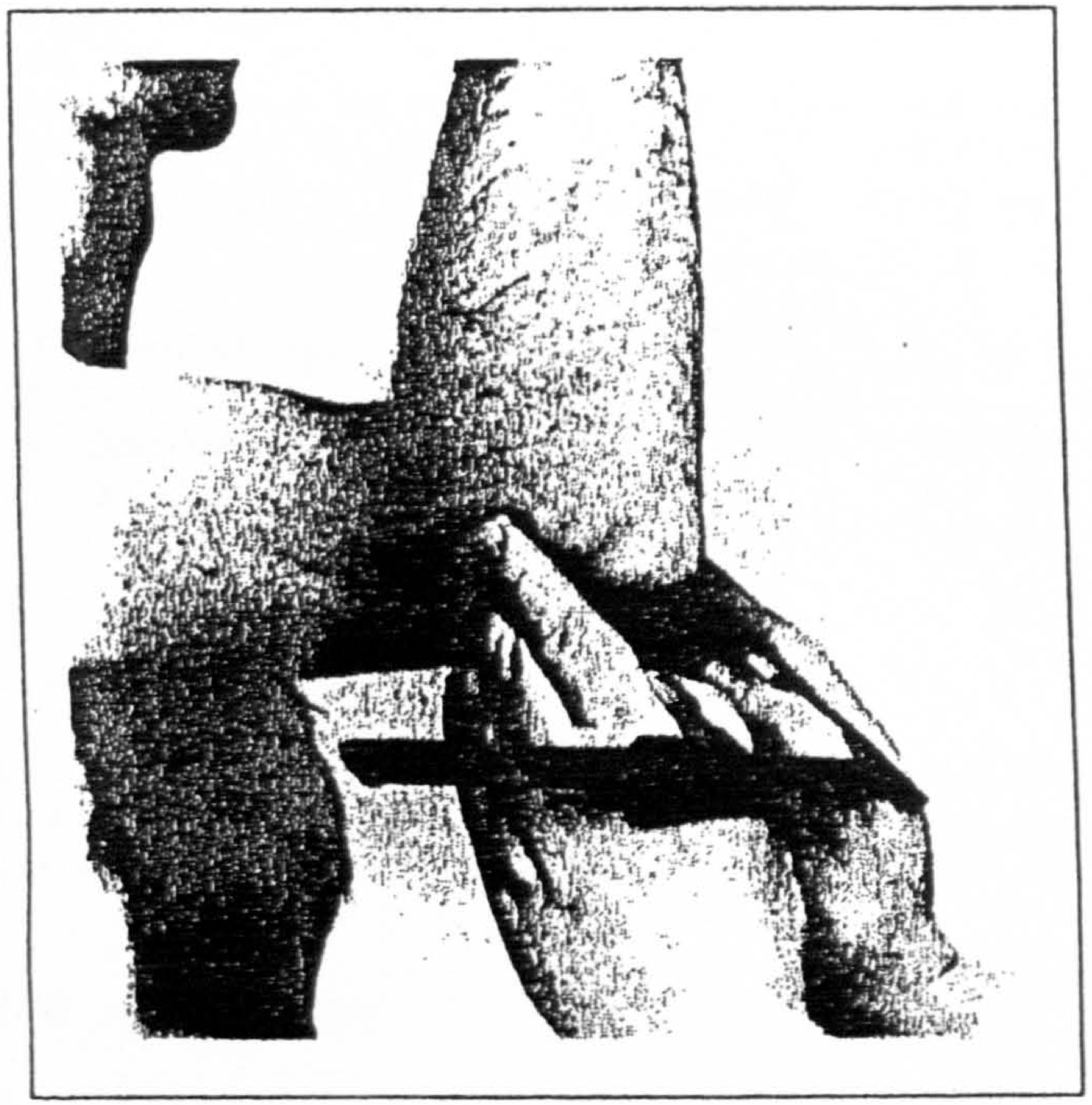
BONE WIDTH MEASUREMENT TECHNIQUES

Two bone breadths are measured as part of the full O-SCALE system protocol. Measurement is made to the closest 0.1 cm using a modified vernier caliper (shown below). These calipers have extended branches with round pressure plates 15 mm in diameter. There are many types of caliper that may be used for this measurement. The ideal characteristic however, is that they have flat plate jaw surfaces rather a point surface as in most spreading caliper.

