

Do particular foot types (intrinsic factors) as well as extrinsic factors of training, flooring and footwear contribute to lower limb injuries in ballet dancers?

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Professional Doctorate

2017

Declaration

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author, Patsy Parfitt. The thesis has not been previously submitted to this or any other university, or for publication. This thesis has been solely funded by the author.

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4th April 2017

Abstract

Title: Primary research question: To what extent do particular foot types pes planus, pes rectus and pes cavus (intrinsic factors), training, flooring and footwear (extrinsic factors) contribute to lower limb injuries in ballet dancers?

The significance of foot type as a precursor for foot and lower limb injury in 47 ballet dancers professional and amateur is explored. Primary focus included intrinsic factors of foot types: pes planus, pes rectus, pes cavus which were measured in stance and First and Fifth ballet positions using 3 proxy measures: Calcaneal Bisection, Navicular Drop Test and the Foot Posture Index. Extrinsic factors focused on training intensity, ballet shoes and flooring. A model for injury prevention was designed for health practitioners and teachers of dance. One hundred and ten injuries were reported current or past, 79 injuries (pes planus), 4 (pes cavus), and 27 (pes rectus) with zero – 6 injuries per dancer, mean 2.75+/2.4. In First position, 43 dancers overpronated above the normal 3-degree level (31 left, 32 right) Fifth position, (34 left, 34 right). Flooring, fatigue and overtraining were reported as cause of injury. An exploratory ordinal regression analysis identified degrees of overpronation as key risk factors for injury.

Method: A study sample (n=47) of 15 males and 32 female dancers, aged 14 to 29 years (mean 18.5 years), consisting of 6 amateur and 41 elite dancers with/without current injuries. Foot type was assessed using 3 proxy measures; the Navicular Drop Test, Foot Posture Index, and Calcaneal Bisection and postural movement (Calcaneal Bisection/NVDT). History of foot and leg injuries, training, age, gender, height and weight, footwear worn and flooring were collected by questionnaire in an interview setting for cross correlation between frequency, nature of injury and foot type / foot posture.

Results: Calcaneal Bisection and NVDT showed 100% correlation. Forty dancers reported current and past injuries (86%), 7 dancers had no previous injury. Foot types were: pes planus (28 left and 26 right), pes rectus (15 left and right), pes cavus (4 left and 6 right). Two dancers had non-matching pairs of feet. All pes planus feet overpronated (male/female), 11/15 males had pes planus. Higher levels of pronation >1.4 cm (ND) saw higher numbers of injuries per dancer, particularly males (4-6 injuries). All pes planus feet overpronated.

Key words: pronation, pes planus, pes cavus, medial longitudinal arch, navicular drop.

TABLE OF CONTENTS

Conference Presentation

International Association for Dance Medicine and Science (I.A.D.M.S.) 26th IADMS Annual Meeting.
October, 2016. Hong Kong, China.

Title page		
Declaration	.....	i
Abstract	.....	ii
Table of contents	.....	iii
List of figures	.....	iv
List of tables	.....	v
List of photos	.....	vi
Acknowledgements	.....	vii
References	.....	viii
Appendices	.....	ix
Chapter 1 Introduction	.....	1
Chapter 2 Anatomical Background	.....	26
Chapter 3 Literature Review	.....	44
Chapter 4 Theoretical Underpinning	.....	77
Chapter 5 Methodology	.....	86
Chapter 6 Findings	.....	139
Chapter 7 Discussion	.....	187
Chapter 8 Conclusion	.....	236

List of figures

Figure 2.1 Foot Orthoses and other Forms of Conservative Foot Care	.....	27
Figure 2.2 -Subtalar joint (medial aspect of the foot)	.....	30
Figure 2.3 Subtalar joint axis planes	.....	30
Figure 2.4 Muscle insertions around the ankle joint	.....	31
Figure 2.5 Ground reaction forces applied during the Contact gait phase	....	35
Figure 2.6 GRF's Fx, y and z expressed as a graph	.....	36
Figure 2.7 Vertical component of a runner over 25msec	.....	37
Figure 2.8 Imprints of foot types	.....	40
Figure 4.1 Theoretical Model of Surveillance of Injuries	.....	89
Figure 4.2 Model of Injury Causation	.....	90
Figure 4.3 Model of Injury Causation for Ballet Dancers	.....	93
Figure 4.4 Grey Box Theory	.....	94
Figure 5.3 Foot Posture Index FPI-6	.....	115
Figure 5.2 overview of study design	.....	105
Figure 8.1 Model of Injury Causation for Ballet Dancers	.....	264
Figure 8.2 Screening pre-pointe	.....	266

List of Tables

Table 1 Participant demographics	2
Table 2a Navicular Drop Test results for all dancers	7
Table 2b Resting Calcaneal Stance Position results by foot type	10
Table 5.1 Comparison of quantitative and qualitative approach	101
Table 5.2 Overview of the study design	103
Table 5.3 Foot Posture Index FPI-6	115
Table 5.4.2 Intra-tester reliability of foot measures	137
Table 5.4.3 Inter-tester reliability of foot measures	138
Table 6.1 Participant demographics	150
Table 6.2 Number of reported injuries	153
Table 6.3 Total of foot types as defined by the Navicular Drop Test	155
Table 6.4 Navicular drop test results for all the dancers	156
Table 6.5 RCSP results by foot type	158
Table 6.6 NVDT results for foot type	161
Table 6.8 Calcaneal Bisection for foot type	163
Table 6.9 Foot Posture Index for all dancers	164
Table 6.10 Summary of correlations	165
Table 6.11 Foot type (right only) related to training	167
Table 6.12 Association matrix (chi square) for foot type and 1 st and 5 th position ...	168
Table 6.13 Degrees of pronation/supination versus foot type in 1 st position (right) ..	171
Table 6.14 Degrees of pronation versus foot type in 1 st position (left)	173
Table 6.15 Degrees of pronation versus foot type in 5 th position (right)	175
Table 6.16 Degrees of pronation versus foot type in 5 th position (left)	176
Table 6.17 First position (left) pronation and supination both genders	178
Table 6.18 First position (right) pronation and supination both genders	179
Table 6.19 Fifth position (left) pronation and supination both genders	180
Table 6.20 Fifth position (right) pronation and supination both genders	181
Table 6.21 Number of injuries per foot	182
Table 6.22 Number of injuries according to gender: current/recovered	183
Table 6.23 Specific injuries to the foot, ankle, knee and leg	183
Table 6.24 Injury type collated according to anatomical location	184
Table 6.25 Injuries to limb segments according to foot type	185

List of Photographs

Photo 1 The Navicular Drop Test, location points	23
Photo 2a The Navicular Drop Test, Measurement points	23
Photo 3 Calcaneal Bisection of lower third of leg	24
Photo 4 Calcaneal Bisection of Calcaneus	24
Photo 5 Bisection of Calcaneus 5 th position	25
Photo 6 Measurement of Hallux Valgus, x-ray	26
Photo 6a Measurement of Hallux Valgus, skin marker	26
Photo 2.1 First Position stance	41
Photo 2.2 Fifth Position stance	41
Photo 2.3 X-ray of a dancer on pointe	42
Photo 3.1 Good and bad pointe	62
Photo 3.2 Amateur dancer with pes planus and Hallux Valgus	64
Photo 3.3 Professional dancer with a good pointe	65
Photo 3.4 Plie and pointe	69
Photo 3.5 Professional dancers in plié position	72
Photo 3.6 Amateur dancing in plié position	74
Photo 3.7 Amateur dancer in First Position overpronating	75
Photo 5.1 The Navicular Drop Test with marker on navicular	117
Photo 5.2 The Navicular Drop Test with tape measure	117
Photo 5.3 Measurement of the Navicular Drop Test (Nilsson)	118
Photo 5.4 Calcaneal Bisection	119
Photo 5.5 Bisection of the Calcaneus	120
Photo 5.6 Bisection of the Calcaneus in Fifth Position	120
Photo 5.7 Measurement for Hallux Valgus	122

Acknowledgements

I would like to thank those who helped me through this journey, Dr. Andy McVicar, my supervisor who was patient and encouraging, and John Tasker, for his academic guidance. This thesis is dedicated to my daughter Charlotte Parfitt.

CHAPTER 1

1.0: Introduction.

This project arose through recognition of the author's podiatric practice increasingly involved treating dancers, particularly ballet dancers, for foot or leg injuries sustained during training and/or performing. Conventionally, dancers would normally consult physiotherapists for management of musculoskeletal injuries so this shift to increased level in podiatric consultation presented new horizons for me and possibly for the profession. Scrutiny of the literature, coupled with attendance at conferences, highlighted a low level of research activity engagement by podiatrists in this discipline. Given podiatry specialist practice in lower limb function, malfunction and management, it appeared that the focus of consultations was actually more applicable to podiatric intervention than they were to physiotherapy. This promoted further investigation and subsequently to this thesis.

By way of introduction to the thesis, this chapter explains how this study evolved. It provides an overview of the author's perspective on this field, with experiences of injury issues for ballet dancers, and of international ballet styles that continue to emphasise specific dance moves and landings, which may expose dancers to potential risk of injury. The nature and types of injuries to which young ballet dancers are exposed warrants further investigation and consideration of the underlying kinetic and kinematic variables, which could be a precursor to injury and devastating for the dancers career. The chapter ends with a plan of the thesis and its indicative structure to provide sign posting for the reader.

1.1: Background.

The author is a Health Care Professions Council (HCPC) Podiatrist with twenty nine years' experience. Undergraduate training was pursued on two continents, the first year at University in Perth, Western Australia and the subsequent two years in London. The Australian ethos was to encourage allied health professions to work as part of a multidisciplinary team to benefit the patient in that podiatrists or other health professionals in isolation cannot always provide a full and comprehensive treatment; a full team is needed to provide a holistic and successful outcome for the patient. This message was firmly imprinted and through the professional years, the importance of working as part of a multidisciplinary team consisting of physiotherapists, general practitioners, and orthopaedic surgeons, particularly in private practice.

1.2: Precursory influences

The second and third year aspect of podiatric study took place in London, at the Chelsea School of Podiatric Medicine, where the author fostered an interest in biomechanics (the study of the function and movement of the body, Mann and Inman, 1964). The gait cycle of a patient focuses on movement of an individual's lower limbs from the moment the heel makes ground contact, the transition of the body's centre of mass through the weight bearing limb and onto the contra lateral limb to repeat the cycle (Hamill J, 1946; Root et al., 1974). Root et al., (1974) were influential for their contribution to the clinical interpretation of walking, whereas Subotnick, (1987), an American podiatrist specialising in sports injuries, paved the way for understanding the relationship of running injuries related to biomechanical malfunction. These forefathers of modern clinical biomechanics have heavily influenced clinical practice over three decades through the NHS and private practice.

The NHS during the 1980's offered the resources and opportunity to develop in areas of specific interest, working with different materials, and designing orthotics in the laboratory. However, the area of podo-paediatrics had little focus and was a relatively new area for podiatry and therefore the biomechanics of a child were not assessed for consideration as to the long-term implications to musculoskeletal injury. Sports injuries were not considered a problem and were dismissed by the NHS as the injuries were considered as 'self-imposed' harm to the body and not strictly a medical problem. In the 1980's, the NHS lacked the foresight of an integrated approach to patient rehabilitation of biomechanical related injuries by podiatrists and physiotherapists. In Australia, podiatrists and physiotherapists work in close conjunction and complement each other with good results for the patient outcomes.

A period of lecturing in Australia (1990–1994), provided the time, scope and funding to analyse the biomechanical issues associated with sports injuries and gait. Queensland University, Brisbane, offered the author a scholarship to undertake a Masters in Science to analyse running injuries, focusing on the sprinter and long distance athlete. At this time American lecturers in podiatry were working at the University who were ahead in terms of podo-paediatric assessment and treatment and from whom invaluable knowledge was gained. A podo-paediatric clinic was established in the University and the author was part of that team. Now, established in private practice based in Hertfordshire, the author's clinic specialises in biomechanics, gait analysis, orthotic manufacture and lower limb injuries for patients of all ages (children to adults) as well as athletes.

1.3: Introduction to Dancers.

The last seven years has seen an increasing number of 9-19-year-old ballet dancers presenting with an assortment of foot and lower limb injuries pertaining to foot type and posture. Before

coming to podiatry, it was evident that the dancers were presenting to either their GP and/or physiotherapist as first point of treatment. Dancers had previously not been aware of podiatry and the scope of treatments available. Initial referrals were from adult sports injury patients whose daughters were keen amateur dancers, sustaining repeated injuries for which traditional therapeutic interventions had failed to provide effective treatments. Where their injuries were not treated successfully or re-occurred frustrated the dancers hence they were coming to podiatry with the hope of being offered something different. A biomechanical examination and gait analysis explained certain injuries. However the author could only observe a dancer walk and run at limited speeds, and not observe the dancer perform various jumps and more intricate ballet moves because of the confines of the practice space, which would aid diagnosis. To become familiar with the ballet positions required a short course in ballet for adults (beginners) so the author could experience the moves and the effect on different muscle groups in the body.

In the same way that treating runners required track side observations, with the dancers the author needed to be in a dance studio observing first-hand how they trained and performed on stage. Ballet requires a high degree of athleticism with a strong artistic component, the latter not expressed in other sports apart from gymnastics. The combination of athletic movement, music, artistic interpretation and acting, a complexity of components is a regularity of the dance world (Schoene, 2013).

Although small numbers of ballet dancers were treated over the years at the Hertfordshire clinics seeking a broad spectrum of treatments ranging from gait analysis to simple toe strapping, there remained a gap in the author's knowledge. An understanding of the dance movements and positions coupled with observation of the dancer in training or performance

would provide information on repeated injuries and how best to treat them. This underpinned the rationale for the author registering on a doctoral research study.

Foremost and fundamentally, was the need to study dancers in depth, away from the clinical situation in a “live” dance studio session, where dancers could be observed both in performance and in daily training to see if there were any particular dance movements, or speed of movement, jumps and landings that may signify potentially injurious. Also, the author wanted to observe foot types in movement to see how they adapted biomechanically to various dance moves. In everyday clinics the author would not be able to observe a dancer running, landing and performing repetitive moves since this would require larger floor space whereas the clinics being small would confine the dancer. As such, in clinic, the author would only be able to witness smaller and static movements, which would result in limitations in understanding the dynamics of dance and consequently effect diagnosis and treatment.

For the purposes of this doctorate the primary aim therefore was to study different foot types and their potential relationship and risk to injuries. A robust understanding of the sport discipline and potential injuries would enable the author to inform by giving lectures or workshops to podiatrists, other health professionals and dance teachers to help them understand this sport in order to treat effectively. The components and combinations of footwear and flooring either collectively or separately could potentially provide insight on how best to reduce injury but such information would require that changes be made to flooring and footwear. Whilst this research aims to consider these extrinsic factors of flooring and dance shoes, the focus is on intrinsic factors, in particular foot type, to explore if there are potential links to lower limb injuries.

Secondly, the author felt that dance schools needed educating on podiatry as a profession and the author would like to be in a position to propose a design to educate schools on how to use podiatrists as one of the first points of contact for treatment by becoming more knowledgeable on foot and leg problems that podiatrists can treat, and at what stage to refer. This would be a future progression on completion of this thesis.

Thirdly, an awareness programme for GPs and physiotherapists was needed. This however would be outside the scope of a doctoral study and so would be a post-doctoral screening and education programme. The author does consider that podiatry is possibly a grey area to physiotherapists and possibly due to lack of inter-professional learning at the physiotherapy schools on the scope of, what they can offer and how the two allied science professions can work together, rather than being viewed as competition i.e. physiotherapists consider that exercises and treatments are sufficient for dancers to overcome injuries and do not realise or consider that biomechanical problems such as foot types are an area that needs addressing, how they affect the rest of the body and how instrumental podiatrists can be in diagnosing biomechanical anomalies and consequently speedily treating injuries.

1.4: Ballet schools – amateur and professional.

There are 5 professional dance companies and an abundance of amateur dance schools of a high standard in North London and Hertfordshire with dancers aspiring to progress from amateur to professional status. The competition is intense for limited places in the professional schools. Within the proximity of Harpenden clinic, there are six amateur ballet schools offering tuition by ex-professional ballet dancers. Dance classes are well attended often full, with children commencing at the age of 4 years through to teenage years when

some dancers take their studies very seriously. It was interesting to note that boys featured in the introductory classes although fewer in number. Ballet being a large profession attracting elite dancers from all over the world, gives insight into the sheer numbers of dancers passing through the elite schools. Dancers who have achieved a high standard in the amateur schools are also competing for the same places.

Prior to, and as part of, this study, the author made contact with various elite and amateur ballet schools as well and additionally had discussions with retired dancers who still engaged in dance training but could no longer perform. Expectation from the dance schools and ballet companies are that the dancers pick up a routine and replicate it instantly and this is due to muscle memory developed from repetition of movements from a young age. Proprioception and space awareness is developed in the dancer in that they can pirouette (spin around), without stumbling (Subotnick, 1987). The difference between novice dancers still trying to perfect this skill and well-trained dancers is evident. Trained dancers, even when out of practice, were still very fit with an erect upper body posture, good mobility and flexibility and of course knew the dance positions. Dancers retire from approximately the age of 29 years, although many do continue into the mid-thirties age group and such retirement relatively young is usually due to injury. Dancers develop a strong sense of rhythm and interpretation of the music to be combined with athleticism and artistic flare, which is akin to floor gymnastics, with a principal difference being that the ballet dancer has to dance on pointe.

In clinic, it was noted that ballet dancers had increased in number; the predominant foot type having problems appeared to be those with flat foot or pes planus. Pes planus defines either a rigid or flexible deformity of the foot (Subotnick, 1987). A flat foot is a generic term

covering structural and functional presentation of the foot posture on weight bearing. Typically, the inrolling ankles, or the collapse of the medial longitudinal arch could be pronated and the forefoot abducted. These variations of foot type are discussed in Chapter 2. Flat feet can accompany ankle instability (ligament laxity) and/or weak or under developed muscles in the sole (plantar) of the foot. The dancer will often show signs of fatigue due to muscle imbalance where some muscles are over working. However, in my observations in the clinic of dancers, even though certain muscles appear well developed, in stance with stronger muscles compensating for weaker ones, the dancer with pes planus will still present with an inrolling ankle (subtalar joint and possibly midtarsal joint area). The very essence of the female ballet dancer is to dance on pointe, which requires stable yet flexible ankles for extreme plantarflexion and dorsiflexion. The dancer with flat feet may appear to have a slight “wobble” or instability at the ankles when moving into “rise”, demi-pointe or pointe. Dance teachers train the dancers to draw in core abdominal muscles and the quadriceps and to not “sink” any weight into the ankles, to keep pulling the torso tall. This is how the dancer can to some degree overcome the problem caused by pes planus. Dancers with variations of ‘flat foot’ are frequent in number in the clinic but the variation in the foot heights have not been measured or numbers of such foot types recorded and all foot types need to be observed to see if there is a correlation of type to injury. For example, very high arched feet may appear aesthetically appealing to the eye as the perfect arch in dancing but may in fact be overextended in the arch, resulting in the dancer falling forward and experiencing ankle injuries with certain dance positions. The author realised from dancers who had been treated so far, podiatry with particular understanding of the lower limb could offer a variety of therapeutic interventions that may help alleviate a number of injuries in the first instance such as paddings and strappings to realign the foot, part of basic podiatry training. Some of the injuries treated in the Hertfordshire clinics were very minor but had been left untreated by

other professionals, most probably due to lack of training in biomechanics, which had the potential to cause injury elsewhere in the lower limb due to inappropriate compensation. Some injuries were biomechanical ones or simply trauma to the feet caused by pointe shoes and the author did not always agree with the treatments given by other professionals which (in the author's view) were why the injuries remained unhealed. The dancers were surprisingly pleased to discover that we could treat both the foot and shoes with all manner of paddings, gels and strappings as well as manage their biomechanical anomalies. This made the difference between the dancer having to stay away from training and getting them back on stage performing quickly; sometimes the simplest of treatments were the most effective.

The literature searches revealed substantial written research on a breadth of topics by physiotherapists who publish in a wide section of journals i.e. The British Medical Journal of Sports Medicine, Physical Therapy and the International Association of Dance Medicine (IADMS). In comparison, little is written by podiatrists, and they concentrate their publishing on Podiatric journals: *Podiatry Now*, *The Journal of Foot and Ankle Research*, but not many mainstream journals i.e. Non-Podiatry. However, Physiotherapists do work with the whole body and Podiatrists specialise with just the lower limb, so that could explain why there is less proportionately written by podiatrists. Apart from Schoene (2014), an American Podiatrist, very little literature exists from podiatry on the subject of ballet dancers and injuries. A contribution from the author's practise would potentially help educate other podiatrists and other professionals, and would improve treatment for the dancers.

A small pilot study was conducted prior to embarking on the thesis which asked podiatrists who specialised in treating sports injuries, how frequently, if at all, did they treat dancers. Did they feel confident in their knowledge in treating dancers of any discipline, and their chosen

treatment protocols and outcomes? A minority treated dancers, particularly classical ballet dancers, the main reason given being they did not have dancers seeking treatment in their clinics. Interestingly, the major dance companies employed only physiotherapists, yet podiatrists being lower limb specialists, would be an invaluable resource. This thesis therefore has the potential to inform the wider podiatry profession.

1.5: The history of dance.

Classical ballet dancing originated at the time of the Italian Renaissance (Malone & Hardacher, 1990) a theatrical, artistic form of expression designed to entertain the royal court of Italy. The dancers appeared as lathlike figures with ethereal qualities, emphasised more as they danced on pointe; which transfixed audiences who marvelled at the performers dancing on their toes. The dancers expressed elegance being light on their feet and able to jump high in the air effortlessly and then land on pointe.

Ballet dance training and moves are interpreted differently among the countries prominent in the world of dance, namely England, Russia, France, Italy and America. The Russian schools introduced a dramatic element to their moves, the English developed an upright, straight posture, and the Italians used more gentle and exaggerated curves to their arm movements. The American schools veered towards an athletic prowess. Universal to all nationalities is French terminology used as a common language for all the dance moves, and all countries use the same basic 5 positions in dance together with plies, vendus, demi-pointe, pointe (see glossary). These countries had their own individual approach in training the dancers (Darcy Bustle, 2014). Darcy Bustle, ex professional, corps de ballet, commented that “*the rigorous training of the Russian schools was the most demanding and that the British schools looked*

for more “lightness” in the movement in their dancers. The American schools adopted a more athletic approach and less emphasis on graceful movements”.

Ballet Russe was developed in France by the Russian schools, for it was felt that ballet would be more recognised in France. The Russian schools produced notable dancers such as Rudolf Nureyev and Anna Pavlova, whilst in Britain Margot Fonteyn gained fame and, unusually, danced well into her forties with her co-star Nureyev who was in his early twenties. Within each country there was a further sub division where different schools of thought or styles were adopted, for example the Russians would favour the Vaganova style, the Italians Cecchetti, the Danish, Bournonville, and the British Rada and Rambert, which are two of many styles chosen.

Although classical ballet does have some national influences, it remains the same in general format worldwide for example the basic positions in ballet and French terminology. Another form of ballet has evolved so called ‘contemporary ballet’. Originating in America it was introduced by key figures such as Martha Graham and Isadora Duncan who injected a modern flavour to ballet. Individual countries have influenced the style and added in either modern dance or their own national dancing style mostly interpreting to their traditional dance of their country. For example, South Americans influenced by their African ancestry adopted many sideways movements in their expression and its Afro-Caribbean population flavoured with Spanish added a gymnastic element to ballet. These individual dancing styles, combined with modern interpretation, is how contemporary ballet evolved. Whereas classical is described as ‘upward’ in movement and traditional costumes are worn e.g. *Swan Lake* or the *Nutcracker Suite* the most famously known ballets, contemporary dance is described as movements which are more “sideways”, often barefoot but still with a lightness of movement using the flat of the foot or forefoot. Contemporary costume is also more in keeping with the theme of the performance. Adapting to new styles and even music was part of the aim to keep

the attention of the audience in the last few decades without which the dancers could not survive.

In terms of what physical features different nationalities look for in a dancer, this appears somewhat variable, specifically in foot posture. The Russians and Polish tend to choose dancers who have a high arch as they believe the dancer can jump a lot higher, and because the arch looks aesthetically pleasing (Volynsky, 2008). Most dance companies worldwide (Australia, United Kingdom, Sweden, Germany and America) are more inclined to choose what is perceived as a ‘good’ arch that is one not too high, and one not too flat, as it will form a ‘good’ arch whilst on pointe and will look visually pleasing to the audience. A ‘normal’ arch height cannot be defined in literature research terminology but in clinical observation terms it can be assessed as one that is approximately 2 cm from the floor to the base of the navicular bone, which is the highest point in the medial arch (Brody, 1982). Excessive high and low arches both increase the risk of physical injury but with pes planus, or flat feet there are variations as to the different heights. For example, a foot may be flat on weight-bearing in that there is no arch and no space between the floor and the navicular. Foot flat is a relative term considering ‘flat’ at various heights up to approximately 2cm. Often this foot type is misdiagnosed in general medicine; if the foot is not viewed as totally flat it is often mistakenly considered to be normal and therefore not having any pathological implications.

The problems of a pes planus foot type of any height are the influence on the knee, hip and back kinematics whereby *over pronation* (or ‘in-rolling’), which naturally accompanies flattening of the medial arch, places increased loads on the medial aspect of the knees and lower back particularly (Nowacki, 2012, Khamis, 2007). High arches can be rigid or flexible and often cause ankle instability so risking ankle sprains (laterally more affected), and damage to the knees. A high arched foot is otherwise known as a *pes cavus* foot.

The *pes planus* or flat foot does not look pleasing on the eye aesthetically in dance terms. It is difficult for the dancer to form a good arch when pointing the toe but if the dancer is only partially flat footed, they will place significant reliance on their intrinsic foot muscles to gain more strength in order to obtain a better “pointe” on stance. They do have to work their foot and ankle muscles more than a “normal” arched dancer (Nowacki, 2012). Yet once on pointe, the foot is inclined to *overpronate* or inroll with the dancer having to ‘pull up’ (isotonic contraction) on the anterior leg muscles and quadriceps to maintain stability.

1.6: Study Ethos.

As with any athletic endeavour susceptibility to injury is a factor which has not escaped ballet dancers. From an academic perspective there is little research evidence to suggest that lower limb injuries in particular are potentially predictable. Furthermore, the podiatry profession has not contributed to the limited body of evidence. The author primarily sought to investigate whether particular foot types present a predictable basis that would predispose the ballet dancer to foot and lower limb injury. These recognised foot types are *pes planus* (flat foot type), *pes rectus* (neutral or normal foot type), and *pes cavus* (high arched foot type). The fundamental differences in structure, particularly *pes planus* and *pes cavus* foot types, suggest they could have a profound effect on the ability of dancers to develop, and perform certain dance moves while maintaining poise. Secondary consideration also has been given to the contributory factors of training: floor composition and shoe design and wear patterns. The results from this research may contribute valuable information for screening guidance to dance companies in the selection process at both amateur and elite level as well as enlighten

prospective individuals of the potential to future injury. The following research questions are posed for investigation:

Primary research question: *To what extent do particular foot types (intrinsic factors) and training, flooring and footwear (extrinsic factors) contribute to lower limb injuries in ballet dancers?*

Aims of study:

- To establish the type of foot and numbers of individuals exhibiting three foot types within a cohort of elite and amateur ballet dancers.
- To determine whether foot type (pes planus, pes rectus or pes cavus) have a bearing on the number and types of lower limb injuries reported in ballet dancers.
- To determine whether extrinsic factors of flooring and footwear are linked to foot type and injury.
- To consider the formulation of a model to aid screening of individuals for risk of injury.

Objectives of study: (Intrinsic factors)

- Determine foot types according to categorise pes planus, pes rectus and pes cavus using 3 proxy measures: Navicular Drop Test, Calcaneal Bisection and the Foot Posture Index.
- Apply the 3 proxy measures to determine the difference between foot type and foot posture, therefore to assess postural movement of pronation in both feet.

(Extrinsic factors)

- By questionnaire to document injury type and history, footwear, and flooring to assess if there is any link to foot types.

- Informal discussions with dancer teachers, physiotherapists and dancers on preparation to dance on pointe, flooring and injury treatment protocol.

1.7: Indicative thesis structure.

Chapter 1 – Summary

This chapter provides an introduction to the thesis regarding the professional background of the researcher (author) and the rationale for the study whereby it was observed that ballet dancers sought treatment at the clinical practice due to injuries not being successfully treated with other professionals. From these treatments came the understanding that ballet dancers sought physiotherapists or GP's as a first line of treatment rather than podiatry, partly because they were unaware of the scope of practice and what the profession offered. Observation of the foot type and the repeatability of certain types in the podiatry clinics flagged up the significance of the foot type as a precursor for injury in dance, which may have been overlooked by all professions and dance schools including podiatry, and this became a concern and then an enquiry leading into the current research. This chapter also looks briefly at the history of ballet dance and the different schools of thought in training.

Chapter 2 – Anatomy

Chapter 2. The anatomical differences of the pes planus, pes rectus and pes cavoid foot types in terms of foot arch types and posture are compared to illustrate their differences as well as the bone development of the foot during adolescence. Ground Reaction Forces and gait will

be discussed in an athlete (runner) and cross compared to the dancer as an initial discussion and will be revisited again in the Discussion chapter with a diagram in appendix iii.

Chapter 3 – Literature Review.

Chapter 3 develops the analysis by focusing in detail of factors that increase the risk of foot and lower limb in ballet dancers. Ballet shoes and dancing on pointe can affect the growing foot as well as attenuating forces through the flooring coupled with overtraining are cross compared in the literature review. The chapter looks at the theoretical perspective and research questions by analysing and contrasting dancers of both amateur and professional status in terms of hip, lower limb (including knee) and foot injuries to date as searched on various search engines from 1974 to present day. Although research specified limb segments in percentage terms in injuries, very little was located on specific injuries and statistics as a cross comparison.

Chapter 4 – Theoretical Framework

This chapter introduces the conceptual reasoning, which underpins the theoretical framework proposed for the study. It highlights two separate theoretical approaches, which are shown to provide a strong underpinning for the proposed framework, and have been adapted and redesigned in the current study to fit the model of the dancers in injury. The first theory explored and applied is related to injury recording with the model adopted looking at both the injured and non-injured dancer, studying any anatomical weakness. The injury surveillance explores the intrinsic and extrinsic factors relating to the injury and whether the dancer's sporting technique can be adapted to prevent further injury if they fall into the injured table

line. The second theoretical model, which again is adapted, is a partial theoretical model looking at all the variables used in the study.

Chapter 5 - Methodology and Methods

This chapter introduces the philosophical underpinning for the study and the rationale for the methods chosen to answer the question on which the study is based. Aspects of ontology and epistemology are presented following onto pragmatism as being relevant to the study. From this platform came the decision to use quantitative measures in the study. The next aspect of the chapter highlights the methods for the study including design, sampling, data collection and analysis. This section follows on to ethics relevant to this study and the ethical boundaries that were particularly essential and needed to be adhered to.

Chapter 6 – Findings

This chapter details the findings from the analyses of the quantitative data. Data of the 3 proxy foot measures used to define foot type, postural changes (pronation/supination), comparison with the First and Fifth dance positions and in analysis were related to each other and to certain demographic data including occurrence of injury. Data analysis followed conventions for descriptive and inferential processes to identify statistical significant associations and correlations between independent variables and the occurrence of injuries.

Chapter 7 – Discussion

This chapter presents a discussion, which places the findings in the context of the most pertinent current literature and the data from the results in the current study identified as

relevant to the key aims of this study. The integration of the theoretical model shows how it can be used as a platform for the conceptual process framework and provides a structure, which can be utilised by practitioners and dance schools as a screening tool. In relating the literature to theory, location of this discussion could be placed in a framework gathered around intrinsic and extrinsic factors, which may help to predict risk of injury. This chapter also identifies limitations of this research and discusses those which warrant further investigation.

Chapter 8 – Conclusions

This final chapter pinpoints the unique contribution that this study has formulated in understanding a process to identify foot types, which are more susceptible to injury as well as a model to monitor injury surveillance of use to clinicians and dance teachers. The conceptual process of a theoretical framework designed to monitor injuries is unique and combined as with the application of proxy foot measures to identify foot type, aims to reduce the incidence of injury or identifies when to change the training programme for reoccurrence.

CHAPTER 2

FOOT ANATOMY AND GAIT

2.0: Introduction.

Chapter 1 considered the history of ballet, international variants and styles, the importance of adaptation to new styles as they become popular, the significance of foot type as a precursor for injury in traditional and contemporary dance moves. This chapter will focus on foot anatomy, foot types and postures, and ballet postures by way of explanation to give an underpinning to the narrative in the literature search and injury sections.

To gain an insight for the mechanisms of injuries, the relevance of anatomy and complexities of the osseous structure, ligamentous support and muscular forces are critical. This chapter provides an overview of pertinent aspects of foot anatomy and how they relate to foot type.

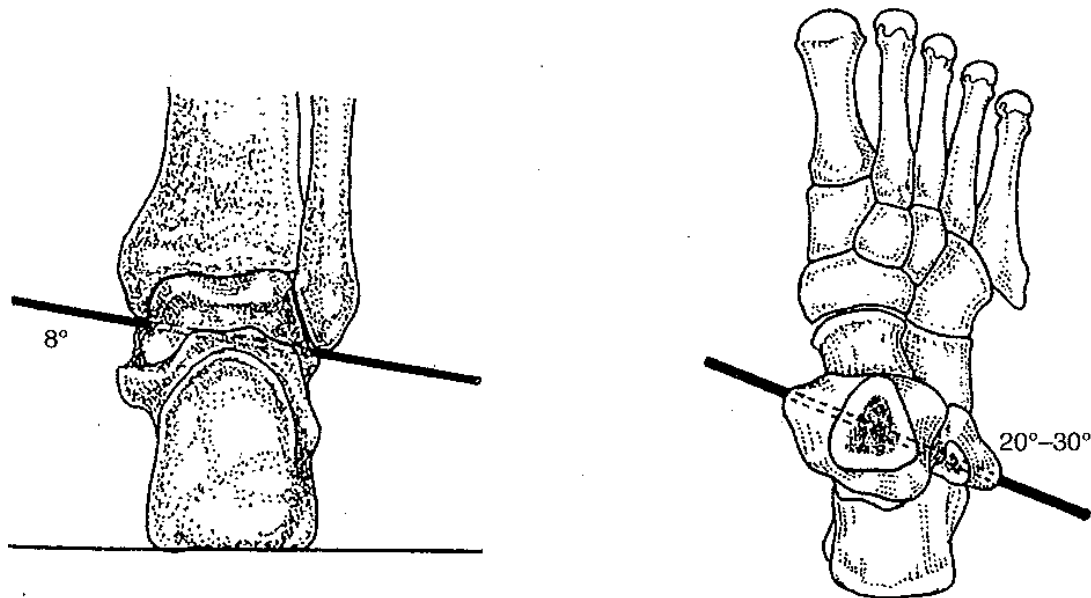
2.1: Foot and ankle anatomy.

2.1.1: The Subtalar Joint and the Ankle Joint.

The major joints of the foot are the ankle joint, subtalar joint and midtarsal joint (*Chopart's* joint). The ankle joint, also called the talocrural joint, consists of the superior (trochlear) surface of the *talus*, bounded on either side by the tibia (medial malleolus) and fibula (lateral malleolus). The ankle joint connects the lower leg to the foot and in dance allows for pointing of the toes (plantarflexion) as well as flexing of the foot during plié (dorsiflexion).

The axis passes medial to lateral approximately 8° - 14° to the transverse plane and 20° - 30° from the frontal plane (Figure 2.1 - Michaud, 1997).

Figure 2.1 - Foot Orthoses and other Forms of Conservative Foot Care. Michaud (1997, p.7).



The dominant motions are sagittal plane dorsiflexion and plantarflexion with minor degrees of frontal plane inversion, eversion and transverse plane internal or external rotation (Deland et al., 2000). Ankle joint congruence results in 75% of total load being distributed through the trochlea facet of the talus, the remaining 25% distributed through the medial and lateral facets of the malleoli (Michaud, 1997). In plantarflexion the articular congruence provide the primary stability when the joint is under load, which is significant for dancers to maintain stability (Russell, 2008).

The subtalar joint (STJ) is a combination of the articular facets of the superior surface of the calcaneus and the inferior surface of the talus (see Figure 2.2). The tendons of the muscles in

the anterior and deep posterior compartments of the lower leg contribute dynamic stability (*tibialis anterior*, *flexor hallucis longus*, *flexor digitorum longus*, and *tibialis posterior*) (see Figure 2.4 later). In pirouettes (performing a turn on the points of the toes), *tibialis posterior* and *flexor hallucis longus* together with *flexor hallucis brevis* are most often subject to strain (see Figure 4 to identify these muscles).

The subtalar joint is positioned inferior to the ankle joint and comprises of the articulation between the talus (inferior aspect) and the calcaneus (superior aspect). The axis of rotation of this joint is aligned within the 3 body planes resulting in triplane motions of inversion / eversion (frontal Plane) abduction / adduction (transverse plane) and dorsiflexion / plantar flexion (sagittal plane) that it comprises of 3 planes of body movement; frontal, sagittal and transverse (compared to the ankle joint which has 2 planes of movement). The average orientation of the subtalar axis is defined as 16 degrees relative to the sagittal plane and 42 degrees relative to the transverse plane (see Figure 2.2 and Figure 2.3 later). (Manter, 1941). Subtalar joint pronation is a combination of eversion of the calcaneus, with concurrent dorsiflexion and abduction of the talus, seen as elongation and depression of the medial longitudinal arch. Subtalar joint supination being a reversal of pronation is a combination of inversion of the calcaneus, with external rotation and plantarflexion of the talus (Kirby 2001). Manter, 1941 described the movement of the subtalar joint as screw-like or translational rotation along the joint axis when the foot is in motion. Differences in static foot posture and dynamic function are potentially associated with foot structure (Hillstrom et al., 2013). Differences in foot types i.e. arch heights will result in different combinations of frontal, sagittal and transverse plane movement, which will affect the relative movements of the leg and foot accordingly during walking (Root et al, 2004).

Root, (1974) concluded that triplane motion when moving from static to dynamic movement makes the subtalar joint a complex joint. The motion in 3 planes is fundamental when placing it in neutral and describing the forefoot in relation to the rearfoot. The term pronation describes a triplane motion of these same three cardinal body planes crossing each other, therefore sagittal - dorsiflexion, frontal (eversion) and transverse abduction. Pronation whilst it includes simultaneous movement in all planes, varies in each foot according or depending on the joint axial locations, joint shape and soft tissue status (Kirby 1987). For example, even though it is normal for all feet to pronate, in the flat foot, the foot overpronates at the subtalar and midtarsal joints i.e. a prolonged contact phase of the gait cycle. The gait cycle commences with heel strike, the foot is slightly supinated at the STJ (Tiberio 1987) then pronates at the subtalar joint during full foot contact with the ground, from midstance the foot then moves back into supination in preparation for toe-off, with the foot moving away from the ground in preparation for the next step (Root et al, 1997). There will be a variance as to the extent of overpronation relative to the severity of the pes planus/arch height.

Figure 2.2 -Subtalar joint (medial aspect of the foot). Copyright Subotnick, 1989.

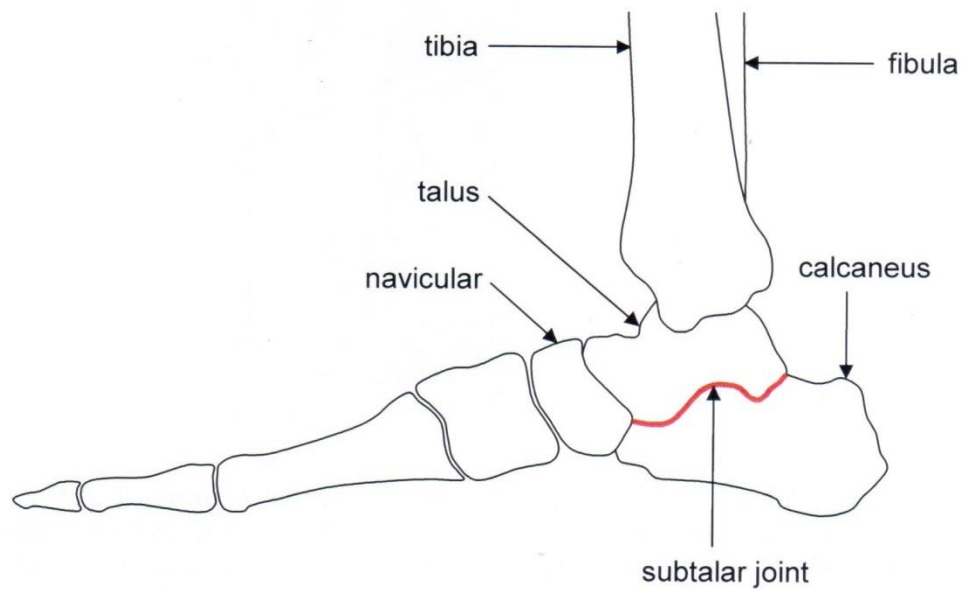


Figure 2.3 – Subtalar joint axis planes. The red line of figure 3a is the orientation of the axis of rotation of the subtalar joint of the transverse plane relative to the sagittal plane. Figure 3b is of the sagittal plane relative to the transverse plane. Copyright, Subotnick, 1989.

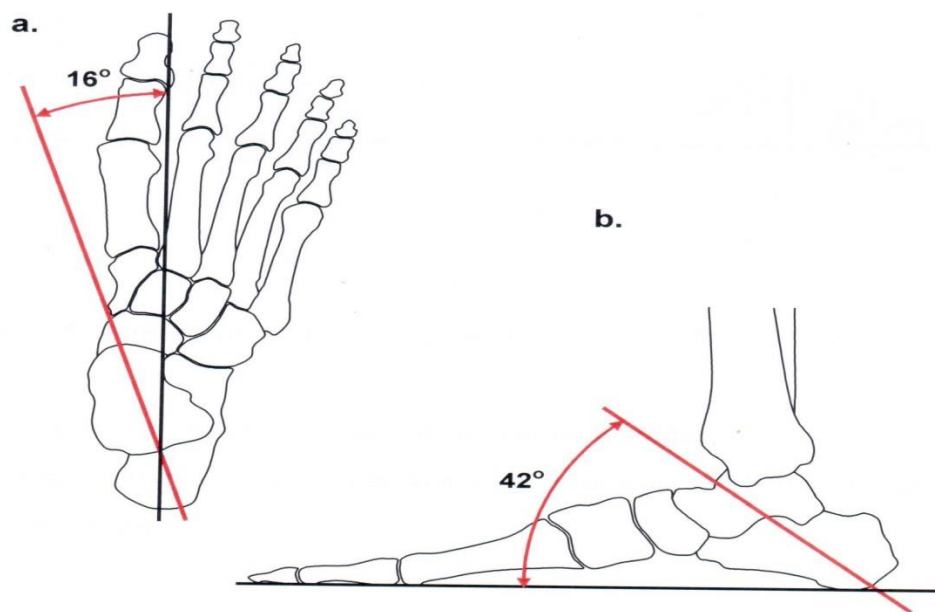
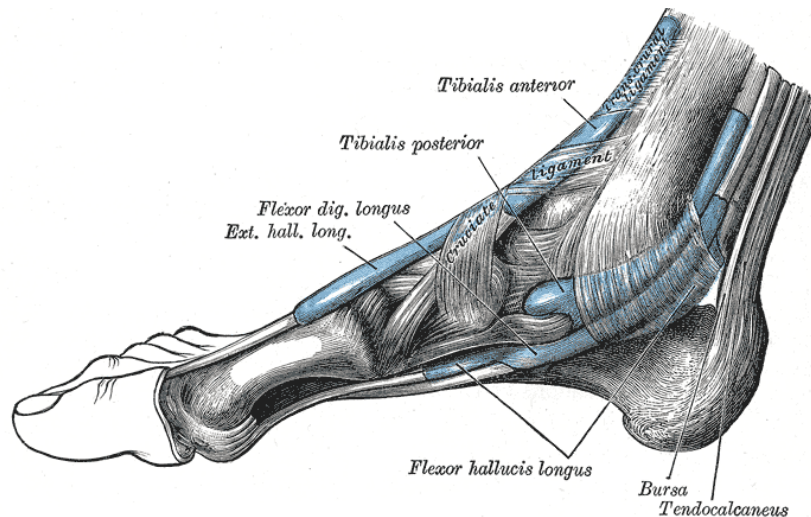


Figure 2.4 – Muscle insertions around the ankle joint. Copyright: <https://www.google.com/search?q=anatomy+of+the+foot+and+ankle+diagram&rlz=&ei/>. November, 2015.

Tendons medial ankle



2.1.2: The Midtarsal Joint.