Two bone breaths are made in the following order: bi-epicondylar humerus width and bi-condylar femur width.



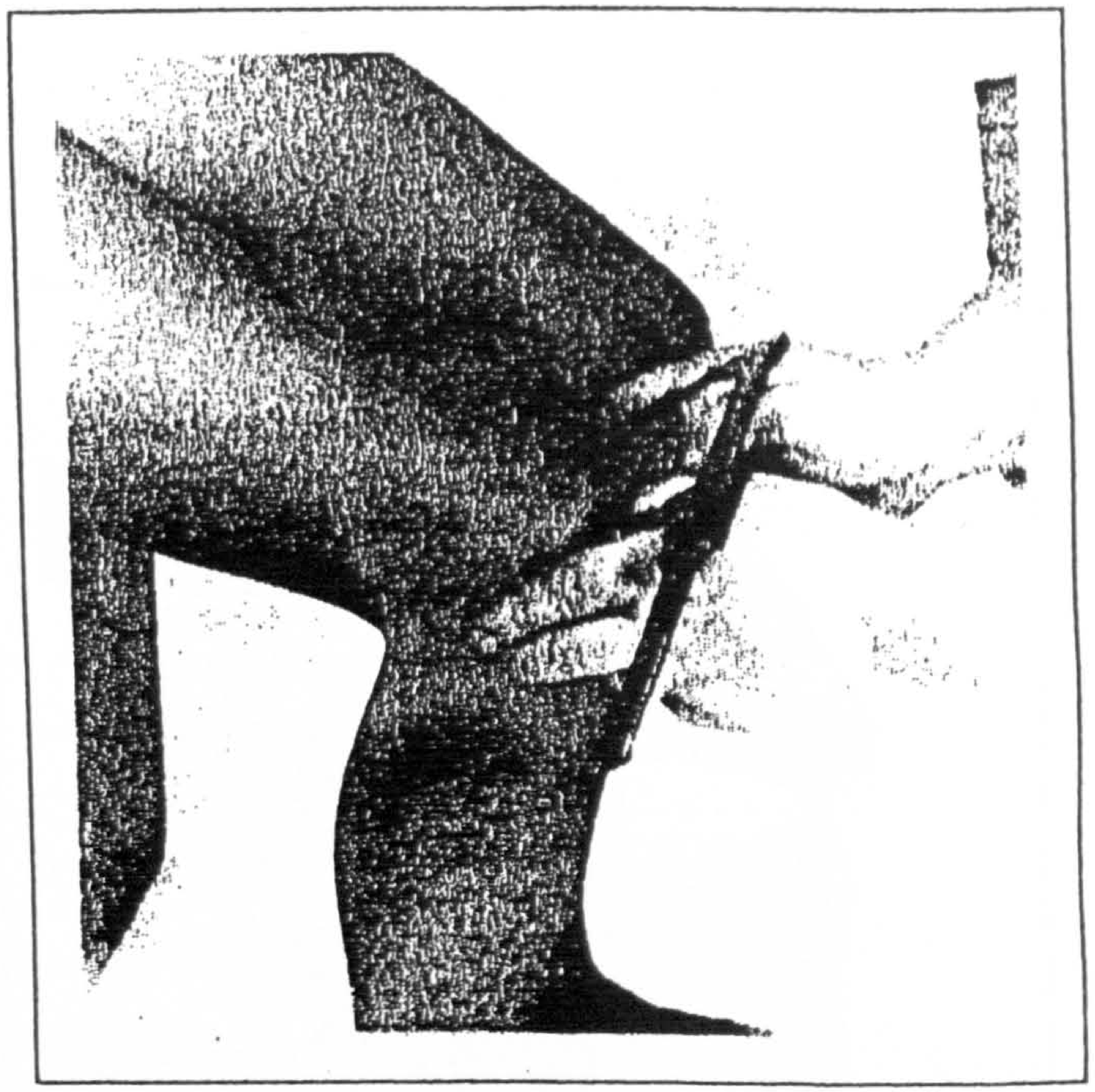
BI-EPICONDYLAR HUMERUS WIDTH



TECHNIQUE

The distance between medial and lateral epicondyles of the humerus is measured when the arm is raised forward to the horizontal and the forearm is flexed to 90° at the elbow. This is the same position for the flexed arm girth. The bone caliper is applied pointing upwards to bisect the right angle formed at the elbow. The epicondyles are palpated by the third digits starting proximal to the sites. The measured distance is somewhat oblique since the medial epicondyle is lower than the lateral.