Themidtarsal joint is formed by a complex of two separate articulations, the *calcaneo cuboid* and the *talo navicular* joints, which function as a single unit. The minor articulations between the wedge shaped tarsal bones: navicular, medial, intermediate and lateral cuneiform, and the cuboid contribute to motion (Figure 1 and 2). In comparison with the *subtalar joint*, the significance of these articulations has been overlooked or ignored in some modelling of foot function (Nester et al., 2007). Nester et al., (2007) observed a significant kinematic pattern in a cadavic study of simulated walking while acknowledging a limitation of the study in reduced mid stance GRF and intrinsic muscle resistance to dorsiflexion moments. This insight provides valuable information formidtarsal kinematics when interpreting foot

posture. The midtarsal joint allows the forefoot to pivot relative to the rearfoot providing triplane motion with dominant motion in the sagittal and frontal planes and less in the transverse plane (Nester et al., 2007).

2.2: Foot posture, pronation and foot measurements used to define foot type.

2.2.1: The normal foot.

From infancy through childhood growth and development account for fundamental changes in the nature and structure of the foot. Muller et al., (2012) reviewed 10,382 children between the ages of 1 and 13 years of age in a study of static and dynamic foot geometry. Muller et al., (2012), noted foot geometry and loading patterns changed significantly during growth and development and varied according to the individual's foot type. The definition of normal has been subject to interpretation. Root et al., (1977) listed eight 'biophysical criteria for normalcy' offering an ideal structure of the foot and lower extremity. These have been found to be so restrictive that few meet 'normal' (Kirby 2000). Kirby offers his own definition of 'normal' which defines normal as absence of deformity or pain. Kirby goes on to qualify this definition as a state where the effects of GRF and the intrinsic forces generated within the foot and leg are in equilibrium therefore no rotation is present about the subtalar axis. Thereby the equilibrium point is between maximally pronated and neutral. Without the benefit of clearly defined parameters, such subjective interpretation is inadequate for the purpose of defining foot type. Foot posture seeks to describe the static alignment of the feet, anthropometric data has been shown to be effective in the establishment of static and dynamic foot posture and therefore function (Rathleth et al., 2012). The observation of

respective foot elements, rearfoot, midfoot, arch height abduction of the forefoot on the rearfoot has been shown to offer subjective assessment. Redmond et al., (2006) devised a six-element assessment system to interpret static foot posture as either pronated, neutral or supinated (see appendix on definitions).

2.2.2: Pronation and measurement of the foot arch.

Foot posture is typically defined as pronated or *overpronated*. The foot pronates up to 3 degrees as measured from a vertical bisection of the posterior aspect of the Calcaneus (the Calcaneal Bisection method, Root et al., 1977) and this is considered to be in the confines of a normal postural movement during walking. If this postural movement exceeds 3 degrees (frontal plane motion), this is interpreted as overpronation and therefore this excess movement has pathological implications since various joints of the foot would be overworking which would affect the gait (Root et al, 1977). Mootanah et al., (2013) suggest foot type is a morphological description comprising structural variations in alignment and arch height, when taken together (posture / type) they offer a categorization of planus (flat) rectus (well aligned) and cavus (high arched). Researchers have associated normalcy with longitudinal (sagittal plane) deformation of the medial longitudinal arch (MLA) in that, the pursuit of measuring MLA deformation provides a categorization of foot morphology and function which could be linked to injury susceptibility (Brody, 1982; Dahle et al., 1991; Nilsson et al., 2012). Brody (1982) examined the relationship between navicular height and normalcy and the change in height from neutral stance to relaxed stance. Brody (1982) considered that the relaxed stance should be the marker to define arch height for an individual and that the difference in measurement between neutral and relaxed stance is the postural movement i.e. pronation movement of the foot (Brody, 1982). Dahle et al., (1991)

considered the Longitudinal Arch Angle (LAA) where normalcy was defined as an angle of $132^{\circ} - 150^{\circ}$ formed by the intersection of two lines at the navicular tuberosity. In clinical practice this assessment has proved unreliable due to the consistency with which identification of three anatomical landmarks, centre of the first metatarsal head, navicular tuberosity and centre of the medial malleolus could be consistently achieved. Nilsson et al., (2012) undertook a prospective study of 254 subjects for static variations in longitudinal arch profile, parameters of a normal foot where maximum MLA height and MLA range of motion (ROM) for navicular height (NH) and navicular drop (ND) 3.6 to 5.5 cm and 0.6 to 1.8cm respectively (Nilsson et al., 2012). Albeit based on adults employed in standing occupations, Nilsson et al., (2012) advocates the Navicular Drop Test results of this study as a possible link between MLA height / change and the development of injuries. This test is applied in the current study and is described in detail in Chapter 5.

A maximally pronated foot (pes planus) is uncommon in dancers as this presents difficulties of standing on pointe due to internal rotation of the lower limb with anterior pelvic tilt, which results in restricted hip extension i.e. tight hip flexors. However there are different degrees of flat foot, ranging from completely flat and therefore no arch, to a normal arch height (Nilsson et al., 2012; Redmond et al., 2006). Even a slightly flat foot is subject to overpronation beyond the normal parameters of pronation in a rectus foot. Such abnormal pronation occurs about the subtalar joint axis, which deviates medially leading to a reduced moment arm for both internal (*tibialis posterior* and *triceps surae*) and external GRF supination moments hence net increase in pronation moments (Kirby, 1989). During the gait cycle, when the heel makes contact with the, the GRF's applied are Fz, the vertical force, Fy, the anteroposterior force, and Fx, the mediolateral force; these forces can be applied and measured using a force platform for identification (Subotnick, 1987) (Figure 2.5).

Figure 2.5 – Ground reaction forces applied during the Contact gait phase. (Copyright, Subotnick, 1987).

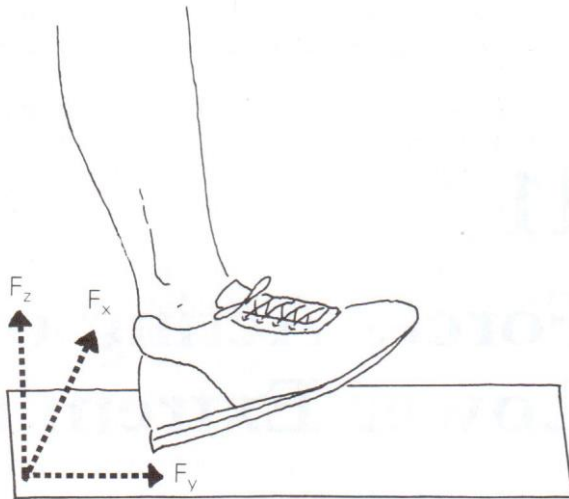


Figure 2.6 presents with a graph of the effects of the 3 forces as described. However, when a runner is measured by GRF's, the 3 forces change due to the different foot loading (Figure 2.7). The runner will have a large impact on heel strike, rapid loading onto the forefoot, and toe-off phase in 25msec. Comparing the vertical force from Figure 2.6 to Figure 2.7 reveals different peak forces through the foot in the contact phase (the foot making contact with the ground). In chapter 7 (Discussion), the GRF's of walking will be compared to those of a dancer and how this will impact the joints of the body, particularly in relation to repetitions of dance moves and landing from a jump.

Figure 2.6 – GRF's F_x , y and z expressed as a graph showing a cross comparison of the 3 forces applied. (Copyright, Subotnick, 1987).

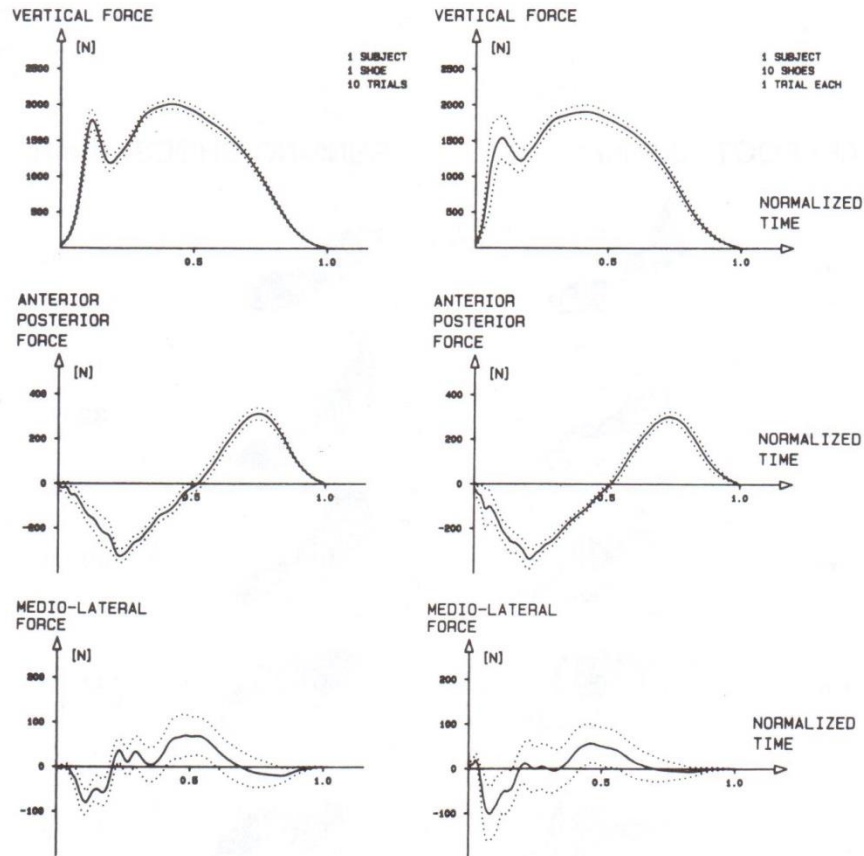
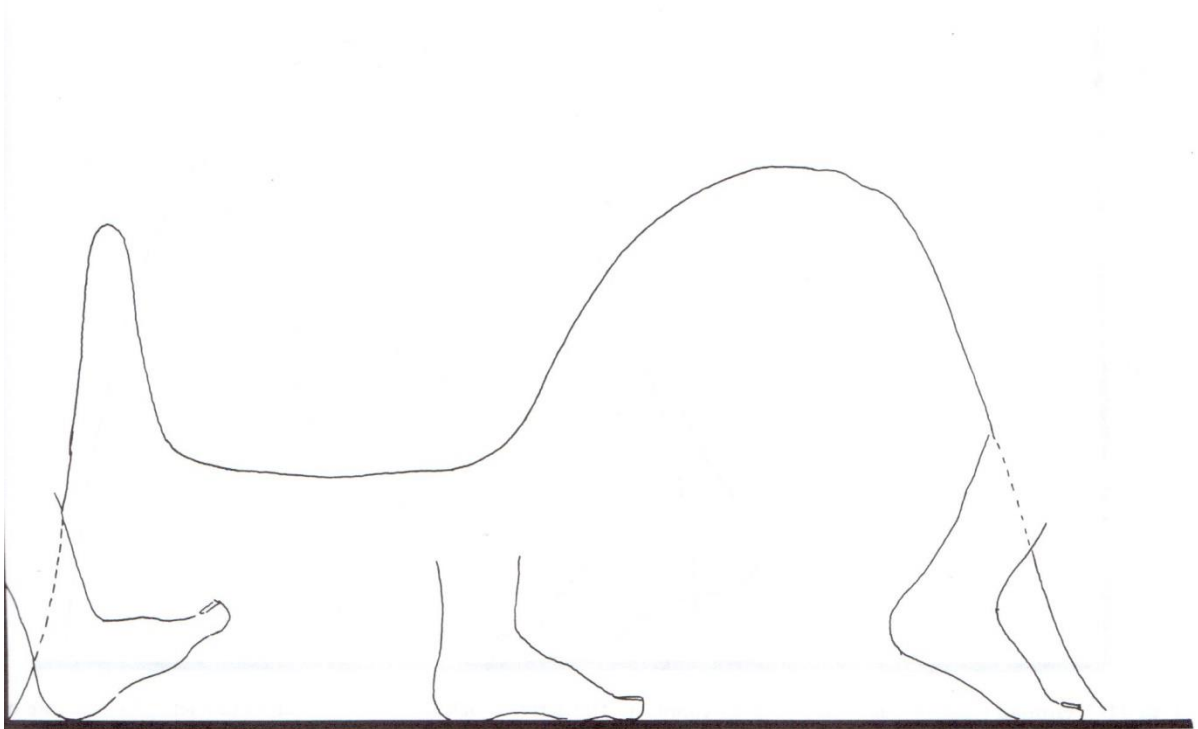


Figure 2.7 – Vertical component of a runner over 25msec. (Copyright, Subotnick, 1989).



Foot posture and foot type are believed to predispose the subject to overuse injuries since a pathological foot posture such as pes planus or cavus will alter the kinematics during movement (Levinger et al, 2010). Levinger et al, (2010) used radiographic measurements combined with The Oxford Foot Model (OFM) to classify the foot into pes planus or cavus and found that flat arched feet associated with prolonged calcaneal eversion, increased tibial internal rotation and forefoot abduction had reduced shock absorption. In order to evaluate the accuracy of the position of the foot bones in stance Levinger et al., (2010) used X-rays of the foot to help identify individual positioning of the talus and calcaneus in relation to subtalar joint. The Oxford Foot Model, which measures the posterior aspect of the calcaneus to the proximal aspect of the head of the first metatarsal, and then measures from floor level to the highest point of the arch is not commonly used in research so this measurement remains incompletely tested and so is debateable (Stebbins et al, 2016). Van Hove et al.,

(2015) undertook a small study (n=9) examining the repeatability of the OFM with moderate to excellent interclass correlation (ICC's) for both inter-rater and intra-rater repeatability. Reported ICC's were based on averaging results for both inter-rater and intra-rater measurements. Carty et al., (2015) in a single case study of marker placement utilising the OFM, determined sensitivity (i.e. how accurate the information was) was highly dependent on calcaneal and distal 5th metatarsal marker placement; slight variations from the anatomical land marks could result in inaccurate information. The fundamental weakness of the OFM is the reliance on multiple anatomical landmark identification and skin movement when placing reflective markers. An alternative application of a single external measure of foot arch height is supported by the work of Levinger et al., (2010) and Nilsson et al., (2012) and applied in this study.

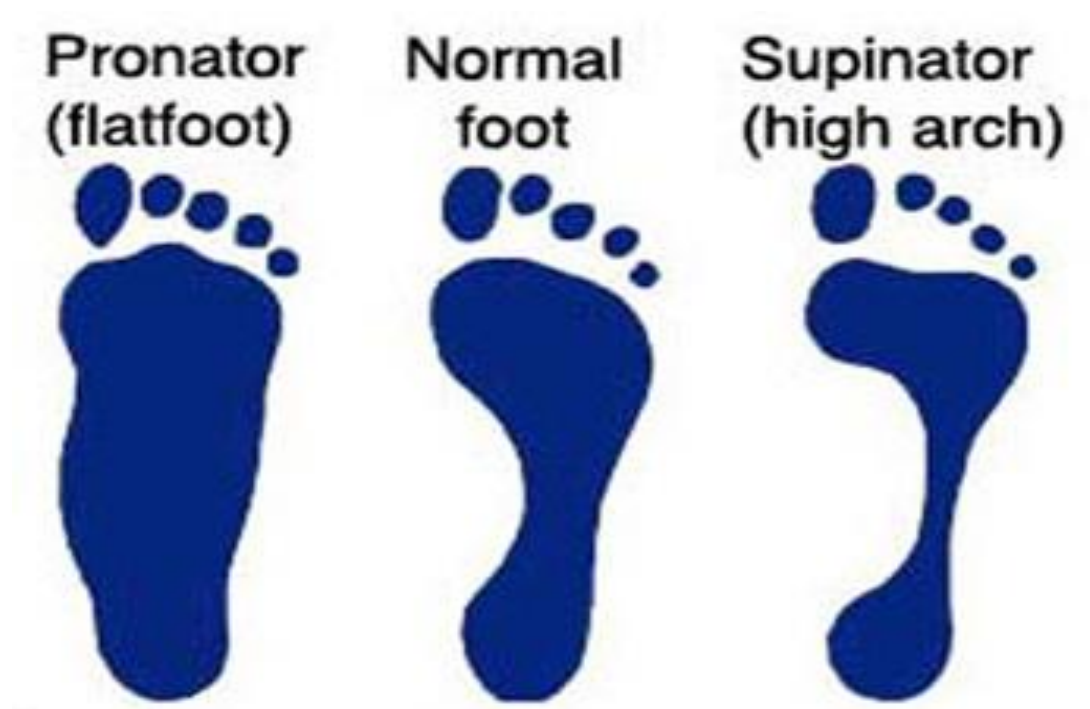
More recent in vivo research has seen bone pins placed in the calcaneus and talus in live recruits with markers to analyse the movement at the subtalar joint in an effort to study foot kinematics (Nester, 2006). Neither x-rays nor bone pins were appropriate (or available) for application in the present study, which was also concerned with the potential for future development of a non-invasive assessment process that could be applied in practice.

Therefore finding a measurement for the feet which is ethical, has an ease of use in a clinical situation, is repeatable and valid, narrowed down to 3 proxy measures that could measure the 3 planes of motion of the foot in terms of posture as well as the height of the MLH, and these were deemed to be the Foot Posture Index, The Calcaneal Bisection and The Navicular Drop Test. This has been described briefly in this chapter yet will be described in more depth by way of usage and application in Chapter 5.

2.2.3: The ballet dancer's foot.

Structurally, the ideal foot for ballet is considered to be a flexible “square foot”, which has equal length first and second toes (Harkness, 2015). Concerning the foot arches, the Russian and Polish schools favour a high arched foot for aesthetic reasons. This foot type is liable to over extension when on *pointe* with a high susceptibility to ankle sprains and fractures (Luk, 2013). Pes rectus is the normal arch type, which would be categorized as neutral (Kirby 2000) and within the range 3.6 to 5.5 cm for navicular height (Brody 1982) or 132° to 150° for the longitudinal arch angle (Dalhe, 1991). It could be surmised that the Russians and Polish dancers indeed have a normal arch height seen in the rectus foot which may have been miscategorised as pes cavus since dance schools may not be able to differentiate between a high arch and a normal arch. For pes cavus the incidence of ankle sprains and foot and lower leg fractures would be significant from continually dancing on *pointe* (Luk, 2013). Simply put, dance schools may perceive the foot as either having an arch or not having much of an arch and that the former choice is the favoured one when recruiting a dancer. Figure 2.8 gives an indication of the 3 foot types of pes planus, pes rectus and pes cavus with an imprint providing the best reference since there are variations to the pes planus and pes cavus.

Figure 2.8 – Imprints of foot types, pes planus (flat foot), pes rectus (normal) and pes cavus (high arched foot).



2.3: Dance Positions.

To give a background as to dance positions such as plié, demi-pointe and en pointe will give a clearer understanding in the literature search.

2.3.1: First and Fifth Positions.

Since the foot needed to be measured with the dancer in stance and not in movement, (as the latter was not possible) and whilst the foot measures chosen would indicate foot type, an observation of the dancers in movement indicated that there were certain dance postures that emphasised biomechanically weak feet. These were the First and Fifth dance positions which could be measured with the dancer in stance position.

Photo 2.1 - First Position.

(Copyright <http://www.danceclass.com/ballet-positions.html>/accessed March 2017.)

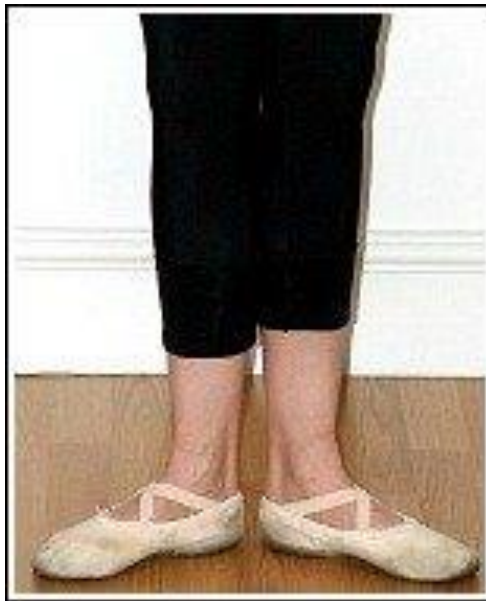


Photo 2.2 – Fifth Position.

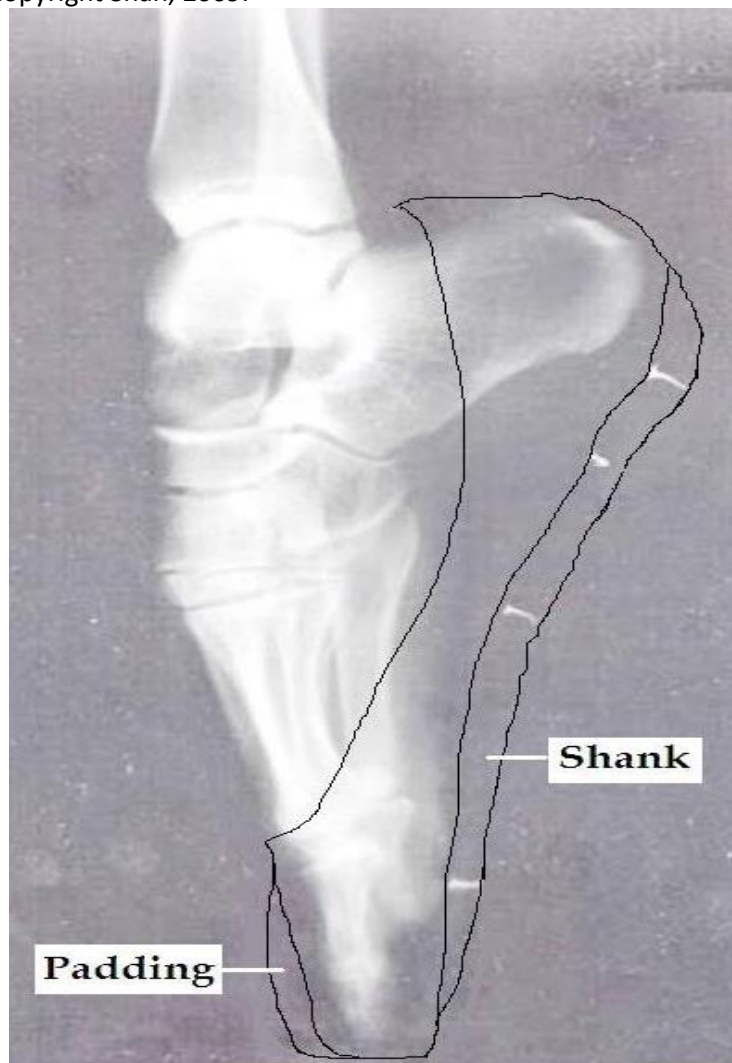
(Copyright <http://www.danceclass.com/ballet-positions.html>/accessed March 2017.)



2.3.2: On Pointe.

This is where the dancer dances on her toes, the ankle in full plantarflexion. Photo 2.3 shows an x-ray of the foot on pointe.

Photo 2.3 – X-ray of a dancer on pointe, with illustration of how the toes are positioned in the block of a pointe shoe. Copyright Shah, 2009.



2.4: Chapter summary.

Discussion identifies the scope for evaluating foot types. Some methods used previously have been evasive and not feasible in practise but there is some suggestion that measures for example, the Navicular Drop Test (NVDT), the Foot Posture Index (FPI) and the Calcaneal bisection can provide an alternative non-evasive means, usable in a clinic situation. These measurements can be taken forward with demographic data.

Complexity of the subtalar joint, planes of movement, coupled with degrees of rigidity and hypermobility in ligamentous structures are not fixed units and vary in individuals. In accordance, Ground Reaction Forces or shock attenuation and absorption of these forces vary according to the anatomical structure of the individual. The construct between athletes and ballet dancers in terms of GRF's is that whilst they both may sprint, dancers also have to stand and move rapidly with the foot fully plantarflexed on pointe, and land from heights onto solid and sprung floors in soft slipper or character shoes and boots. Repetitions of dance moves, in speed whilst maintaining an appearance of lightness and effortless movement, landing from great heights, have implications on foot health. The susceptibility for dancers is likely to be different from other athletes and sports because of the very nature of dance moves. Chapter 3 continues with this theme by providing a literature review to gain more insight into susceptibility and risk.

Chapter 3

Literature Search

3.0: Introduction.

This chapter develops the analysis by focusing in detail on factors that increase the risk of foot, lower limb and hip injury in ballet dancers. Therefore foot types pes planus, pes cavus and pes rectus as well as postural movement of pronation are analysed as to potential injuries to the lower limb. Flooring and dance footwear as extrinsic factor are also explored in relation to foot type, shock attenuation (GRF) and pronation.

A comprehensive literature search was conducted consisting of the following electronic databases that cover the academic papers from 1970 to present day. Medline, Cinahl, Sports Discus, PubMed, Embase, Scopus and the Cochrane Controlled Trials Register, Google Medical Scholar. Search terms were either single words or combined words into strings to represent the key themes, overpronation OR pronation OR pes planus OR pes cavus. Overpronation AND ballet dance injuries OR flat feet, ballet injuries, OR pes planus, ballet injuries OR classical ballet AND leg, foot, ankle injuries OR adolescent ballet dancers AND leg, foot, injuries OR physiotherapy AND ballet dance injuries OR podiatry, podiatrist, ballet injuries, foot; podiatry, flat feet, pes planus, injury, ballet dancer OR professional ballet AND amateur ballet AND injuries OR pointe AND vertical forces AND biomechanical forces OR ballet dance shoe AND injury OR ballet dancers AND floor injuries OR fracture, musculoskeletal, toe, ballet AND injury OR pes cavus AND ballet injury OR foot pathologies AND ballet dancer AND injury OR treatment AND ballet injury AND injuries OR male AND female ballet dancers AND injury OR foot arches AND injury OR measurement of foot

arches OR measurement of medial longitudinal arch OR anatomy AND foot and ankle. Adolescent injuries AND sports, adolescent sports injuries AND overtraining AND OR fatigue. Ballet shoes AND footwear OR ballet shoe components OR ballet shoes and injuries. Dance AND flooring AND injury. Floor components AND flooring in ballet companies. Foot AND leg AND hip injuries in ballet dancers. This was narrowed down to the following:

Inclusion criteria: Adolescence/young adults, foot/ankle injuries/knee/leg versus injury. English language. Ballet dancers, runners, foot types, Athlete and ballet dancer injuries. Growing bones. 167 articles.

Exclusion criteria: Repetitive reviews, non-ballet dancers, 29 years plus or retired dancers.

Annual search: studies cited in selected literature, manual hand search.

3.1: Background review chapter.

3.1.1: Search: Injuries in athletes versus ballet dancers.

In this literature review areas investigated that would be relevant to this thesis included screening through different styles of teaching internationally for both classical and contemporary ballet injuries covering all elements of ballet. Overtraining, the effects of fatigue, floor surfaces, as potential for injury in adolescent dancers and athletes to cross compare fell within the remit for analysis and scrutiny. Contributory extrinsic factors of dance footwear fabrication were investigated. Flooring components and how this may affect ground reaction forces is also explored. Cross comparison between dancers and athletes in terms of hours and years of training was considered. Of interest and inclusion were treatment plans in terms of immediacy for injuries as well as long-term. Health professional intervention, self-treatment and risk assessment as offered by dance schools needed exploring. Whilst a good source of information favours athletes generally, particularly

runners, it appears to be less prominent for dancers, particularly ballet dancers so sourcing information was limited. Foot types and any correlation to injuries particularly foot and lower limb were explored which pertained to ballet dancers; this subject being the main essence of this thesis will be detailed in section 3.1.1. Flat feet (pes planus) or high arched feet (pes cavus) related to biomechanical problems in walking and ballet. Definitions of pes rectus (normal) as well as explanation and description of normal feet as well as in relation to lower limb injuries in dancers and athletes was part of the search. Measurement of arch types as part of foot definition as well as pronation as postural movement in comparison to lower limb injuries was also investigated. In all, 167 pieces of literature were relevant for this thesis.

3.1.2: Lower limb injuries in ballet dancers.

Variation from 'normal' foot posture has long been thought to influence function of the foot and the lower limb during gait therefore predisposing the individual to injury (Levinger et al., 2010). Flat feet, have been linked with altered foot function, prolonged calcaneal eversion, forefoot abduction, reduced shock absorption leading to foot strain and potential injury; while increased internal tibial rotation is related to reduced efficiency of gait and subsequent strain on the knees and hips (Hunt, 2004; Silver and Campbell, 1985; Southard, et al., 2012).

Poor alignment of the lower extremities, (legs and feet) have been implicated in increased risk of injury in athletes (Nguyen, et al., 2011; Kernozek, et al., 2011; Khamis, and Yizhar, 2007) as well as frontal and transverse plane control of the pelvis, hip, knee and foot (Stensrud, et al., 2011; Whatman et al., 2012). Although many sports such as running, basketball, and gymnastics are cited, the area of dance is not quantified in the main stream of athletic injuries (Krasnow, et al., 1999; Nattiv, et al., 1997). Even though research indicates

pathological foot types as a cause for injury in athletes, the area of dance, particularly ballet has been overlooked (Allen, 2013). There are some studies that do indicate that abnormal lower limb biomechanics and poor lower extremity alignment would also be a risk factor for ballet dancers, but used only in reference to ballet without any cross correlation to other sports; whereas areas such as the kinetics and kinematics of landing forces from jumping could be considered as a good cross correlation measure i.e. as in gymnastics where runners sprint at speed and jump (Coplan, 2002; Negus, et al., 2013; Bowerman, 2015). However the speciality of ballet is unique. Whilst they may run at speed, it has to look effortless and artistic which would entail less running on the heel and more running on the forefoot. Also, no other physical activities require an individual to move from forced maximum weight bearing dorsiflexion (*demi-plie*) and forced maximum weight bearing plantarflexion (on *pointe*). Both these positions cause great strain on the ankles and feet with forces increased by 12 times the body weight when landing from a height (Rackoll and Muller, 2013). Such extreme movement of dancing on *pointe* and landing on toes from a jump would benefit from analysis not only of shock attenuation but also video analysis of how much the foot pronates whilst on *pointe*, and if this increases over long periods on *pointe* due to a biomechanical anomaly such as *pes planus*.

Indeed there is a paucity of published literature in the last seven years on lower limb injuries in relationship to biomechanical contribution i.e. the analysis of foot type of the dancer and even a query as to the cross comparison of the variety of foot types in dancers and patterns of the most frequent type and a few studies on systematic reviews with replications of research on incidences of lower limb injuries in ballet dancers, but scant new research being produced (Bowerman, 2015, Nigg, 2001). Pronation or overpronation has been mentioned in studies as to potential causes to knee and hip injuries but have not been linked to foot type (Nowacki, et

al., 2012) since shock attenuation due to overpronation will have implications on the ankle, knee and hip joints in ballet (Cavanagh, et al., 1997; Hincapiés et al., 2008). Certain literature more anatomically specific, which cites overpronation as a potential link to injury by Russell (2010) had a small sample size of 15 dancers. Russell (2010) observed whilst measuring plantarflexion of the dancer on pointe, that neither a goniometer or inclinometric device could provide a consistently reliable measure; he noted however note that dancers on were unstable at the ankle joints and inclined to overpronation and considered that this would be a subject worthy of further investigation. This study highlights the inaccuracy of a reliable measuring device which is required to measure whether a dancer has a sufficient range of plantar or dorsiflexion necessary before being able to dance on pointe and this will be further discussed further later in this chapter on the subject of dancing on pointe.

Studies linking foot anatomical variations such as pes planus, pronation and pes cavus to injuries in athletes in general conveys an awareness that different foot types are linked to joint kinematics and injuries but are unclear as to the exact relationship (Nigg, 2001; Russell, 2013). Nigg (2001) looked at impact forces and pronation yet as a systematic review it does not present with any new research except suggesting a link between pronation and injury. Indeed, Buldt et al., (2015) indicates foot posture as being associated with the development of some lower limb injuries as indicated in a study of 97 adults examined for different foot types using a 5 segmental foot model to measure tri-planar motion whilst walking, with markers placed on segments on the foot. Foot marking measuring segments of rearfoot, midfoot, forefoot that were applied has its limitations in that it is not subtle enough to address the specifics and subtleties of the fine movements of the joints i.e. pronation as it is occurring through the subtalar and possibly more extremely through the midtarsal joint. Buldt (2015) classifies its participants as either having pronation or supination without reference to the

variation in scale in pronation and supination (normal limits) to overpronation or oversupination (beyond normal limits and likelihood to pathology). The study also featured normal adults and not ballet dancers, which are different populations.

Analysing foot types particularly identifying types such as pes planus and pes cavus and measure their relative postural changes of pronation and supination should be a necessity in the dance world in order to provide suitable training programmes to prevent injuries. Observation and identification of biomechanical weaknesses would enable dance teachers and health professionals, particularly podiatrists to devise training and strengthening programmes for susceptible and weak muscle groups.

Whilst evidence supports a high incidence of lower limb injuries in ballet (leg, knee, foot and ankle) foot types and pronation have not been given scrutiny and this may be due to lack of podiatric intervention in research (Leanderson et al., 2011; Gamboa et al., 2008; Russell et al., 2012). Analysing foot type in dancers, the basis of their athletic ability, remains insufficiently explored, which suggest foot experts such as podiatrists could be a valuable missing link.

3.1.3: Landings and Ground Reaction Forces.

Male dancers perform jumps often requiring speed in running to gain great heights and such jumps may be singular or a series of repetitions. For repeated jumps, an expectation is made for the dancer to achieve the same height for each jump to create visual uniformity. Chapter 2 discussed the GRF's of a runner in movement whose foot would make rapid and less contact with the floor during the Contact phase of the gait cycle than a walker (Subotnick,

1987). Whilst there is scant literature on GRF's of a dancer during movement, this thesis suggests that movement of foot on landing is mainly on the forefoot due to speed and elevation required partly to make the movement look effortless, partly to achieve height which is akin to a sprinter who will run on the forefeet to attenuate a rapid speed (Subotnick, 1987). It is proposed in this thesis that shock attenuation would be expected to increase in proportion to the height of a jump and its respective landing and the landings would additionally be affected by the speed of the run leading up to the jump. It is also proposed that sprung flooring will aid shock attenuation allowing the dancer to move into another jump. Male dancers who historically jump to great heights for aesthetic reasons, with repetitions of the same jump i.e. *l'assemble a l'air*, would attain high peak forces on take-off and landing; affected by whether they land on the forefoot or the whole of foot; yet there are not any studies in the literature on this subject. However, studies have shown that landing from a height with foot type *pes planus* or degrees of overpronation can cause knee instability and injury (Koh, et al., 1990a; Nguyen, et al., 2015).

As an occupational group and athletes in their own right having to develop muscular strength and endurance, dancers have received little attention in the health literature (Hincapie et al., 2008; Russell, 2012) considering that dancers need to be fit to perform as this is their livelihood. Gamboa, (2008) reported on the incident of lower limb injuries on 204 dancers (9-20 years of age) from data gathered in a 5 year questionnaire screening programme stating that 53% of injuries were to the ankle and foot and were due to biomechanical anomalies. The results refer to right foot pronation but no explanation as to the degrees of pronation or how the measurements were taken, are explained but the author states that excessive overpronation occurs during forced turnout in a *plié*. The author's methodology does not include measurements of the foot or the specific foot types. The incidences of injury to the

feet are wide and varied, the study lacked detail of specific injuries. The questionnaire data relied on the dancers recalling their injuries over 5 years which can have limitations due to not remembering exact times and injuries or conversely not wishing to report injuries. Additionally, the questionnaires were self-reported which may result in the questionnaire not being filled in sufficiently or correctly than if interviewed. Only injuries treated by the physiotherapists were considered in the study, but these did not account for self-reported or self-treated injury; dancers were not interviewed prior to completing the questionnaire and no appraisal framework was defined or evidence of a validated research instrument. Gamboa, (2008) is not able to determine whether this approach is drawing on the relevant responses; relevant in comprehensively answering a questionnaire (Barbour 2001). Similarly, Arendt, (2003) evaluated (n=77) German dancers (42 female and 35 male) by questionnaire and 80.5% involved injury to the knee, 74% of injuries to the ankle but failing to specify other foot injuries implies no injuries had occurred to the rest of the foot. The variation in reporting serves to highlight a lack of uniformity in methodology.

3.1.4: Lower limb injuries in adolescent dancers.

Competition and training has increased significantly in the adolescent population in various sports and with it has come an increased number of injuries (Steinberg, 2013). Injuries compared to the wider adult population are mainly due to the overuse during skeletal development (Hodgkins et al., 2007). Ekegren et al (2014), in referring to dancers, considers that “*there is a need for more research evaluating the impact of intense training on elite adolescent athletes*”. In an epidemiological study of female dancers aged between 8 to 16 years Steinberg, (2013) pointed out that dancers overtrain just as other athletes but they differ from other athletes. Firstly, they dance en *pointe* resulting in plantarflexion of the ankle and

metatarsophalangeal joints, which places extreme load on these joints and the toes. Secondly, the 5 classical ballet positions require turnout of the lower limbs with external rotation of the hip, knee and leg, with possible tibial torsion occurring. Thirdly, there are excessive repetitive movements resulting in high loads and strain on the muscles and ligaments. Steinberg, (2013), reported that dancers had the highest percentage of knee injuries (36%) when compared to gymnasts (13%) and volleyball players (22%) and purports that “*lack of information concerning young dancers prevents the adoption of any preventive strategy and exposes the dancer to injury*”. The study included a range of dancers, not specifically ballet dancers and this may well be reflected in the results which revealed knee injuries as the most prevalent injury followed by back injuries, the foot/ankle presenting with the least injuries in contrast to other research by Gamboa et al., (2008) and Hincapie, (2008) who identified the foot and ankle as having most injuries in ballet dancers; most probably due to landing and moving across the dance floor on *pointe*. Other dance types studied by Steinberg, (2013), such as Jazz dancers, do not move onto *pointe* but Jazz, by its particular style of dance, is predominately dancing on the forefoot, and landing on the whole plantar area of the foot and may lend the dancer more to knee injury, due to the twisting rotation at the knee joint when landing.

Other authors who found that the highest percentage of injuries in ballet dancers were to the lower limb have also highlighted key risk factors for injuries with particular reference to the adolescent dance population (Fournieri, et al., 1997; Gamboa et al., 2008, Phillips, 1999a; Steinberg et al; 2011, 2013). Indeed ballet is such a strict discipline with long hours of training that concerns about the long-term problems to the body have not been adequately evaluated in the literature even though the high levels of physiological stress with insufficient recovery time coupled with variations in the anatomical structure of the foot may lend the

adolescent athlete to fatigue injuries such as stress fracture tibial periostitis (Steinberg, 2013). In a retrospective descriptive cohort study of 204 dancers aged 9-20 years, screened over 5 years Gamboa et al., (2008) concluded that adolescent dancers account for most ballet injuries. They found that 53% of injuries (the highest percentage) were to the foot/ankle, 16.1% to the knee, 21.6% to the hip and 9.4% to the back. Overuse injuries have been frequently reported for ballet dancers, most being in the foot and ankle but used generically and not expressed in specific foot and ankle injuries or in relation to biomechanical foot types or posture (Hincapie et al., 2008; Solomon et al., 1996; Byhring et al., 2002; Morton and Cassidy, 2008). These authors express concern regarding dancers overtraining excessively at a young age but their injuries are not investigated sufficiently to devise a strategy plan on prevention. Yet, The British Association of Sport and Exercise Medicine (BASEM) whose aim is to promote research into cause and treatment of injuries for the benefit of athletes has not included ballet dancers or more generally the field of dance in benefice; despite the high numbers of amateur and professional ballet dancers in the UK, being 13 per cent of the population (Dance UK, 2010). The International Academy of Dance Medicine and Science was established in America in 1990 and only in 2012 was the National Institute of Dance Medicine and Science founded in the United Kingdom.

Leanderson et al., (2011) conducted a retrospective study which looked at young ballet dancers between the ages of 10-21 years and found that 76% of all injuries occurred in the lower extremities with ankle sprains being the most common trauma diagnosis. Leanderson et al., (2011) cites overtraining as a cause but without stipulating the intensity or frequency of the training programmes adopted, but offers a consensus of what constitutes a high incidence within young dancers. Conjecture exists, according to Leanderson et al., (2011), that perhaps the ankles are not strong enough, that the dancers, being adolescent develop physically at

different rates and that this is not accounted for during selection criteria and training. Overtraining during crucial periods of growth has the potential for a high incidence of injury. Indeed, this is an important consideration since professional schools take dancers from the age of 11 years full-time which consists of 40 hours training a week, increasing for rehearsal times in the lead up to performances. Overtraining has been considered as a common cause for athletes, particularly in adolescence (Hodgkins et al, 2007). Competition for places in the elite schools and for professional dance companies places pressure on dancers to train long hours and to be able to stand out from other dancers. Injury is not only a time of physical difficulty but may also come with psychological stress, since dancers face fears of lost training time, work and income and thus may not seek medical advice when injuries occur (UK Dance, 2010).

Certain dance performances are more rigorous and demanding than others such as Swan Lake which requires long periods of *pointe* work by most of the chorus ballet who have to perform a *pas de bourres* which is continuously running on tip toe on the spot (John, 2006). Strong intrinsic foot muscles are required, and the muscles of the legs and feet can cramp once held in a *pointe* position for too long. Standing on *pointe* and not moving can cause cramping of the muscles of the foot and leg and by the very nature of the position, over a prolonged time, is fatiguing for the dancer. Training including repetition of certain moves to gain perfection can lead to musculoskeletal problems that can be exacerbated if there are any existing biomechanical anomalies. (Russell, 2013; Wilson, M. and Kwon, Y.H., 2008). Professional dance schools perform on stage annually whereas the amateur schools hold a performance every two years. Training and rehearsals increase leading up to the performances with the professional schools under more strain having to train considerably more hours than amateur schools. Amateur schools will train approximately 8 hours plus in a week, which is increased

with performances or approaching examination times whereas the elite schools train 40 hours per week, increasing training for rehearsals. Certain authors specializing in adolescent athletes consider that investigations on how excessive training affects the bone growth of the adolescent and the long-term implications need investigating (Fournier, P.F., Rizzoli, R., Slosman, S.O., Theintz, G. and Bonjour, J.P., 1997).

Considering that all the bones of the foot have not fully ossified during adolescent development, for example the hallux, the phalanges and the 1st metatarsal, abnormal stress / strain can lead to long term damage due to overuse. Overtraining without sufficient rest for the tissues to repair in all adolescent athletes, but dancers particularly, will suffer from the additional strain of pivoting and landing on toes which can stunt full ossification in those bones (Fournier, P.F., Rizzoli, R., Slosman, S.O., Theintz, G. and Bonjour, J.P., 1997). Dancers at amateur level are at further risk of shock transmission injuries due to the absence of sprung floors presenting an additional mode for injury.

3.1.5: Pointe work and the foot.

Pointe work can start around the age of 11 to 12 years, and talented dancers can start full time at professional ballet training schools from around the age of 11 years. Before the age of 11 or 12 much of the cartilage and bones of the feet are still very pliable (*ossification* increases with age). When landing on *pointe*, the force of landing is equivalent to 12 times the dancer's body weight (Spilken, 1990; Dozzi, 1993; Meck, 2014). Consequently, serious damage could occur if *pointe* work is taken up at too early an age; that is before the correct development of all the bones, particularly the first metatarsal head and the phalanges to the first toe (Bloch, 2011). In the foot bones, growth occurs at a specific site: the epiphyseal plate (cartilage

which eventually ossifies as bone). Differences in *ossification* occur in individuals and are sources of risk at different ages (Fournier, 1997):

- The growth plates of the *hallux* and the first metatarsal are susceptible to injury on *pointe* and may be affected negatively if *ossification* has not fully occurred.
- The base and body of the first metatarsal do not completely *ossify* until approximately 18-20 years.
- The phalanges (toes) have 2 *ossification* centres, which do not complete until approximately 18 years of age.

The metatarsal heads of a dancer can present as flattened due to repeated compression on the area during the growth period. Growth plates, although given a fairly standard medical time as to when they ossify clearly are subject to individual variation.

Adolescence is a period marked by periods of rapid growth that can create a weakness in the area of the growth plates (Meck, 2014). This coincides with the period when dancers train hard to be chosen for professional ballet schools and, once accepted in the school, competition is fierce to perform regularly and gain a placement in a professional company. Anecdotal evidence points to lack of consistency for universal standards on deciding when a dancer is ready to go onto *pointe*; schools vary in their decision as to when is the appropriate time (Shah, 2009). Meck (2014) suggests a screening programme is a necessity for deciding when an individual dancer should go on *pointe* in an effort to avoid unnecessary injuries. It is suggested that some schools rush dancers to go on *pointe* for purely financial reasons for fear that they may lose their dancers to other schools (Meck, 2014). The absence of a standard measuring scheme and examination may result from lack of local expertise, or criteria for examination, therefore dancers could be going onto *pointe* too early and could potentially rule out a professional career in the long-term as a result of injury (Meck, 2014; Shah, 2009).

It appears that some schools state that the precise time chosen for an individual dancer to go onto *pointe* is solely dependent on the discretion of the dance teacher (Shah, 2009; Russell, 2008). The teacher decides that the student is ready when the ankles are considered strong enough to support the whole body and the arch is sufficiently developed in that the dancer can “*pointe*” the toe exposing a nicely formed arch, virtually a “C” shape. The ankles have to be strong and stable since the dancer has to stand on tips of the toes and to be able to jump and land once again on *pointe*, as well as having to support the upper body and maintain stability. So dancers have to strengthen the ankles, exercise the arches to gain more of an arch and yet the toes must stay straight as an extension of the metatarsals. Ankle injuries are of a high incidence particularly for females because of going on *pointe*. Pain can be experienced in any part of the ankle, but more so when the ankle is not flexible enough or is not strong enough to stand on *pointe* and withstand the weight of the body. Shah (2009) places emphasis on toes being strong enough to support the body when on *pointe* but fails to mention the importance of the ankles, which must be able to withstand the weight of the upper body with strength and stability before even considering moving from *demi-pointe* onto *pointe*. The author also does not link the problem of a flat foot or a very high arch as restricting ankle movement a factor that may prove relevant from this research and therefore bear consideration in any selection criteria.

Training lasts for several years where the dancer learns to initially balance on *demi-pointe* e.g. the forefoot. This strengthens the intrinsic muscles of the foot in preparation for the next stage, which is moving from *demi-pointe* onto the toes (on *pointe*). The dancer needs to have a good range of flexibility at the front of the ankle and the middle of the foot before commencing on *pointe* work. If the ankles have insufficient flexibility then bending the knee in compensation is necessary to be able to fully rise onto the platform of the shoe (i.e. the toe

of the *point* shoe/box) (Shah, 2009). The problem of restricted ankle joint range of motion is irritation of the ankle from trying so hard to rise or trying to rise onto *pointe* before the dancer has achieved strength. Indeed, a weak ankle when on *pointe* creates instability to the rest of the body and resulting in poor balance. Ballet dancers clearly need to develop excellent balance and co-ordination, hence the need for the ankles to be strong enough to hold the dancer firmly on *pointe* upon landing if they are to maintain perfect upper body poise and gracefulness. Landings must appear controlled, effortless and without any sign of instability in the ankle joint area as it must also be visually aesthetic to the audience. Pirouettes (turns) on *pointe* must have control and perfect balance. The range of motion must be balanced constantly against the need for stability.

3.1.6: Toe structure.

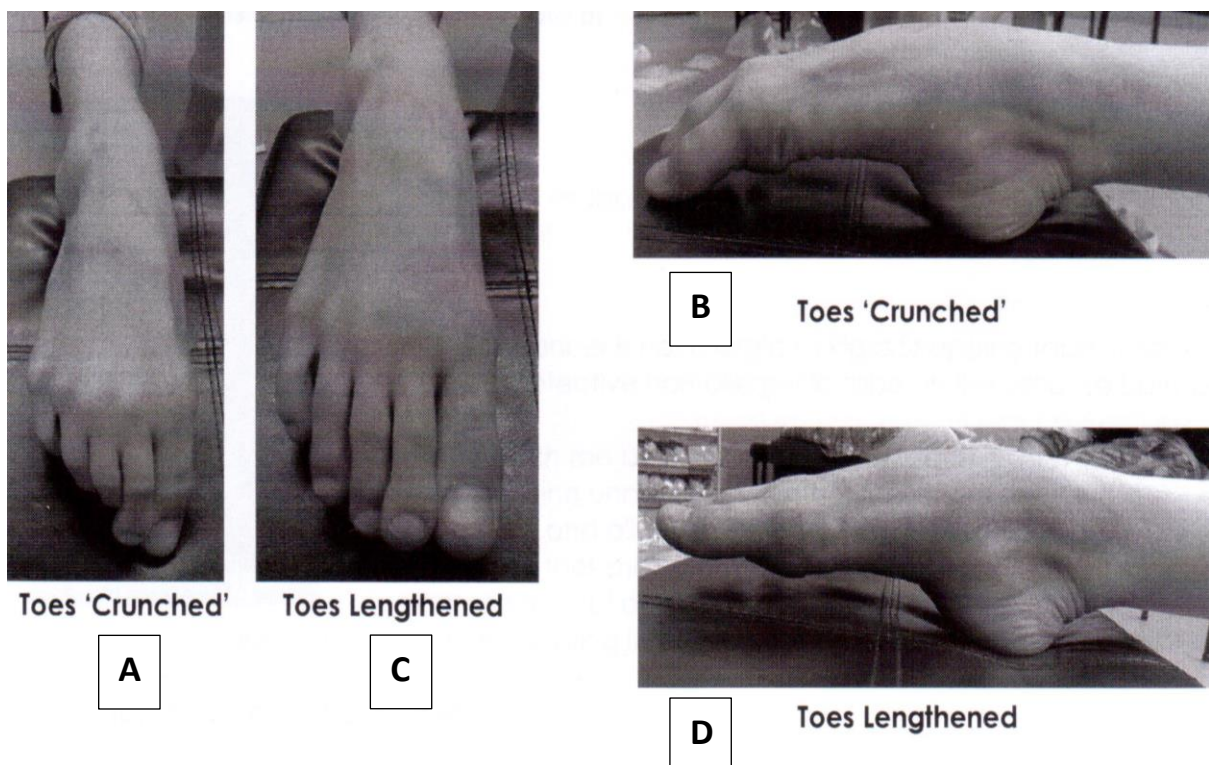
The kinematic relationship between the ankle, subtalar and midtarsal joints (Chapter 2) has a clear influence on foot stability during weight bearing activities including dancing (Russell, 2008).

Apart from needing strong ankles, and sufficient plantar and dorsiflexion, a further issue is the toe structure when on *pointe*. Structurally, the ideal foot for ballet is considered to be a flexible “square foot”, which has equal length first and second toes (Harkness, 2015). The normally accepted digital formula is 2nd longest 1st shorter than 2nd and equal to 3rd then 4th and shortest 5th toe. Normal variation in the population and different foot types and toe lengths can reveal the first toe as the longest or a long third toe in relation to the other toes. Ideally, if the first three toes are of the same length then there is an equal weight distribution. This foot type is rare but is proportionately higher in Brazilian and certain Eastern European

countries where the toes tend to be more square i.e. the same length (I.A.D.M.S. Conference, 2014).

Ideally all toes must extend on *pointe* in that they should be an extended straight line from the metatarsals without the toes bending or plantarflexing (Photo 3.1). In reality this is difficult to achieve for many dancers and it takes years of practice with exercises to achieve this perfect line. Lateral stability of the proximal and intermediate phalangeal joints relies on joint congruency in conjunction with passive (ligaments) and active stability (intrinsic and extrinsic muscles) maintaining a force couple at the respective joints, failure of the mechanism results in plantarflexion of the toes on *pointe*, with resulting injuries to the phalanges and trauma to toenails.

Photo 3.1 - Photo A and B, toes are scrunched and therefore a poor *pointe*. Photo C and D are where the toes are lengthened and therefore create a good *pointe*. (Copyright: Veitch and Swinney 2014).



During landing, to not bear load directly on the tips of the toes may contribute to ankle instability due to poor balance and control since the flexor and extensor tendons of the extrinsic muscles are in part responsible for active stability of the plantarflexed ankle. The injuries to toes range in severity from blisters, callosities to fractures associated with the magnitude of the compressional and shearing stresses. Long-term this leads to degenerative changes leading to *osteo-arthritis* in the joints, particularly to the *metatarso-phalangeal* joint of the first toe. Consistent variation between amateur and professional dancers is the ability to maintain optimal metatarsal and digital alignment when on *pointe*. Amateur dancers fail to achieve the ‘ideal’ rectus position often loading the outer edge of the toes, which buckle (Photo 3.2). This is a significant factor increasing susceptibility to injury and deformity long term. In contrast professional dancers can on the whole able to achieve a ‘rectus’ forefoot alignment due to years of training (see Photo 3.3.). A long first toe creates problems with trauma to the toe and the nail. A toecap or padding can be added to the second toe to equalise load distribution. If the second toe is the longest toe, then padding or a toecap needs to be placed on the first toe to create an equal length (Shah, 2009). Toecaps can be bulky so displacing the other toes laterally creating toe injuries such as bruising, nail damage and ultimately joint deformation. As it is, the *pointe* shoe is tight and restricted and the toes are subject to bruising and nails to injury due to the limited space and the trauma of landing on *pointe* repeatedly.

Photo 3.2 - Amateur dancer who presents with *pes planus* and *hallux valgus* (bunions) having to bend the toe backwards or “scrunch” the toes so that when she moves on *pointe*, this creates instability in the ankle and knee. The weight is pivoted on one small area of each of the first two toes. (Copyright, Parfitt. P, 2015).



Photo 3.3 – A professional dancer who is able to *pointe* on the tip of the toes. (Copyright, Parfitt, P, 2015).



3.1.7: The Ankle.

Research cites ankle injuries as a common concern for dancers with 57% per cent of injuries occurring in the ankle of a study on 204 dancers of both gender (Gamboa, 2008), compared to 74% in the ankle of 77 dancers of both gender (Arendt, 2003). Both authors refer to the ankle in terms of injury site whereas Luk (2013) is more specific anatomically describing *peroneal tendon subluxation*, *posterior impingement syndrome* secondary to a painful *os trigonum*, *posterior talus osteochondritis dissecans*, *flexor hallucis longus tendinopathy*, and *posterior*

tibial tendinopathy. The author does not describe any other injuries to the ankle, which would be useful for health practitioners in treating specific areas of the ankle. Posterior impingement syndrome has been linked to an *os trigonum* being present (an accessory bone formed in the *flexor hallucis longus tendon*). In such cases, moving on *pointe* with the repetition of the *plantarflexion* movement creates irritation to the *flexor hallucis tendon* and impingement of *os trigonum* featuring as pain in the posterior aspect of the ankle. Generally the pain is resolved when the *ossicle* is removed. This is currently a common surgical procedure amongst ballet dancers, once removed the dancer can resume training approximately 9 weeks later although removal of the *ossicle (os trigonum)* may well solve the posterior ankle pain but such a procedure may induce ankle joint laxity when maximally plantarflexed as tendons provide dynamic stabilization during weight bearing (Luk, 2013). Dancers are keen to return to training in order to maintain their position in their schools and dance company; lengthy times out from injury may result in unemployment.

The problem of restricted ankle joint range of motion (ROM) is irritation in the posterior of the ankle from trying so hard to rise or trying to rise onto *pointe* before the dancer is ready. Posterior impingement of the ankle or talar compression is more commonly seen in ballet dancers than in athletes. It is seen with maximum *plantarflexion* of the ankle e.g. on *pointe*, which is a position not seen in other athletes (Quirk, 1982).

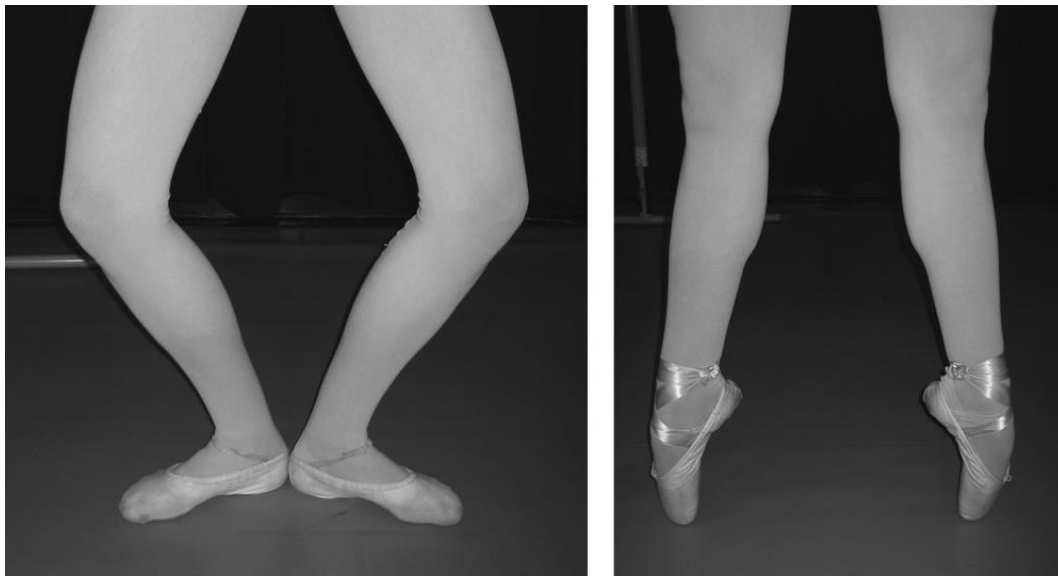
Landing from heights, pirouettes, continuous jumping, and the sheer number of hours spent training, which increase when there is a performance adds to the overuse of the ankle. A *cavus* foot with its inherent rigid midtarsal joints absorbs the energy of impact forces poorly with other joints having to absorb the additional stresses. This foot type is vulnerable to ligamentous strain, fasciitis and stress fractures (Caselli, 2003). The *pes cavus* foot type is

more liable to ankle injuries than a pes planus foot since the high arched foot on point can easily invert at the ankle, particularly when landing on *pointe*. This foot type with its high medial longitudinal arches can present as either rigid or hypermobile. The rigid foot type lacks flexibility with reduced stability and control when on *pointe*, leading to inversion ankle sprains and fractures (Luk, 2013). A less rigid *pes cavus* is more prone to *oversupinate* at the *subtalar* joint. A hypermobile *pes cavus* is an unstable foot type associated also with benign ligamentous laxity as part of general ‘suppleness’ throughout the body and can cause instability through all the lower limb joints. Ankle injuries can occur due to fatigue, leading to instability from repeated landing on *pointe* where abnormal subtalar joint pronation is a factor in the hypermobile pes cavus foot. Knee and ankle strain occur due to a low arch. Fractures at the ankle joint, strains, sprains (particularly the lateral aspect of the ankle) are common (Williams 2012).

The ankle must not roll in or out when on *pointe*, otherwise the dancer will lose her balance, and the dancer should be able to stand firmly on *pointe* for a period of time. This reflects on the stability of the ankle to be able to support the whole body. The ankles tend to internally rotate due to adduction and plantar flexion of the talar head (subtalar joint pronation), which is evident as navicular bulge on the medial side of the foot in stance. The absence of effective passive stability (ligaments) requires the dancer to work hard (contraction of muscles) to control perturbations (Karsavina, 2014). The dancer will often have to work hard to extend the torso, which helps to contract the lower limb muscles. In extreme plantarflexion, the anterior talofibular ligament (ATFL) is under excess strain with the ligament’s inherent weakness and predisposes the dancer to injury (Russell, 2010).

Dancers are expected to be capable of extreme plantarflexion (the whole foot extending fully from the ankle) and dorsiflexion (the whole foot flexes towards the leg). This is achieved in part through natural mobility though the majority of dancers gain the range of motion (ROM) required and ankle strength through extensive exercising, which is on-going throughout their professional career. What defines an adequate level of plantarflexion and dorsiflexion, sufficient for the dancer to go onto *pointe* is not clearly defined in the literature, neither do the dance schools show consistency in their interpretation. Russell et al., (2010), observing ankle ROM range in dancers, noted that female dancers (n = 15) particularly are required to have an extreme ankle motion especially plantarflexion. Russell et al., (2010) measured non-weight bearing and weight bearing plantarflexion on *pointe*, with a goniometer and then with an inclinometer. Details of where the goniometer was positioned on the foot was not described, neither was the ankle described in relation to any particular foot type. The conclusion by the author was that range of plantarflexion increased with ballet proficiency to the detriment of dorsiflexion, suggesting greater training emphasis on foot / ankle extension. In demi-plié, full dorsiflexion is required and on *pointe*, full plantarflexion is required. Photo 3.4 shows both positions of plié and *pointe*.

Photo 3.4 – First photo is plié with maximum dorsiflexion. The second photo shows the dancer on *pointe*, which requires maximum plantarflexion. (Copyright, Russell, 2010).



Russell et al, (2010) considered that plantarflexion was difficult to measure and that goniometers and inclinometers measured plantarflexion differently therefore different results were obtained. This suggests poor repeatability and reliability additional to skin movement which would also influence the results. A larger sample from professional schools would have produced a more robust study. Despite the slight movement in skin on measurement, the goniometer is still the preferred way to clinically measure the foot and ankle and commonly used by podiatrists and physiotherapists in practice. To improve intra-tester reliability of measurements, clinicians are trained to take 3 readings and cross compare (Dickson and Ojofeitimi, 2014). Physiotherapists specialising with dancers assess ankle ROM and suitability for going on *pointe* by using a goniometer to measure the angle of the foot relative to the leg; the references are inferior aspect of the fibula to the middle of the 5th toe. From this assessment a decision is made on the available ROM of plantarflexion. No specific criteria for sufficient range of motion can be given and may be subject to variation in individual dancers. This method is difficult to interpret without a reference framework or scale and may be influenced by age and skeletal development. A further complication is that

it is difficult to assess skeletal development since age alone is not a consistent predictor and radiological intervention may be considered unethical. Joint stability as well as quality and quantity of motion are equally important factors and are influenced by the foot type (Bowerman, 2015).

Considering that literature cites ankle injuries as being a major cause of lower limb injuries, it would seem that a reference framework is necessary to assess when a dancer has sufficient plantarflexion and dorsiflexion movement and when they are ready to move onto *pointe* (Arendt, 2003). Arendt (2003), investigated injuries to 204 dancers with ankle injuries (74%) being the most predominant lower limb injury with males suffering from more shoulder injuries due to lifting of the female dancers. It was a retrospective study and relied on the accuracy of the dancers to recall their injuries. Leanderson et al., (2011) undertook a retrospective study of lower limb injuries for 476 dancers between 10-21 years of age and noted the majority of injuries (76%) were to the ankle. The study reviewed the incidence of injuries from 1995-1998, a more recent study may reflect a change with new insights into training. Although difficult to draw direct comparisons from the results of cited studies without base line information for measurements, this serves to highlight the need for further investigation of the factors surrounding lower limb injury in ballet dancers in order to better inform the individuals, the ballet profession and coaches. The adoption of a multidisciplinary team approach to screening new recruits at both amateur and professional level together with a tailored training program has merit. Whether this approach would effectively reduce injury levels among adolescent dancers without adversely affecting their progress and career prospects would require planning and co-operation of all parties.

3.1.8: Overpronation and pli  .

Pli   is one of the most common exercises performed in ballet. A pli   is a flexing of the knees where the knees bend over the toes while the dancer's heels remain on the floor. The poise and symmetry should be aligned so that looking at the dancer from a side-on view, the knee is exactly over the foot, and the hips turned out to 60 degrees plus. (Photo 3.5 is of professional dancers with good symmetry). By comparison, Photo 3.6 and 3.7 show a dancer with poor symmetry.

Photo 3.5 - Dancers from the Birmingham Royal Ballet performing a *demi-plié*, with the hip and knee directly over the foot. Copyright the Birmingham Royal Ballet - <http://www.brb.org.uk/3945.html>. (Accessed, August, 2014).



3.1.9: Hip and knee injuries.

Each of the five basic positions has a single common dominator and that is the maximum external rotation of the hip (Caselli, 2003). Dancers who present with ligamentous laxity have the potential for superior turnout than dancers who have to work consistently on stretching the hip flexors and adductors to improve the hip turnout. Khamis (2007) suggest that it is poor external hip rotation that makes it difficult for the dancer to bend at the knee in plié, which lead to overcompensation at the foot (Khamis, 2007). This overcompensation presents

as in-rolling at the ankle joints which is achieved by pronation at the subtalar joint and in some instances pronation in the midtarsal joint which allows the forefoot to abduct on the rear foot, referred to by (Khamis, 2007). Yet the consensus is that overpronation of the foot leads to poor external rotation of the leg and hip (Nowacki, 2012). Nowacki, (2012), looked at overpronation on pelvic alignment and found that abnormal pronation of the subtalar and midtarsal joints restricted ROM in the pelvic area. A paucity of literature has focused on this foot posture and the implications on injuries. Nowacki, (2012) is one of the few authors who suggest a link between the two but considers that little is known about the incidence of overpronation related injuries in dancers. Nowacki, (2012) states: *“hyperpronation is a common finding when examining the dancer-patient and is thought to be implicated in several dance related injuries”*. This author measured overpronation by measuring the angle of the calcaneus (calcaneal eversion) in relation to the tibia which is a measuring technique routinely used by podiatrists to determine foot type with the aim of measuring the angles of calcaneal inversion and eversion. Characteristically, a pes planus foot type in the dancer presents with excessive internal rotation of legs with overpronation and the accompaniment of tight hip adductors making it difficult to externally rotate the hips and restricts the pli  . Photo 3.6 and Photo 3.7 demonstrates an amateur dancer with pes planus and overpronation and poor hip turnout occurring in pli  .

Photo 3.6 - An amateur ballet dancer performing a plié who has pes planus with excessive internal rotation of the legs and therefore has difficulty in hip turnout. (Copyright, Parfitt, P., 2015).



Photo 3.7 – An amateur ballet dancer who has pes planus and has to excessively overpronate in an effort to externally rotate the hips. (Copyright, Parfitt P., 2015).



In addition to ankle/foot injury, foot types and overpronation also have implications for injuries to the knee and hip. Knee and hip problems account for up to 40% of injuries in ballet. Despite apparent flexibility, many dancers appeared to have a tight ilio-tibial band which contributes to lower limb problems (Reed et al, 1987). Dance schools emphasise the importance of a perfect ‘turnout’, external rotation of the hips as far possible. ‘Turnout’ requires a combined external rotation of the hip of approximately 60 – 70 degrees and approximately 10 – 40 degrees from the remaining lower extremity (Champion and Chatfield, 2008, Nowacki et al., 2012). Most dancers can achieve less than 70 degrees combined lower limb external rotation (William and Turner, 2005). In reality, average hip turnout is around 60 degrees though in cases of hypermobility at the hip joint this can be increased to 70 degrees and more (McCormack, 2014).

Part of the postural adaption would include the dancer having to tilt the pelvis forward therefore arching the lower back (hyperlordosis). As the dancer forms a small demi-plié and externally rotates at the knees and then extends the legs fully, the dancer needs to grip the toes on the floor to maintain balance in order to keep the hips externally rotated as far as possible. Dancers with overpronation subtly flex at the knees or relax the knee extensors, which allow the foot to roll inwards. The pelvis is allowed to tilt anteriorly, for the hips to move into flexion both of which relax the ilio-femoral (or Y-) ligament of the hip and this allows the hip to externally rotate (Nowacki et al. 2012). Dance teachers will emphasis to the dancer that they must contract the leg muscles particularly *tibialis anterior* which passes around the ankle. They are told to “pull up” these muscles in an effort to prevent overpronation. This is difficult for the dancer to achieve. Those who adopt compensatory strategies can achieve an average of 25.4% extra “functional” turnout; Nowacki et al., (2012), suggest that such extreme compensation has been associated with an elevation of reported injuries by dancers (Nowacki et al, 2012). Hamilton et al., (1994) in a study of Swedish ballet dancers states: “*the increased external rotation of the hip in women was accompanied by a loss in the internal rotation, resulting in an increased range of motion with an externally rotated orientation*”. Generally, dancers are more likely to have difficulty with external rotation rather than internal rotation, as this is the major position required in ballet. Dancers with pes planus who already have to overpronate will need to pronate further i.e. hyperpronate. If the feet of adolescents are turned out further than the rotation of the hip joint allows, the growing ends of the bones can be damaged (Koplan, 2002).

Nowacki (2012), states; “*looking through the literature hyperpronation is cited as a common link to injuries yet there is scant literature in relating the two*”. She cites authors dating back over 20 years (Subotnick, 1975; Tiberio, 1987; Rothbart and Esterbrook, 1988) an indication

of the limited research in this field since the 1980's. Subotnick, (1975) was cited by Nowacki, (2012) as a key author in several current papers for research in sports, particularly running yet dancing was only briefly mentioned in Subotnick's (1975) literature. Nowacki (2102) does conclude that a standard and time efficient method of measuring and grading overpronation is needed and that health professionals should be aware that there is a link between overpronation and its relation to compensatory turnout, and that such overpronation needs to be addressed and treated. In the profession of podiatry where little has been added to research on ballet dance injuries, Schoene, (2013) describes some injuries; her research provides an in-depth description of the most common injuries presented to her clinic and how to treat them, which is a good practical contribution for clinicians. However no link is made between injuries and foot type rather more an overview of injuries experienced in the lower limb by ballet dancers.

To demi-plié, the dancer has feet flat on the floor, bending the knees slowly with both knees in line with the feet and turn out is from the hip joints. The extent to which the knees bend is determined by the length of the Achilles tendon and the suppleness of the calf muscles, (Karsavina T, 2014). The knees become strained on the medial aspect if overpronation occurs (Nowacki et al, 2012) and also the lower back becomes strained, as it has to bend in a lordotic position to compensate. A dancer has to keep a fairly flat lower back for aesthetic purposes and therefore would need to refrain from arching the lower back. If limitation occurs in the external rotation of the hips, then the dancer would overpronate to externally rotate further as a compensatory mechanism. Conversely, a dancer may have a good turnout at the hip and knee but overpronates at the foot not as a compensatory measure but due to a biomechanical anomaly.

Jumping in plié often puts great strain on the medial aspect of the knee when there is not good alignment. The dancer then may overpronate at the foot to compensate for poor turnout (see photo 6) at the hip as well as the knee having to move in front of the medial aspect of the foot but generally it is because the arch is low. Poor turnout and possible inappropriate compensatory strategies were consistently reported as the major cause of injury (Khamis, 2007). Some schools of thought consider that it is diminished hip strength that causes lower limb misalignment (Bowerman, 2015). Bowerman, (2015) considers that research is lacking in the area of lower limb biomechanics and that overpronation may cause misalignment of the lower extremity, frequently leading to structural and functional deficits both in standing and walking since interaction between the foot and pelvis occurs in a kinematic chain reaction manner. Khamis et al., (2007) in their study to induce overpronation at the foot by using wedges under the heels found that this increased internal rotation of the pelvis. When the foot is pronated, it is forced to unlock themidtarsal joint, which medially rotates the knee. The medial aspect of the knees is strained due to overpronation at the foot and certain ballet positions such as plié and landing on *pointe* will aggravate the knee.

3.2: Extrinsic Factors.

3.2.1: Flooring.

Flooring has been considered a key factor in causation of injury due to the properties of the flooring not always being appropriate for dancers (Harlequin, 2007, Hopper et al., 2014). Flooring has to suit the sport for example sports hall floors have different intrinsic factors to identify the composition and construction of floor to fit the sport. A sprung floor is advantageous in gymnastics, basketball or indoor tennis which requires a high degree of

energy return when jumping and landing. The floor therefore has to be constructed to meet demands of the sport (Hopper et al., 2014). Indoor sports people can tolerate a stiffer floor as they usually have cushioned footwear, a luxury not available to ballet dancers with flimsy shoes with no shock absorption (Dance UK, 2010). Scant evidence is available, examining the relationship between floor properties and athletic injury, dancers being subject to rapidly changing lower limb kinematic and kinetic patterns alter leg mechanics and that dancers alter leg mechanics during movement across floors with changing mechanical properties (Hopper et al., 2014).

Literature does reveal that dancers who spend more than 40 hours training on dance floors have been associated with increased risk of stress fracture to the lower limbs (Kade, 2006) and that flooring is a risk factor (Hincapié et al., 2008). Problems of slippage and falling are issues for dancers as they lose confidence and do not perform so well, or jump so high, for fear of injury (Harlequin, 2007).

Hopper et al., (2014) in a retrospective study of 1056 dancers, 20% to 28% of the dancers suggest that floor surface is etiologically associated with the development of a prior injury. The author looked at dance floors at three theatres regularly used by touring professional ballet companies, flooring mechanically quantified with the aim of comparing floor properties with injury incidence in dancers. Test points on the floors were quantified and injuries of the dancers during activity on the three floors were recorded by medical staff. Injuries were recorded if a dancer experienced an incident that restricted the dancer from performing all normal training or performance activities for a 24 hours period. Only lower limb and lumbar spine injuries were recorded. Floor construction mechanical properties varied between venues and a range of floor mechanical properties were observed. None of the floors complied with the range of force reduction values required by the European sport

surface standards. The highest injury incidence occurred with the greatest variability of force reduction magnitudes. No injury between the venues with the highest and lowest mean force reduction magnitudes occurred. The participants had to self-complete questionnaires relating to their injuries, so how adequately and sufficiently the questionnaire was answered was not stated (Sudman and Bradman, 1982). As to the content of the questionnaire, whether or not questions were presented to suggest flooring as a cause and were there are other links to possible cause or if injury rather than just flooring was not mentioned (Balfour, 2013). Although Hopper et al. (2014) discusses the different flooring, the author links the injuries to flooring without suggestion of previous injuries and other variables such as foot type, training, increased training and rehearsals before a performance. Hopper et al., (2014) does qualify that it is not clear if biomechanical adaptations are related to the perceived injury risk associated with the floor mechanical properties which suggests a 'grey area' as to whether flooring causes the problem or if there is a biomechanical anomaly of the dancer's foot that has not been identified. There is a possibility the dancer does not know the cause and therefore implicates flooring and possibly some of the questions on the questionnaire could be misleading. The importance of a 'one to one' questioning is to monitor the response of a participant and to gain clarity from the participant. However, it still remains that there is little evidence relating flooring properties and mechanics to the injury.

Athletes are protected by their footwear from floors that might be considered a slip hazard for dancers, for example some hard lacquered floors. In dance, lower limb problems such as tendonitis, shin splints, knee pain and ankle strain can be attributed to shock wave attenuation through incorrectly sprung floors leading to weeks of physiotherapy and recovery (Harlequin, 2015).

The type of flooring available for a dancer was originally either a wooden floor or linoleum until purpose-developed vinyls were developed during the 1970s where a wooden surface was chosen for aesthetic reasons or a commercial grade vinyl for reasons of cost. Today well-installed hardwood forms a sprung floor if properly finished and maintained. Some ballet companies are affected by cost for example in Russia unfinished pine floors are still used in some traditional Russian dance studios until finances allow for more improved flooring (Harlequin, 2015).

Flooring has improved over the years in that the floor components are multi-layered interspersed with latex qualities (Harlequin, 2007). These components provide more spring and shock absorption. Yet, the multi-layered floors are not without fault and do not suit all dancers. As the dancer lands on the floor, the forces reverberate to the outer aspects of the floor edges and then return with the same forces back to the dancer and up the foot and leg often causing shin splints. If several dancers were on the floor at the same time, then the reverberating forces would increase in intensity, which can cause injury to the ankles, knees and vertebrae (Nigg, 2003). Some dancers therefore will suffer from the reverberations of the forces across the floor, whilst for others there are minimal effects.

Elite dancers in professional dance schools will train full-time which is 40 hours plus per week. The dance surface is one of the extrinsic variables that have great bearing on the dancer's ability to perform adequately. Dance surfaces must provide adequate shock absorption yet be firm enough to provide sufficient energy return to the dancer to enhance performance and reduce fatigue (Caselli, 2003). Various constructions of vinyl sheet will differ from commercial vinyls in that they are formulated to give controlled slip resistance. They are not virtually non-slip like some rubber floors, a property which blocks movement

and is a hazard to dancers. Such non-slip rubber floors have shown to be a cause for injury to tennis players since a rubber soled shoe together with a non-slip floor which has a coefficient of friction when the tennis player attempts to run forward, falling forward as a consequence. Shoe manufactures and tennis flooring specialists have since remedied the problem.

Whilst shock absorption and energy return differs for each sport, there is an additional difference between male and female dancers. Female dancers tend to prefer floors with some sponginess and this may be due to the fact that they land on *pointe* with increased return of shock forces through a small surface area being transmitted to the through the lower limb/vertebrae. The males appreciate a dance floor with more spring for more energetic choreography (Dance UK, 2010).

As the dancer lands, the hardness of the floor is in direct proportion to the force (the body) that lands on it. The forces through the body of jumping and landing maneuvers in classical ballet dancing have been suggested to be as high as 3.5-5 times body weight on total flat foot contact to the ground compared to 12 x body weight on *pointe* (McKay et al., 2005; Dozzi, 2012) .

Most of the major dance schools will have sprung floors incorporated in the training rooms (although not always in all the training rooms). A roll-up portable floor is often used for stage work, which can be transported to the various venues. Flooring chosen for dance can depend on what the flooring is specifically chosen for e.g. portable or permanently laid and cost is a factor.

In contrast, most amateur dance classes are held in Church halls and community venues and do not provide sprung floors due to the multi-use of the halls. Training hours are from 4 hours plus a week, although dancers of intermediate standard train approximately 16 hours plus per week. The floors are hard, lack shock absorption, and have slippage issues.

Considering the kinematics of movement of the body on landing in relation to a flimsy dance shoe which lacked shock absorption, and where only the tips of toes are the point of contact with the floor then the forces and reverberations and injury risk need to be considered for the dancer. This current research will investigate floor structure used for training and stage performance by the participants.

3.2.2: Ballet Shoes.

Unlike other athletes who wear a shoe specially designed to stabilise the foot and absorb shock, the ballet dancer wears a thin flimsy shoe. The majority of the forces of impact, particularly if dancing on a hard floor, have to be absorbed by the lower extremities. It is the lack of shock absorption in a thin ballet shoe or slipper that lead to injury to structures of the foot and ankle/lower limb (Caselli, 2003). Factors that contribute to ineffective absorption of forces from the floor are anatomic variation, improper technique and fatigue (Caselli, 2003). Fatigue could possibly have been mentioned as a factor by this same author as the dancers lands they will “spring” back in response, but if tired then the dancer will land heavily without a responsive spring which results in less shock absorption thorough the ankle and knee joints. Although Caselli, (2003) does not describe in detail the anatomic variations, the author does consider the link between floor and poor biomechanics.

Pointe shoes are made of satin, ribbon, a stiff cardboard midsole, a thin cotton insole and a stiff cardboard outsole. The tip or point of the shoe is glued canvas that forms a hard block and this platform allows the dancer to move onto *pointe*. There are approximately four major companies who design and manufacture *pointe* shoes, and the dancer will have their preferences as to the shoe design. Depending on the company, the shoe variation will have designs for a novice dancer, a shoe for a broader foot, a higher instep (cavus type) and one or two variations, but not extensively since the shoes are made en mass from a wooden shoe frame and cost is a factor. The experienced dancer will usually take the shoe and remove the cardboard backing to bend the shank to match the arch of their foot.

Dancers will wear out 6 pairs of shoes or more in a week, which increases in performances or increased training (Bloch, 2011). Although wear marks may not indicate anything significant due to the flimsy material, they can show particular areas worn that may signify a biomechanical anomaly. The number of shoes worn out in a week, or during a performance could be recorded and to monitor if there is any correlation to foot type. In this current study, dancers shoes will be examined for wear marks, design, and numbers used during training and performances. Whilst dance footwear is confined to ballet slippers, character shoes, boots, or *pointe* shoes, podiatry intervention could help by making adaptations to the inside of the footwear.

3.3: Chapter summary.

There are suggestions that foot type and postural changes of pronation are linked to lower limb injuries in ballet dancers. Literature search cites a good quantity of types of lower limb injuries but there are repetitions of the same research as they are presented in systematic

reviews. There is scant literature on foot types and literature but particularly on foot type, foot posture and lower limb injury. Podiatry is a missing link in offering valuable research in this area, which this thesis seeks to address.

Complexity of the subtalar joint, planes of motion, degrees of rigidity and hypermobility conveys that the joint varies in individuals.

Ground Reaction Forces (shock attenuation) is in proportion to the elasticity of the ligaments which has a bearing on landing on the ground from various heights. The construct between dancers and athletes is unique to dancers in that they use the forefoot more and stand on their toes and landing from heights in these positions. Therefore there are functional considerations when landing on solid or sprung floors together with repetitions of dance moves; all have implications on foot health.

The susceptibility of dancers in comparison to athletes is likely to be different because of the very nature of the dance moves and resulting attenuating shock absorption.

It is apparent that foot and ankle injury incidence is high in ballet dancers. Dancers are historically dancing through injuries to achieve a high standard and to maintain this level, which is required, to perform. The additional fear by the dancer of potentially losing their place at the dance school or dance company through lost injury time increases the risk of more serious or chronic injuries, which shortens their career.

In the literature, there are a number of potential extrinsic factors such as ballet shoe type, flooring components with or with sprung floors, intensity in training hours which are increased in rehearsal and performance time; performances cannot allow any margin of error,

combined with intrinsic factors such as foot type, age, sex, height and weight. These demographics are multi-factorials in injuries reporting.

Amateur and pre-professional dancers may be putting their female dancers onto *pointe* too soon, and there are no set criteria for when to go on *pointe*. Dancers may not be resting sufficiently and there is a concern that this may affect growth plates in adolescents. This thesis seeks to design as part of theoretical underpinning advice on when is the most suitable time to move onto *pointe*.

Relating the literature to theory, location of this discussion can be placed in a framework gathered around intrinsic and extrinsic factors, which may help to predict risk of injury. This provides the underpinning theoretical model for this thesis, explored in Chapters 4 (next chapter) and Chapter 8.

Chapter 4

Theoretical underpinning

4.0: Introduction.

This chapter introduces the conceptual reasoning, which underpins the theoretical framework proposed for the study. It highlights two separate theoretical approaches, which are shown to provide a strong underpinning for the proposed framework, and have been adapted and redesigned in the current study to fit the model of the dancers in injury. The first theory explored and applied is related to injury recording with the model adopted looking at both the injured and non-injured dancer, studying any anatomical weakness. The injury surveillance explores the intrinsic and extrinsic factors relating to the injury and whether the dancer's sporting technique can be adapted to prevent further injury if they fall into the injured table line. The second theoretical model, which again is adapted, is a partial theoretical model looking at all the variables used in the study.

4.1: Injury recording.

Injury reporting for sports injuries in research has been presented in a manner of forms including surveillance of injuries, injury reporting prospective and retrospective, cohort, observation and epidemiological, injury versus non-injury (Van Mechelen, 1992). Epidemiological studies of injuries using prospective and respective injury recording may overlook a degree of vitally missed data. For example, respective studies may have skewed results in that the athletes cannot always record the time, incident and anatomical area of the

injury, so the data may be exaggerated or the athlete may have forgotten key relevant injuries in hindsight of other injuries sustained which they may consider more important.

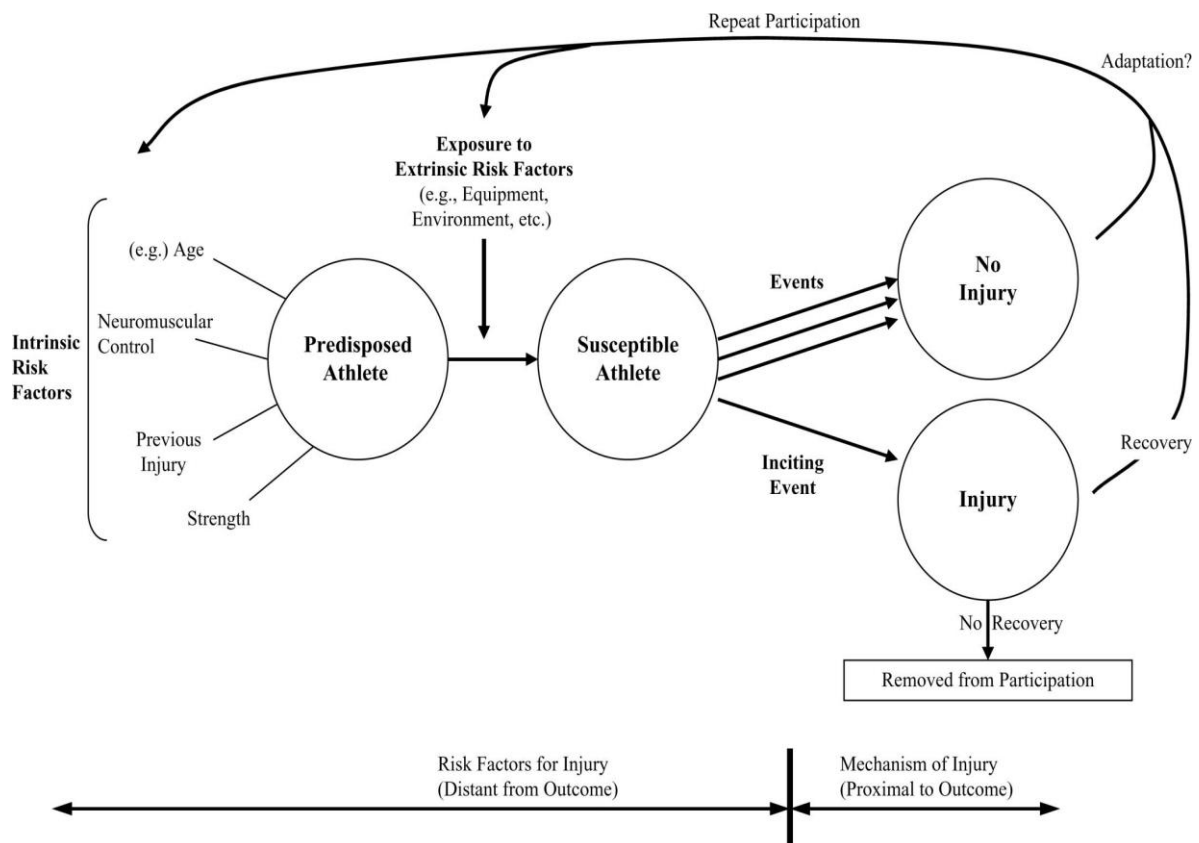
Other studies on injury recording have looked at the number of sports injuries per 1000 hours of sports time exposure (Meeuwisse, 1991). This appears to be a common model used in research yet variables such as increased training or repetition in a move or even the latter of hours in training when fatigue sets and the likelihood of injury incidence would increase, does not seem to be discussed. It appears there is a set model using time but not how the sport changes within that time frame.

There seems to be a consensus that a model needs to be adopted to look at both the injured and non-injured athlete, studying any anatomical, physiological or neurological weakness, and whether the athlete's sporting technique can be adapted to prevent further injury if they fall into the injured table line (Meeuwisse, 1991 and Van Mechelen et al., 1992). Such a model is one designed by Van Mechelen et al., (1992) who based his model on injury surveillance exploring the extrinsic and extrinsic factors in relation to any sport. Though designed for sports injuries the model has relevance for dancers and will be used as a theoretical foundation to underpin this thesis.

Hershman (1984) stated *“risk factors for a particular sport are derived by combining the epidemiology of injuries for a particular sport and the predisposing conditions that may lead to injury”*. This general statement does not address the need for more specific combination of risk factors, which are directly attributable to injury pattern. The enquiry is as to whether a particular set of predisposing and epidemiological factors when combined always lead to specified injury or predisposition to injury. Risk factors can be categorised as intrinsic or

extrinsic (Fuller and Drawer 2004; Bahr and Holme 2003; Van Mechelen et. al., 1992; Meeuwisse, 1991). Meeuwisse (1991) based his research on surveillance of injuries and developed a theoretical model describing the causation of injury (Figure 4.1).