BI-CONDYLAR FEMUR WIDTH



TECHNIQUE

This is the maximum width of the femur when the subject is seated with the knee flexed at 90°. The same position is used in measuring the front thigh skinfold. The caliper is applied pointing downwards to bisect the right angle formed at the knee. The condyles are palpated by the third digits starting proximal to the sites to obtain the maximal width. The caliper pressure plates are applied firmly. In this position it is the edges of the condyles rather than the epicondyles that can be palpated and measured, hence the measurement is termed bi-condylar rather bi-epicondylar).

Stretch Stature Prediction Equations for Females.

6-9 years of age:	S.E.E.
SS = 3.54(UA) + 45.89	4.5 cm
SS = 2.71(TIHT) + 38.58	2.7 cm
SS = 1.70(TIHT) + 0.94(SITHT) + 6.96	1.7 cm

10-14 years of age:

SS = 3.82(UA) + 44.83	5.3 cm
SS = 3.04(TIHT) + 29.81	4.1 cm
SS = 1.65(TIHT) + 1.08(SITHT) - 0.17	1.9 cm

15-18 years of age:

SS = 2.31(UA) + 93.73	4.1 cm
SS = 2.31(TIHT) + 65.45	3.4 cm
SS = 1.67(TIHT) + 0.93(SITHT) + 12.04	2.1 cm

18-35 years of age:

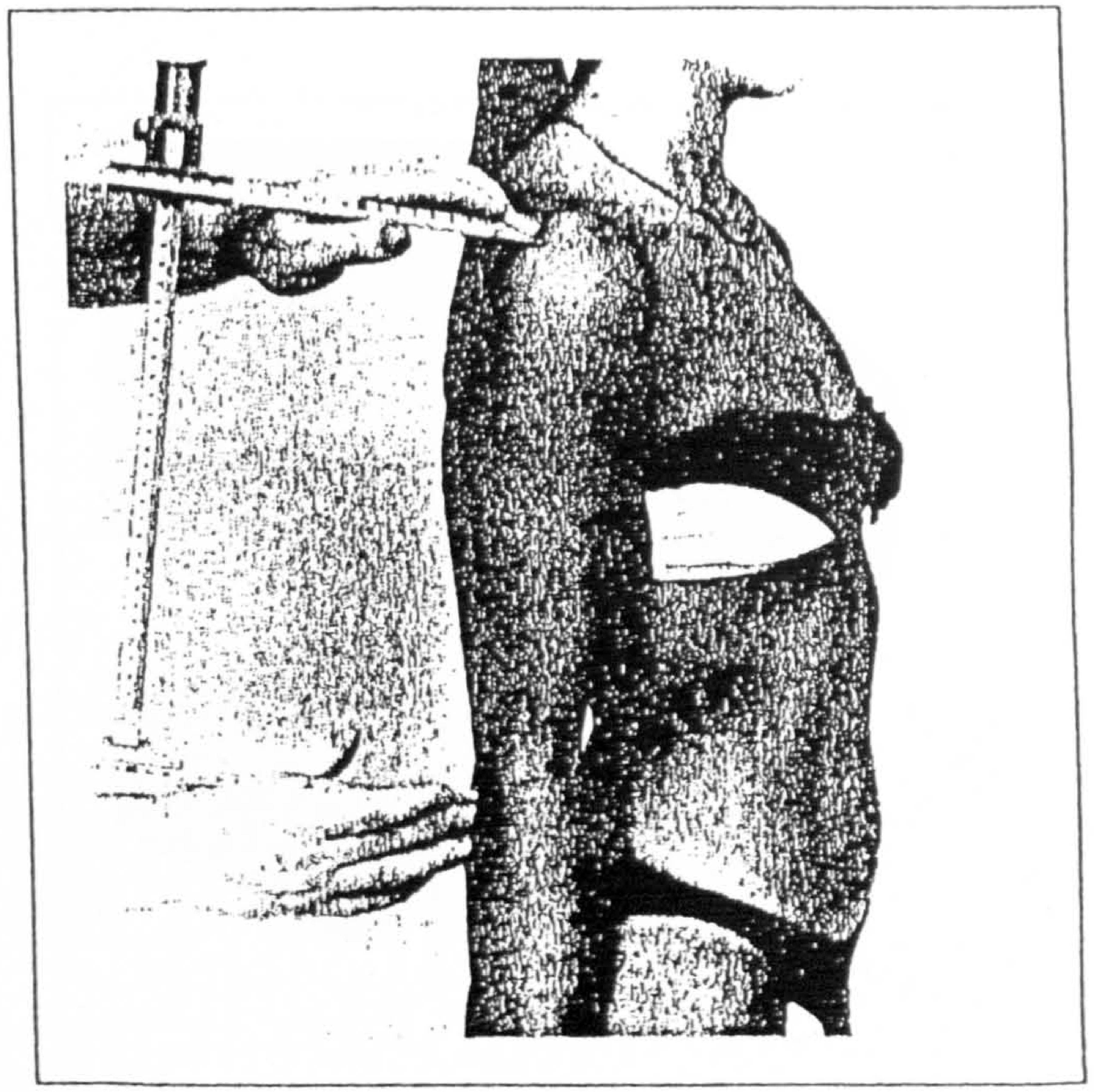
SS = 3.11(UA) + 69.67	4.2 cm
SS = 2.25(TIHT) + 68.37	3.6 cm
SS = 1.52(TIHT) + 1.09(SITHT) + 3.97	2.2 cm