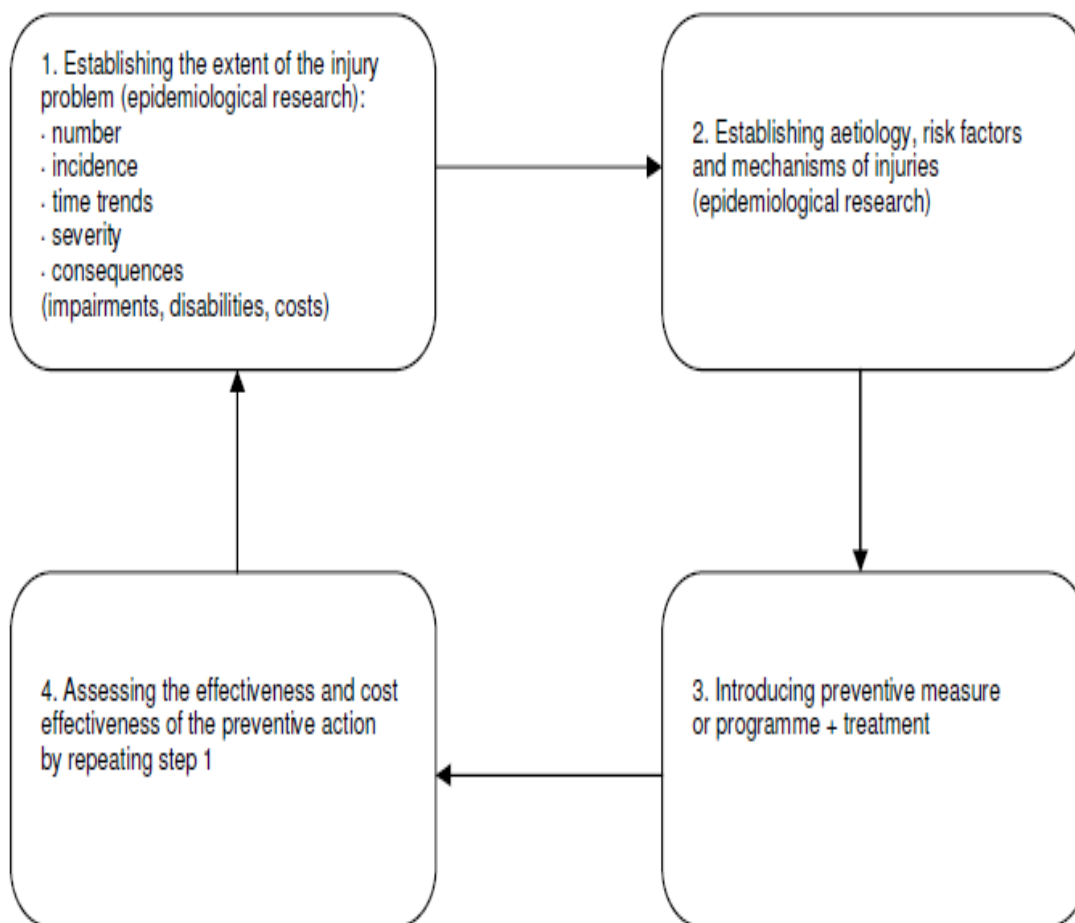
Figure 4.1 - Theoretical Model of Surveillance of Injuries (Meeuwisse, 1991).



Meeuwisse, (1991) surmised that intrinsic factors predispose athletes to injury, but they seldom lead to any injury alone, and it is the combination of both the intrinsic and extrinsic factors that could leave the athlete susceptible to injury. Intrinsic factors are considered to be those specific to an individual participant for example, the participant's age and physiology whereas extrinsic factors pertain to external sources, and would include surfaces, protective equipment and the activity's 'laws' (Fuller and Drawer, 2004). Injury surveillance systems and epidemiological research may serve a number of functions. Whilst Van Mechelen et al.,

(1992) designed a good model from which injury causation could be explored; it was Meeuwise et al., (1994) who expanded on this model on injury prevention. Bahr and Holme, (2003), further developed the model by discussing the need for an inciting event (Figure 4.2).

Figure 4.2 - Model of Injury Causation (Bahr and Holme, 2003).



Meeuwisse (1994) suggests that it is an “inciting event” which provides the final variable in the injury causation model he devised for example ice hockey players receiving face lacerations from their sticks. Lorentzon, Wedren and Pietilae (1988) through their data collection, were able to conclude that 47% of facial injuries would have been prevented by a visor. The inclusion of the inciting event by Bahr and Holme (2003) provided a further

insight into the dynamic nature of injury causation, emphasising that a multitude of risk factors may be involved in injury causation, including position within the playing area and skill, rather than just biomechanical factors. Through epidemiological research in various sports, a greater understanding of incidence and aetiology has been acquired, leading to the implementation of specific intervention strategies and rule changes to reduce injury incidences. Whilst rule changes do not apply to ballet dancers, certainly intervention and prevention strategies are needed from the outset when a ballet dancer chooses to make dance their profession. In this current research, all risk factors will be considered as possible inciting events due to their potential to cause injury.

Meeuwse and Love, (1997) adapted the injury prevention model designed by Van Mechelen et al., (1992). The version designed included:

1. Estimating the burden of morbidity or mortality in population groups;
2. Identifying risk factors and high risk groups;
3. Safety decision making and allocation of healthcare and other resources;
4. An outcome measure for research on injury prediction; and
5. As the basis for assessing the effectiveness of interventional strategies designed for injury prevention.

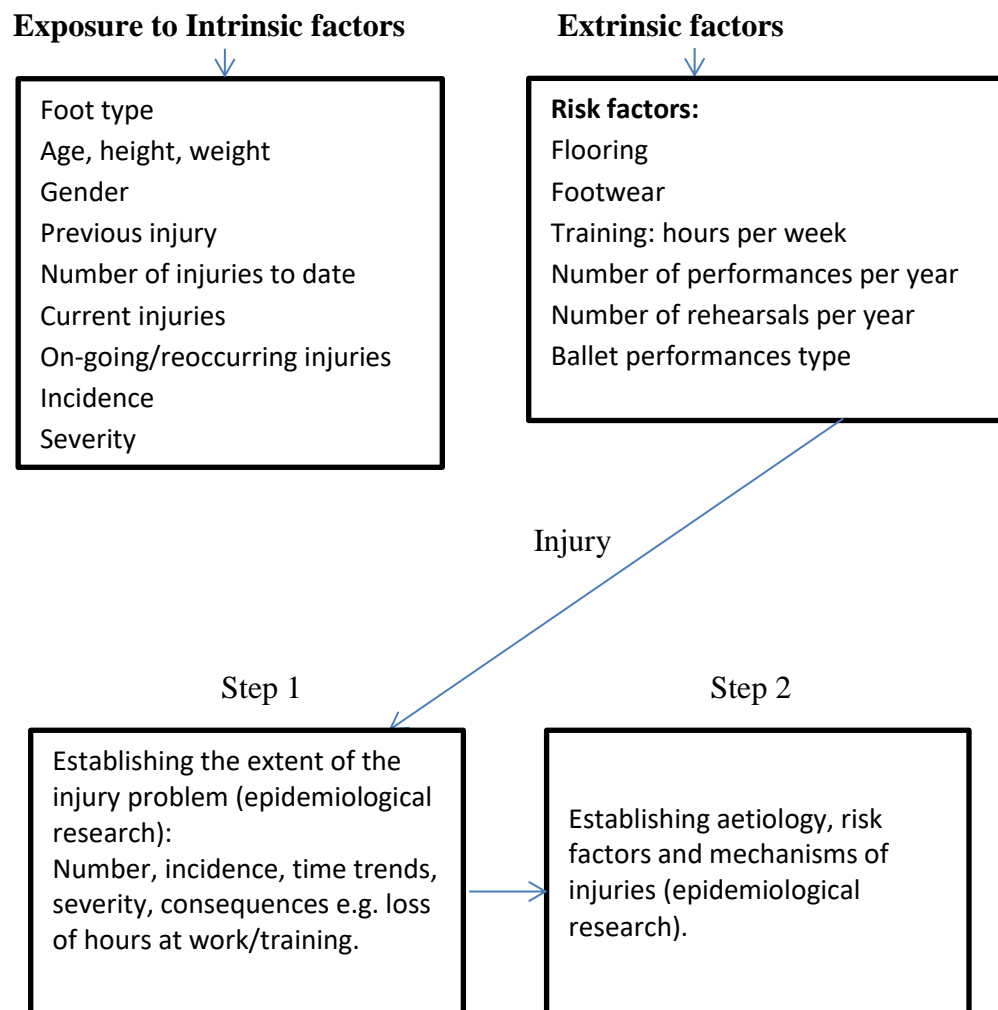
4.2: Interaction of intrinsic/extrinsic factors in dancing.

Bahr and Holme, (2003) examined the extrinsic factors such as the flooring and footwear. Interactions with intrinsic factors such as high arched or very flat feet prone to overpronation, or hypermobility and lax ankle ligaments may lead to a different interaction and cause a new or different injury (Allen, 2012). A dancer who overpronates but exhibits tight hip flexors

may on landing fail to adequately absorb ground reaction forces (GRF) thereby increasing the likelihood of repetitive shockwave related injury. A dancer with greater hip flexibility, less overpronation and internal leg rotation when jumping may lead to increased ground reaction forces (GRF) and therefore increased susceptibility to different injury (Allen, 2012). Injury specific v sport specific, injury surveillance for all sports, does not account for the specificity of individual sports in terms of movement, terrain, footwear. A model would need to be adjusted to reflect the method adopted (Pakkari et al., 2001). Using an adapted model designed for this thesis would be more appropriate to ballet dancers in terms of risk assessment.

Drawing on the model devised by Meeuwise (1991), Figure 4.1, which is non-specific to particular athletes, this current research will apply the model to dancers with some appropriate variations. Intrinsic factors would include pes cavus and pes planus foot types with pes rectus used as a cross reference since it is considered a normal foot type, as well as age, sex, height and weight. Extrinsic factors would include hours of training, hours in performance, number of injuries sustained, current and on-going injuries, flooring, and usage of footwear, amateur and professional and injured and non-injured. Four steps are envisaged (below) however in context of this thesis, only steps 1 and 2 are reported as the foundation for steps 3 and 4 are for future development and are discussed in Chapter 8.

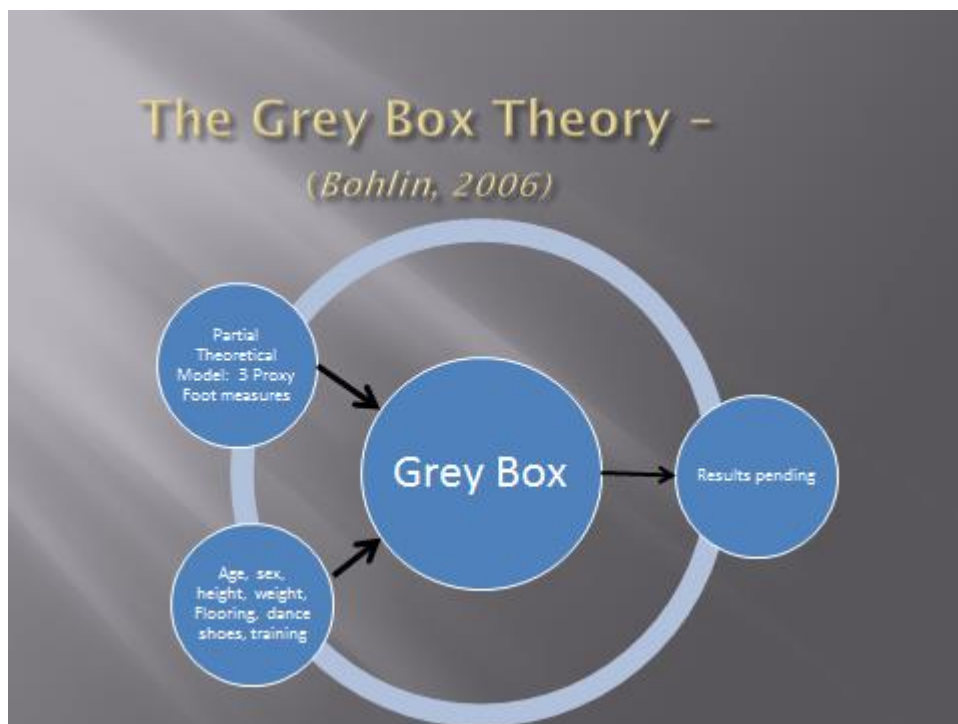
Figure 4.3 – Model of Injury Causation for Ballet Dancers (Parfitt, P., 2016).



The intrinsic factors of foot type combined with the extrinsic factors of flooring, training, and footwear can also be applied to the Grey Box Theory (Bohlin, 2006). In science, the Black Box Theory is a device or object which can be viewed solely in terms of its input and output reactions without any knowledge of its internal workings (Ashby, 1956). An observer will make observations over time of the elements entering the box with a different set of outputs emerging. This is compared to a ‘white box’ or glass box where the inner components or logic are available for inspection. The Grey box model lies somewhere between and combines a partial theoretical structure with data to complete the model, in contrast to the

white box model, which is purely theoretical, and the black box where no model is assumed (Bohlin, 2006). In the current research, foot measures, providing a proxy analysis of foot type can be regarded as a partially theoretical model. Information of the foot measures, combined with training hours, age, sex, height and weight in correlation with floor types and dance shoes enters the ‘grey box’ with observation of the data recorded in the output (results pending).

Figure 4.4 - The Grey Box Theory – Bohlin (2006) – adapted (Parfitt, P., 2016)



Chapter summary

This chapter has investigated injury models as a basis for underpinning the thesis and which could potentially be used as predictors of injury within the framework.

The next chapter introduces the Methodology using the 3 proxy measures of the Calcaneal Bisection, Navicular Drop Test, and Foot Posture Index in measuring foot height to categorise foot type e.g. pes planus, pes rectus and pes cavus, as well as measuring postural movement of pronation. These postural measurements will be applied to two ballet positions the First and Fifth positions since these particularly reveal any biomechanical anomalies if present.

CHAPTER 5

Methodology, research design and study implementation

5.0: Introduction, philosophical context and objectives.

In chapter 4, exploration of the underpinning of this thesis was defined and discussed, concluding that an ‘injury model’ would be a practical method of providing a screening tool to examine the dancer’s foot profile and type before taking up dance at a high amateur or elite level. The adoption of a ‘injury model could provide consistency of approach in foot examination, with reassessment to be repeated either annually or bi-annually and both the dancer and teacher kept informed in terms of advice for potential biomechanical aberrations and injuries. Such evaluation tools would be a guide, which can be referred to, primarily as a foot type guide but with training and treatment to be considered in times of injury; such a model needs to have ease of use and to demonstrate good repeatability. A model to assess the dancer was defined briefly based on a concept by Van Meeuwse, (1991) and revised for this thesis, and the final remodelling will be presented in the discussion chapter.

5.1.1: Study Ethos.

Ballet is as physically demanding as any intensive floor activity such as gymnastics and therefore should be considered a parallel to other sports in identifying risk of injury and the requirement for preventive planning. In the UK, 13 million dancers are registered and it is estimated that up to 95% of those employed for more than one year will suffer significant

injury predominately of the foot and ankle and primarily associated with going on pointe (Allen, 2012). It was concluded that although ballet dancers suffer predominately from lower limb as opposed to upper body injuries, a general consensus among authors highlighted a need for more scientific rigor in the methodology (Allen, 2012). Recommendations are for more improved diagnostics to give robust data involving specific anatomical sites rather than just lower limb segments. This study aims to address some of the shortcomings of general analysis by adopting approved diagnostic considerations. Identification of potential ‘at risk’ anatomical structures will aid treatment planning and avoidance of injury or re-injury.

Chapter 3 also identified that injuries could be more susceptible in the lower limb in relation to the dancer’s foot type (Luk, 2013; Kennedy et al., 2006; Byhring and Bo, 2002). Foot type analysis therefore may provide a basis for screening by dance companies when deciding to take on a dancer at an amateur or pre-elite level; or highlight risk factors associated with foot types of pes planus, cavus or rectus and potential injuries. This information can also be of value to the dancer who may reconsider dance as a profession or at least be aware of the potential weaknesses and where to seek professional intervention at an early stage. Extrinsic variables such as flooring and footwear may additionally contribute to the injury types and patterns being experienced due to the biomechanical forces of landing from a height in repetition, particularly on pointe, combined with thin dance shoes that have poor shock absorption.

All-encompassing time loss for athletes or dancers through injury equates to time lost in sport matches/performances (Hodgeson et al, 2007). Injury risk through training intensity and multiple performances could be amplified with particular dance moves, flooring and flimsy ballet footwear when variation in foot type are factored in, leading to adverse loading

(kinetics) and joint motion (kinematics). These are areas in which Podiatrists may contribute to the dance field. This study explores these factors, particularly foot type, by seeking to answer the following research question:

Primary research question: Do foot types (intrinsic factors) and extrinsic factors of training, flooring and footwear contribute to lower limb injuries in ballet dancers?

Study Objectives:

This study primarily aims to evaluate the impact of foot type on frequency and susceptibility for lower limb injury. Foot type affects foot placement, the ankles, knees and hips in movement and stability and landing from a jump. For example, pes planus coupled with overpronation at the subtalar and midtarsal joints results in strain to the knees and hips. These excessive strains to the joints and musculature increase significantly in relation to the speed and particular sporting moves akin to that sport exacerbated in sport (Kennedy et al, 2007). The implication is that anatomical variance may make the athlete prone to certain injuries. Evaluation and description of a “normal” (rectus) foot can be used as a reference for comparison with pes planus (flat foot) and cavus (high arched) foot types and their effect on the lower limb. The foot can be classified into these three types by means of the Foot Posture Index (FPI) (Redmond et al., 2006), the Navicular Drop test (NVDT) (Nilsson, 2012) and the Calcaneal bisection (Root et al., 1977), explored later.

For the extrinsic factors, training and ballet shoe wear were addressed in a questionnaire delivered in an individual interview and followed by examination of dancers’ current footwear (see appendix vi). Informal discussions on ballet shoe construction took place with dance schools staff and specialist ballet shoe outlets. Floor type was also discussed with

school staff and informal discussions took place with floor manufacturers on construction and composition of floors.

5.1.2: Philosophical position: Ontological.

The philosophical framework of this research is predominately one of objectivism, which underpins the design of this study from which the basis of the epistemological position and methodology of the research have been formulated. As defined by Bryman (2004) objectivism assumes that entities have a reality independent of social interaction and interpretation. Objectivism therefore would suggest that foot types of planus, rectus and cavus, are entities that exist beyond the researcher's influence, as do extrinsic factors of training hours, floor composition and ballet shoes. Objectivism is a key aspect of the positivistic (or natural sciences) paradigm, setting it apart from the subjective constructs of the interpretivistic paradigm (Kuhn, 1970) in which underlying assumptions centre on cognitive or socially constructed realities. This is not to say that understanding objective realities through empirical research can be entirely without doubt, even if the research is rigorously applied. For example, to understand scientific reality we can only work within the limitations of what we know at that particular time i.e. our knowledge evolves as we understand more (Popper, 1972). Therefore we can only use the information we have to understand a phenomenon. That principle is encapsulated in post-positivistic constructs. Whilst positivists accept 'concrete' reality and consider that the researcher and the participant are independent of each other, post positivists accept that theories, background, and knowledge of the researcher may influence what is being observed. In the current research, parameters were explored that claimed to represent a concept, 'foot type' which may be influential on foot injury. There is no direct 'measure' of foot type but three distinct

evaluations of foot morphology and anatomy are applied here and will contribute to understanding. These evaluations necessitate certain measures to be made so locating the paradigm for this research as one of post-positivism in that 3 proxy measures of foot type are applied, being the Foot Posture Index, the Navicular Drop Test and the Calcaneal Bisection method, the data integration of which describes the foot type. Potential user or conceptual errors in trying to evaluate these measures are not necessarily error free. As models, from which spring coherent traditions of scientific measurements, this study therefore links into positivism in relation to concepts of reality and how we understand that reality (Kuhn, 1970) but subscribes more to the post-positivistic views of Popper (1972) that ‘reality’ cannot always be directly accessed.

5.1.3: Philosophical position: Epistemology and methodology.

As noted, the Post-positivistic aspects of this study subscribes to fundamental concepts of positivism. Positivism makes the assumption that reality is ‘concrete’ i.e. it is external, objective and measurable as viewed in the natural sciences. Being objective, claims can be made that research findings (if reliable) are generalizable to a specified research population i.e. relevant to anywhere that the phenomenon occurs in a defined group of individuals such as ballet dancers. Since it relates to an external reality, this means that the researcher can remain detached from it and therefore context-free; that is the research is ‘on’ something and not ‘with’ something (Bryman, 2004). The development of positivistic epistemologies are rooted in empiricism, a longstanding philosophical tradition (e.g. Locke; 17th century) that considers the only route to knowledge is through the application of our senses to ‘experience’ (i.e. measure) the external phenomenon. Scientific statements therefore can be attributed to

that domain whereas normative (i.e. non-scientific) statements that cannot be confirmed by the senses place such knowledge in a very different epistemological position appropriate to interpretivism. (Post)-positivism affirms a research approach associated with an epistemological viewpoint that is quantitative, whereas interpretivism is associated with qualitative approaches. Quantitative research is described as the systematic empirical investigation of observable phenomena and its data is expressed in a numerical (statistical) form (Bryman, 2015), whereas qualitative measures are contextual: they could take the form of narrative, recorded interviews, observation of participants, or taking notes. Words rather than numbers are normally applied supported by associated relevant analytical strategies for example thematic analysis, but the individual, subjective nature of qualitative data makes it sensitive to potential researcher and/or participant bias (Bryman, 2012). For this study measurements of quantitative data were required which had the benefit of mathematical verification of patterns and relationships within the data critical to answering the research question. Table 5.1 below contrasts the main principles of quantitative and qualitative approaches.

Table 5.1 – Comparison of quantitative and qualitative approach (Copyright, Bryman, 2015).

Quantitative	Qualitative
Numbers (applying measurement procedures in social life)	Words (using words in the presentation of Analyses of society).
Point of view of researcher (question setting)	Point of view of participants
Researcher distant	Researcher close (involved with the subjects)
Theory testing	Theory emergent
Static	Process
Structured	Unstructured
Generalisation (able to test hypotheses But may miss contextual information)	Contextual, understanding (time consuming)
Hard, reliable data (numbers/statistics)	Rich, deep data (words/pictures)
Macro (large scale trends)	Micro (small scale aspects of reality)
Behaviour	Meaning
Artificial settings	Natural settings

The questionnaire was delivered within an interview setting and was designed with closed questions seeking information, with a numerical coding used in the data analysis. The interview structure therefore was driven by the questionnaire. Whereas the researcher in qualitative research will try to open up the interview and will become involved with the subjects to enable them respond fully, in quantitative research the researcher keeps objective, although a warm and professional approach is still used to extract the best from the participants so that they can engage and feel confident and secure enough to answers the questions with thought rather than a quick and dismissive approach. An interview room is used which can imply an artificial setting; yet such a room will also evoke professionalism. A qualitative approach inclines more to a semi- or unstructured interview with the researcher usually still working from a guideline but also being open to whatever direction the

interviewee may take. The quantitative questionnaire is structured in this study with the option to skip questions if considered not appropriate.

In quantitative research measurement validity applies predominately to the search for measures of social or physical concepts; it relates to the tools used (Bryman, 2015). A measure that is devised of a concept must reflect the concept that it stands for and this is termed ‘construct validity’ (Bryman, 2015). This proves a complex problem with qualitative researchers who consider that the term ‘measurement’ does imply carrying out measurements rather than non-quantitative assessment. Furthermore, the terms reliability, validity and generalizability normally used in quantitative settings are difficult to apply for qualitative research where social settings cannot be replicated; data are subject to the interpretation of the participant and researcher. Another debate is on social research methodology and on how the inquiry should proceed and which method of qualitative versus quantitative approach is more scientific (Clough 2007, Cresswell, 2008). Dawson (2010) considers that different methodologies become popular at different social, political, historical and cultural times and that all methodologies with their strengths and weaknesses should be acknowledged and addressed by the researcher. Indeed Bryman (2008, p 523) states: “that he debates whether qualitative research is conceptualized as a distinctive epistemological stance or as a cluster of research methods”. However, “the view that the two approaches (i.e. quantitative and qualitative) are mutually exclusive has itself become ‘unscientific’” (Greenhalgh, 2009; p 352). For the current research, the data analysis is dependent on correlative outcomes and this is its strength in answering the research questions. However, since there are a few informal interviews with dance teachers and floor manufacturers, this could potentially add in a qualitative element and therefore the methods are blended.

In summary, the ontological and epistemological positioning of this study is as follows:

Paradigm: Post-positivism

Reality: external/objective

Epistemology – Quantitative

Focus – biomedical

Data: Numeric; reliable, generalizable.

Assumptions: concrete realities

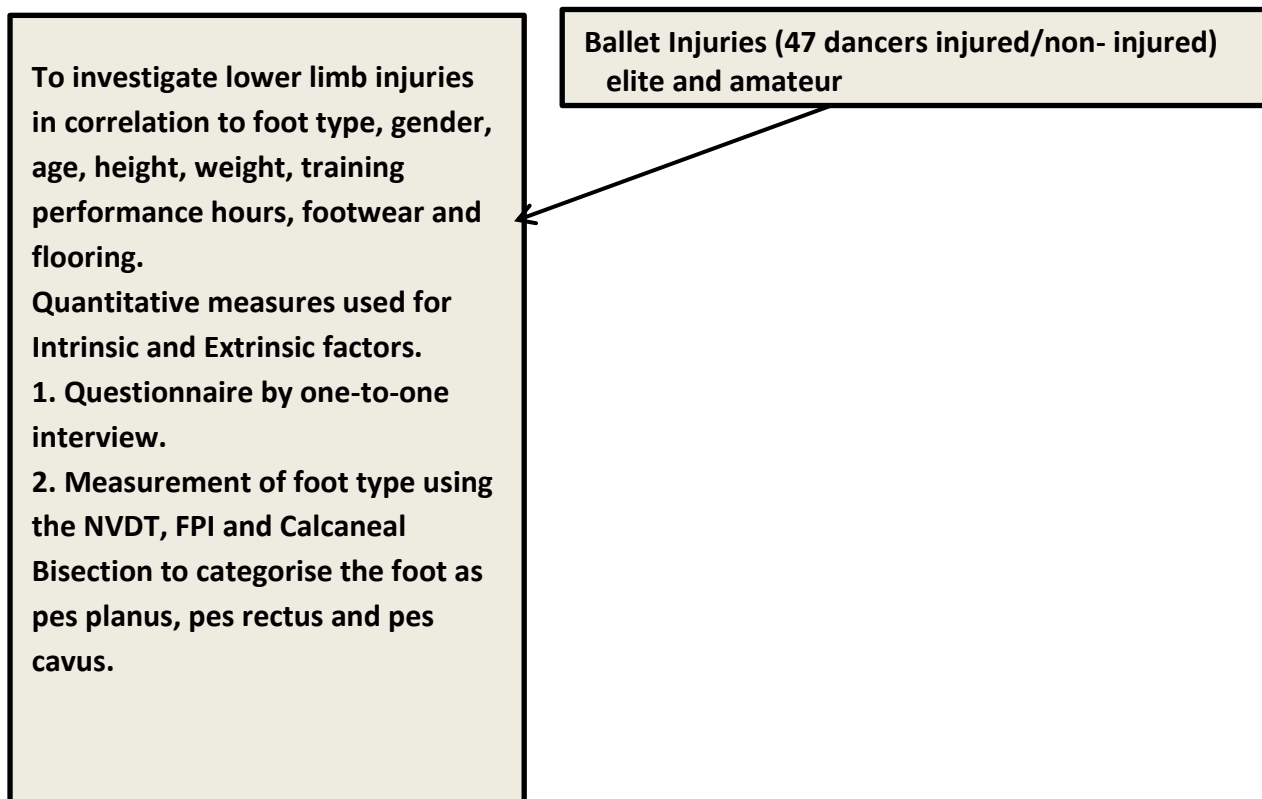
5.1.4: Research design: overview.

The chosen methods are consistent with an exploratory research design appropriate to the research questions that entails quantitative assessments. The methods discussed in this chapter are divided into two aspects, firstly an interview with a questionnaire seeking information on dance background, injury record to date, training and performance schedules, flooring and footwear assessment. This was followed by the measurements of the foot to define the foot type (see Figure 5.2 below which is a summary of the design). Sometimes data do not naturally appear in a quantitative form but can be collected in a quantitative way by designing research instruments specifically aimed at collecting and converting phenomena that do not naturally exist. Questions asking participants interpretation of causes of their injuries related to a limited range of answers (e.g. overtraining, competition to gain a place in a dance company, tiredness, dancing through an existing injury, footwear) and participants were asked to give each of these a rating from 0 to 5 where 0 = disagree strongly, and 5 = agree strongly. These phenomena can then be analysed statistically.

In terms of how the research was implemented, interviews for the questionnaire were undertaken prior to taking the 3 proxy foot measurements as this personal contact provided an

opportunity to confirm consent helped with the introductions and informed the professional ‘eye’ when observing the individual dance. Informal discussions regarding training, flooring and ballet shoes, took place both before and after the interviews with the participants and so added further context and a qualitative mixed blend to the study. Informal discussions with floor manufacturers dance teachers and ballet shoe companies, was on going in communication over two years.

Figure 5.2. - Overview of the study design.



5.2: LOCATION OF THE RESEARCH, AND RECRUITMENT

5.2.1: Setting for the research: dance schools.

The study was designed to incorporate dancers from both amateur and professional schools. Each school has a different method of teaching and sampling from three professional and two amateur schools gave an indication of individual dance methods and the number of performances. The difference between the amateur and the elite schools in terms of training hours would be approximately 40 hours a week in the elite professional schools whereas in the amateur schools training would be up to 8 hours plus inclusive of pointe work. Even though the amateur dancers would train fewer hours, they would likely still be pursuing a dance career, and often these dancers would be auditioned for professional schools around the age of 14 to 16 years. All of the amateur participants had to have parental consent.

For convenience, amateur schools were approached in a county local to the researcher which enabled participants to attend the author's clinics. The teachers from the schools approached were keen to be included and were able to advise which were the best training classes to observe, and able to match the dancer with the requirement of the study, which was at least Grade 6 dance qualification, i.e. Intermediate-plus, by which time the dancer would dance on pointe.

Data gathering for the pre-professional (elite) schools took place on site and for the amateur dancers, in the podiatry clinics since the amateur schools were located nearby to the clinics. The schools were visited initially in order to assess the most appropriate rooms for both the interviews and the foot measurements. Due to the demands of training schedules flexibility

on the part of the author and repeat visits were necessary. The researcher had to accommodate to last minute changes in routine, which encompassed having to wait for periods before the next influx of participants, were available. It was important to accommodate to the routine of the school entailing several visits to each school otherwise lack of flexibility would block any further access.

The elite schools were more challenging and evasive than the amateur ones possibly due to tight training schedules and performances away from the school. Participants were only available at restricted times. Discussions with the school Principal were followed up by a letter of invitation to dancers which explained the study (see appendix iv).

The three elite schools chosen were of high calibre with the dancers moving onto professional dance companies. The schools understood that a large sample of dancers was preferable. An information sheet was provided and time afforded to each participant explaining the nature and content of the interview i.e. foot measurements and a questionnaire on the day of the interview (see appendix v).

5.2.2: Recruitment methods.

Initially, both amateur and professional schools were contacted by letter and followed up by email. Information sheets were given to explain the study. The Principal and teachers put forward potential participants who had repeated injuries and who they were concerned about. Many dancers came forward when they heard of the study and were interested in taking part. The elite ballet schools had a mix of female and male dancers, even though there were higher numbers of females and were selected purposively by the researcher whilst observing the

dancers in training, for example a few observed who for overpronation were invited. Other dancers were not chosen for any specific reason other than to try to achieve a balance of males and females, although females predominated in the final sample. The amateur schools had smaller numbers of students and participants were selected by convenience i.e. those who were available on the day of the study, but also may have been suggested by the Principal, or following a direct approach by students who wished to participate. Again there was a predominately female to male ratio in these schools.

5.2.3: Recruitment criteria.

The age group chosen was between 14 years and 29 years, a range, which encompasses adolescent dancers who are becoming proficient on pointe, up to the usual age when professional dancers retire. Dancers carrying an injury, or having a history of injury, as well as non-injured dancers were of equal value to study to see if there was a correlation of injury to foot type, or none. Convenience (those available on the day) and purposive (those suggested by the schools) sampling enabled consideration of large numbers of dancers prior to screening. Recruitment involved a combination of the physiotherapists and dance teachers suggesting dancers who already had injuries, repeated injuries or were chronically injured, as well as dancers who chose to take part on the day, and dancers who were keen to be involved. During recruitment the researcher was however unaware of precise details of a history of injury or those who were currently injured.

5.2.4: Inclusion and Exclusion criteria.

Any dancers outside the age group parameter of 14-29 years were excluded since they did not represent the majority of the performing dancing population. Dancers below the age of 14 years were not chosen, as they were not yet on pointe. Since most dancers retire in the twenties age group, and under the advice of the dance schools, 29 was considered to be the upper limit for this study. Although there are professional dancers beyond this age group, they are considerably fewer in number than the twenties age group.

Inclusion criteria therefore were:

- Age group would be from 14 years to 29 years.
- Elite, semi-elite or high amateur standing were eligible (Grade 6/Intermediate).
- Dancers were eligible even with current or prior history of lower limb injury, no limitations were applied on the basis of number of frequency of injury.
- Dancers were chosen whether they had a lower limb injury or not. Dancers with injuries of the upper body (with the exception of the back), shoulders, head, and arms, were not included in the selection to maintain the focus on limb/foot/ankle injury.
- Male and female participants were equally eligible, though larger numbers of females took part due to the attraction of the discipline.
- All dancers from the amateur school had to be of an intermediate standing (i.e. Grade 6) a level that could be considered for a professional school intake.

Inclusion of amateur and elite dancers allowed the study to incorporate a wide range of dance experience e.g. from amateur dancers who train 3 hours plus per week to elite dancers who train 40 plus hours per week. Ensuring a gender mix enables a comparison of gender data

important because of the different requirement of dance moves and jumps, and the gender experiences regarding flooring in terms of injuries. The age group was essentially adolescent and young as this is the time of greatest stage performance. Adolescence is the time of bone growth and completion of ossification of certain foot bones, which may affect the foot type.

Exclusion criteria:

- Dancers outside the age parameters of 14-29 years.
- Dancers less than Grade 6 ballet and those not on *pointe*.

Total recruitment was 47 dancers. The professional schools total number of students were one school: 100 (16 recruited), a second school 70 (15 recruited), and a third school 90 (6 recruited). The amateur schools had smaller numbers of 40 (3 recruited), and 50 students (3 recruited). Initially there were higher numbers recruited (71) but many of the dancers could not be present where repeated measures were required (see later) either because they were performing or for other reasons not stated. Time restriction limited recruitment of even higher numbers. Further, even though professional schools advised they would take part in the study, in reality it was difficult to get dancers to attend the interviews as timetables would have changed on the day or dancers may be away due to illness, or because measurements would take longer than the dancers had expected and therefore had to leave. The constrained sample is a limitation of the study but discussions with a statistician at Anglia Ruskin University reinforced that 47 dancers was an adequate sample size to go forward as this is an exploratory study. At least 30 participants are recommended by some writers in this respect (Cohen, Manion & Morrison 2011).

5.3: Research Methods.

5.3.1: Introduction.

The variety of classical methods used to measure the foot in both static and dynamic posture is limited for example ankle dorsiflexion and plantar flexion requires accurate measurement to assess if there is any limitation in range of motion; this is particularly needed for female dancers before they move onto pointe. The measurement of choice still is the goniometer for dorsiflexion even though the instrument is not always accurate (Dickson et al., 2014). Plantarflexion is more difficult to measure and inclinometers are still the measure of choice since there have not been any new developments in design (Russell, 2012). Whilst for measuring foot arch heights, there has been great controversy over the years and debate as to what would be the most suitable measurement to use. (Kirby, 1997; Levinger, et al., 2010). Some measurements used over decades in a clinical setting have not always proved reliable (Nielson, 2012; Redmond et al., 2006) due to inconsistencies arising from variations in foot posture classification and methods of biomechanical modelling methods (Hunt, 2010). The methods used have included static, open kinetic chain goniometric evaluation, and dynamic observations of the feet without applying a measuring framework. Whilst these methods have provided useful information, they are not shown to be reliable or consistent for clinical measurements. For example goniometers are subject to movement of skin, and two clinicians may achieve different measurements on the same subject (although minimal), which limits their methodological strength in research yet from my professional experience it is clear that the goniometer is still the measurement of choice in the clinical setting for convenience and cost.

Various measuring tools are available and the benefits and disadvantages therefore have to be considered. Such tests as placing bone pins into live subjects to observe movement within the joints (Nester, 2006) are clearly not feasible within the boundaries of this study. Radiological examination of the foot bones to allow precise measures of joint positions may provide a ‘gold standard’ but in reality are also unfeasible in the current setting. Another approach, the Oxford Foot model, using a Vicon 3-D camera (240 Hz, Vicon Motion Systems, Ltd., Oxford, UK), motion analysis system with markers placed on foot and leg segments does have merit when assessing motion of the foot in larger segments. However, skin markers are subject to the same limitations of skin movement relative to the underlying osseous structures (Stebbins et al. 2015). This model claims to measure segments of the foot and leg but it cannot accurately measure the movements of each of the individual foot joints such as the subtalar and midtarsal, since it can only measure larger segments of the foot. Therefore this tool lacks precision in measuring overpronation (Stebbins et al., 2015). The specialist equipment also is expensive.

Other measures have been used over the decades to ascertain the medial longitudinal arch (MLA) height such as an ink print (pedobaragraph) taken of the weight bearing plantar aspect of the foot (see Figure 2.8, Chapter 2). The foot type is assessed by the absence of ink in the MLA on the print e.g. imprint in the MLA (low arch) assessed as pes planus, no imprint in the MLA, then the foot is defined as pes cavus. This observational assessment can be difficult to interpret especially when considering a ‘normal’ or rectus foot, resulting in poor intertester reliability. Modification with the overlay of a grid pattern (1 centimetre squares) offers some opportunity for scaling by measuring the area (number of squares in the medial longitudinal arch) not imprinted with ink. However, Razeghi and Batt, (2002) suggest that “*direct*

measurement of the highest point of the medial longitudinal arch (MLA) in the sagittal plane is one of the simplest methods providing the clinician with quantifiable information regarding foot structure". The prominent navicular bone represents the highest point of the MLA and a ruler may be used to measure the distance between this point and the supporting surface. Alternatively, the highest point along the soft tissue margin of the medial plantar curvature may be used as the reference point but this is subject to inconsistent interpretation and error due to skin movement. Instrumented measurement with callipers may improve the accuracy and consistency of the measurement. However, inaccuracies occur due to movement of soft tissue and therefore the measurements would be unreliable, though if it was only marginal movement then it could be a possible consideration. A more reliable alternative for measuring arch height– the Navicular Drop Test – was eventually applied in this study (below). The added advantage of that test is that it provides a direct rather than eye-balled measure of pronation.

5.3.2: Foot Posture Index (FPI).

The assessment method for foot type evaluation chosen for this research was the Foot Posture Index (FPI) which is used widely in research by both Podiatrists and biomechanical specialists to assess the foot type in a relaxed stance (Redmond et al., 2006). It is easy to use and requires the subject to stand barefoot in stance. The calcaneus is bisected vertically and using this as a guideline of overpronation and oversupination, the clinician observes the feet from behind the subject and counts how many toes are to the right and to the left of each foot, which indicates a pes cavus or pes planus, or if equal or non-apparent, then a pes rectus foot. The talus is palpated above the calcaneus and depending how much is palpated either medially or laterally, as well as observed medially or laterally, or neither, defines the foot

type (Barton et al, 2010). Foot Posture Index (Table 5.3) is an observational scoring system devised by Redmond et al, (2006) originally assessing eight elements of foot posture and then refined to the current system of six elements (Redmond et al., 2006) and a reference point of neutral, pes planus and pes cavus defined by scoring the individual elements (+2, +1, 0, -1,-2) to achieve a total score between, (-12 - +12) where -4 (supinated foot) to +4 (pronated foot) are defined as 'normal' or neutral (see Figure 5.2). The FPI is purported to have good reliability (Intraclass correlation coefficients = 0.62–0.91: Redmond et al., 2006) and validity (Evans et al., 2003; Noakes et al., 2003; Yates et al., 2004; Menz et al., 2005; Chuter 2010). The 6 elements of the assessment are undertaken while the participant is viewed standing barefoot. Three of the assessments are observation of skin contours (lateral malleolus, medial arch curvature and talo-navicular bulge). One element considers angular displacement of the calcaneus (inversion / eversion) and finally counting the lesser toes for forefoot to hind foot alignment. In the later toe counting, the clinician observes the subject from behind and counts how many toes are visible to the right and to the left of the hind foot. The talus is palpated above the calcaneus and depending how much is palpated either medially or laterally, as well as observed medially or laterally, or neither, defines the foot type (Barton et al, 2010). The FPI is proposed to have good repeatability and validity (Menz et al., 2005). Care is required in the interpretation of the observed elements to achieve consistency of outcomes and the limited scoring options reduce the opportunity for wide discrepancy. However, since it is a scoring system widely used in research, due to its validity, repeatability and ease of use, and describes the arch of the foot, then this system will be used for this thesis (Menz et al., 2005, Evans, 2003).

Figure 5.3 – The Foot Posture Index. Copyright Leeds University, Redmond, A., and Keenen A. (2007).

THE FOOT POSTURE INDEX® **FPI-6**

Reference Sheet

The patient should stand in their relaxed stance position with double limb support. The patient should be instructed to stand still, with their arms by the side and looking straight ahead. It may be helpful to ask the patient to take several steps, marching on the spot, prior to settling into a comfortable stance position. During the assessment, it is important to ensure that the patient does not swivel to try to see what is happening for themselves, as this will significantly affect the foot posture. The patient will need to stand still for approximately two minutes in total in order for the assessment to be conducted. The assessor needs to be able to move around the patient during the assessment and to have uninterrupted access to the posterior aspect of the leg and foot.

If an observation cannot be made (e.g. because of soft tissue swelling) simply miss it out and indicate on the datasheet that the item was not scored.

If there is genuine doubt about how high or low to score an item always use the more conservative score.

Rearfoot Score	-2	-1	0	1	2
Talar head palpation	Talar head palpable on lateral side but not on medial side	Talar head palpable on lateral side/slightly palpable on medial side	Talar head equally palpable on lateral and medial side	Talar head slightly palpable on lateral side/ palpable on medial side	Talar head not palpable on lateral side/ but palpable on medial side
Curves above and below the malleoli	Curve below the malleolus either straight or convex	Curve below the malleolus concave, but flatter/ more shallow than the curve above the malleolus	Both infra and supra malleolar curves roughly equal	Curve below malleolus more concave than curve above malleolus	Curve below malleolus markedly more concave than curve above malleolus
Calcaneal inversion/eversion	More than an estimated 5° inverted (varus)	Between vertical and an estimated 5° inverted (varus)	Vertical	Between vertical and an estimated 5° everted (valgus)	More than an estimated 5° everted (valgus)
Forefoot Score	-2	-1	0	1	2
Talo-navicular congruence	Area of TNJ markedly concave	Area of TNJ slightly, but definitely concave	Area of TNJ flat	Area of TNJ bulging slightly	Area of TNJ bulging markedly
Medial arch height	Arch high and acutely angled towards the posterior end of the medial arch	Arch moderately high and slightly acute posteriorly	Arch height normal and concentrically curved	Arch lowered with some flattening in the central portion	Arch very low with severe flattening in the central portion – arch making ground contact
Forefoot abd/adduction	No lateral toes visible. Medial toes clearly visible	Medial toes clearly more visible than lateral	Medial and lateral toes equally visible	Lateral toes clearly more visible than medial	No medial toes visible. Lateral toes clearly visible

For further information, manuals and extra datasheets see: www.leeds.ac.uk/medicine/FASTER/FPI/

5.3.3: The Navicular Drop Test (NVDT).

The second measure chosen for this research is the Navicular Drop Test (NVDT), which again is widely used by clinicians and researchers (Adhikari, 2014; Allen et al., 2000; Nilsson 2012). The navicular identifies the highest point of the medial longitudinal arch in the mid tarsus (Root et al., 1971). Sagittal plane changes in navicular height occur with subtalar joint pronation and resupination (Kirby, 1997). Measuring the subject barefoot in its natural stance (referred to as the Resting Calcaneal Stance Position RCSP), the prominent and inferior aspect of the navicular is palpated and marked. Using a metal measuring tape, the distance is measured from the floor to the skin mark to provide a measure of the height of the medial longitudinal arch (MLA) (Brody, 1982). The foot is then palpated and moved into subtalar joint neutral (corrected position) and the measurement repeated. The difference between the two measurements is the arch depression associated with subtalar pronation. Normal parameters for MLA height and MLA range of motion range between 3.6 cm – 5.5 cm and 0.6 to 1 cm respectively. A change of 1 cm between subtalar joint neutral (STNJ) and RCSP for example would be considered as overpronation. A normal foot could still potentially have an excessive foot drop of over 1cm (Mueller, 1993). To clarify a cavoid foot type would exhibit a STNJ of greater than 5.5 cm and a navicular drop of 0.6 cm or less.

A pes planus foot having a flatter arch meaning that the bony landmarks of the navicular, cuneiforms and subtalar joints are closer to the ground, would show less change between the Resting Calcaneal Stance Position (RCSP) and a STNJ than a pes rectus and pes cavus foot type. Photo 5.3.2., shows the skin mark on the navicular bone with the dancer standing on a wooden plinth in resting stance (RCSP) for the measurement for the NVDT. This measuring

tool is considered reliable, valid, and repeatable as well as easy to use and is widely used in research in defining the foot as pes planus, pes rectus or pes cavus (Adhikari, 2014, Nilsson, 2012). As a precaution, this current study applied repeated measures to evaluate performance of this measure in the current study. It is usual for 3 x repeat measurements to be taken (Shrader et al, 2005, Shultz et al., 2006).

Photo 5.3.1 – The Navicular Drop Test where the foot is in normal stance on the wooden plinth with the inferior aspect of the Navicular bone marked by a skin marker. This is the RCSP or foot in a normal resting position. (Copyright, Parfitt, P., 2015).



Photo 5.3.2 – Measurement from the floor/base of foot to the Navicular, measured with a metal tape. (Copyright, Parfitt., P., 2015).

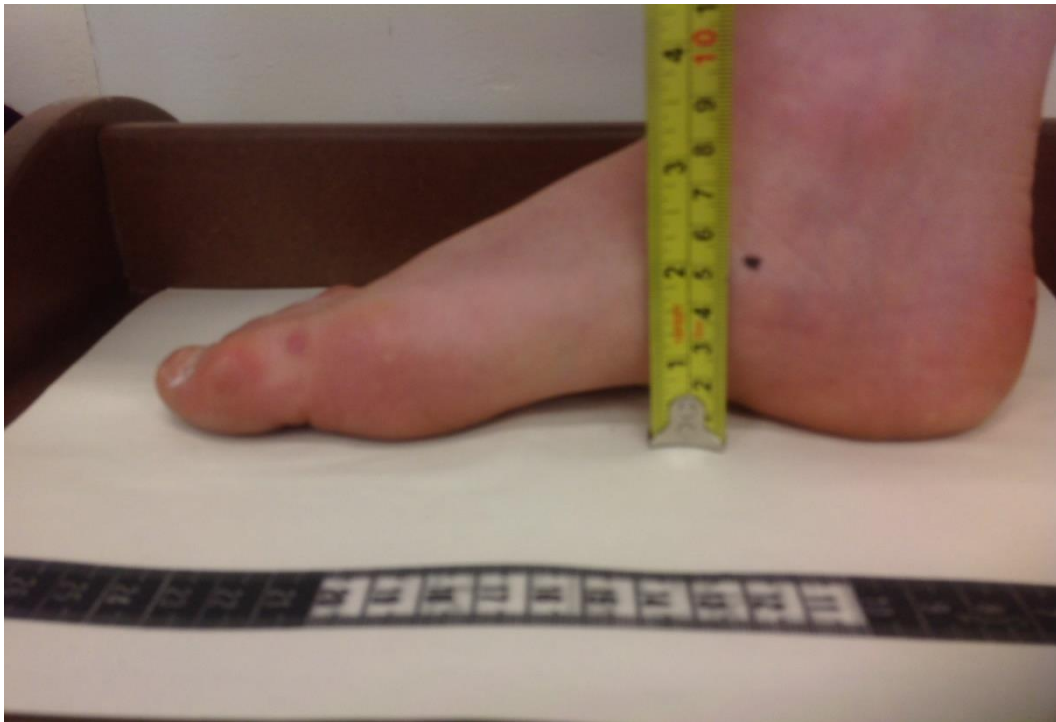
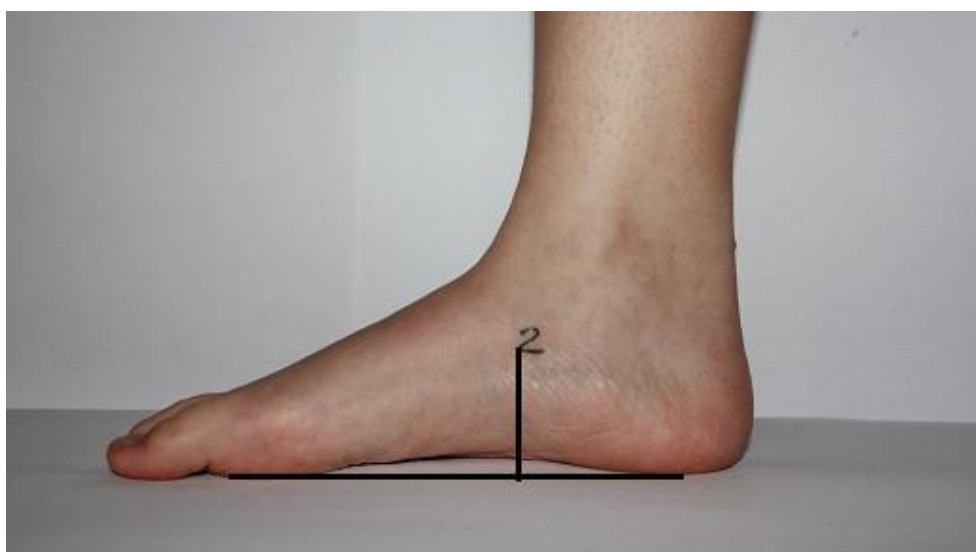


Photo 5.3.3 – Measurement from the floor/base of foot to the Navicular in the study by Nilsson et al., (2012).

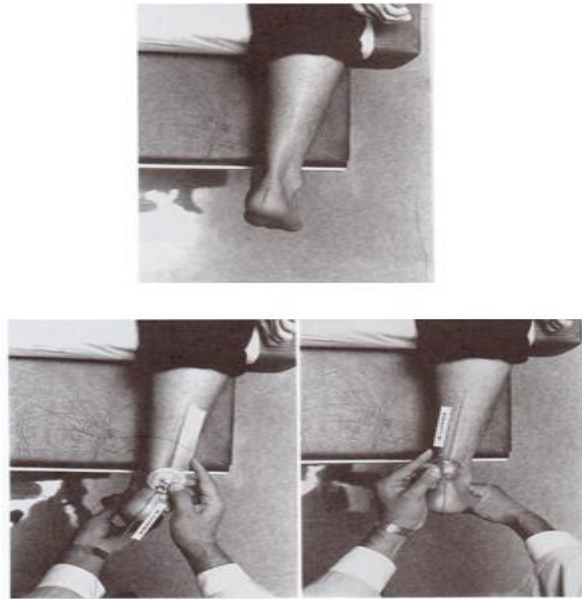


Photos 5.3.1., and 5.3.2. show the Navicular Drop Test, with the measurement from the floor to the base of the navicular, firstly to mark the inferior aspect of the navicular, then to place the measure from the floor to the mark on the navicular. Photo 5.3.3., taken of a subject in a reliability test comparing the measurement to thresholds recommended by Nilsson et al., (2012) which the current study has adopted.

5.3.4: Calcaneal bisection.

The third proxy measure used in this study to evaluate foot type entailed drawing a vertical bisection of the calcaneus to define the mid-point of the posterior aspect of the heel (calcaneal bisector), and then a bisection of the posterior aspect of the tibia/fibula, relating one measurement to the other (Root et al., 1971), achieved by the subject lying prone on the examination couch. The margins of the calcaneus at the point of insertion of the Achilles tendon are assessed and a line drawn. The examiner then repeats the process to define the mid-point of the lower one third of the leg (Root et al., 1971). These reference points are commonly used in a clinical setting when measuring the degrees of valgus (pronation) or varus (supination) of the subject's heel (Photo 5.3.4.). This measurement is widely used by the researcher, other clinicians and researchers who found the Calcaneal Bisection accurate for their studies (La Pointe et al, 2001; Levinger, 2008).

Photo 5.3.4. – Bisection of the lower one third of the leg and the bisection of the Calcaneus and the two measurements of the angle. (Copyright Neale, 1998).



With the subject standing, the degree of change in the angle between the RSCP and STJN are viewed by the observer, an indicator of postural position of the feet (Photo 5.3.5.). One advantage of this method is that pronation/supination can readily be measured in different dance positions (Photo 5.3.6.) which proved to be critical in this study due to time involvement in measuring the NVDT.

Photo 5.3.5. - Bisection of the posterior aspect of the calcaneus (the heel bone) with the feet standing in a normal resting stance position (RCSP). The feet in normal stance are supinated (pes cavus). The first toes can be observed which indicates a supinated foot (Posture Index Test measurements). (Copyright, Parfitt, P., 2015).



Photo 5.3.6. – Bisection of the posterior aspect of the calcaneus to measure pronation and supination of the foot in fifth position. (Copyright, Parfitt, P., 2015).



5.3.5: Hallux Valgus.

The Hallux Valgus is an additional observation for this research but its measurements are not crucial and are not part of the 3 proxy measures nor of foot type per se. However, Hallux Valgus is commonly found with overpronation of the foot, and so its observation provided potentially useful supplementary data (Subotnick, 1989). Pes planus particularly is accompanied with forefoot abduction with the first metatarsal moving towards the midline of the body and the first toe deviating toward the midline of the foot forming a “V” shape (Subotnick, 1989). This is known as Hallux Valgus and is often accompanied with a thickened metatarsal head, commonly known as a bunion. Whilst this is commonly accompanied with pes planus, it can also be found in pes cavus individuals, particularly hypermobile pes cavus foot types. The measurement of the angle between the 1st and 2nd metatarsals and the bisector of the 1st metatarsal and phalanges of the hallux are determined from radiological examination (Hardy et al., 1951; Piggott 1960). However, it is not deemed practical to undertake this approach and is unnecessary in order to determine the severity of deformity (Menz et al., 2005). Therefore for the purposes of this study a photographic comparison method (The Manchester Scale) was adopted as described by Garrow, et al., (2001) which compares the subject under assessment against 4 photographic presentations of hallux valgus graded none, mild, moderate, and severe (Menz et al., 2005). In their study of 95 subjects, Menz et al., concluded that The Manchester Scale offered a valid method of assessment (Spearman’s $\rho = 0.73$, $P < 0.01$) for hallux abductus angle (Appendix ii).

This assessment is taken with the subject standing barefoot in accordance with the method applied by Menz et al., (2005), comparing the subject’s feet to the 4 photographs and recording them as (grade 1) None; (grade 2) Mild; (grade 3) Moderate and Severe (grade 4).

Figure 5.4 shows the marking up of the bones for radiographic measurement and a photograph of dancer with mild (grade 2) Hallux Valgus.

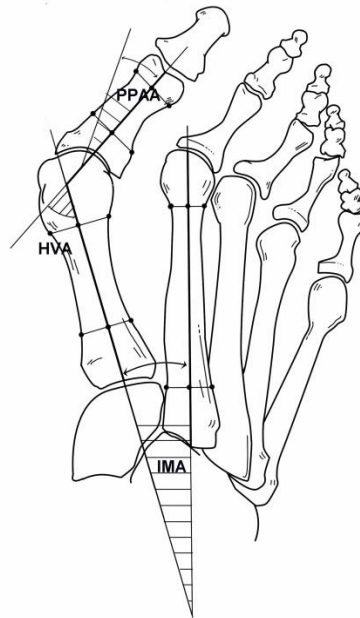


Figure 5.4. – Measurement of Hallux Valgus. (Copyright Piqué-Vidal, C. and Vila J., 2009).

5.3.6 Summarising the process of taking the foot measures of a dancer.

1. In stance, the foot type of the dancer was assessed by observation (FPI).
2. The NVDT was then taken of both the left and right foot of each dancer.

The foot was measured on a wooden plinth to measure the arch height in RCSP and then again in a subtalar neutral position (STNJ). The measurement difference defined the amount of pronation in millimetres of the right and left foot.

3. For the calcaneal bisection method the calcaneus (heel bone) was bisected with a vertical line, with the dancer lying prone on the examination couch. A goniometer was used to assess the degrees of valgus (pronation) and varus (supination) in degrees.
4. Hallux Valgus graded against The Manchester Scale.
4. The Calcaneal Bisection was repeated in First and Fifth dance positions.

5.3.7: Questionnaire (Appendix 1).

The questionnaire was designed to deliver short questions to avoid “respondent fatigue” with the option to skip questions if they were not pertinent. Research has shown that participants do not always answer questions either at all or incompletely if allowed to self-complete therefore a one-to-one format was chosen with the researcher asking the questions to ensure that all questions were answered fully (Balfour 2004). In a self-completed questionnaire, the researcher cannot prompt or probe. There is a potential issue that a respondent may read the questionnaire as a whole, not working systematically through the questions where one question might prompt forward to another, perhaps asking for a more in-depth answer (Bryman, 2001). The questions included an enquiry into the dance history, at what age did the participant commence dancing, when did they start increasing the training hours, at what stage did they embark on a professional career. Information relating to incidence of injuries, treatments, any on-going injuries and concerns of the injuries, with concerns rated from 0 (disagree) to 5 (strongly agree). Further information included at what stage did the participant seek treatment, was cost a factor (although pre-professional schools had in-house physiotherapist and amateur schools did not), what was their own level of understanding or expertise on treating their own injuries. Other information sought was the hours required in training, rehearsals and performance.

The interviews were held using a standard uniform questionnaire with the researcher reading out the questions and filling in the answers from the respondent. The researcher has to aim not to be controlling in the interview, to keep professional and neutral. In asking questions in the questionnaire, Creswell (2003), identifies the skill in when not to question or perhaps be too assertive on gaining an answer, which is linked to the participants right to privacy and

autonomy in self-disclosure. In terms of ethical practice as advised by Diener and Crandall (1978), it is important to form a good trusting connection with the participant and this was achieved by reassuring the participant that all information was confidential, the questionnaires were coded rather than using names, and the questionnaires were locked away at the Podiatry clinic. The questions were worded as to not be an invasion of privacy and the approach would be just to allow the participant to speak freely.

Short succinct questions were asked with an option to skip questions if necessary. A vertical rather than a horizontal format was chosen in the delivery as it is thought to cause less confusion and error in answering (Sudman and Bradburn, 1982). Although a predominately closed question format, the participant needed to fill in the area on their injuries which required explanation of anatomical site; the researcher being knowledgeable in anatomy could then ascertain a more accurate answer.

It was important to test the questionnaire evaluation to ensure that questions were understood, and it was piloted with a small sample (5) of dancers drawn from 3 pre-professional schools. The current researcher, being an expert podiatrist, chose to question the participants solely in order to evaluate the responses in interview. The danger of this is that there could be a bias which formed the debate of whether to consider asking another podiatrist of the same level of expertise to act as a peer check. However, Greenhalgh (2006) suggested that having a second interviewer may actually create a double bias. Having conducted interviews in the past, and also that the questionnaire was of a quantitative nature with more emphasis placed on extracting factual information from the participant in a friendly, professional manner, it was decided that a second interviewer would not be required. This supports Dawson, (2010) who suggests that it is more important that one qualified interviewer in the subject area does all

the interviewing since any additional interviewer may have a different approach. The current researcher aimed to follow good practice methods which are trustworthy in order to maintain credibility in the data and that the information collected would be a good account (Bryman, 2012).

An awareness of sensitive issues such as long-term implications of injury on career for the dancer needed to be addressed only in terms of observation. No statutory obligation to duty of care was required by the researcher as a professional to inform school staff on any injuries without prior consent from the dancers. Other concerns included interviewing under 16 year olds as they could potentially hold back information if an adult was present for fear by the participant's injury status being reported to the Principal. Reassurance was given to the participant that information was confidential and also to reiterate the importance of maintaining confidentiality to the adult present when the dancer is under 16 years of age. It was important for the interviewer to keep a relaxed, friendly yet professional manner during the interview, not to coerce, which I did by keeping a measured and relaxed tone as well as a relaxed body posture. As mentioned, from the beginning of the interview, I did reassure from the outset that all information was confidential and that coding was used on the questionnaire rather than referring to a name which assured anonymity. Dancers may be concerned on information being divulged to external parties in the dance school which could affect their careers, so trustworthiness is essential. The last question on the questionnaire was open-ended, and was an enquiry as what the participants considered their cause of injury to be, which resulted in 4 main answers, the information of which, helped to redesign the question, rating the answers from 0 to 5 (strong disagree to 5 strongly agree).

5.3.8: Delivery of the interview.

The questionnaire had to be clear both for the researcher and the dancer and timing was a factor since the participants needed to return to training or rehearsals. The questions were written in a vertical format as recommended by Dillman et al., (2009). The print was darker on the questions, so that questions could be easily read and to maintain a steady flow without hesitation; keeping the participant engaged and interested. The questionnaire was evaluated for clarity, for timing of the interviews and foot measurements, re-writing of the questionnaire. The questionnaire was delivered in the interview room with just the lead researcher and the participant prior to taking the foot measurements. Anonymity was not feasible with the under 16 year olds since another adult had to be present, but as noted above, no names or specific identifiers other than research coding were utilised in the findings, discussion. The participant signed a form to agree to participation and this was an opportunity to explain the study further or answer any questions. The interview took place in an office room and was followed by the measurements of the feet in the dance studio or treatment room.

5.3.9: Informal Discussions.

Dance flooring construction in terms of its usage in the training rooms and stage floors were part of the discussion with floor manufacturers and the schools, taking in account hours of usage, and the different components of flooring and its suitability for different dancers. Training hours per week were recorded as well as hours of performance and rehearsals in hours and documented in the questionnaire. Flooring manufacturers specialising in flooring

for ballet were contacted to investigate the different flooring as well as roll up flooring available and the components that make up the flooring. The enquiry included the most popular flooring chosen for training rooms, theatre stages and if costing was a factor in choice. Equally, ballet shoe suppliers were contacted regarding the different types of ballet shoes available, popularity, as ballet shoes types do vary according to the supplier. This will be explained in the discussion chapter.

5.3.10: Flooring.

The participant was asked in the questionnaire regarding the flooring that they have used over the years and currently. If they were unsure the teacher or principal was asked for confirmation and the information recorded in the questionnaire. Also, participants were asked which floor type suited them and which did not, and could they recall any injury occurring.

5.3.11: Footwear.

The dancers' pointe and flat shoes were examined to note where the shoes were worn and where the *pointe* shoe was broken or buckled in. Comments were added in note form to the back of the questionnaire but for statistical purposes, the number and type of shoes (*pointe* and flat) that the participants wore through in a week and through a performance was documented. This information subsequently was added on to the questionnaire.

5.3.12: Reflections on implementing the study.

Implementing this study was not straightforward in terms of access, recruitment and delivery. Gaining access required careful negotiations with elite ballet schools. Getting past the gatekeepers required perseverance, repeated emails and telephone calls. Broadhead and Gist, (1976) consider that gatekeeping can influence research in a number of ways: by limiting conditions of entry, by limiting access to data and respondents and by restricting the scope of analysis. Strategies are not taught for managing problems associated with gatekeeping. Yet overcoming gatekeeping in this research required informing the Principal of the nature of this research and emphasis on non-injured and injured and not just a bias towards injured. The Principals and even physiotherapists were not knowledgeable on foot types and fortunately were keen to have a podiatry input so that they may learn more about injuries. The problem was gaining access in the first instance, to convince the schools that the study could potentially be of value in the future. Attending the International Academy of Dance Medicine Science (I.A.D.M.S.) was beneficial in gaining contacts with physiotherapists who specialised in dance and could give an insight into training schedules, performance types, and injuries and who considered that podiatry is overlooked as a profession in the dance world and could make a valid contribution.

In the pre-professional ballet companies for those under 16 years of age, either a teacher or an older dancer was present. The author felt that having an adult present may impede the dancer in answering the questions on injuries but in fact found that most of the dancers were open about their injuries. However when asked the question on what could have caused the injuries, some of the dancers did seem more guarded. Some did not want to answer the question (this was whether an adult was present or not). Some answered that they often

danced through an injury as they did not want to take time out and lose the chance to perform or be chosen for a performance.

Teachers were often coming into the interview room to check that all was well and may stay for a few minutes before leaving. The author explained that confidentiality was needed and found teaching staff very sensitive and not sure that the author might criticise them in my findings or report the information. It was also extremely difficult because the door had to be left open when doing the measurements. This allowed other dancers to stand in and observe so the author had to ask them to leave. Sometimes there was a gap between the dancers because they had to get on their next training schedule. The author did not want to work too quickly due to the need of being absolutely accurate. Yet the author found that she did work well with the dancers in the time they were with me. They were very candid about their injuries, and how treated.

It was also greatly useful in being present in a dancing school, for example one physiotherapist advised me in passing that they observed dancers who had a biomechanical weakness would overpronate particularly in the 1st and 5th position. This was valuable information which was incorporated this evaluation into the study and it proved to be a key modification of the design. An iPad and a Sony wide lens camera were pre-tested for the foot measurements, but the photos proved inaccurate when it came to measuring on the photo despite consistent measuring distances. Photos would not aid the study, as they were additional information if needed; therefore it was decided to keep purely to the foot measurements.

An additional asset was being invited to observe the dancers actively in training. The original intention had been to immediately measure the height of the foot arch and assess foot type, but the Principal asked if the author would like to sit through the training class to observe the dancers and then take the measurements afterwards due to time constraints. This proved invaluable, as observation of the dancers in movement, jumping, landing, and performing various moves, which were repeated several times as part of their training. Observation of some dancers who were fairly flat footed on landing and biomechanical anomalies such as overpronation at the ankle and subtalar joints and instability whilst landing, were noted for further consideration (See appendix for full explanation of these terms). In consequence the ankles would inroll medially, with internal rotation of the Tibia/Fibula, placing the knee in a more medial, or valgum position. Observation was made of how dancers with in rolling ankles would “pull up” on the muscles of the ankles, as trained, to form a better arch. The dancer was able to stabilise the ankle and foot and therefore the upper body appeared in a straight, upright and corrected form even with the ankles medially in rolling when the foot was flat on the floor. Yet when they walked away, the foot had collapsed into a flat footed or pronated stance. Overpronation was apparent in the first dance position if there was evidence of pes planus.

Additionally, observation of the dancers when standing in fifth position, revealed the front foot in-rolling (overpronating). As noted above, a decision was taken to involve these two dance positions of first and fifth position into the study. This observation in the training rooms, observing different foot types and biomechanical anomalies, where potential injuries were possible, confirmed the need to recruit injured as well as non-injured dancers.

5.4: Validity and reliability.

5.4.1: Validity.

Epistemologically, validity is used in terms of the measures. For example, does a measure or measures of a concept really do so? Validity is about the structure of the tools, and that the tools are doing what they are intended to do and whether they produce the data required. In evaluating foot type, validity refers to the issue of whether an indicator (or set of indicators) that is devised to gauge a concept really measures that concept. Establishing validity can be explored in various sub components (Bryman, 2001) described below.

5.4.2: Face validity.

Face validity pertains to a new measure developed by the researcher and is essentially an intuitive process (Bryman, 2001). The current research has used established measures which are being retested and so face validity was not an issue.

5.4.3: Concurrent validity.

Concurrent validity is where the researcher might seek to test the concurrent performance of a measure with an alternative measure. In this study 3 proxy measures were utilised to evaluate foot type. In principle all should provide the same answer, and so establish concurrent validity for those tools. Convergent validity refers to agreement between two independent tools that purport to measure aspects of related constructs. It does not relate to the current context in that the 3 proxy measures are likely to overlap as they are evaluating very similar

aspects of foot anatomy and hence convergence should be assumed. Similarly, observation by the researcher of the social settings of dancers in training, and then of the same dancers in an interview setting with one-to-one interviews, allows the researcher to gain a high level of congruence between concepts and observations (Bryman, 2012).

5.4.4: Construct validity.

Concurrent and convergent validity are sub-components of construct validity, which relates to the characteristics of the tool itself and if they are likely to provide answers appropriate to the study objectives. The 3 proxy measures are recognised and widely used in podiatry practice to evaluate foot type, albeit less so in the context of ballet dancing hence this study. The questionnaire is more challenging in this respect since it offers individual viewpoints and perspectives, and hence is subjective. The questionnaire had to be piloted with a small group of dancers to check for ambiguity and sense.

5.4.5: Internal validity.

Internal validity is concerned with the soundness of findings that specify a causal connection, an issue that is most commonly of concern to those doing quantitative research (Bryman, 2001). For example, the combining of the foot measures in the analysis as a composite for “foot type” are used as they are measures of specific aspects of foot anatomy. Variation in any one of these 3 proxy measures might relate to the development of foot injury and in combining the measures, being modelled to see if any one measure is dominant in this respect. No other measures can replicate the 3 proxy measures either individually or be effective collectively.

5.4.6: Descriptive validity.

Descriptive validity pertains to the accuracy and objectivity of the information collected. Provided the valid quantitative measures are applied diligently and recorded accurately then descriptive validity should not be of concern. It is less assured in qualitative research where individualised viewpoints, context etc. prevent objectivity.

In this respect, surveys applying rating scales fall in the middle in the sense that they are quantitative measures of individual perceptions. The prevailing assumption is that the questions provide a scale of perceived view, and that strength of view/opinion can therefore be ‘measured’ using self-report. Interviews in this study applied a piloted questionnaire with short concise questions answered by the researcher reading out the questions and filling in the questions for the respondent. This ensures detail of the answers, which may not occur if the interviewee filled in the questionnaire by themselves and also allows for any further questions or explanation of the study. However, there can only be an assumption that the participant has filled in the questionnaire accurately, as there is no way of knowing otherwise.

5.4.7: External validity.

External validity of a tool implies that it can be applied in similar contexts elsewhere as its construct remains pertinent. If this holds then data obtained might be claimed to have generalisation in respect of that context. For example in this thesis the foot measures might be applied to anyone in any context when the interpretation of findings might differ but the performance of the tool itself is assured.

5.4.8: Reliability.

Reliability and replication are a close combination and deal with issues of consistency of the measure(s). To be reliable a study must be able to be replicated by another researcher performing the same measurements on a particular study. Reliability is concerned with reproducibility, that is, can the researcher reproduce the data (internal reliability) and does it have external reliability in that someone else could reproduce the data (Bryman, 2004)? In this study, reliability applies predominately to the search for measures of foot type. Foot type in this study could only be understood with using a combination of proxy measures which independently represent different aspects of foot anatomy/pronation. These measures can individually and collectively be put together. The measuring tools used such as the metal tapes to measure foot arch height and bisect the calcaneus, give actual measurements, they are repeatable. The first two tools, the NVDT and the FPI test have been used consistently by researchers and are said to have good repeatability and measurability (Nees et al., 2011; Christensen et al., 2014; Cornwall et al., 2008). The Calcaneal Bisection measure is used daily in clinic in podiatry since the 1970's and has consistently good results with small margins of error due to movement of skin (Root, Orien and Reed, 1974). The bisection of the posterior Calcaneus and that of the posterior Tibia and Fibula is compared and used routinely in Podiatry as measurements to manufacture orthotics or prosthetics. Implicit in reliability is that reproducible, objective data can be generalised to the population from which the study sample was drawn.

In internal reliability, another podiatrist or clinician should be able to use the same measures and produce the same results as the researcher. As noted above the tools are widely recognised and applied in practice and each has been demonstrated to be valid and reliable.

For this study, the researcher's ability to maintain reliability in evaluating a foot type was checked by intratester and intertester assessment of applying the navicular drop test, chosen because of the higher precision of data required compared with the calcaneal bisection and foot posture index.

5.4.9: Intratester reliability of the NVDT.

A reliability test was undertaken to test the Navicular Drop Test measurements for repeatability, ease of usage, and reliability. Five dancers participated in this pre-study evaluation. A wooden plinth 10 cm high provided a platform on which to rest the subject's foot while performing measurements (a plinth was also utilised in the main study) and a measurement for the NVDT was taken at different time points (Day 1, 1 week later, 1 month later) for intra-tester reliability (see Table 1), but also to identify if soft tissue movement in the intervening periods between measurements had a measurable impact on the evaluation. The data are shown in Table 5.4.2. which identify a good level of reproducibility with no evidence of significant soft tissue variation over the period of 1 month.

Table 5.4.2. – Intra-tester reliability of foot measures and consistency of repeat measures over time.

Measure	Rf			Rf Corrected			Lf Rest			Lf Corrected		
	1	2	3	Diff 3-1	1	2	3	Diff 3-1	1	2	3	Diff 3-1
Time point												
Dancer1	2.5	2.5	2.5	0	4.2	4.1	4.2	0	1.5	1.6	1.5	-1.3
Dancer2	4.0	4.0	4.1	0.1	6.2	6.1	6.3	+0.1	4.1	4.7	4.6	+0.3
Dancer3	6.0	5.9	6.0	0	6.2	6.2	6.2	0	5.9	5.9	5.6	-0.2
Dancer4	4.3	4.3	3.9	-0.4	4.5	4.6	4.4	-0.1	4.0	4.2	4.2	-0.2
Dancer5	4.2	4.1	4.3	+0.1	4.5	4.4	4.6	+0.1	4.3	4.1	4.1	-0.2
	4.2+/- 1.2	4.2+/- -1.2	4.2+/- 1.2	0+/-0.2	5.1+/- 1.0	5.1+/-1.0	5.1+/- 0.9	0+/-0.1	4.0+/- 1.6	4.1+/- 1.6	4.0+/- 1.5	-0.3+/-0.6

Time points 1-3 indicate measures taken from individual dancers at 1 day, 1 week, 1 month.

Differences +/- 1 standard deviation between measures at 1 month and 1 day are shown. B-A differences not significant (Paired t-test).

Intertester reliability.

For this assessment the NVDT was evaluated on a single occasion by 2 podiatrists (the researcher and a colleague) from 5 volunteers. 3 measures were obtained from each volunteer to yield 15 separate pairs of values for comparison. Data are shown in Table 5.4.3. The similarities are evident and no differences between data pairs are statistically significant (Paired t-test).

Table 5.4.3. – Inter-tester reliability of foot measures. Comparison of researcher’s methods (A) and those of colleague (B). RfRest or LfRest = right or left foot in resting stance posture. RfCorrected or LfCorrected = Right or left foot in corrected stance (subtalar joint neutral).

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Mean +/-1SD (B-A Difference +/-1SD)
RfRestA	2.5	2.5	2.5	6.0	6.0	6.0	6.1	6.0	6.0	4.4	4.4	4.5	4.5	4.3	4.3	4.7+/-1.4
RfRestB	2.5	2.5	2.5	6.0	6.0	6.0	6.0	6.0	6.0	4.4	4.4	4.4	4.3	4.3	4.3	4.6+/-1.4
																(-0.1+/-0.1)
RfCorrectA	4.1	4.1	4.1	6.1	6.1	6.1	6.2	6.1	6.1	4.5	4.5	4.6	4.4	4.5	4.5	5.1+/-0.9
RfCorrectB	4.1	4.1	4.1	6.1	6.1	6.1	6.2	6.1	6.1	4.5	4.5	4.6	4.4	4.5	4.5	5.1+/-0.9
																(0+/-0.1)
LfRestA	1.6	1.5	1.6	5.7	5.6	5.7	5.6	5.6	5.6	4.1	4.2	4.2	4.2	4.2	4.2	4.2+/-1.5
LfRestB	1.6	1.6	1.7	5.7	5.7	5.7	5.6	5.6	5.6	4.2	4.2	4.2	4.2	4.2	4.2	4.3+/-1.5
																(+0.1+/-0.1)
LfCorrectA	3.7	3.7	3.6	5.9	5.8	5.8	5.9	6.0	6.0	4.7	4.7	4.7	4.6	4.6	4.6	5.0+/-0.9
LfCorrectB	3.7	3.7	3.7	5.9	5.9	5.9	6.0	6.0	6.0	4.7	4.7	4.7	4.6	4.5	4.6	5.0+/-0.9
																(0+/-0.06)

5.5: Ethical Considerations.

5.5.1: Ethical approval.

Within the study Seedhouse's (1998) and Beauchamp and Childress (2001) ethical principles are applied as the theoretical perspective underpinning the ethical framework. The adoption of the most appropriate design, methods and procedures to meet the research aims and the needs of the participant, is crucial in developing a research study that is effective and inclusive of those involved. Consideration had to be made as to how best to design this research, clearly defining the methods and protocol, then gathering in depth information from the dancer in a sensitive manner; such information being effective in its outcome. Research ethics are integral to the research process providing clear guidelines and protection to the researcher and the participants. This current research was awarded ethical approval by Anglia Ruskin University ethics committee.

Gelling (1999 REF. Ethical principles in healthcare research. Nursing Standard 13(36): 39-42) identifies the 7 underpinning principles of research ethics as : *Beneficence, Non-maleficence, Fidelity, Justice, Veracity* and *Confidentiality*. These principles are enshrined in the Department of Health Governance Framework (DOH) which was established in 2001 (Research Governance Framework for Health and Social Care)

www.ncor.org.uk/wpcontent/uploads/2012/.../Research_governance_framework.pdf/Accessed /March 2016.

Gaining ethics approval is required of researchers and their studies must be in line with this framework. Ethics implies the philosophical principles that underpin the morality of actions (Skorupski, 2012), and good governance in terms of research. A significant essence of ethics is non malficence or “do no harm” even if the outcome achieved is not of direct benefit to the

participants in the research. Therefore the researcher has a duty of care to the participant (Foster, 2001). Research ethics are integral to the research process providing clear guidelines and protection to the researcher and the participants. For the individual, and researcher, there are a number of guiding principles, explored below in the context of this study. By non-maleficence or “doing no harm”, in this research, all tools were physically safe to use, and no discussion of the participant’s injuries or the problems of the foot type would take place. The questionnaire would be coded and names would not be attached to the questionnaire. Confidentiality would be emphasised to the participant so that they can talk freely without any possibility of repercussion.

Welfare of the participants (and researcher) is paramount and in recruiting participants it is essential that participants are fully informed of the study and its implications for them, and the giving of consent on that basis. It is also a given that steps will have been taken to ensure the likelihood that the research will progress to completion and be of value. Details of the principles and issues pertaining to this study follow below.

5.5.2: Welfare of the participants.

All participants were given a letter of invitation, and a consent form, which they signed to agree to take part in the study. A letter was also given explaining the study. The participants were informed that they could withdraw at any stage before or during the study. Confidentiality and consideration for the welfare of the participant is essential in ethics. The information received from the participants both verbally and with measurements to the feet was kept confidential. The aim was not to cause harm be it psychological or physical and therefore advise that all information is purely for research. The equipment for the foot

measures was non-invasive. The researcher was to maintain a sensitive and non-judgemental approach and to not give any false expectations on new injury treatments. Each participant was treated with respect, care, and explanation given on each procedure as it progressed for example: the first stage is the questionnaire, now we are measuring the feet; this is what is being used.

The professional dance world is very competitive and there are more dancers in training in proportion to the numbers auditioned and chosen by the professional ballet companies worldwide which may result in dancers being very cautious about involved in research and who are the recipients of this information. The participants were advised that the study was in complete confidence, and that no information would be passed to the dance schools, principals, parents, and would purely be used in research with no reference to particular schools or people. All dancers would be coded instead of using a name on the questionnaire and measurement forms. Information could be considered of a sensitive nature since it records those who have had injuries, which may or may not have been reported to their school by the participant. Although there is no direct benefit to the participant, the information would be of value to future dancers and schools. Therefore there was no physical, emotional harm or financial benefit to the participants.

5.5.3: Informed consent.

It is the researcher's responsibility to explain the study to the participant including the foot measurements and questionnaire. Also, to explain the commitment of repeated visits for foot measurements, and that the benefits may not directly help them but future populations. The participants were informed that they could withdraw at any stage of the study. Contact

details, which were an email contact and telephone number, were given to the participant in case they had any other questions or wished to withdraw. Participants under the age of 16 years required parent consent and forms were duly signed. In the amateur schools, parents readily signed the forms, and these students were interviewed, and measured in the clinics with parents present. In the professional schools, if under 16 years of age, with dancers being both national and international, then another student or teacher of the participant's choice were chosen by the dancer. A trusted student or teacher would help put the participant at ease for the study.

5.5.4: Confidentiality of the data and Anonymity.

Measurements were taken in the dance studio or the Podiatry clinic and the questionnaire one-to-one interview was taken in a private room with no disturbance. For participants less than 16 years of age, then an adult or chosen teacher or older student was present although there would be the possibility of the participant withholding information. All questionnaires were coded and the interview and measurements locked away in a cabinet in the Elstree clinic. Only the lead researcher would have access and it is the researcher's responsibility to keep all information confidential and not to be discussed with any other party.

The information is sensitive because of the possibility of the participant not informing their school of their history of injuries or any current injuries for fear that they may not be chosen for dance companies or performances. There may be other concerns from the participants, which might be revealed in the interviews. Anonymity (protection of identity by not using names and replacing them with codes) was assured by reference being made only to

participant coding during analyses, and care was taken to ensure that participants could not be identified within this thesis. Data from individuals were not discussed with school staff.

5.5.5: Use of time and dissemination of findings.

The participants undertook to commit to 30-45 minutes for the measurements and questionnaire. Due to any last minute rehearsals or training, the researcher would need to accommodate the school and wait until various dancers would be available for the interview as was advised by the Principal. The process of data analysis, presentations at conferences and the writing of the thesis are all part of the process (Foster, 2001). For inter and intratester reliability, the participants needed to be available for 3 meetings to repeat the measurements. Dancers regularly attended the schools and repeat measures did not present a major difficulty for them.

5.5.6: Autonomy.

To ensure that the participants were autonomous (in that participants were able to act independently and not being influenced), information was provided in detail in writing and explained again before commencement of the interview. The participant was advised in the invitation and with a signed form that they could withdraw at any stage before or during the research. The researcher aimed not force or coerce people to answer a question and nor keep delving for further information as this would taint the results. Informed consent is an important outcome of this principle (Creswell, 2003). Also, to be sensitive if the participant is feeling pressured by a question. Within the study Seedhouse's (1998) and Beauchamp and

Childress (2001) ethical principles are applied as the theoretical perspective underpinning the ethical framework.

5.5.7: Non-maleficence.

Non-maleficence is pertaining to not causing harm (Beauchamp and Childress, 2001). One possible risk could be that the participant discovers that their dance injuries are due to a pathological foot type, which may imply a short dance career. Sensitivity of information received from the participant is essential. Professional conduct expectancies to report any dancers that they are carrying an injury is not expected and particularly as emphasis is on confidentiality to the participant and sensitivity as they may lose their place in the school or company.

5.5.8: Beneficence.

Although the aim was to benefit the participants, it most probably would not benefit directly the current participants but dancers' and health professionals in the future in potential screening programmes. Regarding injuries, no information of diagnosis was given to the participant, because to assess the injury would necessitate a full and thorough examination which would not be part of the remit of this study. This study is essentially a collection of information needed on foot type and of injuries.

5.5.9: Justice.

Justice refers to acting in a non-discriminatory way and having respect for peoples' rights (Beauchamp and Childress, 2001). The aim was to be non-bias at all stages of the research and to allow the participant to withdraw at any stage. The participant information sheet (P.I.S.) was given to the participant. The Participant information sheets, informed consent and ethics approval are all part of the statutory requirements of Anglia Ruskin University who on this basis, granted approval.

In addition to these guiding principles, the adoption of the most appropriate design, methods and procedures to meet the research aims and the needs of the participant, is crucial in developing a research study that is effective and inclusive of those involved. Methodological considerations are increasingly recognised as ethical aspects of research since it is a given that participating in a study will provide useful outcomes. Ensuring validity and reliability in the measures to be utilised for data collection are critical to this process.

5.6: Data Analysis.

Recruitment proved problematic due to difficulty of accessibility. However, discussions on sample size with a statistician suggested that the 47 dancers recruited to the study was a suitable sample bearing in mind its exploratory nature; ideally more would have produced a more robust sample size with increased statistical power. All quantitative data (foot measures, questionnaires) were entered into an electronic database (Statistical Package for the Social Sciences, version 20). The analytical strategy was to initially subject the data to descriptive statistical analysis, and then progress through increasing depth and breadth of inferential

statistics to explore emergent patterns or trends towards an understanding of injury risk, and finally to utilise regression analysis to model the data in terms of risk of injury. With data from just 47 participants it was recognised that this weakened statistical power and hence the value of the testing, particularly the application of regression methods. Nevertheless this is an exploratory study that generated considerable volume of data and, with the caveat that statistical outcomes should be interpreted with caution, a stepwise regression was conducted with the aim of gaining some insight into which if any variable was especially strongly related to injury risk.

Podiatrists are increasingly asked to treat dancers who have developed foot or lower limb injuries but as identified in Chapter 3 there is a paucity of evidence as to risk factors. Chapter 3 identified these as either ‘intrinsic’ to the dancer, or ‘extrinsic’ influences related to the environment or equipment utilised by the dancer. The aim of this study therefore was to seek evidence of critical factors that potentially related to or influenced the incidence of injuries in ballet dancers. The study is predominantly quantitative in this respect.

Intrinsic factors in foot injury

To identify the potential influence of intrinsic factors data were collected that provided measures of foot anatomy and posture, together with demographic data and injury history obtained via a questionnaire delivered in a confidential interview setting. A total of 22 variables were evaluated. Intrinsic factors provided a mixture of continuous (scalar) variable data (foot arch height and related in the NVDT; weight, height, age, years dancing in demographics) and ordinal data (angles of pronation in the Calcaneal Bisection measures and foot posture index; number of injuries, amateur or professional in the demographics).

Remaining data were categorical (gender, presence or absence of hallux valgus or nail injuries, injury type).

Extrinsic factors in foot injury

Data collected as responses to the closed format questionnaire were categorized as necessary or, where relevant, were recorded ordinally according to a rating scale. The data were largely categorical: floor type, training time, shoe wear and tear. The number of shoes utilised was treated as ordinal as this had to be considered in terms of numbers replaced rather than degree of wear. Otherwise extrinsic factors were explored in informal discussion with appropriate authorities in what might be considered non-research settings.

5.7: Analysis strategy.

All quantitative data relating were collated into Excel spreadsheet for later import into the Statistical Package for Social Sciences software (SPSS Version 20; SPSS Ltd). The first stage of analysis was to complete a descriptive analysis of frequencies and, where appropriate with scalar or ordinal data, measures of central tendency (e.g. mean values for foot measurements +/- standard deviations; median number of injuries, respectively).

The descriptive/frequency analysis was followed by analysis of statistical associations between variables initially using the 'Crosstabs' feature of SPSS. This is a chi square analysis of data distributions that evaluates the statistical probability of association between two variables. In some instances (for example foot posture index) data were numerically categorized (e.g. 0 = normal, 1 = pes planus, 2 = pes cavus). This process also aided analysis by increasing the number of data points within the test 'cells' (e.g. number of years training

categorised within discrete year ranges) and so strengthened the analysis. As a precaution, the Fisher Exact correction was also applied to compensate for potentially low numbers within the 'cells' that might skew the analysis. Statistical significance was set at a probability of $p < 0.05$.

The analysis was then extended by exploring relationships between foot measures. A variety of tests were applied. Bivariate correlation analysis was applied to evaluate relationships between pairs of variables. Where data were continuous (scalar) most notably regarding the NVDT parameters, the Pearson's coefficient was evaluated. For non-parametric ordinal data (e.g. Calcaneal Bisection or Foot Posture Index) the Spearman rank correlation test, rho coefficient, was applied. Differences between means, when appropriate, were mainly tested using independent or paired-t test according to the use of independent or paired samples. Where there was some doubt as to the normal distribution of the data then non-parametric testing was applied, either Mann-Witney U test for independent samples, or Wilcoxon signed-rank test for paired samples. Significance was again set at $p < 0.05$.

As noted, the original intention of the data analysis was to evaluate variables as potential risk factors to foot/limb injury by applying linear regression tests to continuous/ordinal data. With the caveat that the subsequent analysis would have benefited from a larger dataset and so is underpowered, stepwise regression was conducted using the SPSS software by entering of variables to explore which, if any, looked to have potential value as predictors of injury.

Prior to regression analysis the database was referred to an Anglia Ruskin statistician for help with evaluating which variables might be acting as co-variables that is not acting independently in any relationship with the dependent variable. For this all of the data (a total of 16 variables) were imported from Excel into the computer program R (R Core Team 2015).

A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. See www.R-project.org).

5.7.1. Informal observations and discussions.

These data obtained informally from attending the dance schools and in discussion with school principal, dance teachers and attendant physiotherapists were analysed only descriptively. The additional information on floor compositions, shoe construct and wear, and insights into dance training and performances were primarily utilised as additional data that helped to further contextualise ballet dancing and injury risk.

5.8: Chapter Summary.

This chapter has described the research theory that underpinned the study design, and presented the implementation of this study. Recruitment identified 47 participants drawn from a mix of amateur and professional dance schools. Data were collected according to tools to ascertain foot type according to recognised normal/abnormal constructs, and by closed questionnaire in an interview setting using a survey designed for the purpose. Informal discussions with significant members of the dance schools and commercial companies provided further contextual data particularly in relation to training, shoe construction and flooring. Three proxy measures were used to define foot type and in analysis were related to each other, to 1st and 5th dance positions in stance, and to demographic and certain contextual data to identify any relationships with occurrence of self-reported injury history, and to type of injury.

Data analysis followed conventions for descriptive and inferential processes to identify statistical significant associations and correlations between variables and the occurrence of injury, and an exploratory regression analysis finally conducted to ascertain where statistical data might support a predictive model of those factors that contribute most strongly to the risk of injury for ballet dancers. Findings are presented in the next chapter.

Chapter 6

6.0: Introduction.

The Methodology (chapter 5) described the 3 proxy measures of the Navicular Drop Test, Foot Posture Index, and Calcaneal Bisection to categorise foot types and the Navicular Drop Test and the Calcaneal Bisection to measure the postural change of foot profile, STJ pronation.