SS = Stretch Stature (cm)
UA = Upper Arm Length (cm)
TIHT = Tibiale Height (cm)
SITHT = Sitting Height (cm)

To the right of each equation is listed it's associated standard error of estimate (S.E.E.). This indicates the degree of certainty with which each equation can estimate statures. Approximately two out of three times a prediction will be within plus or minus one standard error of the correct stature.

MEASURING UPPER ARM LENGTH

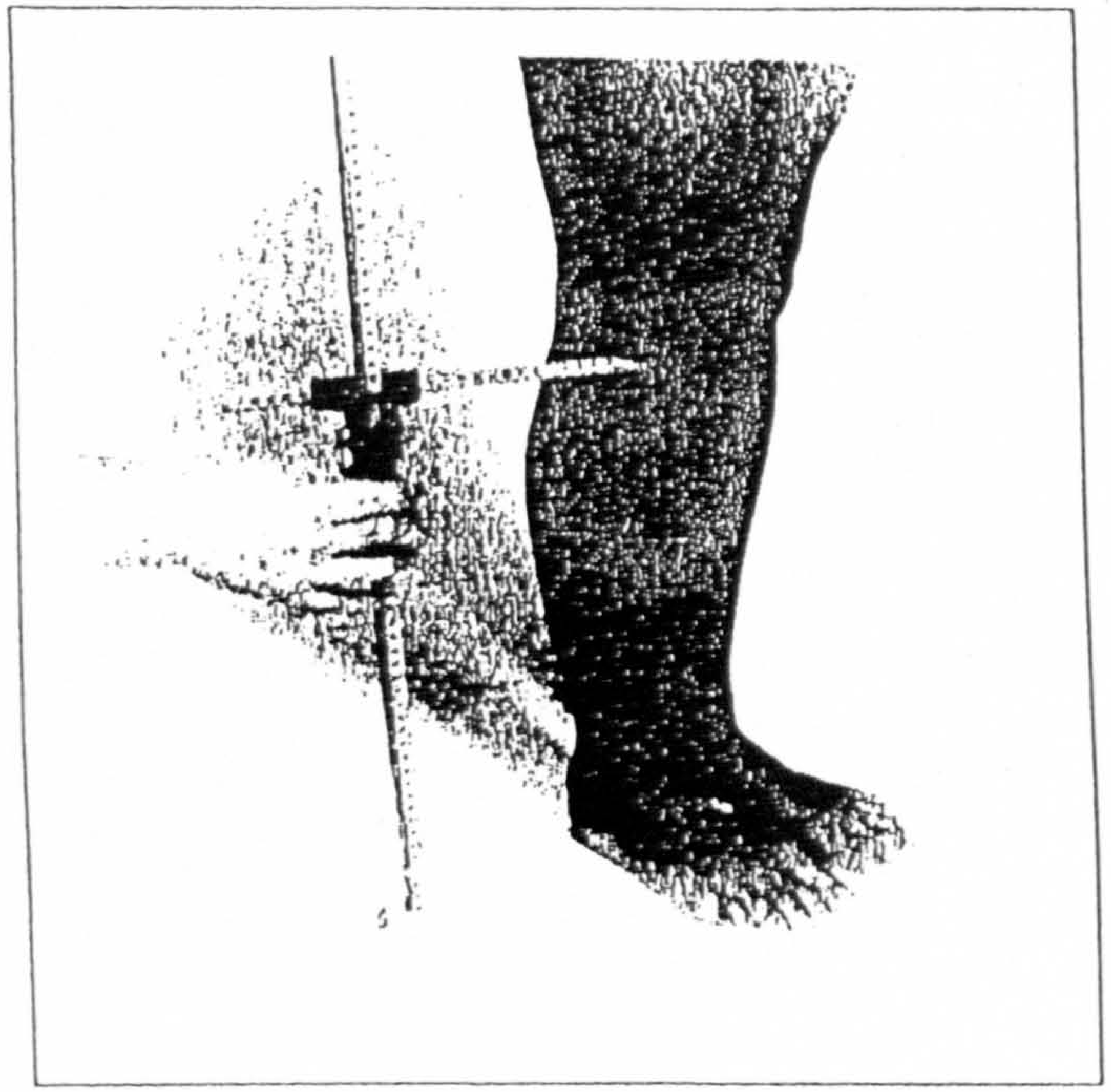
The acromiale and radiale landmarks are marked on the skin. The measurer then measures the distance between the marks using an anthropometer ensuring that the anthropometer remains parallell to the long axis of the arm.