This chapter details the findings from the analyses. Data of the three foot measures used to define foot type, and in analyses, how they are related to each other and to certain demographic data including occurrence of injury. Data analysis followed conventions for descriptive and inferential processes to identify statistical significant associations and correlations between independent variables and the occurrence of injuries (Methods chapter, p145).

The demographics of participants in this study are first presented in Section 6.2, which is followed by an analysis of foot type according to the 3 proxy foot type measures (Navicular Drop Test, Foot Posture Index and Calcaneal Bisection), and their relationship to demographics and the ballet positions – First Position and Fifth Position. The final foot variable considered is Hallux Valgus (commonly known as bunions) which is a pathology commonly attributed to particular foot postures and its relationship as a cross comparison to foot type. Injuries and their association with foot evaluations are then described in section 6.6. leading into an exploratory analysis of potential predictors of injury. Finally, Section 6.8

identifies extrinsic issues from the interviews and discussions with dancers, shoe makers and physiotherapists. The chapter concludes with a summary of the key findings from the study that informs the Discussion in the next chapter.

6.1: Sample profile.

Forty seven dancers (94 feet) participated in this study. The demographic profile of the sample is shown in Table 6.1. Thirty two dancers were female and 15 male. 41 were elite, professional dancers while 6 had amateur status. Age range was 14 – 29 years and years of training ranged from 8 – 22 years.

Table 6.1. Participant demographics (n=47 dancers)

Gender	32 Female (68.1%), 15 Male (31.9%)
Age (years)	Mean = 18.5+/- 3.1 (SD) (range: 14-29) Females: 17.7+/-2.6 (14-27) Males: 20.1+/-3.4 (17-29)
Height (cm)	Mean = 165.6+/-8.5 (SD) (range: 157.4-182.8) Females: 162.2 +/- 2.7 (157.4-170.1) Males: 178.8+/-4.4 (165.1-182.8)
Weight (Kg)	Mean = 60.3+/-12.3 (SD) (Range 48.9-86.2) Females: 52.9+/-3.0 (48.9-58.9) Males: 76.1+/-9.0 (53.4-86.1)
Dancing status	41 professional dancers (87.2%) 6 amateur dancers (12.8%)
Hours of training per week	Professional dancers = 40 Amateur dancers = 3.5 – 4
Years of training	Mean all dancers = 12.5+/-3.2 (SD) (range 8-22)

Of the 47 dancers, the youngest were 14 years of age; not surprisingly these were amateur dancers. Intense training in dance schools starts from 12 to 17 years and is particularly intense in the 14 -17year age group. The mean age was 18.5 years, and the oldest dancer, a male professional dancer was 29 years of age.

Age and Years of engagement in dance were significantly associated ($p=0.014$) which might have been anticipated bearing in mind the time it can take for dancers to achieve professional status. The duration of participation, years of training and performance could conceivably lead to adverse strain on ligaments though evidence for this effect in ballet dancers is scant.

6.1.2: Height.

Table 6.1 reflects a distribution of height range for both genders 157.5-182.9 cm. The female height was predominantly in the range 160 -167 cm, although the smallest dancer in the sample was female at 157.5 cm in height. Males reflected a range of 177 – 182.9 cm. The heights are typical of dancers in both the male and female groups: in the corps de ballet, dancers of the same height are chosen to provide uniformity and a back-drop to the principal dancer. Variance might have been introduced in the sample as dancers might be chosen for soloist and principal roles although height is no longer a strong criterion for the females as it used to be since companies primarily now focus on a dancer with talent. However, depending on the dance company the maximum height for the female will vary, and since this study covered several schools then this may be reflected in the height distribution, for example 9 female dancers were 160 cm in height.

Male dancers can be of any height provided that they are strong enough to lift a female dancer. Therefore, although talent is important, female dancers still need to be slim or lithe, but not thin, so that they can be lifted with relative ease with less likelihood of placing strain to the back or shoulders of the male dancer.

6.1.3: Weight.

Table 6.1 shows the mean weight for the female group as 50.8 kg; males were considerably heavier at 82.5 kg. These represent a mean BMI for the female dancers of 20.2 kg/m² and for the male dancers of 23.8 kg/m². Observation of a highly significant ($p < 0.001$) association between height and weight might have been anticipated as reflecting a general relationship between build and stature. However, the findings do not support a clear relationship between the effects of weight and a pattern of injury. In terms of current, recovering and previous injuries reported (Table 6.2) males experienced consistently less injuries than female dancers.

Table 6.2 Number of reported injuries.

Number of injuries (past and current) per dancer	Mean = 2.75 (range 0-6)
Dancers currently with injuries, recovered from injuries, or no injuries	<p>Current = 13 or 27.7% (males = 6, females = 7)</p> <p>Recovered = 27 or 57.4% (males = 7, females = 20)</p> <p>No injuries = 7 or 14.9% (males = 2, females = 5)</p>

6.1.4: Gender.

Table 6.1 also identifies two thirds of the cohort as female which is not unusual for ballet dancers as a profession. Of the 47 dancers, 32 (68.1%) were female and 15 (31.9%) male. This group also reflexed the injury pattern as 54% of current and 74% of recovering injuries reported related to female dancers. In terms of foot type (detailed in Section 6.3.1.) there was a higher proportion of males (76% vs 50% females) presenting with pes planus. In contrast just four dancers presented as pes cavus and all were female and elite, professional dancers.

6.1.5: Amateur and professional dancers, and hours of training.

The inclusion criteria to participate in this study did not specify one or other status, and looked for a mix of both. Forty one (87.2%) participants were elite, professional dancers and 6 (12.8%) were amateur dancers. Hours of training per week are considerably lower in the amateur dancers (3.5-4 hours vs 40 hours, respectively, Table 6.1). The hours of training increase for rehearsals according to the choreographic requirement of performance. For amateur dancers, performances are held every second year, for the elite dancer it is annually and may involve several performances. Similarly, duration and complexity of the routines has a bearing on the physical demands imposed by this schedule. Performance times vary in terms of the role played by the dancer and how many performances there are for that ballet. Observation of an association between ‘Amateur/professional status and ‘Hours of training’ ($p < 0.001$) therefore is unsurprising as the sample was heavily weighted towards professional dancers who train for an average of 40 hours per week.

6.1.6: Injuries.

Most dancers (40/47; 85.4%) had a history of injury, of which thirteen dancers (27.7%) acknowledged that they were experiencing a current injury at the time of the study, but many had a history of injury. The number of past/present limb injuries experienced by dancers ranged from zero to six and averaged 1.9 per dancer, and a median of 2 (Table 6.2). More details are presented on injuries in the context of foot types explored in this study and are reported in section 6.2.

6.2 Foot type measures.

No single measure that is commonly used in practice to classify foot type (pes rectus, pes planus and pes cavus) has been thoroughly evaluated. Accordingly this study applied three recognised methods of evaluation as measures for foot type and foot posture to evaluate their utility. This section explores these in terms of viability.

6.2.1: Navicular Drop Test (NVDT).

The principle of this test is to measure and categorise foot type in stance position and also to measure postural change (pronation) by measuring the navicular height in stance (RCSP) and then in corrected position (subtalar joint neutral – STJN), to compare the two measurements which reflects the degree of postural movement of the foot i.e. pronation. The categorisation of foot type varies between individuals but ranges are accepted for pes rectus feet (3.6 – 5.5 cm STJN) outside of which is claimed to identify either pes planus or pes cavus (Nilsson,

2012). Table 6.3 shows the total number of foot types as categorised by the Navicular Drop Test.

Table 6.3. Total of foot types as defined by the Navicular Drop Test.

Foot type	Left foot	Right foot
Pes Rectus	15 dancers (31.9%)	15 dancers (31.9%)
Pes Planus	28 dancers (59.6%)	26 dancers (55.3%)
Pes Cavus	4 dancers (8.5%)	6 dancers (12.8%)

As discussed in the Methodology chapter (section 5.3.3.) a normal foot posture lies within the parameters 0.6 – 1.0 cm sagittal plane navicular displacement (Mueller, 1993) when translating from a neutral to relaxed or compensated stance position. Using this criterion it is therefore possible to define a foot as being of normal (pes rectus) foot type but exhibiting a planus posture (i.e. over- or hyperpronated due to laxity) if the change in navicular drop exceeds 1.0 cm between Subtalar Joint Neutral (STJN) and Resting Calcaneal Stance Position (RSCP), or as pes cavus if the drop is less than the lower threshold of 0.6cm (i.e. inflexible or stiffer due to a high arch). In other words, the movement (pronation) is from STJN to “corrected” position of RSCP Position. NVDT data and classification of foot type for participants in this study are shown in Table 6.4.

Table 6.4. - Navicular Drop Test results for all dancers (n=47).

	LEFT FOOT	RIGHT FOOT	
Foot stance	Mean +/-1SD (cm)	Mean +/-1SD (cm)	Left vs Right foot Paired t-test
Neutral stance navicular height (A) Subtalar Joint Neutral (STJN) (n=47)	4.57+/- 0.85	4.70+/-0.84	P<0.001
Resting Calcaneal Stance Position (RCSP) (B) (n=47)	3.59+/- 0.96	3.83+/-1.02	P=0.007
Difference between A and B (A – B) = Navicular Drop	0.94+/- 0.49***	0.91+/- 0.45***	Ns

***difference between STJN and RCSP p<0.001

The data identify a significant difference between the left foot and right foot with the left foot being flatter both in the STJN and RCSP. However, the navicular drop, a measure of foot pronation, was not significantly different between the left and right feet.

According to the Mueller (1993) classification it would appear from the data in Table 6.4 that participants collectively might be considered to exhibit a normal (i.e. pes rectus) foot type albeit toward the lower end of the range (lower threshold is considered to be 3.6 cm). Table 6.4 data provides consistency in that differences in RCSP were observed in foot arch heights between the left and right foot of dancers, with the left foot being flatter than the right in STJN and in RCSP stance, though differences were only statistically significant (paired t-test) for the pes planus classification (but dancers with pes planus in this subset were too few to

test). Further testing for independent samples identified that pes rectus and pes planus foot type data are highly significantly different from each other for RCSP (independent t-test; both feet $p<0.001$) as is the navicular drop (independent t-test; both feet, $p<0.001$). The navicular drop remained similar in the left and right foot for each type of foot. Likewise the mean value for navicular drop (left 0.94 ± 0.49 SD and right 0.91 ± 0.41 SD) gives an impression of a foot posture which reflects normal flexibility (range 0.6 – 1.0cm). However, the size of the standard deviation values relative to the mean indicates that at least some dancers were likely to be supra- or sub-threshold values, and there was a broad range of values for the navicular drop from 0.1cm to 1.6cm across all individuals. The collective mean values therefore do not appear to give a true indication of the variation in measurements across all individuals. Table 6.5 identifies RCSP values (i.e. resting calcaneal stance position) and navicular drop data for those dancers whose foot type classification was the same for both feet ($n=45$). Foot type classifications are explored in detail in the narrative below.

Table 6.5. RCSP results by foot type. ($n=45$ dancers): *Note sample selected where left foot type = right foot type in order to facilitate paired analysis.

	LEFT FOOT RCSP (mean\pm1SD; cm)	RIGHT FOOT RCSP (mean\pm1SD; cm)	Left - right foot Paired t- test	Navicular drop Left foot	Navicular drop Right foot	Left – right foot Paired t-test
All foot types ($n=45$)*	3.47 \pm 0.91	3.67 \pm 0.92	$P=0.003$	0.84 \pm 0.51	0.87 \pm 0.47	ns
Pes rectus ($n=15$)*	4.19 \pm 0.76	4.50 \pm 0.59	ns	0.35 \pm 0.27	0.47 \pm 0.39	ns
Pes planus ($n=26$)*	2.95 \pm 0.31	3.09 \pm 0.31	$p<0.001$	1.18 \pm 0.40	1.16 \pm 0.30	ns
Pes cavus ($n=4$)*	5.90	5.70	-	0.35	0.15	-

Table 6.5 appears consistent in that differences in RCSP were observed in foot arch heights between the left and right foot of dancers, with the left foot being flatter than the right in neutral stance and in RCSP, though differences were only statistically significant (paired t-test) for the pes planus classification (but dancers with pes planus in this subset were too few to test). Further testing for independent samples identified that pes rectus and pes planus foot type data are highly significantly different from each other for RCSP (independent t-test; both feet $p < 0.001$) as is the navicular drop (independent t-test; both feet, $p < 0.001$). The navicular drop remained similar in the left and right foot for each type of foot.

Overall, 28/47 (59.6%) of dancers had a change in navicular height that classifies their left foot as pes planus and 4 dancers (4.3%) as pes cavus, and 26 dancers (55.3%) and 6 dancers (12.8%) presented with pes planus and pes cavus, respectively, of the right foot. Just 15 of the 47 dancers (31.33%) had both feet classified as ‘normal’ (pes rectus). In 1 female dancer and 1 male dancer the foot type of one foot did not correspond to the foot type of the other foot. Together these represented an incidence equivalent to 4.2% of the sample. *This had implications for the later data analysis when at times right and left feet measures had to be considered separately.*

Table 6.6 relates to foot type distributions based on the navicular drop data according to gender, although analysis was limited by the consequent effect on sub-group sample sizes particularly of pes cavus foot type and pes rectus in the male dancers. The high proportion of pes planus feet in the whole sample noted above was observed in both female and male dancers. Fifteen females presented with pes planus of the right foot, and 16 presented with pes planus of the left foot, again indicating that both feet of an individual do not always demonstrate the same foot type. Considering that 32 dancers in the sample were female this

means that 47-50% of the female sub-sample presented with pes planus. The number of female dancers with pes cavus feet (left and right) was much lower in the sample; all 4 were female and professional dancers.

For all females the amount of pronation measured as navicular drop from STJN to RCSP ranged from 0.1 cm to 1.3 cm for the left foot, and 0.1 cm to 1.2 cm for the right foot. For the males, the left foot ranged in pronation from 0.4 cm to 1.6 cm, and for the right foot 0.4 cm to 1.6 cm. The start and end points therefore were slightly different for the two gender groups, with males having slightly higher start and end points.

Eleven males presented with pes planus of the right foot, and 12 with pes planus of the left foot, so confirming that both feet of an individual do not necessarily demonstrate the same foot type in either gender. Considering that there were 15 male dancers in the sub-set then the occurrence of pes planus equates to 76% of the male sub-sample, a proportion considerably higher than in the female dancers although the distribution difference between genders was not statistically significant (Chi square=2.743; $p=0.254$). However, there was a borderline significant association of weight with foot type ($p=0.053$) that particularly reflected the males since on the whole they were heavier than the females (Table 6.1).

Whilst Table 6.4 relates to the total number of foot categories per gender i.e. right versus left feet, table 6.5 reveals the total number of dancers (45) whose feet paired into categories for data comparison. Table 6.6 and 6.7 explores this further in relation to individual foot type assessed according to the Mueller classification. In doing so it should be noted that a small number of dancers (2) were classified as presenting with unilateral foot types (Table 6.7).

Table 6.6. NVDT results for foot type (RCSP) by gender (n=47).

	LEFT FOOT (cm +/- (SD) RCSP	RIGHT FOOT (cm +/- (SD) RCSP
Female dancers		
All foot types	32 dancers 3.82+/-0.98	32 dancers 3.92+/-1.06
Pes Rectus	12 dancers 4.40+/- 0.66	13 dancers 4.46+/-0.95
Pes Planus	16 dancers 2.9+/-0.35	15 dancers 2.97+/-0.3
Pes Cavus	4 dancers 5.4+/-0.05	4 dancers 5.75+/-0.15
Male dancers		
All foot types	15 dancers 3.50+/-0.91	15 dancers 3.64+/-0.89
Pes Rectus	3 dancers 4.14+/-0.75	2 dancers 4.4+/-0.66
Pes Planus	12 dancers 2.9+/-0.35	11 dancers 3.05+/-0.2
Pes Cavus	0 dancers	2 dancers 5.4+/-0.05

Table 6.7. RCSP for foot type by gender. Paired foot type data only for comparison (n=45).

Both genders NVDT foot category N = 45	LEFT FOOT RCSP (mean+/-1SD; cm)	RIGHT FOOT RCSP (mean+/-1SD; cm)	Left-right difference (paired t-test)
Female dancers			
All foot types (n=32)	3.82+/-0.98	3.90+/-1.09	p<0.001
Pes Rectus (n=12)	4.11+/-0.73	4.49+/-0.62	p=0.051
Pes Planus (n=16)	2.87+/-0.35	2.97+/-0.33	p=0.007
Pes Cavus (n=4)	5.70	5.90	-
Male dancers			
All foot types (n=13)	3.49+/-0.91	3.67+/-0.85	p=0.022
Pes Rectus (n=2)	4.60	5.20	-
Pes Planus (n=11)	3.05+/-0.22	3.25+/-0.20	p=0.002
Pes Cavus (n=0)	-	-	-

To further evaluate the potential of differences in the degree of pronation between genders the data analysis was facilitated by trichotomizing the raw pronation values into low (0.1-0.5cm), medium (0.51 – 1.0cm) and high (1.1+cm) categories. A chi square test identified significant association of pronation of the left foot ($p=0.050$) and of the right foot ($p=0.013$) with gender. For both feet females showed a distribution that especially linked to the low and high levels of overpronation categories: 14/32 (44%) dancers for the left foot, and 11/32 (34%) dancers for the right foot, respectively. For the males it was the high pronation category that dominated: 11/15 (73%) dancers were linked to this for the left foot and 12/15 (80%) for the right foot. The prevalence of high pronation in the male dancers of this sample therefore is especially clear. Consequently, possible gender influences were sought within the later data analyses.

6.2.2: Calcaneal Bisection measures.

This method of measuring foot type takes a very different approach to the NVDT by measuring angles of eversion relative to a vertical line on the lower 1/3 of the leg (see methods 5.3.4.). Like the NVDT it purports to provide an objective evaluation of foot type, and so offers comparison to the results from the NVDT. Results arising from the Calcaneal bisection data are shown in Table 6.8. Though a different way to measure foot type compared with the NVDT the two methods triangulated perfectly and classification of foot type coincided exactly with that derived from the NVDT (Table 6.3 in section 6.2.1). The data (Table 6.8) therefore provides strong support for the NVDT results, including for a difference between the incidence of left and right foot type in the same individuals, and a high incidence of pes planus in the dancers.

Table 6.8. Calcaneal Bisection for foot type. Results for all dancers n=47.

Foot type	Left foot	Right foot
Pes Rectus	15 dancers (31.9%)	15 dancers (31.9%)
Pes Planus	28 dancers (59.6%)	26 dancers (55.3%)
Pes Cavus	4 dancers (8.5%)	6 dancers (12.8%)

The data mirror those of the NVDT in the previous section (6.2.1) in terms of incidence of foot type and a difference between left and right foot type in the same individuals as detected with the NVDT, and a high incidence of pes planus in the dancers.

6.2.3: Foot Posture Index (FPI).

The FPI results identified a total of 30 left foot and 25 right foot as pes planus foot type with males 13 and female 17 for left foot and 11 and 14 right foot respectively (Table 6.9). There were slight differences from the NVDT/Calcaneal Bisection method data but the numerical difference in pes planus of right and left feet, including by gender, followed the same trends of a high incidence of pes planus and different left and right foot type in some individuals. This trend is evident across all three foot types for both gender and is discussed further in the discussion (chapter 7).

Table 6.9. Foot Posture Index results for all dancers n=47.

Foot type	LEFT FOOT	female	Male	RIGHT FOOT	female	male
Pes Planus	30 dancers (63.8%)	17 (36%)	13 (27%)	25 dancers (53.1%)	14 (29.7%)	11 (23%)
Pes Cavus	3 dancers (6.4%)	3 (6%)	0	7 dancers (14.9%)	5 (10%)	2 (4%)
Pes Rectus	14 dancers (29.8%)	12 (25%)	2 (4%)	15 dancers (31.9%)	13 (27%)	2 (4%)

6.2.4: Comparing the three measures of foot type.

The three foot measures are commonly used in clinical practice and as a basis in research studies (Weinraub et al., 2000; Yeap et al., 2001; Barton et al., 2011; Langley et al., 2015) to evaluate foot type and static bipedal foot posture. Ostensibly they should therefore produce similar results for comparison of foot type. Correlations are extremely good in this respect (Table 6.10). As noted in sections 6.2.1-6.2.3 above, all three measures also supported a difference between left and right foot types in a small number of both males and females, and a high proportion of pes planus of both left and right feet. The case for employing these measurements was made in the Methodology chapter (5.3.) since pronation being a triplane motion is subject to proportionality of motion dependent on the relative position of the axis to the three planes which define motion.

Table 6.10. Summary of correlations (Spearman's rho) between the 3 proxy measures

Foot type	Left Foot	Right foot
NVDT vs FPI	rho = 0.813 p = 0.001	rho = 0.816 p < 0.001
NVDT vs Calcaneal bisection	rho = 1.000 p=0.000..	rho = 1.000 p=0.000..
FPI vs Calcaneal bisection	rho = 0.813 p <0.001	rho = 0.876 p < 0.001

However, whereas the NVDT and Calcaneal Bisection methods exhibited perfect triangulation (boldfaced in Table 6.10) the FPI distributions were different. For example 30 left feet and 25 right feet pes planus in both male and female were identified as pes planus by the FPI against 28 left and 26 right foot pes planus with NVDT in both genders. The FPI method relies entirely on line-of-sight rather than an objective measurement of height (NVDT) or angles (calcaneal bisection). This might therefore explain the slight variability in the FPI compared with the other two measures. Thus, although all 3 measures agreed extremely well the slight variability in the data for the FPI suggests a slightly inferior reliability for this measure. *The FPI is much easier and quicker to undertake in practice but it lacks involvement of any objective measure and so for this reason a decision was taken that foot types determined using the FPI would not be utilised in any further inferential statistical analyses that involved foot type categories.*

6.3: Foot type versus height, weight, amateur/professional status, hours training per week, and years of training.

Of the twenty six dancers who presented with pes planus of the right foot, 23 were elite dancers who train over 40h per week (Table 6.12). Eleven of those were in the 18 years age group, the largest number of dancers for all age groups, but otherwise pes planus (right foot) was distributed across all age groups. 28 dancers (26 professional, 2 amateur) also presented with pes planus of the left foot, 12 of whom were in the 18 year age group.

There was no clear relationship between hours training per week and foot type defined by Calcaneal Bisection or NVDT (Table 6.7; $p = 0.655$). The distribution of foot type also was not significantly associated with age ($p = 0.327$) although considering the different feet separately a (marginal) positive association between foot type (right foot) and the collated age groups ($p=0.053$) was identified suggesting a weak relationship between pes planus of that foot and dancer's age. Making a distinction of left or right foot did not identify any further significant association with other demographic variables.

Table 6.12. Foot type (right foot only) related to training.

Foot type (Calc Bisection/ NVDT)	Training per week: 3.5-4 hours	Training per week: 40 hours	Total
Pes Rectus	3	12	15
Pes Planus	3	23	26
Pes Cavus	0	6	6
Total	6	41	47

6.4. Foot type and foot positions in dance.

Two key dance positions were evaluated in this study: 1st position and 5th position. These are explored in detail, below, but it is noteworthy that in most instances foot type (pronation) evaluated in the dance position were highly significantly associated with foot type at rest, measured either by NVDT or Calcaneal bisection (Table 6.11).

Foot types were identical using both tests (Table 6.11). Significant associations are shown in boldface. Shaded boxes denote associations of foot type in the dance positions when measured either by NVDT or Calcaneal Bisection methods.

Table 6.12. Association matrix (chi square) for foot type and 1st and 5th dance positions, for the right and left foot of all dancers (n=47).

	1	2	3	4	5	6	7	8	9	10
1 Foot type R	1									
2 Foot type L	P<0.0 01	1								
3 1 st Pos R	P=0.0 05	P=0.5 22	1			.				
4 1 st Pos L	P=0.0 05	P=0.0 15	P<0.0 01	1						
5 5 th PosR	P<0.0 01	P=0.0 06	P<0.0 01	P=0.01 4	1					
6 5 th PosL	P<0.0 01	P<0.0 01	P=0.2 01	P<0.00 1	P=0.0 02	1				
7 1 st Pos CalcB R	P=0.1 42	P=0.0 66	P<0.0 01	p<0.00 1	P=0.0 27	P=0.1 91	1			
8 1 st Pos CalcB L	P=0.0 03	P<0.0 01	P<0.0 01	P<0.00 1	P=0.0 88	P=0.0 08	P<0.0 01	1		
9 5 th Pos CalcB R	P<0.0 01	P<0.0 01	P=0.2 14	P=0.00 8	P=0.0 14	P<0.0 01	P=0.1 56	P=0.0 08	1	
10 5 th Pos CalcL	P<0.0 01	P<0.0 01	P=0.0 02	P=0.02 9	P<0.0 01	P<0.0 01	P=0.0 61	P=0.1 56	P=0.0 26	1

Note: PosR and PosL denote evaluation of foot type in 1st or 5th positions determined by the NVDT, while Pos Calc BR and Pos CalcBL denote evaluation of foot type in the dance positions using the Calcaneal bisection method.

Table 6.12 also identifies associations of foot type between 1st and 5th dance positions, but associations are not entirely consistent as evidenced by lack of significance of some. Table 6.10 earlier had identified the complete agreement of NVDT and Calcaneal bisection outcomes so such variability in evaluating foot type when in the dance positions seems surprising. The most likely explanation is methodological error arising from constraints in making the measures whilst dance stances were maintained. In applying the NVDT to measure foot positions it was observed that dancers at times could not hold position for more than 30 seconds as a consequence of the subtalar joint either in- or out-rolling so affecting reliability of the measure. Also, evaluation of the 5th position is complicated since the other foot blocked access to evaluate the NVDT. The Calcaneal Bisection test is more readily and quickly applied and so a decision was taken that this most likely provided a more accurate evaluation of foot position; it had also correlated perfectly with the NVDT as to foot type when the dancers were in the resting stance. To evaluate this further the relationship of foot types determined in the 1st to 5th dance positions was further explored using a bivariate correlative test (Spearman Rho) applied to the NVDT and Calcaneal bisection data to compare further the consistency of the two methods in evaluating foot position in the same dancers:

1st position right foot (NVDT) vs 1st position right foot (Calcaneal test): $\rho = 0.734$; $p < 0.001$

1st position left foot (NVDT) vs 1st position left foot (Calcaneal test): $\rho = 0.686$; $p < 0.001$

5th position left foot (NVDT) vs 5th position left foot (Calcaneal test): $\rho = 0.336$; $p = 0.021$

5th position right foot (NVDT) vs 5th position right foot (Calcaneal test): $\rho = 0.278$; $p = 0.058$

It is evident from these data that 5th position (Right and left foot) especially was variable, showing only a weak correlation between the two methods. In view of the potential inaccuracy *a decision was taken to utilise only the Calcaneal bisection data on foot type in further analyses involving foot position data..*

The following subsection explores further the associations of dance position with foot types.

6.5. Foot type and First position in dance.

First position is a ballet movement (Appendices Chapter 2, Photo 2.1 for this ballet position) that requires a dancer to maintain a good foot arch with the knee positioned over the foot. To maintain this position requires both a strong and stable medial longitudinal arch (MLA), and good external rotation at the hip (60 degrees plus). In bipedal stance, if the foot is pronated (i.e. pes planus), this results in poor external rotation at the hip joint (Chapter 3.1.9.). Further, if there is an abnormal degree of pes planus then despite all the years of training to strengthen the intrinsic muscles of the foot to develop an appropriate arch, an inherent musculo-skeletal weakness is still likely to result in the foot having difficulty in forming that arch because the extensor muscles of the leg will be under strain, resulting from the calf muscles often being too tight with the Tibialis Anterior muscle showing prolonged contractile activity. Overpronation also affects the hip joints, which may result in the dancer having to twist or externally rotate the tibia and fibula, placing additional strain on the knee joint and the patella in an effort to maintain this ballet position. Table 6.13 identifies the degrees of

pronation and supination of the right foot in the First position as defined by calcaneal bisection measurement (degrees pronation).

Table 6.13. Degrees of pronation or supination versus foot type determined by Calcaneal Bisection in dancers' maintaining the 1st dance position according to foot type (Right foot only).

Foot Type using Calcaneal Bisection	NORMAL CRITERIA 0-3 degrees Pronation	4-6 degrees Pronation	4-6 degrees Supination	Total Number Of dancers
Pes Rectus	8	7	0	15
Pes Planus	4	22	0	26
Pes Cavus	2	3	1	6
Total	14	32	1	47

Seven dancers with pes rectus (i.e. a 'normal' foot type) overpronated 4-6 degrees, outside the normal range of 0-3 degrees. This could be considered reflective of a flexible foot although as noted foot type at rest with the calcaneal bisection method triangulated with the NVDT, which suggests that the overpronation was not solely a reflection of individual deviation of the subtalar joint axis (STJA) from the frontal plane. Conversely, amongst dancers with the pes planus foot type four pronated in the normal range where, according to the narrative above, one may expect less in that range and more in the overpronation range of 4 degrees plus. Even so, twenty-two dancers with pes planus overpronated (4-6 degrees). Overpronation therefore was the most consistent feature of the right foot in the 1st dance position; 22/26 dancers demonstrating overpronation were of the pes planus foot type.

Observing the pes cavus foot type also demonstrated that three dancers overpronated 4 -6 degrees. This is a ‘high arch’ foot type (see Table 6.13) and it is likely therefore that these dancers would have to make a subconscious compensatory musculo-skeletal effort in order to roll the foot inwards to enable the foot to be placed evenly on the floor, that is with the first and fifth metatarsal heads and the calcaneus all making ground contact, and to allow the knee to be positioned evenly over the foot. This would help to explain the occurrence of overpronation in these few dancers. Just one dancer in this sub-group demonstrated supination (4 – 6 degrees) when in the 1st dance position.

Observing the left foot in the 1st dance position (Table 6.14), 25 dancers with pes planus foot type overpronated (4 -6 degrees), 3 more on this foot than they had on the right foot. Thirteen dancers with pes rectus fall into the expected normal range of pronation (0 -3 degrees) with just 2 dancers overpronating in the 4-6 degrees range but 4 dancers with pes cavus overpronated excessively, 3 in the 4-6 degree range and 1 in 10 degrees plus. No dancers demonstrated supination in the 1st position when related to left foot type. As with the right foot, data indicated overpronation was the most expressed feature; 25/28 dancers expressing this in the left foot were of the pes planus foot type. The slightly higher number of dancers who overpronated in the left foot compared with the right indicates an asymmetric foot pronation in some dancers when taking the 1st position stance.

Table 6.14. Degrees of pronation versus foot type determined by Calcaneal Bisection in dancers maintaining the 1st dance position (Left foot type only).

Foot Types using Calcaneal Bisection	NORMAL CRITERIA 0-3 degrees Pronation	4-6 degrees Pronation	10 degrees + Pronation	Total Number Of dancers
Pes Rectus	13	2	0	15
Pes Planus	3	25	0	28
Pes Cavus	0	3	1	4
Total	16	30	1	47

The implications of these data are that the majority of dancers in this study, both amateur and professional, presented with 1st foot position data that were outside those considered as normal criteria. In some dancers there was variation in the relationship of the left and right foot between foot type and 1st dance position. Although the majority of those with pes planus overpronated in this dance position, the implication is that evaluation of the foot type per se is not necessarily predictive of this. *This implication is revisited later in Section 7.0.*

6.5.1: Foot type and fifth dance position.

The Fifth position in ballet is the placement of the feet in preparation for the next movement in dance, particularly a jump. It places pressure on the hips to externally rotate equally even though one foot is placed in front of the other (see background chapter 2, photos 2.1 and 2.2). This is a particularly taxing dance position and places more strain on the dancer than the 1st position, in terms of keeping the hips square and two equally matching good foot arches formed. A dancer with a pes planus foot type would be under strain to stop the foot from overpronating in an effort to keep the hips open in unison. The Tibialis Anterior muscle is often observed as tensing as the dancer attempts to maintain and hold in the 5th position. Therefore, if there is a biomechanical anomaly then it may be observed in the 1st position but is likely to be more apparent in the 5th position.

Tables 6.15 (Right foot) and 6.16 (left foot) show that overpronation was indeed more evident in the 5th than the 1st dance position, being observed even in some dancers who had a normal pes rectus foot type in the resting position. A slight difference therefore is the incidence of overpronation in relation to foot type: for example, 25/26 dancers for right foot

pes planus foot type (Table 6.15), compared with 27/28 dancers who presented as overpronating with the left foot (Table 6.16).

Table 6.15. Degrees of pronation versus foot type determined by Calcaneal Bisection in dancers' maintaining the 5th dance position (Right foot type only).

Foot Type using Calc Bisect.	NORMAL CRITERIA 0-3 degrees Pronation	4-6 degrees Pronation	7-9 degrees Pronation	10+ degrees Pronation	4-6 degrees Supination	7-9 degrees Supination	Number Of dancers
Pes Rectus	8	7	0	0	0	0	15
Pes Planus	1	14	11	0	0	0	26
Pes Cavus	0	1	0	1	2	2	6
Total	9	22	11	1	2	2	47

Table 6.16. Degrees of pronation versus foot type determined by Calcaneal Bisection in dancers' maintaining the 5th dance position (Left foot type only).

Foot Type using Calc Bisection	0-3 degrees Pronation (normal range)	4-6 degrees Pronation	7-9 degrees Pronation	10 + degrees Pronation	4-6 degrees Supination	7-9 degrees Supination	Number Of dancers
Pes Rectus	10	4	1	0	0	0	15
Pes Planus	1	18	8	1	0	0	28
Pes Cavus	0	0	1	1	1	1	4
Total	11	22	10	2	1	1	47

Looking more closely at details of the data, Tables 6.15 reveal that 7 dancers with a (normal) pes rectus right foot and 4 dancers (Table 6.16) overpronated at the 4-6 degrees range, and 1 dancer overpronated at the 7-9 degree range with a pes rectus left foot. Since the majority of the dance sample were elite, professional dancers and will have trained intrinsic foot muscles and leg muscles extensively over the years this occurrence in only the left foot is not clear. For the dancers with a pes planus foot type, only 1 dancer pronated in the normal pronation range, with high numbers of this sub-group overpronating between 4-7 degrees (14 dancers) or 7-9 degrees (11 dancers).

Regarding the pes planus foot type, 25/26 dancers overpronated with the right foot, and 27/28 with the left. One dancer with pes cavus overpronated 10 degrees plus and 4 dancers overly

supinated. Considering the small number of dancers presenting with pes cavus in the overall sample group of 47 these findings indicate that, as with the 1st dance position, the majority were either overpronating or oversupinating.

Overall, Tables 6.15 and 6.16 therefore reinforce the narrative, above, that a high incidence of overpronation is exposed in these dance positions and that any influence of foot type on degrees of pronation is likely to be more apparent in the 5th dance position than in the 1st.

6.5.2: Gender influences on 1st and 5th dance positions.

Earlier in this chapter, Table 6.6 had suggested possible gender differences in the NVDT data, albeit marginal. With overpronation more evident in stances in the 1st and 5th dance positions it is possible that gender influence might be evident. The following tables therefore compare the 1st and 5th dance positions in respect of gender.

Table 6.17. First Position (left foot) – degrees of pronation and supination in males and females.

First dance Position (left foot)	Females	Males	Total
Degrees of Pronation/Supination			
0-3 degrees pronation Normal range	12	7	18
4-6 degrees pronation	19	9	28
7-9 degrees supination	1	0	1
Total	32	15	47

Table 6.17 identifies that most dancers overpronated on their left foot for the 1st dance position, with 19 females and 9 males overpronating by 4-6 degrees. Considering the right foot, Table 6.18 identifies that 19 females and 7 males overpronated in this foot in the 4-6 degrees range. There was therefore a slightly higher female/male gender ratio with the left foot when compared with the right (2.7:1 compared with 2.1:1). Over pronation across all ranges is noted in 29 dancers (left foot) and 27 dancers (right foot) for both genders predominantly in 4 -6 degree range.

Table 6.18 - First Position (right foot) – degrees of pronation and supination in males and females.

First Position (Right foot)	Females	Males	Total
Degrees of Pronation/Supination			
0-3 degrees pronation (normal range)	12	9	21
4-6 degrees pronation	19	7	26
10+degrees supination	1	0	1
Total	32	15	47

For the 5th dance position (Table 6.19), 21 female and 13 male dancers (>4 degrees) overpronated with their left foot (gender ratio 1.6:1), higher than those observed in the 1st dance position and also identifying a lower female/male ratio (1.6:1) indicative of a disproportionately higher number of males. 20 female and 13 male dancers overpronated (right foot; gender ratio 1.5:1) in the 5th dance position, as seen in Table 6.19. Comparing these gender ratios with those from the 1st position data (see Tables 6.17 and 6.18) suggests that the increased incidence of overpronation in the 5th dance position compared to the 1st is evident in both genders but disproportionately more in the males. Further, the most excessive overpronation (10+ degrees) was observed in 1 female (left foot) but in 4 males (3 left foot and 1 right foot). Supination in the ranges of 4 -6 and 7 -9 degrees also identified gender variations. Of the 4 females and 1 male exhibiting supination of the left foot, 3 female supinated abnormally in the 7- 9 degrees range and the 1 male dancer. Whereas only 1 female over supinated the right foot (10+degrees) and no males. The demands of maintaining 5th

position may have some barring on the proportion of over pronated foot position (left 24 and right 26) in both gender and significance in females which is considered in chapter 7.

Table 6.19. Fifth Position (left foot) – degrees of pronation and supination in males and females.

Fifth Position (left) Degrees of pronation/ supination	Females	Males	Total Number of Dancers
0-3 degrees pronation	7	1	8
4-6 degrees pronation	13	5	18
7-9 degrees pronation	7	5	12
10+ pronation	1	3	4
4-6 degrees supination	1	0	1
7-9 degrees supination	3	1	4
Total	32	15	47

Table 6.20 - Fifth Position (right foot) – degrees of pronation and supination.

Fifth Position (right) Degrees of Pronation/Supination	Females	Males	Total Number of Dancers
0-3 degrees pronation	10	2	12
4-6 degrees pronation	16	9	25
7-9 degrees pronation	4	3	7
10+ pronation	0	1	1
4-6 degrees supination	1	0	1
7-9 degrees supination	1	0	1
Total	32	15	47

6.6: Injuries.

6.6.1: Number of injuries and relation to foot type, foot pronation, dance positions and gender.

40/47 dancers (86%) reported at least one past/present injury. The range of injuries was 0-6 injuries per dancer and the total injuries reported by the whole sample were 110 giving a mean of 2.75 per dancer. Additionally, all of the dancers had toenail injuries probably indicative of time spent on pointe.

For all dancers (n=47) pronation was significantly, positively correlated with number of injuries (right foot, Spearman's $\rho=0.339$; $p=0.020$; left foot $\rho=0.402$; $p=0.005$). Relating number of injuries to foot type (Table 6.21) identified that 15 dancers with a normal left foot (i.e. pes rectus) and 15 dancers normal right foot had history of 1.8 injuries to left and right foot type respectively. 28 dancers who had a left pes planus foot and 26 dancers who had right pes planus foot had a higher total injury count of 79 injuries equivalent to 2.82 and 3.04 injuries each according to left or right foot types respectively suggestive of possible higher risk with this foot type. Dancers presenting with pes cavus included 4 dancers with a left cavus foot and 6 dancers with a right cavus foot with a total number of 4 injuries (1 per dancer) although the small number of pes cavoid feet type means that this should be considered tentative at best. However, distinguishing foot type in the analysis of association with number of injuries did not demonstrate a significant correlation (Spearman ρ) or association (Chi square) between pes rectus or pes planus foot type and the number of injuries.

Table 6.21. Number of injuries per foot type.

Calcaneal bisection/ NVDI	Left Foot type	Right Foot type	Number of injuries for foot type
Pes Planus	28	26	79
Pes Rectus	15	15	27
Pes Cavus	4	6	4
Total	47	47	110

6.6.1: Gender and number of injuries.

Section 6.5.2 identified a significant association between gender and degree of pronation, with a indication that males were particularly likely to excessively overpronate. The potential for gender influences on number of injuries was therefore explored.

Table 6.22 shows the number of injuries experienced according to gender. Amongst the 47 dancers, 40 identified past and/or current injury. Thirteen dancers (27.7%) reported a current injury but were still dancing, of which 6 were male and 7 were female, and 27 (57.4%) dancers had a history of injuries from which they had recovered (20 female, 7 male). Collating current injuries and those recovered, therefore, indicates that 27/32 (84%) females in the whole sample and 13/15 (87%) males had experienced injuries over their training time.

Table 6.22. Number of injuries according to gender: current, recovered or no injuries.

Gender	Recovered from injuries	Current injuries	Never had an injury	Total no of dancers
Females	20	7	5	32
Males	7	6	2	15
Total no of injuries	27	13	7	47

Association of number of injuries according to gender was analysed using Spearman rho bivariate correlation, and also Chi square test, and was statistically significant in each case (rho = 0.3012, p=0.039, and 4.880, p=0.018. respectively).

6.6.2: Type/location of injury in relation to foot type and pronation.

Type of injury varied according to anatomical site, and even within a location specific injuries were also varied (Table 6.23).

Table 6.23. Specific injuries to the foot, ankle, leg and knee.

Foot	1 st and 5 th Metatarsal, Sesamoid, Cuneiform fractures, Bursitis, Painful bunions, Plantar Fasciitis, Flexor Hallucis Longus tendinitis, Peroneus Longus, Peroneus Tertius, Cyst 3 rd Met.
Ankle	Sprains, tendinitis, Os Trigonum
Leg	Shin splints, Hamstring tears, Tendo Achilles, Fibula fractures,
Knee	Torn ACL, Swollen knee,

For analysis purposes injuries were categorised by anatomical location for evidence of any emergent pattern (see Table 6.24.). The categories reflected individual sites but also combinations of sites. Injuries occurred either in isolation to specific limb segments or to 2 or even 3 segments.

Table 6.24. Injury type collated according to anatomical location.

Injury category		No. of dancers with this category of injury (no. of injuries in total)	Males with this category of injury.	Females with this category of injury.
0	No injury	7	2	5
1	Ankle injury only	8	2	6
2	Foot injury only	16	3	13
3	Knee injury only	6	2	4
4	Leg injury only	2	0	2
5	Ankle, foot and knee injuries	6	1	5
6	Foot and leg injuries	2	1	1
Total		47 dancers	15	32

The frequency distribution of sites of injury in Table 6.24 was statistically significant (Chi square; $p=0.001$) with most injuries particularly being associated with involvement of the foot and/or ankle. From a podiatry perspective, and hence the objectives of this thesis, it is injuries to these sites that are of particular interest.

Association of foot type with injury category exhibited borderline significance (left only, $p=0.054$). The 1st dance position, assessed by calcaneal bisection method, was also associated with type of injury ($p=0.044$, left foot; $p=0.048$, right foot). In each case foot-only or foot and leg injuries were prominent. Injury type did not associate with 5th dance position.

Injury category in Table 6.24 also did not associate with the degree of pronation either in the whole dataset, between genders, or according to foot type. However, the categories do not take into account the number of injuries or their relation to pronation. The data identified 13 dancers in the high pronation subgroup who had acquired a large number of injuries per person i.e. 3 – 5 injuries each. This is considered further in the next sub-section.

6.6.3: Specific injuries and foot type.

For further analysis, data on injury type and category were then stratified according to foot types, though of course this reduced the number of dancers in each analysis: the pes cavus sub-group was not analysed due to low numbers of dancers with this foot type (Table 6.25.).

Table 6.25. Injuries to limb segments according to foot type.

Injuries to the Foot	Pes Rectus	Pes Planus	Pes Cavus
Toes	0	7	0
Cuneiforms	0	4	0
Sesamoid	2	6	0
Bursitis	3	3	0
Bunions (Painful)	2	5	0
Plantar Fasciitis	2	7	0
Peroneus Longus	1	0	0
Peroneus Tertius	0	3	0
Capsulitis	1	3	0
Bursitis	0	3	0
Cyst	2	1	0

Metatarsals	0	4	3
Navicular	0	2	0
Total	13	48	3
Injuries to the Ankle			
Os Trigonum	1	5	1
Ankle	4	10	0
Total	5	15	1
Injuries to the Leg			
Tendo Achilles	2	6	0
Flexor Hallucis Longus	2	2	0
Fibula	0	1	0
Bone Bruising	0	1	0
Vastus Medialis	1	0	0
Hamstrings	3	1	0
Shin Splints	0	2	0
Total	8	13	0
Injuries to the Knee	1	3	0
Total	1	3	0
TOTAL All segments	27	79	4

Overpronation creates instability at the ankle and therefore the number of ankle injuries therefore an association could be expected. Considering foot type, in dancers with pes rectus (n=13) there was indeed a strong association between injury site (primarily ankle/foot and foot/leg) with degree of pronation (left foot only; Chi square $p=0.002$) and 1st position (right

foot only; Chi square $p=0.002$). Comparing dancers with pes planus foot type with pes rectus and pes cavus, injuries in those with pes planus were especially evident to the feet, ankles, knees and legs, with a modal number of plantar fasciitis (i.e. sole of foot/foot arch) and to the ankles, although the association of specific injuries in those selected as having pes planus foot type ($n=28$) did not evidence a significant association with any particular category(ies).