If an anthropometer is unavailable, a less accurate measurement can be made with the anthropometric tape. This has the disadvantage that the tape will tend to follow the soft tissue contours and result in a slightly larger value.

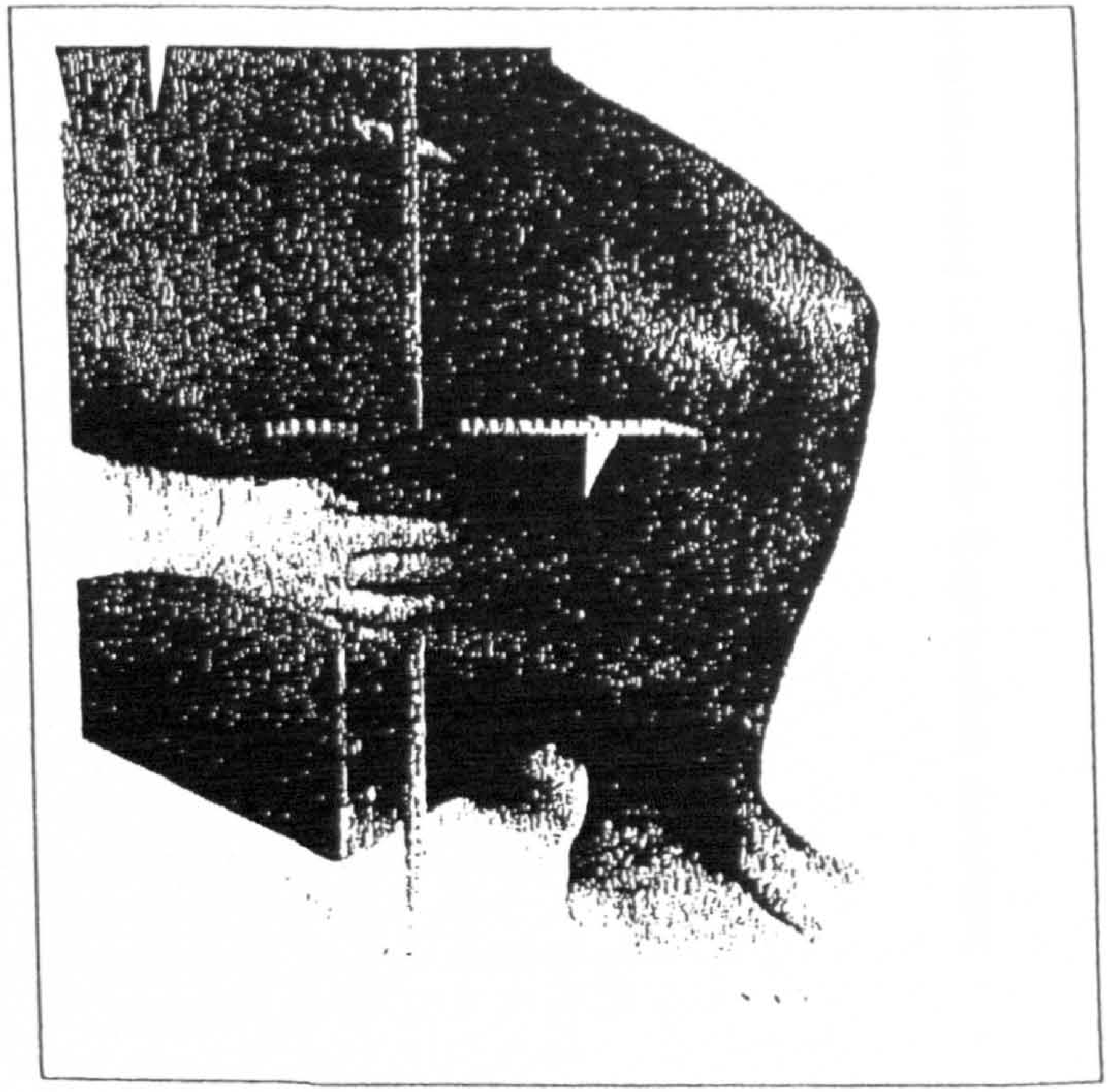
TIBIALE LATERALE LANDMARK

The most proximal point on the lateral border of the head of the tibia, the tibiale laterale landmark, is often easier to locate by having the subject bend their knee slightly or sit down. The tibiale laterale can be located by first finding the depression or dimple in the knee. This is bounded by a triad of prominences; the epicondylar femur, the anterolateral portion of the head of the tibia and the head of the fibula. From this depression press inwards and downwards locating the border of the tibia. Palpate posteriorly along this border until the most superior point is reached. This is the tibiale laterale landmark's position, which when located is marked on the subject's skin when the subject stands erect.



MEASURING TIBIALE HEIGHT

To measure both tibiale height and sitting height an anthropometer is required. The tibiale height is the perpendicular distance from the floor to the landmark when the subject is standing in an erect position.



If the subject is unable to stand it is possible to make an estimate of the tibiale height by measuring in the seated position as shown in the photograph above. This may result in a marginally larger value for the tibiale height.

Appendix 7

Variables used in Logistic Regression Analysis

Orthopaedic Alignment Variables (n=16)

Height

Right and left leg length

Right and left Q angle

ASIS distance

Greater trochanter distance

Outer femoral condyle distance

Inner femoral condyle distance

Medial malleoli distance

Right and left greater trochanter to lateral malleolus distance

Right and left greater trochanter to outer femoral condyle distance

Right and left outer femoral condyle to letaral malleolus

Strength Variables (n=4)

Leg strength

Back strength

Right and left grip strength