6.7: Hallux Valgus.

Hallux Valgus, commonly known as bunions, was determined in this study by application of The Manchester Scale. The pes planus foot type, by the nature of its flatness, overpronates more excessively than any other foot types and so is considered more prone to Hallux Valgus. Hallux Valgus ranging from grade 2 - 3 was present in 35/47 (74%) dancers. The higher the grade (range 1- 4) the less the proximal phalange (base of 1st toe) is positioned on the head of the first metatarsal and is liable to partially or fully dislocate during the gait cycle including when moving onto pointe. Those with Hallux Valgus comprised 28 dancers with pes planus, 6 with pes rectus and 1 with pes cavus.

Hallux Valgus of one foot was associated with its occurrence in the other foot ($p<0.001$). Its presence in the right foot was highly associated with foot type (right; $p<0.001$), predominantly pes planus, and 5th dance position (right; $p=0.049$) but not with 1st position (right; $p=0.428$). Hallux Valgus of the left foot was also highly associated with the left foot type ($p<0.001$) again predominantly pes planus. Association with the 5th dance position (left foot) was marginal ($p=0.061$) at best and Hallux Valgus was not associated with the 1st dance position (left foot; $p=0.133$).

Finally Hallux valgus was associated with 'Years of training' ($p=0.042$) suggesting a cumulative outcome of dance training, though no association was apparent with 'Hours of training'.

6.8: Predictors of injury in dancers.

As noted, 86% of dancers reported at least one past/present injury, with dancers having a history of up to 6 injuries. The Findings so far in relation to potential risk factors for injury have mostly been presented according to foot measures/foot type, pronation/dance positions, and gender:

- The left foot is consistently flatter than the right in this sample of dancers, but both genders demonstrated a high incidence of pes planus and overpronation which was weakly related to body weight but significantly linked to gender and age.
- Application of the navicular drop test and calcaneal bisection in the resting stance produced exactly the same differentiation of foot type category. The foot posture index was less reliable than these though still performed very well.
- In the 1st and 5th dance positions calcaneal bisection performed more reliably due to likely methodological issues related to measuring the navicular drop.
- The incidence of overpronation was higher in the 1st and 5th dance positions and slightly higher than in the resting stance, especially in the 5th position. In relation to gender and overpronation, female/male ratios appeared lower in the 5th position indicating a disproportionate number of males were affected.
- Number of injuries was significantly correlated with foot pronation with a trend suggested regarding pes planus, though the latter was not statistically significant.
- Number of injuries was also significantly associated with gender.

- Injury type was predominantly related to foot or foot/leg sites, and associated with degree of pronation.
- Hallux Valgus was likely to be present in both feet and was associated with degree of pronation, pes planus foot type and years of training.

Some though not all of these associations/correlations were statistically tentative but warrant further analysis of their involvement in contributing to an increased risk of injury in dancers. Accordingly, an exploratory ordinal regression analysis was performed though in doing so it is recognised that the sample sizes mean that outputs from such analysis must be treated with caution. Sample size is frequently set at 100+ numbers of variables (Knofczynski and Mundfrom, 2008) in order to provide the necessary analytical rigour for prediction but in a more exploratory setting a sample of 2+subjects per predictor variable (SPV) is suggested to have a respectably low level of bias. With the current sample of dancers this suggests that application of up to 20 potential predictors might be of value in further assessment of the data.

Ordinal regressions were conducted using the appropriate function in SPSS. Firstly, ‘Number of injuries’ was defined as the dependent variable. Foot type (right and left foot), pronation (left and right foot), 1st dance position (right and left foot), 5th dance position (right and left foot) and gender were initially entered as independent variables. The model fit was highly significant ($p=0.003$) with foot type (left) and 1st and 5th dance positions (left) as the main factors. However the Test of Parallel Lines, a measure of parallel regressions suggestive of co-variance, was highly significant suggesting a likelihood of a lack of independence of the variables; in the main findings foot type at rest and in the dance positions were highly correlated. Repeating the test with removal of the dance position data produced a significant

model ($p=0.016$) with non-significant Test of Parallel Lines, with 'Foot type left' prominent as a factor, and gender a borderline factor. Exclusion of gender also produced a significant model ($p=0.033$) but now identified 'foot type right' as a major factor. Substituting pronation in place of 'foot type' as independent variables, with gender, produced a highly significant model ($p<0.001$) with 'Pronation left' and 'Pronation Right' as factors, but not gender, suggesting a 2-factor model based on resting stance measures of pronation.

In a further analysis, 'Injury category' was defined as the Dependent variable, with Foot type left and right and gender as independent variables. The model was not significant ($p=0.279$) and remained so even ($p=0.237$) with deletion of 'gender'. Replacing foot type with 'pronation left' and 'pronation right' produced a highly significant ($p<0.001$) model with both 'Pronation left' and 'pronation right' as contributory factors, but not gender. Deleting gender from the test retained the high significance of the model ($P<0.001$) and again the pronation of both feet were factors.

Finally, an ordinal regression was conducted to see if the occurrence of Hallux valgus (bunions) was also related to pronation. The tests for the left and right foot identified highly significant models (both $p<0.001$) involving pronation of both feet.

A tentative conclusion of this process, in a relatively small sample of dancers, is that foot pronation, especially of the left and right foot are intrinsic factors that appear integral to the risk of injury in this sample of dancers. 5th dance position (in which overpronation was very apparent) did not appear to be a major contributory factor but the analysis is complicated by those data being strongly correlated with resting stance data. Pronation alone might be

sufficient in any model of practice, but more research is required to extend this sample and strengthen any predictive analysis.

6.9: Cause of injury: flooring, landing, overtraining, fatigue, competition, shoes.

As identified in the previous Sections there was some suggestion within the foot data for an association of number and type of injury with foot type (pes planus), foot pronation, and potentially with dance stances in the 1st or 5th position that are affected by foot types. Discussions with dancers sought to elaborate further on this by considering extrinsic factors that might be factors in number and type of injury.

Seventeen dancers considered their injuries occurred during training; 19 cited that their injuries occurred during increased training hours. Six dancers considered that due to increased training leading up to a performance they had “overworked” or over trained.

The dancers could not always be specific as to what caused their injuries. Fourteen dancers considered their injuries occurred whilst landing from a jump. These injuries were described as due to a poor landing encompassing landing through overtraining and/or fatigue; nine dancers considered their injury occurred due to fatigue.

Flooring is a potential extrinsic factor in this study. However, two of the elite schools had sprung floors in all the training rooms, one school had one training room with unsprung floors, otherwise all training rooms and stages were sprung floors. Whilst the majority of the elite dancers found the sprung floors invaluable, 4 female dancers felt that too much “spring” on the flooring caused their shin splints and ankle injuries; one dancer had a pes cavus foot type and 3 others a pes planus foot type. These dancers were in the 14-16 age group. One

elite school had one hard floor training room, yet the dancers were unaware if that particular floor caused problems and were even unaware that it was unsprung.

In personal informal discussions regarding training, many of the elite dancers commented that it was highly competitive to be selected for a dance company, so they would train rigorously to gain perfection in their moves. Even though some of the dancers commented that this could be considered as overtraining they felt that it was essential to train at a high intensity in the dance world: this was their normality. Other dancers (7) commented that they could not afford to take time off when injured for fear of either not being chosen for a performance or “dropped” from a performance and would dance through injuries (specific injuries that they danced through were not stated). Five of the dancers did not realise that they were injured until after training or a performance, and 2 dancers felt that assessment of the injury or treatment was not needed whilst 3 others said that they immediately sought out treatment from a physiotherapist.

Dance teachers were generally not familiar with the difference in foot types. When discussing pes cavus and high arches, the teachers (n=5) were not aware that there are the two types, rigid and hypermobile. They were generally aware of in-rolling ankles, flat feet and bunions and felt that dance training would correct the problem i.e. exercises were the answer. They did not consider orthotics would help and was not a consideration for their treatment rationale.

Perceptions that flooring was not considered a critical factor for the dancers appears surprising, although in most instances the floors were sprung for training and performance so may not have been a foremost consideration. Training, fatigue and the incidence of injury

incurred during training appeared to be of greater concern. Dance teachers seemed uninformed about foot types (and presumably the potential impact on dance positions) suggests that findings from the present study on intrinsic factors will make a significant contribution to dance schools and dancers' well-being. This is not to say, however, that some teachers are not aware of weak ankles and suitability for when to move onto pointe. In informal discussions with the ballet school teachers from the amateur schools, one teacher advised that she was very strict as to when her students could dance on pointe. The teacher was strict on technique and concerned about injuries hence her belief in good ankle strength and core muscle strength before allowing the student to dance on pointe. However, two teachers commented that over the years, they have had the experience of amateur dancers who considered that they were being delayed or held back from moving onto pointe and left the school for another, suggesting that education of dancers and parents is a further factor to consider when taking up dance training.

6.9.1: Ballet shoes.

Dancers (n=21) of all foot types reported that they had worn through 3-120 pairs of ballet shoes (mean = 102.3 +/-34.9 (SD)). The number of shoes associated strongly with 'Hours of training' and 'Professional/Amateur' status ($p < 0.001$ in each case) indicative of attrition and attainment of professionals' status, although 'Years training' did not associate significantly with number of shoes. Shoe attrition was not associated with 'Age group', 'height category' or 'Weight category', nor with the number or type of injury ($p = 0.872$ and $p = 0.395$, respectively),

Shoe use was not associated with foot type of the right foot ($p=0.418$) but was marginally associated with foot type of the left foot ($p=0.059$). Dancers with pes planus, the largest subgroup in this sample, (right foot, $n=14$; left foot, $n=16$) wore through 114 pairs of shoes per year with suggestion (though not statistically significant) of higher wear of the left foot. None of the associations with dance positions were statistically significant.

6.10: Chapter summary.

The main aim of this study was to seek to identify if risk of injuries in ballet dancers might be attributed to intrinsic factors of foot type and therefore offer a predictor for injury, extrinsic factors, were noted for their influence on foot type for response to impact loads particularly in male dancers where jumping and landing presented uncontrollable variables. Most participants were female and professional dancers, having trained for 8-22 years. Those with amateur status trained for 3-4 hours per week, whereas professional dancers trained for up to 40 hours per week.

Forty seven dancers were recruited and 3 distinct and widely recognised methods to evaluate foot type. These data were applied to subsequent evaluations of the 1st and 5th dance positions in the same dancers. Number of injuries reported by the dancers were recorded, as were the anatomical location and type of injury. Data pertaining to injury were then evaluated statistically to identify potential demographic and foot anatomical factors that might relate to those data. Additional extrinsic data obtained from participants and the dance schools where they practice were also evaluated for additional possible influence on injury profiles. These data included shoe attrition, floor composition, and training hours. The main findings were:

- Most participants were female and professional dancers, having trained for 8-22 years. Those with amateur status trained for 3-4 hours per week plus, whereas professional dancers trained for up to 40 hours per week.
- Of the 3 measures applied to evaluate foot type the Navicular Drop Test and the Calcaneal Bisection presented with a 100 % correlation, and good repeatability. The Foot Posture Index measurement generally compared well with the other two but showed some inconsistency. A decision was taken to only introduce degree of pronation measured by the NVDT or calcaneal bisection measures of foot positions into later statistical analyses.
- Of the 47 dancers, the predominant foot type was pes planus (flat feet) identified in 28 (59.6%) dancers, both male and female. This is a high incidence and had not been anticipated in respect of incidence in the general public. An assumption that both left and right feet would be of the same foot type was disproved as 28 dancers had pes planus type of the left foot but 26 of the right foot. Pes cavus foot type, present in low numbers of dancers, also presented with this disparity. Overall 4 dancers had different foot types of the left and right foot reflecting 12% of the sample. Gender influences were also apparent.
- The 1st and 5th dance positions associated strongly with foot type, though not invariably. The NVDT identified a high incidence of overpronation when in stance. Associations between foot type and number of injuries did not meet statistical significance.
- Injuries ranged from 0-6 per dancer, the mean being 2.75. Some of these were current others historical. Only 7 dancers reported no injury history. Specific injuries were quite variable but when related to anatomical location injuries of the foot alone or in

conjunction with the leg were the most prevalent, and significantly higher than other categories. **Associations of 1st and 5th foot position (left and right) and pronation (left) with foot and foot/leg injuries were largely significant.**

- In considering different foot types and injury sites, 1st dance position (right foot) and pronation (left foot) associated with injuries to the foot/leg and ankle/foot when the foot type was pes rectus. A breadth of sites to the foot and leg were observed in dancers with pes planus foot type, and this type did not associate with any particular site, although a concentration of foot injuries, especially plantar fasciitis, suggests a prominence. There were no associations of injury type or site with demographic variables.
- Both males and females presented with Hallux Valgus (bunions) of varying degrees and its incidence was strongly associated with foot type (especially pes planus) and 5th dance position, but there was no statistical association with injury location or type although it can be surmised to affect the stance when standing on pointe which was not evaluated in this study. Regression analysis indicated foot type or pronation as important factors in the incidence of hallux valgus.

The findings therefore provided some support for foot type and/or foot position as possible factors in risk of injury for ballet dancers. An exploratory regression analysis, albeit to be considered with caution in view of the sample size, was applied to seek evidence of a potential predictive model. The analysis suggested that overpronation in foot types are most predictive of risk of number of injuries incurred.

Discussions with dancers themselves identified training fatigue as a primary concern, and link to injury. Flooring and ballet shoes did not seem to be a concern as perceived risks of

injury. Education of dance teachers (and dancers) on intrinsic factors is required. The following chapter contextualises further the anatomical findings from this study in terms of gender and of injury risk, leading to a development of the conceptual model presented in Chapter 4 and proposed as a framework for podiatry practice.

Chapter 7

Discussion

7.0: Introduction.

In this chapter, the discussion contextualises the findings from the results to promote understanding within the context of the current literature. From this integration a theoretical model is proposed which identifies those parameters deemed to reflect ‘at risk factors’ which can be used to assess and interpret the susceptibility of ballet dancers to injury thereby empowering the dance coach or dance teacher in their selection and training of the dance pupil. In formulating this assessment model intrinsic as well as extrinsic factors are considered in order to provide the most comprehensive tool.

Primary research question: *To what extent do particular foot types (intrinsic factors) and training, flooring and footwear (extrinsic factors) contribute to lower limb injuries in ballet dancers?*

Aims of study:

- To establish the type of foot and numbers of individuals exhibiting three foot types within a cohort of elite and amateur ballet dancers.
- To determine whether foot type (pes planus, pes rectus or pes cavus) have a bearing on the number and types of lower limb injuries reported in ballet dancers.
- To determine whether extrinsic factors of flooring and footwear are linked to foot type and injury.
- To consider the formulation of a model to aid screening of individuals for risk of injury.

Objectives of study: (Intrinsic factors)

- Determine foot types according to categories pes planus, pes rectus and pes cavus using 3 proxy measures: Navicular Drop Test, Calcaneal Bisection and the Foot Posture Index.
- Apply the 3 proxy measures to determine the difference between foot type and foot posture, therefore to assess postural movement of pronation in both feet.

(Extrinsic factors)

- By questionnaire to document injury type and history, footwear, and flooring to assess if there is any link to foot types.
- Informal discussions with dancer teachers, physiotherapists and dancers on preparation to dance on pointe, flooring and injury treatment protocol.

Summary of main findings:

- Measures of foot type using the Navicular Drop Test, Calcaneal Bisection and the Foot Posture Index, showed good correlation but with a slight variance for the Foot Posture Index. The first two measures demonstrated greater validity in this study and were applied in subsequent analyses.
- Foot type and degrees of foot pronation show a correlation with the First and Fifth Dance positions.
- In First dance position there was an increase in navicular drop in all foot types overpronating, particularly those with pes planus. However, in Fifth position, a wider range of overpronation and oversupination was exhibited by most foot types with the largest group being the pes planus foot type.

- Forty of the 47 dancers (both genders) had a history of, or currently suffered from, injuries. Number and type of injury was associated with foot pronation and foot type, and dance positions.
- Dancers who exhibited the highest measurements of pronation (postural change) experienced a higher number of injuries. The females overpronated in a narrower band at the higher ranges of pronation than the males, however with the males overpronating at higher ranges, it is at the higher end of the range that larger numbers of injuries per dancer were noted.
- Distribution of foot type concentrates mainly with a pes planus type in all dancers; the male dancers particularly presented with a proportionately high number of pes planus foot type.

The common factor within these findings is that foot pronation/overpronation has a significant influence during ballet dancing and associated risk of injury. In normal dance movements, pronation at the subtalar joint is a natural postural mechanism, progressing through to the midtarsal joints and then to toe-off when the whole foot is in contact with the dance floor. Pronation as an essential part of the kinetic chain of the foot, pronation facilitates shock absorption and as such increases in velocity in proportion to duration with speed of running as well as being a necessary component when landing from a jump to deflect forces (GRF) from the floor. However, excessive movement or overpronation at the subtalar joint is not a normal progression and is an indication that there is a biomechanical anomaly in the foot and or lower limb. Pronation is also not a normal movement when the dancer is on pointe as the ankle joint is required to be held in a stable plantarflexed orientation and any degree of pronation would place strain on this primarily sagittal plane joint.

Extensive input of search terms in the current literature for support of progressive medial longitudinal arch flattening over time as a natural occurrence within the aging process provided no evidence. Examples of MLA collapse are related to pathological process leading to dynamic failure of joint stability as seen in posterior tibial tendon disruption or proprioceptive feedback deficiency with neuropathic disorders such Diabetes mellitus.

7.1. Limitations to this study.

These findings must be taken into context regarding the limitations in this study. For example there were more females than males, which can be expected in this population. Also, there were more elite than amateur dancers. Yet, having the higher number of elite dancers is useful in that they professionally train long hours for many years and maybe subject to cumulative change i.e. changes to the feet, types and numbers of injuries, responses to flooring types, and this gives this study the opportunity to expose potential collective changes.

The dancers came from several elite and amateur schools and therefore bias in selection was unlikely.

Self-reporting in the questionnaires relies on honesty; face to face interview may have influenced younger individuals. Participants seem to be keen to be involved in the study although sensitive about responses which may affect their dance status.

Looking through the literature and noted in daily clinical application, there is a lack of an acknowledged single measure to assess foot type and for this study a valid and reliable measure was required. Three approaches were used and 2 met the criteria (see section 6.1).

The sample size (47) was based on projected variables (intrinsic and extrinsic) but the study also identified foot type ratio (predominantly pes planus) as an original outcome, and also statistical associations of outcomes with gender. This meant sub-groups along these lines had relatively small sample sizes. Nevertheless there appeared to be adequate data in terms of the foot measurements both to define the category and pronation to provide an exploratory snapshot in the analyses. Also injuries were reported for both feet and lower limbs.

7.2: Measuring the foot type.

The proxy measures consisted of the anthropometric Navicular Drop Test (NVDT), and Calcaneal Bisection and the subjective Foot Posture Index.

Two of the proxy measures, the Navicular Drop Test and the Calcaneal Bisection performed well in that they correlated precisely to reflect the same results however only one was adopted which was the Calcaneal Bisection due to its convenience whilst measuring the Fifth position since access could not be gained to the inside of one of the feet in this position using the NVDT. This could potentially present a paradox that if such correlation occurs, then only one of the proxy measures needs to be adopted. However, for this research both of these measures were necessary because although the measures equated, they were in fact measuring two different aspects of the foot; one of foot motion, and the other of foot type. The Navicular Drop Test allows interpretation of foot type when the foot is in a STJN

standing position, (from the ground to the inferior aspect of the Navicular) and also measures the posture or movement of the foot i.e. pronation by change in navicular height in relaxed standing. The Calcaneal Bisection was used to measure the foot in resting bipedal stance for calcaneal frontal plane motion of inversion or eversion; it was an invaluable measure in that it could measure pronation in a static held dance position. Both measures arrived at the same results for foot type although they should be treated as two separate yet parallel measures. However, since the two measurements did form a 100 per cent correlation, only one was entered into analyses for evaluation of the 1st and 5th positions in order to standardise them as far as possible. In all other instances the Calcaneal Bisection measure, a more convenient tool to use was combined with the NVDT, for foot type (STJN) and pronation (change in NH) measures.

The third proxy measure, the Foot Posture Index was a useful tool for subjective interpretation of relaxed standing foot posture even though it did not have a 100 per cent correlation with the other two proxy measures. Although the errors were relatively small, the two anthropometric measures proved far more reliable and for this reason of difference, the Foot Posture Index was not used in final statistical analysis.

7.2.1: The Navicular Drop Test.

In a number of dancers the results showed differences in the postural measurements between the left and right foot of an individual i.e. the movement (pronation) between resting stance position and corrected (STJN) stance position; no left or right feet were exactly equal in postural measurement i.e. one foot would pronate more than the other foot. In a resting stance

position, 26 dancers presented with pes planus, with the left foot being flatter according to the NVDT measurement for 12/15 male dancers (from floor to inferior aspect of the Navicular). This outcome agrees with the study by Nilsson et al., (2012) which comprised of office workers (n=254) who found a significant difference between both feet in terms of height and length but because the focus was on cut-off points for the NVDT, only one-foot measurement i.e. right or left, were used for the final analysis and therefore there was no description of which foot had the higher or lower arch profile. What is interesting is that considering that there is the suggestion that no two feet are identical in a person in terms of postural change (pronation) both in this thesis and by Nilsson (2012), these variances in the measures were not documented by Brody, (1982). However foot arch differences between gender has been researched in other studies aiming to analyse Brody's (1982) NVDT measurements and were not seeking to assess foot type. Adhikari (2014) found a variation in foot arch height between individuals in both genders which equates with the findings of the current thesis. The females had very slightly higher arches in pes planus than the males, although the difference was marginal in this sample. Although useful in measuring arch heights, the study described by Adhikari, (2014), lacked description of the different foot types. However this current thesis is unique in that it measures foot type category in the sample of dancers together with postural change with the aim of finding a relationship if any with the number or types of injuries.

As a measurement, the NVDT proved to be reliable in this thesis, easy to use and with very good repeatability. Methodologically, there is a debate that the parameters need to be re-explored and defined since different researcher's demarcated different upper and lower limits of the postural change (Brody, 1982, Mueller, 1993). In the current study findings, the classification of foot type correlated 100% with the Calcaneal bisection method, which

evaluated degrees of pronation rather than navicular height and so appear to support the parameters advocated in Mueller's (1993) classifications.

7.2.3: The Foot Posture Index.

The Foot Posture Index measurement is described as being a reliable assessment protocol and has been cited for validity and moderate to good repeatability, referred to in the Methodology chapter, section 5.3.2. However, the practicality of this assessment proved to be questionable when dancers have to be measured at a reasonably rapid pace so that they could return to their training schedule. NVDT and Calcaneal Bisection testing measures provided a fast efficient and reliable measure needed in a general clinical setting. The problems of how to take the measurements with the FPI became apparent because there is no actual reference frame to refer too; assessment is made through eyeballing. Redmond et al., (2006) who designed the 6-element assessment protocol did not specify logistics of where to position both the participant and the researcher in relation to each other. For example, how far back behind the dancer should the researcher or clinician position themselves, or how should the dancer be positioned, close as possible to floor level or up on a plinth above it. Also, there is no explanation as to how far apart the feet of the participant should be placed. Even at ground level, the researcher is looking down towards the calcaneus, which gives a different interpretation to one if positioned higher. Since there are no clear parameters for either the observer or the positioning of the patient this could render the FPI liable to wide interpretation and poor repeatability in its results.

In the current study, the participant was placed on a plinth 20 cm high, to help maintain an eye level position to assess each foot. Therefore just by moving up higher or lower than the

plinth or slightly to the left or right of the same would give different interpretations. This could account for the slight variances of results in the current findings when comparison with the other two proxy measures.

Secondly, Redmond et al (2006) explains that the researcher needs to count how many toes are to the outside or inside of the foot. In the current research, it was found that parts of a toe may be visible but not whole toes. There is no description on how to define these variations. In all, the testing method is subjective and therefore liable to variable interpretation by the clinician/researcher, and may be different to a second observer looking at the same element therefore inter-tester reliability is also a concern. Redmond et al., (2006) had attempted to mitigate the subjectivity of the assessment by restricting the marking criteria (-2, -1, 0, +1, +2). However in the current study it was considered even this five point scale led to variance of finding in the results. The suggestion would be for the authors to devise a measure, possibly a large sturdy plastic sheet with a cross and separations of where the feet should be and where the researcher should be positioned, in order to improve consistency and reliability.

In the forefoot assessment element, a description is given of the arch heights but the descriptions are again subjective and liable to misinterpretation as to how a clinician/researcher would define a “high arch” or interpret the statement “acutely angled towards the posterior end”. Researchers would define a high arch as to their own definition without some means of measuring devices.

The lack of a reference frame for the FPI or a clear description of where the researcher needs to position themselves in terms of distance from the subject and the eyelevel height appears

to be reflected in the results for some dancers. Consequently there were discrepancies for the results in comparison with the Calcaneal Bisection and the Navicular Drop Test, both of which use valid measuring devices (goniometer, Vernier calliper, tractograph or ruler). However, acknowledgement of these application issues was reconciled and intra-rater repeatability therefore was minimal in this study with only a slight difference in measurements to the other two proxy measures. For example, where the other two proxy measures found 28 (left) and 26 (right) pes planus foot type, the FPI found 30 (left) and 25 (right). In pes rectus, NVDT/Calcaneal Bisection found 15 (left) and 15 (right) compared to FPI 14 (left) and 15 (right). In pes cavus, NVDT/Calcaneal Bisection found 4 (left) and 6 (right) compared to the FPI 3 (left) and 7 (right). Despite variability, the FPI did identify the higher number of arch types in the pes planus type and that the left also presented with more pes planus than the right foot. In applying the FPI overall, this study demonstrated that the Foot Posture Index may offer some validity and intra-rater reliability for subjective assessment of foot posture provided that each element is categorised from exactly the same position for each participant.

7.2.4: The Calcaneal Bisection.

This anthropometric measure proved to be easy to apply consistently in the study setting. Bisection of the posterior aspect of the Calcaneus is a straightforward procedure with experience offering a consistence which served to enhance the NVDT in this thesis; equality of outcomes indicate it is a reliable tool. The Calcaneal Bisection has ease of use and is commonly used in a clinical setting. It measures frontal plane motion of the calcaneus, inversion and eversion, which is a component of subtalar joint pronation. (Root et al., 1977). Calcaneal eversion is only one component of the triplane motion and therefore does not

adequately measure the degree of pronation in all subjects i.e. in those who have subtalar joint axis, which is closer to the frontal plane. The further the axis is from a plane of motion, the greater the degree of motion that occurs in that plane. Both the Calcaneal Bisection and the NVDT therefore measure different elements of pronation or subtalar joint motion and even though the two measures did perform as a 100 per cent correlation in this thesis, they were needed as individual measurements to cover the natural variance occurring for subtalar joint axis orientation within the population, and with reference to evaluating stance in both the 1st and 5th dance positions.

In summary, both the Calcaneal Bisection and the Navicular Drop Test provided a 100 per cent correlation in assessing foot type and therefore the Foot Posture Index was not used in further statistical analysis. Calcaneal Bisection was predominantly used for in-depth statistical analysis.

7.3: Intrinsic and Extrinsic Factors.

The main findings have been highlighted in 6.1, which were derived from the influences of intrinsic and extrinsic factors that might coalesce to cause injuries. Such factors include gender specific, age, adolescence and the growing body, training, footwear, flooring, and other causes affecting foot structure and integrity such as hypermobility.

7.3.1: Demographics: age, weight, height.

The gender age range from 14 to 29 years and the mean age of the dancers was 18.5 years with the amateur dancers predominately in the early teenage years; 4 females aged 14-16 years and 17 of the 47 dancers (10 females and 7 males) were in the 18-year age group category. Within this latter sub group, 5 males and 6 females presented with bilateral pes planus, which is proportionally high (64.7%) and is reflected in the incidence of pes planus in the total sample of 47 dancers (94 feet) with 26 dancers presenting with a bilateral pes planus and a further 2 dancers (1 male and 1 female) presenting with a unilateral pes planus (left foot). Overall there was a weak statistical association ($p=0.053$) between age and pes planus although males had the widest age range (17 – 29 years old).

Whilst a high proportion of male dancers exhibiting pes planus (13/15) might suggest a gender influence, there was no statistical correlation with age, height, or length of training versus foot type and only a marginal association ($p=0.053$) with weight to be found.

Whilst the females weighed on average 51.7 kg, the males varied in weight ranging from 51.7 kg to 87.09 kg. Perhaps it is not surprising that the female dancers weighed around 51 kg, since dancers are chosen to look similar in physical structure i.e. they present generally with a slightly male shape in terms of having wider shoulders in relation to hips, with long neck, legs and arms. The aim is to give a picture of gentle curves and straight lines. Not only do the female dancers look visually similar when chosen for the corps de ballet, but traditionally they also have to be of the same height; in all to provide a uniform appearance. However, apart from an even height range required for the corps de ballet, ballet companies are now not generally so strict on height since they focus more on talent and will therefore choose dancers

approximately between the heights of 160-165 cm so future weight range may show more variation.

Considering the average BMI NHS guidelines for an 18-year-old female is BMI = 17 -19, that is 52kg for a height of 160 cm to 63kg for a height of 165 cm; then the mean weight of ballet dancers falls to the lower level and below of the guidelines 48.9 kg – 58.9 kg (height range from 157.4 cm to 170.1 cm). In theory dancers, like athletes, should be heavy in proportion to their height since their intense training schedule metabolises adipose tissue and promotes skeletal muscle development, which is a more dense tissue. Weight is also related to bone density and with muscle development and load bearing due to running, lifting, jumping and landing in dance, body mass could be expected to be higher in this group compared to the general population of the same demographics. However, the mean weight for an 18-year-old female dancer in the sample of this study was 50.8 kg, which falls slightly below the mean weight of 52 kg in the average population. This highlights the pressure of maintaining a low body weight, partly to appear similar in stature to their male counterparts but also so that the male dancers can lift them with ease since too heavy an additional load could present as an injury threat for the males. Good technique by the female dancer in preparing for a lift helps the distribution of load onto the male. However if a dancer is attempting to keep weight down by maintaining a low calorie diet, then bone density is affected which highlights the high proportion of osteoporosis in female ballet dancers and the increased likelihood of fractures (Nattiv, et al., 2007). Bone density was not evaluated in this present study, which was mainly concerned with foot anatomy and type in relation to injury risk but the results did convey fractures to various bones of the feet and leg (section 6.19).

7.3.2: Variation of foot arch height in an individual.

A consistent finding is that in all foot types, one foot is flatter than the other (section table 6.3.) although marginal this was defined by measurement of the RCSP from the floor to the Navicular as described in the Methods chapter (5.3.3.). For pes planus, females presented with a slightly higher mean of arch height (3.23cm left and 3.03 cm right) in comparison to the males (3.08 cm left and 3.23 cm right). This reflects slightly different results to Adhikari, (2014) using the NVDT who found in their study that females in the normal working population had lower arch height scores in comparison to the males. This fact may be a reflection on the sample populations and the relative demands on foot structure and kinematics, for example the a normal working population is different to a dance population with dancers performing long hours of dance, strengthening foot muscles, repetitions of movement and landings as well as wearing flimsy footwear which do not provide shock absorption as would a day shoe. A normal population would not have their feet and lower limbs subjected to continuous jumping forces, torsional twists on the feet, or are positioned on the toes.

The second measurement is the postural change (navicular drop; ND), which measures the amount of pronation or postural movement from the RCSP to the corrected position STJN. The variance in arch height in terms of postural change as found by Nilsson, (2012) and Adhikari, (2014), supports the current thesis which identified a margin of change in navicular drop for both males and females (section 6.3.), suggesting that pes planus and overpronation by the criteria could reflect an increased risk factor for injury within the foot and lower limb. Cross comparison of the results for the largest ND in both males and females against previous or current injury in the current study provided meaningful information. A large cluster of 13

of the females who exhibited pronation from 1.1 cm (ND) had acquired at least one injury, whilst other females (n=17) distributed across the 0.1 cm – 1.3 cm range had sustained 2-5 injuries. For the males there was the difference in that injuries tended to occur at the higher end of the pronation scale i.e. from 1.2 cm to 1.6 cm (ND). In this range not only did 13 dancers acquire injuries but they also acquired a greater number of injuries per individual i.e. 3 – 6 injuries. The higher range of overpronation increased when observing both the 1st position and particularly in the 5th position it was noticed in the measurements and this is because in the 5th position (see Methodology chapter, photo 5.3.6), the foot is placed in front of the other and the hip has to externally rotate placing strain on the ankles and knees in an effort to try and maintain a good arch position which could not be achieved in a number of the dancers due to biomechanical anomaly i.e. pes planus and hypermobile pes cavus foot types.

Therefore there is the suggestion of high postural change i.e. excessive pronation causes instability or an adverse stress at the foot and ankle. This is likely to have repercussions on the limb (and also hip and spine), and the number of injuries and type of injury to the limb in this sample of dancers were positively associated with pronation. Discussion of pes cavus and pes rectus have not been discoursed due to the lower numbers of dancers, (Table 6.3) particularly pes cavus, although they have not been immune from injuries (Table 6.21) and the connections will be highlighted later in the injury section.

Differences in the amplitude of navicular drop (ND) in females of 1.1 cm and in males of 1.6 cm from STJN to RCSP could likely be exceeded as these are static measurements and would forcibly increase given the demands of repetitive high impact manoeuvres associated with ballet. In their case control study of 43 men and women (age 18 – 39 years) with a history of

patellofemoral pain syndrome (PFPS) McPoil et al., (2011) found a fourfold increase in arch height differential and foot mobility magnitude compared to a demographically similar asymptomatic control group although foot posture may not have varied between individuals of either group. Although not explored in the current study, dynamic measurement of the rapid transition to a maximally pronated foot position of those individuals exhibiting a more flexible foot (ND > 1.2cms) and susceptibility for foot and lower limb injury warrant further investigation. Allen et al., (2000) investigated the association between knee injury and pronation. Though only in a relatively small sample (n=18) of dancers, they determined anterior cruciate ligament (ACL) injury could be attributed to a ND of 1.2cms in 6 females and 1.7cms in 12 males. Allen et al., (2000) also cited McClay and Manal (1998) for evidence of excessive foot pronation (1.1 cm) in runners associated with statistically high peak velocities of calcaneal eversion and internal tibial rotation seen in 3 dimensional kinematic analyses. Although these findings are comparable to the current study only McClay and Manal (1998) give consideration for the effects of velocity on change in navicular height as a significant factor.

To summarise, this study has identified a higher-than expected incidence of pes planus in both male and female dancers, and of overpronation that is associated with injury. While no single demographic showed more than a marginal statistical significance with foot posture, there remains the possibility that cumulatively these factors may influence susceptibility to injury. The following sections provide propositions as to the musculoskeletal foundations of those findings.

7.3.3: Pes planus and overpronation: theoretical propositions.

One obvious feature in the characteristics of dancers is pes planus. Returning to the search terms in Chapter 3, in the follow-up search, there is no reference to pes planus being observed in dancers or dancer versus runners (sprinter and marathon levels).

Possible explanations, offered as a theory in this thesis, of the increase of number of pes planus foot type could be related to a few factors.

The inference is that pes planus is not related simply to age and suggests that a more likely implication is that the repetitive landings particularly bearing in mind the adolescent age of the dancers, is affecting the arch of the foot. Not all the foot bones have fully ossified in adolescence, which means that non-ossified bones are pliable and can be compressed; therefore this bone (cartilaginous model) no longer supports the other bones in the foot and can become a weak link in the kinetic chain during motion of the foot. Interestingly, The adolescent amateur dancers who came to the Hertfordshire clinic all presented with pes planus and symptoms consistent with plantar fasciitis and shin splints.

Another theory is in reference to the considerable height that male dancers jump and their consequent foot positioning on landing and will be discussed in the next section.

An additional theory pertains to overpronation and the dominant side of the body in both genders as bearing an influence on the initiation of a foot movement in a ballet position and

how this can affect their balance, resulting in one foot having to overpronate more than the other foot.

The final theory can be described as how the male dancer has to balance the weight of the female dancer both as he catches her, lifts her, and having to maintain stability whilst holding her as a reason as to the increased number of pes planus foot type i.e. the arch lever of the foot having to flatten to absorb the additional load the male dancer is carrying.

7.3.4: Proposition1: Jumping and landing for the male dancer.

The first theory can best be described by explaining the gait cycle in normal walking and comparing this to running and jumping (as well as landing) seen in field and track by different types of athletes. It is the repeated landings by the male dancers that could perhaps explain flattening of the arch over time by necessity to dissipate impact forces throughout the body, some which is available as potential energy, and from eccentric contraction in the plantar foot muscles for a “take-off” or jump.

During a normal walking gait cycle, the foot moves through an average rate of 120 - 125 steps per minute, each walking cycle i.e. from heel strike to heel strike of the same foot, takes approximately 1 second of which support phase constitutes 0.6 seconds. A runner moving at a pace of 60 steps per minute moves through a cycle time of 0.6 seconds with the stance phase i.e. the amount of time the foot is in contact with the ground, of approximately 0.2 seconds (Subotnick, 1989). It follows that all anatomical and biomechanical processes during the stance phase must occur in a third of the time. As the speed of running increases, contact time decreases, the frequency of ground impact increases thereby forces and the amount of energy

absorbed by the musculoskeletal system will progressively increase. In the same way a runner moves on to the forefoot as speed increases, so the male ballet dancer jumping and landing has to manage similar forces and dissipate the energy absorbed by the musculoskeletal system with abnormal loading patterns inherent of the artistry of dance. Consequently, pronation on impact occurs with increased velocity about the midtarsal joint and subtalar joint potentially leading to an unstable platform and therefore the foot arch flattens to create balance.

Male dancers, in particular, as evidenced in the findings of 1.1 cm – 1.6 cm navicular displacement during static measurement, it is conceivable there is considerably greater pronation occurring during running jumping and landing. More importantly the pronation/overpronation has greater velocity imposing a higher magnitude of stress and strain on the foot. Indeed, excessive pronation was also observed in dancers in the present study in moving from a resting stance into the 1st and especially 5th positions. These movements place considerable load on the tibialis posterior tendon and the calf muscles (gastrocnemius/soleus) as they act to decelerate the internal rotation of the tibia with concurrent lowering of the medial longitudinal arch.

Male dancers have a variation in gait pattern to a normal runner since they will not always run in a straight line, they often perform jumps in clockwise rotations, movements in rapid succession, both on the ground and in the air, whilst maintaining an appearance of lightness and fluidity; appearing both athletic and graceful in making a jump look effortless. The dancer will run forward at speed and just as a high jumper accelerates to “take-off” and jump as high as possible, so does the dancer whilst running on the forefoot, missing out the component of heel strike and equally landing on the forefoot, followed in rapid succession by

the heel meeting the ground (i.e. a reverse to a normal walking cycle) in preparation for the next jump and this is possibly where overpronation occurs to absorb the ground reaction forces, to maintain stability and prepare for the next “take off”. The dancer has to land lightly and gracefully (deceleration) and yet generate strong muscle power in readiness to jump high. Dance positions such as *l’assemble*, *tour en l’air* (see appendix I for explanation) where rapid external rotation of the tibia and fibula will occur which will move the calcaneus into an inverted position with the foot pointed to maintain an artistic shaping are all examples of dance positions enabled through great height elevation.

Biomechanically, the forefoot has to absorb and dissipate the energy associated with ground reaction forces, which in running and landing can be up to 12 times body weight (Dozzi, 2012). Dancing technique increases compressional loads on the foot and ankle by 4 times the dancer’s weight, whereas *pointe* work, due to its small toe platform, concentrates body weight through this small surface area with potential increases of up to 12 times the dancer’s weight (Spilken, 1990). Biomechanically, the forefoot has to absorb and dissipate the energy associated with the ground reaction forces (GRF) when landing momentarily on the ground in preparation for the next jump with significant degrees of overpronation occurring at the subtalar joint. Personal observations of the dancers in movement from video revealed that the forefoot lands first quickly followed by the heel then the heel is then lifted rapidly to place bodyweight onto the forefoot for the next elevation. The speed and height attained by the body from running to landing is proportional to forces met from the ground. A sprung floor will decrease the shock wave associated with contact and the energy returned would enable the dancer to achieve a great height similar to a spring board. Conversely a hard floor will increase shock wave transmission and provides no energy return due to its rigid nature i.e. the musculoskeletal system will be under increased stress. However, it is of note that the

dance schools involved in this study, and from which most of the study sample was formed, had sprung floors in the great majority of training rooms.

As sprinters require degrees of overpronation when the runner takes off on the forefoot out of the blocks so does the dancer require pronation and possibly an extent of overpronation to absorb the forces of the floor contact to allow acceleration (Subotnick, 1989). Such overpronation flattens the transverse arch, broadening the foot platform, increasing the surface area, which allows great spring of the foot in both take-off and landing. Spring is provided at the forefoot and driven by the power supplied by the supinator and plantarflexor muscles. Mann and Inman (1964) considered the intrinsic muscles of the foot as a functional unit that are active from early midstance until just before toe-off; the intrinsic musculature in a pronated foot becoming active earlier and remaining active longer during each cycle. Mann and Inman (1964) also consider that this is an attempt to reduce the amount of hypermobility around the oblique mid-tarsal as well as the subtalar joint axis. This spring-like action can be likened to a gazelle which has been described as having a ‘catapult’ mechanism’ due to the glide of the fascial-silk body suit around the musculature which creates an easy, effortless movement; this tissue movement being similar to humans in that there is the capacity for the fascial web to provide a springy, fluid and wave-like movement (Kram and Dawson, 1998).

This thesis puts forward a proposal that persistent overpronation occurs due to the nature of the movements required of the dancers i.e. the lightness and seemingly effortless movement required necessitates running on the forefoot while maintaining control and this will place additional stress on the system from shock wave attenuation. In normal running, the heel makes contact with the ground and shows a high vertical force (Chapter 2, Figure 2.5, p 35). The male dancer runs forward on the forefoot, similar to a sprinter (see appendix iii), which

will exhibit a forefoot ground shock and although the total amount of force generated may exceed the impact spike of heel contact, the overall effect on the musculo-skeletal system is less damaging due to a reduced rate of force generation (Subotnick, 1987). However, long hours of training and performing with running and landing on the forefoot requires stable ankle joints and may necessitate degrees of pronation thereby attenuating shock forces which destabilises the ankle and knee and lends the foot, ankle and leg vulnerable to injury. Zhang et al., (2000) in their study of 9 males performing step off landings found that the ankle plantarflexors were consistent contributors to energy dissipation. Dancers with their long hours of training, and repetition of certain moves such as pirouettes, will tax the plantarflexors. Overpronation at the subtalar joint will occur to take the overload, and this will particularly occur in pes planus with arch fatigue over time from absorbing the forces. That is part of the process of running on forefoot and may result in not just normal degrees of pronation but possibly overpronation in an effort to dissipate forces on landing and to provide the necessary muscular energy to jump. The higher levels of overpronation recorded in the results for the males although showing a weak statistical significance to weight, age and duration of performing, could be linked to a notion of cumulative and gradual development of pes planus in dancers due to repetition of movements, males catching and supporting female dancers. This coupled with the sheer number of hours in training and performance could be the effects of repeated impacts becoming permanent.

To summarise; the arch of the foot becomes a spring platform to flatten, absorb the weight of the body, dissipate forces evenly and economically as possible to provide a consistent landing. Whilst female dancers do not lift, or have to jump as high as the males, they still have to run at speed to perform a seemingly effortless jump so the same principal of running

on the forefoot to provide an appearance of lightness and fluidity and stresses on the musculoskeletal system would apply for both genders.

7.3.5: Proposition 2: Dominant side of the body.

The second theory proposed to explain the current pronation/foot type data is the dominant side of the dancer's body (either gender). Certain dance positions require the dancer to land with their feet in unison such as in releve, which requires precise symmetry between the dominant and non-dominant sides of the body. In this current study, the questionnaire did not make enquiry of the dancer's dominant side of the body so this thesis is offering the hypothesis for one foot undergoing overpronation more than the other foot in the same person since there was a variability in the amount of pronation as defined by RCSP foot posture (NH) between the two feet of a dancer as measured by the NVDT (16 female/Lt foot 2.82 cm, 15 female/Rt foot 2.93 cm ; 12 male/Lt foot 2.90cm, 11 males/Rt foot 3.23cm). Even though possibly not even apparent to the choreographer or the dancer where symmetry is required, is the likelihood that the dancer favours one foot over the other and will balance, even though slightly and subtlety, on the favoured foot. This was observed in the training rooms during this study where the male dancers would perform repeated jumps into the air and land into fifth position with alternate feet in landing i.e. with the right foot in front in one landing and the left foot in front in the next landing, with one foot appearing to pronate more than the other (section Methodology chapter, Photo 5.3.6 of Fifth position).