Flexibility Variables (n=15)

Stand and reach flexibility test

Right and left hamstring flexibility

Right and left adductor flexibility

Right and left quadriceps flexibility

Right and left hip extension flexibility

Right and left hip rotation flexibility

Right and left gastrocnemius flexibility

Right and left soleus flexibility

Kinanthropometric Variables (n=25)

Mass

Arm girth

Arm girth flexed

Upper arm length

Forearm girth

Wrist girth

Chest circumference

Waist circumference

Gluteal circumference

Thigh girth

Calf girth

Ankle girth

Humerus width

Femur width

Tibial sitting height

Sitting height

Triceps skinfold

Subscapularis skinfold

Biceps skinfold

Iliac crest skinfold

Supraspinale skinfold

Abdominal skinfold

Axilla skinfold

Thigh skinfold

Calf skinfold

Questionnaire Variables (n=7)

Age of subject

Age when subject started dancing regularly

Years in regular dance participation

Hours spent in dance class

Hours spent practicing outside normal class time

Preferred dance style

Dance style in which injury was reported

Additional Calculated Variables (n=24)

Body mass index (BMI)

% body fat as calculated using the Carter method

Ratio of height to sitting height

Right and left grip strength to body mass ratio

Back strength to body mass ratio

Leg strength to body mass ratio

Ratio of leg strength to standing height

Ratio of back strength to standing height

Ratio of medial malleolus distance to inner femoral condyle distance

Right and left ratio of femur length to ASIS distance

Right and left ratio of femur height to standing height

Right and left ratio of femur length to greater trochanter to medial malleolus distance

Right and left ratio of femur length to medial malleoli distance

Right and left ratio of tibial length to ASIS distance

Right and left ratio of tibial length to standing height

Right and left ratio of tibial length to trochanter ot medial malleouls distance

Appendix 8

Explanation and Numerical Example of Logistic Regression

Adapted from Altman (1991), Bland (1991) and Norussis (1994).

Logistic Regression Model

Logistic regression directly estimates the probability of an event occurring. If only a single independent variable was available the logistic regression model may be written as:-

Probability of event occurring = $1 / [1 + e^{-(B0 + B1X)}]$

B_0 = constant coefficient

B_1 = coefficient estimated form the data

X = independent variable

e = base of the natural logarithms

If there were more than one independent variable then the model may be written:-

Probability of the event occurring = $1 / 1 + e^{-Z}$

$Z = B_0 + B_1X_1 + B_2 X_2 + \ldots\ldots..$

In logistic regression the parameters of the model are estimated using the maximum-likelihood method, i.e. the coefficients that make the observed (recorded) results most 'likely'.

An example of data was reported by Norussis (1994). In this example the author was attempting to predict the occurrence of cancer (dichotomous variable) from a number of independent (continuous) variables. The author reported the coefficients as;

$Z = 0.0618 - 0.0693$ (age) $+ 0.0243$ (acid) $+ 2.0453$ (xray) $+ 0.7614$ (grade) $+ 1.5641$ (stage)

Therefore using the equation:-

Probability of cancer occurring $= 1 / 1 + e^{-Z}$

and example data (66 year old man, acid = 48, xray & stage & grade = 0)

Probability of cancer occurring $= 1 / 1 + e^{-(-3.346)} = 0.0340$

The probability value of 0.034 is interpreted as a low probability of cancer occurring. This is based on a probability value of less than 0.5 which suggests that the event will not occur. A probability value of greater than 0.5 suggests that the event will occur (Altman, 1991, Bland, 1991).

Interpreting the Regression Coefficients (Norussis, 1994)

The regression coefficients are an estimate of the amount of change in the dependent variable for a one unit change in the dependent variable. The odds of an event occurring is defined as the probability that it will occur to the probability that it will not. For logistic regression:-

Odds = Prob (event) / Prob (no event) $= e^{B0 + B1X1 + \ldots}$

Therefore *e* raised to the power B_1 is the factor by which the odds change when the 1st independent variable increases by one unit. If B is a positive coefficient then this factor will be greater than one which will increase the odds. If B is negative the factor will be less than one and so the odds will be decreased. If B is 0 the factor equals one which does not change the odds.

Using the previous example, the probability of the event occurring was 0.034, therefore the probability of the event not occurring is 0.966 (1 – 0.034). The odds of the event occurring is therefore,

Odds = 0.034 / 0.966 = 0.035

By having a variety of values for the independent variables the odds of the event occurring will differ. If the value for the *grade* of the subject changed to 1 and the score for the *acid* variable changed to 62 then,

Z = -0.54

The estimated probability of the event occurring would then be equal to 0.37. Therefore the odds of the event occurring = 0.37 / (1-0.37) = 0.59, i.e. by increasing the *acid* variable and the *grade* the odds changed from 0.035 to 0.59 a factor of 16.8.

Goodness of Fit of the Model

In logistic regression the goodness of fit of the model is assessed using 'likelihood', i.e. examine how 'likely' the sample results actually are given the variable estimates. The probability of the observed results is known as **likelihood** (Altman, 1991, Norussis, 1994). As the likelihood is a number less than 1 it is usual to use –2 times the log likelihood (-2LL) as a measure of how well the estimated model fits the data. A good model is one which results in a high likelihood of the observed results, which results in a small value for –2LL (Norussis, 1994). If the model was to fit perfectly then the likelihood is equal to 1 and the –2LL is 0. The example reported by Nourussis (1994) displayed the –2LL for a model with a constant as 70.25. However when a variable was added to the model the –2LL changed to 48.13, i.e. a smaller value than the model with the constant only.

An additional measure of goodness of fit is the 'Model Chi-Square'. The Model Chi-square is the difference between the –2LL values for the two models. This tests the null hypothesis that the coefficients for all the terms in the current model, except the constant, are 0. In the example reported by Norussis (1994) the Model Chi-square between the constant only model and the model with one variable was 22.13. This value was compared to the Chi-square distribution with 1 degree of freedom. The degrees of freedom represent the number of variables added to the initial model at any one time. The value, 22.13, was reported as a significant result in that the inclusion of a variable significantly increased the fit of the model to the data.