It is on the landing into fifth position when observation of one of the feet as pronating more than the contralateral foot could be detected which could suggest that one foot is being subject to additional stresses and overpronating more than in the other. There is not any

evidence to date to suggest that ballet dancers ordinarily default to the left foot which may reflect right-foot dominance seen more frequently in the general population. Other studies have shown variations between the ground contact in one foot compared to the other, in a study by Subotnick, (1989) on 117 runners where their ground reaction forces were recorded. Although not referring to dancers, certain characteristics in gait patterns cross-over in closely related sports such as sprinting. Other research on symmetry in dancers has also been explored by Chong Feng Lin (2005) in observing 13 ballet dancers to investigate the symmetry between dominant and non-dominant sides found who that even though the non-dominate ankle revealed the same excursion patterns they showed different joint moments when compared to the dominant ankle in *releve en pointe*. The authors concluded that the two ankle joints may play different roles in controlling balance and movements throughout the entire aspect of the dance movements. Koh (2012) found ankle joint eversion angle and eversion moments were higher during unilateral than bilateral landings of 10 male subjects ($p < 0.05$), whilst the knee joint valgus angle was elevated during bilateral landing with the knee joint valgus moment being about 2.6 times higher during unilateral than bilateral landing which could increase the probability of an anterior cruciate ligament (ACL) injury. Neither Koh, (2012) nor Zhang et al., (2000) had dancers as their sample study but the study gives an indication of how kinematics of one foot is not in equal to that of the contralateral foot.

Some research suggests that excessive pronation of one foot in comparison to the contralateral foot results in functional limb length discrepancy, as well as torque and counter-torque to the hips and knees (Subnotnick, 1989). This can pertain to dancers since overpronation requires an internal torsional twist to the tibia as well the knee. Also, if the hips cannot externally rotate to the same frontal plane level, particularly in fifth position, then this could potentially create a marginal limb length discrepancy with the foot of the less rotated

hip having to overpronate in compensation. Despite all the years of training to open the hips equilaterally in order to present the hips as square when viewed from a frontal plane, the less dominant side of the body may result in a restriction to the same side hip flexor. Although this difference could be subtle and not overly apparent in observation of the dancer when standing in first position, the restriction may become more apparent when placing the feet into fifth position where the hips are not equilateral due in part to one foot overpronating. Fifth position is a challenging dance position when one foot is placed in front of the other (see photo 5.3.4. in Methodology chapter of this dance position).

A suggestion is that the foot that overpronates more of the two dissipates more shock load of the two feet and in doing so prepares the limb for the next move. The brief storage of potential energy within the intrinsic muscles and ligaments of the plantar foot is available for expenditure assisting the concentric contraction of the plantarflexors. However this state places increased tension (stress and strain) within the ligaments and could therefore be a contributory factor for injuries (Mann, 1964).

A dancer like all dance artists would learn how to work with their biomechanical weaknesses to their best advantage for a single overpronated foot may present itself as either the front or the back foot in fifth position i.e. the overpronation may be subtle and not apparent to the audience, but it is there nonetheless; the dancer may overcompensate with other muscle groups, externally rotating the knee, the tibia and fibula, pulling up at the quadriceps, tightening the gluteals. In pronatory compensation, with prolonged abnormal pronation there is increased concomitant muscular activity and secondary fatigue which often leads to injury and high impact forces from jumping to landing, which are known to increase the risk of shin splints and stress fractures (Chockley, 2006; Walter et al, 2011).

In this thesis there were two dancers i.e. 4 feet, who presented with two very different unilateral arch heights. One male and one female presented with a pes planus left foot and a pes cavus right foot. No other literature has focused on different foot types in individuals within ballet however research on variation of foot types within an individual has been explored, although the author did not discuss the implications of the differences (Adhikari et al., 2014). The suggestion is that years of training and jumping and landing may see changes in the arch heights to accommodate loading and ground reaction forces. However, since the numbers were small, it is difficult to test for statistical support.

7.3.6: First and Fifth Dance Positions.

The results showed a difference in pronation of a pair of feet in all dancers regardless of foot type. The First position was a difficult position for the amateur dancers to maintain and hold. Often the knees were not aligned directly over the feet which is the required ideal position (see Chapter 3, photo 3.5). The elite dancers had better alignment due to the years of training, although some variability was present even here, some dancers had a better alignment than others. The results showed that all 3 foot types were susceptible to overpronating i.e. over 4 degrees. Twenty five dancers, both genders and of all foot types, overpronated in the 4-6 degree range for the left foot, and 28 dancers for the right foot. The pes planus foot had the higher numbers. Looking at the male and female dancers in 1st and 5th position showed pes planus foot postures of 26 right and 28 left feet which when compared with the finding for male and female ND showed a relationship with those individuals which exhibited the higher values of 1.3cm (female) and 1.6cm (male). Given the technical difficulty of maintaining poise in both first and fifth position the pes planus posture and

excessive pronation seen in tables 6.19 for calcaneal bisection (18 right foot, 20 left foot) in first position could be a factor for development of injuries due to the torsional stresses generated around the knee and hip from external rotation of the limbs if also mirrored in fifth position.

Watkins (2009) considers the impact of anteversion of the hip joint on the ability of ballet dancers to achieve turnout (Watkins 2009, p355). Turnout (first position) should be accomplished through external rotation of the whole leg. Where this is not achieved overload of the knee joint leading to subluxation can occur. Consequently, forced calcaneal eversion subjects the ankle and subtalar joints to gross abnormal loads and medial longitudinal arch (MLA) collapse (Watkins, 2009; p356). Males particularly had prolonged or extended amounts of overpronation in the 10 degrees plus range which despite the years of training, reveals a difficulty in holding and maintaining the position and indicates also a biomechanical weakness. The findings statistically indicate injuries are linked to first and fifth positions, where overpronation occurs in both these ballet positions an increased or broad range of overpronation is noted in the Fifth position. That is, the higher the amount of overpronation, the greater the number of individual injuries in a dancer, particularly for male dancers.

The Fifth position where one foot is directly placed in front of the other (see Methodology chapter, photo 5.3.4.), is a more challenging position to achieve than First position, and this revealed some very interesting results. Thirty two dancers (right foot) and thirty three dancers (left foot), both genders and all foot types overpronated extensively for both feet, ranging from 4 – 9 degrees Calcaneal bisection. There was 1 pes cavus dancer who overpronated at a high degree of 10 degrees plus in the right foot only (table 11), against 2 who reflected an

oversupinated right foot and 1 dancer a left foot (table 12). The dancer who overpronated extensively would most probably exhibit hypermobility, and therefore the foot having to overpronate extensively at both the subtalar and mid tarsal joints in order to bring the foot plantigrade. The pes cavus feet which oversupinated are where the dancer most probably has more of a stiff foot and is having difficulty in pronating due to lack of range of motion (ROM) in the subtalar joint particularly and is therefore having to supinate abnormally in an effort to keep the hips open and limbs externally rotated. This is likely why, if there is a biomechanical anomaly, then it may be observed in the 1st position but is likely to be more apparent in the Fifth position by the nature of this demanding position.

7.3.7: Proposition 3: Increased load to the male dancer.

The high GRF experienced by male dancers and the potential for effects on the musculoskeletal system and foot type was discussed in an earlier section. A third possible theory for male dancers presenting with high numbers of pes planus is that the load is increased when they have to catch, hold and lift up the female dancers for a period of time which requires strength, precision and good technique. In carrying the weight of the dancer, or having to catch the female dancer as she runs forward, increases further the forces applied to the ankle, knee, hip and back joints of the male dancer with his body needing to absorb the additional weight. In our results 13 /15 (87%) male dancers had current or previous injuries with a significant correlation for right ($\rho=0.339$; $p=0.020$) and left ($\rho=0.402$; $p=0.005$) feet and pronation. It could be that over time, the feet flatten further to help absorb and dissipate the forces applied by the additional weight and inertia of speed applied by the female dancer. In some sports, a pronated foot is essential such as in skiing or in golf when pronation is an essential part of the golf swing and stance, and it could be that male dancers

particularly may develop a flatter foot and increased pronation over time to merit the activity (Subotnick, 1989). So, it could be with the dancer a pes planus foot type which overpronates is a necessity in ballet and yet at the same time this excessive postural motion could be directly linked to injuries.

In all, pes planus and overpronation is associated with proximal instability and malalignment of the ankle, knee, hip, and spine. If the theory from this thesis is accepted that the foot has to flatten or overpronate extensively to absorb ground reaction forces, particularly from jumping and with taking on the additional load of another dancer, it would follow that compensation has to occur in other parts of the musculoskeletal system. The knees, spine and shoulders are highly susceptible to injuries in the male dancers (Arendt and Kerschbaumer, 2003). Whilst shoulders are prone to injury due to repeated lifts of the female dancers onto their shoulders, other key injury areas of the knees and spine may be susceptible to pes planus and overpronation which places torsional stresses on the knees and in turn affects the spine. As an example of increased weight onto the foot i.e. from lifting a dancer, plantar fasciitis as a condition, occurs due to increased stress / strain on the plantar aponeurosis of the plantar surface of the feet and was evident in 7 dancers classed as pes planus.

7.3.8: Female dancers.

There was also a high incidence of pes planus in this gender group (13 dancers) and one dancer presented with a unilateral foot difference. Possible explanations for the incidence of pes planus, and a flatter left than right foot, have been covered in the section on male dancers in terms of landing and overpronation. However, an additional factor for the female dancer is pointe work.

7.3.9: Pointe work and Ground Reaction Forces.

Female dancers perform predominately on pointe and positions such as releve on pointe (see appendix i) should be symmetrical; therefore, no differences should exist in the range of motion and moment demands between the right and left ankles. However, the pointe shoe provides a small precise area whereupon the foot and whole body has to balance, and where the dancer has to land with ease and grace without sliding or appearing unbalanced at the ankle joint. The foot has to be fully plantarflexed, the ankle remains a stable unit not moving into a pronated or supinated position (in ballet language this is referred to as sickling i.e the ankle is inrolling or outrolling and not able to maintain a 'neutral' position). The ankle has to remain stable keeping the body upright and in perfect balance. When landing on pointe from a jump, the dancer will perform a lower level jump than if the dancer was landing on the full foot (Chockley, 2006). Landing on pointe requires a precise landing and provides a small area with which to transmit full shock load through the foot to absorption by the body.

Landing on the whole of the foot in comparison is a larger surface area and is able to absorb the ground reaction forces allowing the ankle to follow through its normal movements of plantarflexion and dorsiflexion without restriction, in preparation for the foot to pronate, absorbing the impact forces from the ground (GRF). Female dancers can present with pes planus and yet are still able to form a good arch on the foot or pointe as seen in this current study. Females dancing on pointe are expected to form such a good arch whereas the requirement is not as highly regarded for the male dancer as he does not dance on pointe, although a relatively good arch would still have to be formed.

In informal discussions female dancers in this study considered that pointe shoes were uncomfortable and caused toe and bunion problems. Care has to be taken on preparing the tip of the pointe so that there is no slippage and therefore injuries. Dancers wore through many shoes through a performance although no evidence was identified in the current study that shoe attrition reflected injury risk. However, attrition per se does not necessarily relate to shoe construction and so warrants further research.

Female dancers once on pointe, must 'lock' the ankle into a stable position to balance on the toes for periods of time and to prepare for their next move. This means that the ankle has a wider range of motion in jumps when landing on the full foot rather than being limited when the foot is on pointe (Chockley, 2006). Chockley, (2006) states that "ankle mobility restriction is related to the ankle ground reaction force duration". For example, in their study of 13 female dancers, the ground reaction forces recorded when the dancers jumped onto pointe was 531.14W (+/-82.28) compared to when the dancers landed on the whole foot which generated a mean maximum force of 735.93W (+/-95.70) because there is a greater surface area i.e. the whole of the foot is now able to absorb the proportionately higher shock loading. The landing ground reaction forces are absorbed by the lower extremity in twice the amount of time in jumps landing on the whole foot and allowing pronation versus landing on pointe (Chockley, 2006). For example, when dancing in technique (canvas or leather) shoes, forces on the foot and ankle will increase by 4 times the dancer's weight whereas dancing on pointe will increase these forces by up to 12 times body weight; therefore the whole body weight is concentrated on a small area of floor contact via the pointe shoe (Spilken, 1990). The fact that dancers have to land on this small platform requires precision and pirouettes additionally may irritate the knee. In this study, only a few dancers suffered from knee injuries, but metatarsal fractures, Achilles tendonitis, tendinopathies and Os Trigonum were

prominent in female dancers dancing on pointe and proportionately more prevalent in pes planus feet. Fractures were common, (6 total) and dancers reported that they did not realize they had suffered a fracture until after a performance; this could be that dancers do have a high pain threshold attained through years of sheer long hours of training.

7.3.10: Hypermobility and Overpronation.

This current thesis did not attempt to assess hypermobility ranges in the dancer, since this was not the primary question. However, the higher range of overpronation in both genders may well suggest hypermobility and could account for the higher numbers of injuries that have occurred for them. Hypermobility and ligament laxity could be an area of concern for dance companies since ligamentous laxity allow too abnormal ROM at the joints. The muscles supporting the joints (dynamic stability) will respond by early and longer activation in attempt to maintain joint stability, but the muscles and their respective tendons coursing around the joint, for example the ankle joint may not be equally strong. Ankle plantar flexors are more powerful than ankle dorsiflexors, a factor which may be magnified by training. This imbalance lends the dancer susceptible to injury (Gamboa, 2008). Hypermobility can vary in an individual person for example, an adolescent dancer may have tight ligaments in the vertebrae due to their growing body and may also show ligament laxity in the ankle(s) or knee(s), (Kennedy and Hodgkins, 2006). Female dancers are also encouraged to hyperextend at the knees for visual artistic effect which creates an imbalance to the quadriceps and hamstrings, with one group working harder than the other trying to maintain a stable knee joint which is under additional strain with certain dance movements such as repetitions of pirouettes on pointe.

The higher degrees of pronation in the dancers in this thesis linked to a higher number in injury count for the dancer. For example, 4 to 5 injuries per dancer in those with excessive pronation compared to lower numbers of injuries, approximately 2, in the dancers with smaller degrees of pronation. High amounts of postural motion or pronation may be found in all foot types, as indicated in the results chapter, yet were more evident in the pes planus foot type.

7.3.11: On Pointe.

Whilst there were only a small number of amateur dancers in this study, all of them had presented for treatment at the Hertfordshire clinics for plantar fasciitis and all had a pes planus foot type. The integrity of the ankles was not sufficient in that the foot could not achieve full plantarflexion and dorsiflexion. Muscle groups need to be evenly balanced otherwise if one group is disproportionately stronger i.e. the plantarflexors, then this places strain on the joints and the ligaments of the ankle; the latter can become strained and liable to weakness or tears. The potential strength of the plantar flexors is 7 times stronger than those of the dorsiflexors (Silver et al., 1985; Wickiewicz et al., 1983). Concerns of the amateur dancers not presenting with strong ankles lead to informal discussions with the dance teachers of the amateur schools as to when was the appropriate time for an individual to start to dance on pointe since a few of these amateur dancers were dancing on pointe. As mentioned in Chapter 3, 3.1.5., there are no standard measures to assess when a dancer is ready to dance on pointe. In this study, the amateur dancers were predominately in the younger, 14 years plus teenage years. The amateur dance schools varied in terms of numbers of students, yet they all aimed to achieve a high level in dance. It was reported in this study via informal discussions as relayed in the Results chapter that some teachers were strict on

when their pupil's ankles were 'strong' and ballet technique developed sufficiently to move onto dancing on pointe, which was sometimes to the financial peril of the dance school however others were less strict. In addition, a pupil impatient because they felt that they were being held back then this would sometimes result in them leaving the school to find another who would accommodate and allow them to dance on pointe.

The dancer needs integral ankle stability, good stability, strong core and a high level of fitness, but for an amateur dancer who ordinarily trains for 3.5 – 4 hours per week, this may not be achievable. Extending training is sometimes not feasible since the amateur dancer will attend a normal school full-time and attend ballet classes only in the evenings or weekends. Instability in the ankles could account for ankle sprains and ankle injuries as well as fractures as indicated in the types of injuries located in the results chapter. Over extension of the ankle results in conditions such as os trigonum impingement, which often needs surgery (Luk, 2015).

7.3.12: Hallux Valgus.

The elite dancers in this study were also predominately in their teenage years with a mean age of 18 years. The elite dancer studies full time at a dance school and trains 40 plus hours per week. Therefore, even though the dancer is strong enough to dance on pointe since they will have attained a high level of physical fitness, and foot and ankle intrinsic muscle strength, they remain susceptible to injury since long hours of training places stress on bones in the foot that have not fully ossified e.g. the proximal phalange in the first toe. Yet in this study, all foot types presented with Hallux Valgus (bunions) in the great majority of dancers and this was most probably due to long hours on pointe, pivoting on the forefoot, overpronation

and or hypermobility (Kirk, 2000). Some of the males too presented with Hallux Valgus and these were predominately the dancers who had a pes planus foot type since having to overpronate, creates instability at the first metatarso-cuneiform joint and phalangeal joint (Subotnick, 1989). Pointe work, forefoot pivoting and dance shoes also accounts for most of the dancers reporting toenail trauma or injury.

7.3.13: Footwear.

Both ankle (20 injuries) and foot injuries (61 injuries) appeared as the highest injury count in this study, which indicates the importance of a ‘strong’ ankle joint, but also the correct type of dance shoe for the individual. In normal walking, hypermobility in the ankle or foot can be controlled with good supportive footwear and orthotics, yet for a dancer, the dance shoe has to be like a second skin to the foot and such a shoe is thin and flimsy but provides little support or protection.

In this thesis, although footwear was examined in the interview process, little could be gleaned, for all the dancers wore through considerable numbers of ballet shoes, more or less depending on performance or role. Also, because the footwear does not have a firm outer sole, it was difficult to analyse footwear marks which would give an indication of foot type or which parts of the feet were subject to peak loading. However, as mentioned earlier, dancers found the toe pointe uncomfortable and restrictive and felt that they caused toe nail damage and bunions.

Once on pointe, jumping is not high, purely for the logistics of having to land back onto a small platform of shoe and maintain control and composure, but the subtalar joint would

compensate by pronating to accommodate shock absorption from the floor. When dancing on pointe, twisting movement of pirouettes will additionally create torsional stresses to the knees. In the injury results, female dancers reported toe injuries, knees, ankles, tendo achilles and os trigonum injuries. These could potentially relate more to dancing on pointe than to foot type and pronation. Yet in all, 79 injuries were categorized for the pes planus foot type suggesting a link to injury, which is a high proportion of injuries in relation to 47 injuries for the pes rectus type. An interaction of foot type and dancing on pointe is also feasible but could not be discerned with present data.

7.4: Pes Cavus foot type.

The discussion so far has revolved around pes planus and its close relationship to overpronation. Pes planus was the predominant foot type in this sample of dancers, followed in incidence by pes rectus. Pes cavus was in the minority but as a distinct foot type warrants some discussion here. The results in this thesis found that 4 dancers had a pes cavus foot type and 2 dancers had a unilateral pes cavus foot type. Pes cavus is characterised by a 'high arch' and as a foot type, has poor shock absorption, particularly if the arch is rigid in structure, which limits any normal degrees of pronation and is more likely to move into supination, which is more natural for this foot type. Injuries that pertained to this foot type in this study were to the 4th and 5th metatarsals, resulting in fractures (2 dancers with pes cavus foot type). In athletes presenting with pes cavus, fractures to the metatarsals are a common occurrence and most likely due to the restricted range of pronation needed for the tibia and fibula to internally rotate during single leg manoeuvres resulting in a prolonged period in supination during which excessive forces are imposed on the 4th and 5th metatarsals. Not surprisingly, the lateral torsional forces on the knees due to prolonged supination creates irritation,

however in this study the 1 recorded knee injury in the cavoid foot type reflects the small numbers within the cohort and is therefore proportional to the number of injuries overall.

Pronation is a necessary tri-plane movement in order that the foot can dissipate ground reaction forces and adapt to the contours before resupination in preparation for weight transfer in gait and the pes cavus foot type lacks this unless it is hypermobile. Limited pronation can be as detrimental as excessive pronation since it results in lateral instability of the foot and ankle (Subotnick, 1989). Whilst certain sports benefit from this foot type such as Halfbacks in American football or soccer teams who do well with a semi rigid cavus foot as the foot type permits quick cutting and manoeuvrability, this foot type is poorly adapted to jumping and this is probably due to the rigid arch lacking any “give” or any pronation is limited (Subotnick, 1989).

A possible explanation as to why there is only a smaller number of pes cavus foot types among the dancers could simply be due to the recruitment of the dancers in the interview process. Schools will focus on physical attributes, ability, talent and also the aesthetic features of the “perfect pointe” when arching the foot. Whilst a hypermobile pes cavus would through training have the ability to form a good arch, a rigid type would not. The cavus foot can have an appearance of a very high arch, which would not look aesthetically pleasing.

In informal discussions, whilst talking to teachers regarding high arches, they were not aware that there are the two types of rigid and hypermobile pes cavus foot. Conversely, as mentioned, teachers are aware of inrolling ankles, bunions and flat feet, but if the dancer can produce a good pointe with their arch as seen during these interviews for foot measurements

in the dance schools, then the individual's foot type is acceptable and possibly a link has not been made by dance school selection and long-term implications. In contrast, present findings suggest such considerations would be beneficial in continuing assessments for dancer welfare.

7.5: Injuries.

7.5.1: Type of injury.

Types of injuries were diverse over all the foot types in that no matter what foot type, the dancer of either gender suffered from an injury and in all there were 110 injuries suffered by 40 dancers whether currently or previously or ongoing. Seven dancers stated that they have never had or were not currently suffering from an injury. Injuries were diverse to the leg and foot, with a higher number of injuries to the ankle and foot. The pes planus foot type encompassed 79 injuries, pes rectus 27 injuries and pes cavus 4 injuries. Injuries to the pes cavus foot were metatarsal fractures to the 4th and 5th, and trauma to the knee and ankle. However since the number of dancers was very small, conclusions cannot be drawn as to links of particular injuries to this foot type.

The pes planus foot revealed a wide selection of injuries with slightly higher numbers with plantar fasciitis and shin splints (the latter is often associated with flat feet due to deceleration of the foot during loading). Ankle injuries were relatively high in number and dancers stated in informal discussions that these injuries often occurred during landing and sometimes due to overtraining and fatigue; the latter increasing the amplitude for accidents and injuries. Os trigonum was found in a few female dancers, caused by dancing on pointe, where the ankle is

plantarflexed for long periods of time in end range of motion under compression leading to irritation to the accessory ossicle in the Flexor Hallucis Longus tendon. Considering 26 dancers presented with pes planus, 79 injuries (2.8 per dancer) is high relative to 15 pes rectus dancers who accumulated 27 injuries (1.4 per dancer). Also, although all dancers were susceptible to injuries, 7 did not experience any injury. One possible explanation might be they had a high pain threshold i.e. dancing through pain and musculo-skeletal problems and they may perceive that they did not have an injury or that any treatment was necessary or they have been fortunate not to experience an injury. Another possibility is that dancers may not want to report an injury for fear of being penalised from performing or not obtaining a position in a dance company. Of those who reported injuries, male dancers had injuries clustering towards plantar fasciitis, knee and metatarsal injuries whereas the female dancers injuries were more widespread in the lower limb. Overall injuries for the total sample predominated at the ankle and foot supporting the significance of this thesis to podiatrists.

The mean age of dancers was just 18 years old. Young dancers are growing and not all the bones have ossified fully. Growth spurts can result in some muscle groups overworking and therefore creating an imbalance in movement, which reinstates according to the individual; adolescence is a vulnerable time for elite athletes generally and can render the dancer more prone to injury (Kennedy and Hodgkins, 2006). Rapid bone growth creates stress in the ligamentous area, which renders the body susceptible to injury, especially if overtraining. The balance between resting as a necessary requirement in the adolescent and training does not appear to be a consideration for elite dancers (Bowerman, 2014). Part of this is self-imposed where the dancer wants to train for perfection, but repeated landings from a jump, pirouettes (providing a twisting action to the hallux) will, despite intrinsic muscle strength, place trauma

on cartilaginous models in the foot, which have not yet ossified, and degrees of overpronation will weaken the foot structure further.

The findings in this research support literature citing ankles experiencing the highest proportion of injury tally to the foot and ankle (21.4%) (Roberts et al., 2013; Gamboa, 2008). In some respects this could be linked to a flimsy pointe shoe, and depending on the performance, the dancer may have to spend many hours landing and balancing on a small platform of shoe. Lack of firm footwear support around the foot and ankle which is held together by ribbon, does not provide the support the ankle would need in this plantarflexed position; it would account for torsion injuries to the ankles, sprains, potential fractures to the tibia and fibula and torsional injuries to the knees. Gymnasts, although they do not dance on pointe, are allowed strapping and padding to the lower limb which provides the support and control the gymnast needs to sprint and jump. i.e. the foot is constrained through strapping.

7.5.2: Landing Forces and Flooring.

The number of amateur dancers in this thesis were small relative to the elite dancers, and considering the former are the ones most subject to dancing on hard floors in amateur schools, then the query of injury on hard floors and lack of shock absorption is important but has to be taken in the context of the small number of amateur dancers. All of the amateur dancers recruited for this study were treated in the Hertfordshire clinic for plantar fasciitis, or tendo achilles problems, and all of them presented with pes planus. All of these dancers had recovered from their injuries and were wearing orthotics during the day. However, training hours were only 3.4 – 4 hours per week, so possibly it is difficult to ascertain whether this small period of time would cause injury.

However, the elite dancers as a group, who were chosen from different elite schools and danced full time, and for the females spent considerable hours on pointe, proved to be a better measure in terms of consistency of their training in any one week. A few of the dancers in informal discussions considered that the sprung floors provided too much reverberation, and suffered shin splints and ankle problems as a consequence. This supports research which points to the incidence of injuries such as shin splints and ankle and knee joint problems as being due to poor shock absorption (Chockley, 2006). Yet the majority of the dancers considered that the flooring helped in jumping, landing and helped prevent injuries. However, quite a number of the dancers considered that long hours of training particularly leading up to a performance, or if they danced in several performances, lead to fatigue and injury. This observation is pertinent to the findings in this study as injury risk of abnormal pronation associated with hypermobility were consistent trends.

Flooring was considered to be an extrinsic factor in this study. However, two of the elite schools had sprung floors in all the training rooms, one school had one training room only with unsprung floors, otherwise all training rooms and stages were sprung floors. The amateur schools trained in hired halls, which are hard floors and not sprung floors. However, considering the training hours for the amateur group are limited to 3.5-4 hours per week, and there are only a small number of the dancers in this sample group, it is difficult to establish the influence of the flooring; only to add that the floors are hard, not sprung, and that all the amateur dancers experience injuries. Considering too that all the dancers treated in the Hertfordshire clinic for plantar fasciitis predominately, tendo achillitis, and tendinopathies so therefore a common area of injury which were linked to pes planus and overpronation. From clinical observation it has been interesting to monitor how the same amateur dancer's foot

arches have developed, become stronger from a combination of ballet training on intrinsic foot muscles, the daily wearing of orthotics, and improved supportive daily footwear. These same amateur dancers reported having had injuries in the questionnaire but became injury free. However, two attended the clinic within two years as plantar fascia pain and shin splints had reoccurred and in both cases it was associated to a growth spurt. Once new orthotics had been made and fitted, the symptoms resolved. This suggests a biomechanical problem that may need regular monitoring, also that the adolescent needs to be monitored during their growing stages.

Whilst hard floors found in Church Halls are designed for everyday use, sprung floors which are widely used in dance studios, training rooms and on stage, are designed to provide some attenuation of the impact generated shock wave. Furthermore, the energy generated is dissipated in proportion to those applied by the dancer when jumping singularly or continuously; absorbing the forces of landing, and providing positive feedback in the form of potential energy, to help elevate the dancer. A sprung floor not only contributes to the dancer being able to jump high but is also designed to avoid or lessen the incidence of injury. The flooring is of a similar design used by gymnasts, and other dance specialities to minimise injury.

Response from the elite dancers was mixed regarding sprung floors yet the majority of the dancers of both genders stated dancing on sprung floors as invaluable and felt that the numbers of injuries were probably lessened because of this floor structure. Four dancers felt that too much “spring” on the flooring caused their shin splints and other injuries, 2 of the dancers had a pes cavus foot type and 2 had a pes planus foot type. Whilst sprung floors do suit many dancers, there is a small proportion who, due to the large attenuation of shock

waves ricocheting to the outer part of the floor and returning inwards, moves rapidly up the leg and foot causing pain and injury. One elite school had one hard floor training room, yet the dancers were unaware if that particular floor caused problems and interestingly, were even unaware that it was unsprung; yet agreed that it was harder on the feet on landing. On “cause of injury”, 11 cited that their injuries (either gender) were caused when landing, 17 dancers considered that injuries occurred during a time of training. Nineteen dancers considered that their injuries occurred during increased training hours. Considering the hours of training to learn a new routine, to repeat a move many times over so that it is perfect, developing good muscle memory, then performing dance moves in perfect time with the music, as well as artistic interpretation, is a considerable task for a dancer. The drive for perfectionism can result in overtraining and there may also possibly be an increase a level of pre performance anxiety in the dancer for fear of making a mistake. Fatigue both mental and physical causes injury as has been found in literature in various sports; it is finding the delicate balance of how much to train, when to stop, rest, manage a good appropriate diet for the sport, receive recuperative massages for build-up of lactic acid in the muscles and to prepare the dancer for the next phase of training or performance (Meeuwise, 1991).

Age and experience is a factor in injuries. Four dancers felt that the sprung floor was the cause of their injury (all were elite dancers). These 4 dancers (4 female) considered that they had suffered shin splints and felt unstable at the ankle joints when landing on pointe. These dancers were in the 14-16 age group. This might suggest that with more training, the lower limb muscles become stronger and adapt not only more readily to a sprung floor, as the general fitness of the dancer improves with time. However, there may be a relationship to grow spurts during these teenage years and muscle imbalance (Kennedy and Hodgkins, 2007). Whilst the dancers may consider the flooring as not working for them as this stage,

another area worthy of exploration could be the ballet shoes; perhaps the dancer is not wearing the right make or type of pointe shoe and to perhaps consider trying a different make and type. For example a longer vamp on the front of the shoes may give the foot more of a glove effect and control. Additionally to add gel toe caps inside the pointe of the shoe may provide, although slight, an additional amount of shock absorption helping to manage shock attenuation.

In all, not all sprung floors suit everyone yet they appear to suit the majority, and to find flooring to suit all dancers could be complicated and costly. Perhaps the dance shoe needs further investigation on its construct in that if the toe box of a pointe of the shoe could be redesigned to suit that of an individual this may solve the issue of shock absorption for that dancer.

7.5.3: Adolescence and the growing body.

As discussed in Chapter 3, overtraining can have adverse effects both short term and long term for an athlete. During the adolescent years where bones are developing and ligaments softening during each growth spurt, muscles having to be allowed time to lengthen to meet the bone growth. Although it is a time where exercise should be encouraged, it is also a time when rest is essential and it is finding that balance, particularly for an elite dancer. Growth spurts can render an adolescent clumsy in movement as the motor neurones re-establish spacial awareness and proprioception. Muscle imbalance and growth pains can occur until the muscles have caught up with the growth of the bones, which is a time where increased rest is required (Kennedy and Hodgkins, 2007). Whilst amateur dancers only train for relatively short hours which are most likely interspersed with main school sports, elite dancers will

train long hours at their dance schools and depending on what age they start i.e. 12 or 14 years, and possibly are not having sufficient rest time. This should also be taken into consideration when dancing on pointe since an overbalance of the muscle structure i.e. an overpull of the ankle extensors (dorsiflexors) over the plantarflexors can lead to instability and sprains at the ankle joint; ankle injuries being high in number (21) in the results of this thesis.

As also discussed in Chapter 3, not all the foot bones have ossified in the teenage years, particularly the hallux, the phalanges and the 1st metatarsal which renders them susceptible to damage and possible stunting in ossification due to dancing on pointe (Kennedy, 2007). This is not to advocate that a dancer does not move onto pointe in adolescence, it is rather looking at a more suitable design of block in the toe area of the pointe that may be more forgiving to the toe area for example, for shoe companies to manufacture a block toe pointe area with various densities of gel rather than the stiffness and rigidity of the combination of glue and paper which is very hard and lacks any form of shock absorption. In essence, the design of shoes has not changed since their origin and it is an area that needs exploration and re-designing. In the results of this thesis, all dancers had damaged toenails.

7.5.4: Pain threshold.

Dancers through intense training over the years have learnt to train through injuries and have a high pain threshold. Their training forms part of a strict discipline to provide perfectionism in their dance, which means gruelling long hours of training. The professional dancers often have to dance performances of different ballets at the same time. In the results, there were 6 dancers who were unaware of their injury until after a performance. It has been reported that

dancers may dance through painful ‘niggles’ when performing and are helped through by adrenaline. It is when they stop that they experience the pain and it is then to make the decision to either self-treat or to seek physiotherapy. Hence, of the dancers who had recovered in this current thesis, a few had commented that they experienced minor niggling pains but not enough to stop dancing and this dancing through injuries or pain may possibly account for the 7 dancers who said that they had never been injured i.e. there were niggles or injuries but not serious enough to seek treatment i.e. their pain threshold was high and therefore they may be either used to dancing through pain or they do not experience the pain even though they are injured. Research has been reported on dancers who have trained or performed even though they had sustained metatarsal fractures with the dancer commenting that they did not realise or did not feel the pain until the condition had worsened.

Table 6.2 (Chapter 6) shows 7 dancers with no injuries to date. As previously mentioned, this could be that dancers develop a high pain threshold and may consider that they have not experienced any injuries previously or currently because they did not deem the injury as a problem. All the amateur dancers had been injured but this could possibly be due to the fact that they are not as highly trained as the elite dancers, may still experience certain weak muscles and will not have the high overall level of fitness of an elite dancer. The elite dancers, as mentioned in Chapter 6.7, commented that most injuries occurred when they were training longer hours in rehearsals, or simply just overtraining, that they became tired and lost concentration. Some of the dancers cited overtraining as a problem but they also said that it was essential to train hard in order to perfect moves. Others cited competition as strong and were ambitious to be selected by a dance company and to maintain that position (which could be lost through injury).

A professional dance career is a short window of time, competition to join ballet dance companies, as with any dance company, is high. A dancer once part of a ballet company could feel tentative about taking any time off due to injury which may result in loss of employment. This usually leads to insecurity for the dancer as they could be replaced permanently and with this comes not only lost income but also detriment to their reputation. This could account to some degree why dancers may not report an injury. Repeated injuries limit employability and question reliability of the dancer i.e. for a completion in performances in a season. In informal discussions regarding training, many of the elite dancers commented of the high selection criteria and the equally high level of competition in being selected for a dance company, so they would train long hours to gain perfection in their moves.

Even though some of the dancers commented that this could be considered as overtraining they felt that it was essential to train rigorously in the dance world and many enjoyed the challenge; they loved to dance i.e. hard training equated to perfection of moves. Other dancers commented that they could not afford to take time off when injured for fear of either not being chosen for a performance or “dropped” from a performance and so would dance through injuries (specific injuries that they danced through was not stated). Six of the dancers did not realise that they were injured until after training or a performance, and 2 dancers felt that assessment of the injury or treatment was not needed whilst 7 others said that they did immediately seek out a physiotherapist.

7.6: Chapter conclusion.

This final chapter pinpoints the unique contribution that this study has formulated in understanding a process to identify foot types, which are more susceptible to injury as well as a model to monitor injury surveillance of use to clinicians and dance teachers. In all, in this thesis I set out to measure and categorise foot types as well as measure levels of pronation and to observe if there is a pattern amongst the dance population using a sample of 47 dancers of both genders. Using the foot types, I wanted to see if there was any relationship between foot type and injuries. Also I wanted to investigate whether there were any differences in foot postural changes (pronation) between the 1st and 5th dance positions as well as in normal stance, and comparing right to left foot of the dancer. Injuries were documented both current and historic and ongoing, and these were cross-compared against foot type, gender and degrees of pronation. Even though the number of amateur dancers were small in number, cross comparison with the elite dancers in terms of hours of training, years of training and extrinsic factors of flooring and footwear, as well as the intrinsic factors of foot type, pronation and injury as well as 1st and 5th dance positions proved invaluable in that the difference in training and consequent injuries became apparent. Whilst literature search does not reveal any research on 1st and 5th dance positions or investigates whether pes planus is a usual finding in the ballet dancer population, it does however refer consistently to excessive postural movement or overpronation as the cause of ankle injuries, sprains and fractures (Gamboa, 2008; Russell et al., 2011). Postural changes (pronation) proved to be a key factor in this thesis in that large postural changes or degrees of pronation were linked to the dancers, mainly male, who individually would present with high number of injuries; these are most likely related to the landings, jumps and extensions. Landings and jumps have been cited in the literature as cause of injury since choreographers are demanding that male

dancers develop the same flexibility as the females; this places additional strain on the feet (McCormack et al., 2004).

Regardless of foot type, the injury tally proved high for the dancers with the exception of 7 dancers. Since the dancers in this cohort have had at least one injury, some many, and others ongoing, it suggests that injuries seem to be an inevitable occurrence. Dancers as with other athletes are cited as having a high pain threshold and often dance through injuries, which may explain 7 dancers not presenting with an injury history, or it could be that dancers may not want to draw attention to the injuries since a dance career is hierarchal. Interestingly, the high number of pes planus feet in both genders was apparent and even though statistically they did not relate to specific injuries per se, they did reflect a proportionately high number to the other two foot types.

Possible explanations for the high number of pes planus in both genders, particularly the male group, may be accounted for by particular dance movements, repetition of a movement, long hours in training, repeated jumps from high landings. Additionally, both genders run on the forefoot with the subtalar and midtarsal joints undergoing overpronation to compensate which taxes the ankle and foot joints and creates overuse injuries. Despite the rigours of dance training to form strong and normal arch types in the foot, the reality may be that whilst the intrinsic foot muscles do become strong and can contract to form a good pointe, they cannot improve the arch height since the integrity of the arch is also reliant on ligamentous structure i.e. ligaments cannot contract and shorten. Where there is inherent laxity (benign) the effects of repeated jumping and landing may further strain the ligaments resulting in accumulative weakness of passive joint stability over a period of years. This strain on the ligaments would have a cost of injury. The majority of dancers were elite performers, and pes

planus was the dominant presentation in both genders together with significant levels of postural change (1.2 – 1.6cm both gender). Therefore whilst dance companies may seek to increase arch type, the very nature of repetitive moves, landings, moving on pointe actually aids the foot arch to flatten and overpronate to meet and adapt to shock absorption forces from the ground. This is an important consideration for dance schools since it implies performance benefit arising from overpronation but an associated increased risk of injury. Assessment of dancers over their professional careers would seem to be warranted. A theoretical model, linked to practice assessment, is presented in Chapter 8.

CHAPTER 8

Study Conclusions

8.0 Introduction.

The impetus for this study was a realisation from clinical practice that injuries sustained by young girls predominately (11 years plus) in the pursuit of their involvement in amateur ballet were associated with an apparently consistent biomechanical presentation of flat feet and higher than expected flexibility. On further investigation it became apparent that these individuals reflected a wider picture of foot type and foot posture, and that these factors could provide insight into the nature and frequency of foot and leg injuries. An investigation of the published literature confirmed a personal view that podiatrists were not actively engaged in ballet per se, neither were they represented in the academic arena. This was largely the domain of the physiotherapist for their recognised involvement in injury rehabilitation.

From this premise the germ of the study was formulated to investigate the incidence and nature of lower limb injury with particular reference to the individual foot type and posture. Whether this alone could be associated with all injuries or were other factors implicated to a greater or lesser extent in the type and frequency of ballet dancer injuries. An awareness of both intrinsic factors and extrinsic factors was developed from the observation of amateur and elite dancers, the demands of the dance routines on lower limb kinematics, and the possible influence of the dance shoes and flooring.

This study was developed over time due to the increase in numbers of ballet dancers seeking treatment in our clinics. The dancers felt that either they were not recovering from their injuries or injuries were reoccurring or additional ones were occurring. Physiotherapy played an important role yet could not successfully treat certain injuries and therefore the dancers sought podiatry as a possibility of providing key treatment or advice.

The podiatry profession appears to lag behind other professions in its contribution to published research on injuries and certainly in the realm of dance injuries and this could be due to lack of engage in a specialism. Coincidentally the scope of clinical practice particularly in biomechanics is not appreciated partly as a result of career structure which is concentrated in palliative care and consequences of co-morbidities in an aging population. Yet podiatry as a profession whilst sought out by runners and athletes does not seem to be considered in the dance world; this thesis seeks to address this short coming by educating dance schools.

Physiotherapists as an allied health care and profession are not always aware of the scope of a podiatrist and how valuable the two professions could co-ordinate in treatment. Podiatrists provide in-depth analysis on gait and biomechanics and even footwear. This same lack of awareness applies in General Practitioners who traditionally refer lower limb injuries to physiotherapists. Podiatrists with expertise in biomechanics and sports injury management have much to offer in a multidisciplinary approach to prevention and rehabilitation.

This current study will offer valuable information for podiatry as a profession to educate podiatrists on ballet injuries and how engagement in this arena offers mutual benefits.

8.1 Contribution to the field.

In the formulation of the question to be answered by this investigation two factors were apparent, the nature and effect of individuals foot parameters. Were choreographers and dance schools even aware they existed and failing that, what if any selection criteria existed and more importantly was it universally applied. The literature review offered some insight into past and current expectations of dancers style and portrayal and influential effects of international companies. Currently schools consider prospective dancers on physique particularly the females, for slight features, pose and height. Males are taller with good physique and upper body strength. To the best of my knowledge no previous studies have considered the influence of foot type and foot posture on lower limb injury in a population of amateur and professional male and female ballet dancers. The findings of this study offer a further dimension to the selection process, which highlights an individual's susceptibility to injury and recurrence of injury. The inclusion of a foot assessment to determine foot type and degree of pronation / hypermobility as highlighted in these results would require education and training of those with responsibility for student dancer selection.

The primary research question for this thesis is: *To what extent do particular foot types (intrinsic factors) and flooring and footwear (extrinsic factors) contribute to lower limb injuries in ballet dancers?*

Objective 1. To evaluate and describe a “normal” foot with reference to foot types.

At the outset defining the ‘normal’ foot identified the range or individuality that applies to ‘normal’, flat or high arched feet. The literature review highlighted the consensus approach to defining ‘normal’ as lying within specified parameters, which offered continuity. By the adoption of three proxy measures this study was able to better interpret foot type and foot posture while adopting a criterion for normalcy. The application of these assessment tools enabled critical appraisal of the finding for defining foot posture, (planus, rectus and cavus) which lead to the rationalisation of assessment tools due to issues of investigator application and interpretation with the Foot Posture Index (FPI). Consequently this study has provided a rationale for applying the NVDT and Calcaneal bisection methods to evaluate foot type in a small but representative sample of ballet dancers. It has identified a predominance of pes planus foot type (flat foot) bilaterally but in some instances, a different foot type of the left and right foot. In making this evaluation the study has identified the significance of foot pronation, and more specifically of overpronation as associated with injuries, particularly when executing the demanding 1st and 5th dance positions.

Objective 2: How does foot type relate to incidence and type of injury.

A clear picture evolved which identified a high proportion of pes planus feet, particularly and disproportionately in male dancers within the study population irrespective of whether they were amateur or elite dancers. This factor when coupled with evidence of high degrees of pronation (overpronation) in both genders was directly related to the number of injuries sustained, particular injuries of which the foot and ankle featured significantly. The great majority of dancers had a history of injury and many were nursing current, or recovering

from injuries and still dancing. Injuries were apparent in the rectus and cavus foot types. These were in the case of rectus foot types associated with those individuals exhibiting abnormal degrees of pronation and although fewer in number showed a similar distribution of injuries between the foot and leg as with pes planus types. Cavus foot types being in the minority where associated with injuries characterised by the limitation of pronation and therefore lesser metatarsal stress fractures and impingement injuries of the ankle where present.

Statistically, there was no relationship between foot type and specific injury or between the dancers demographic profiles for males and females and injury pattern. The number of individual injuries was higher (3 – 5) in elite dancers who exhibited high degrees of overpronation. The findings of this study indicate greater complexity to the aetiology, that susceptibility to injury is not confined to duration (years) of performing alone but multifactorial by way of intrinsic factors alone.

Objective 3: To evaluate extrinsic factors.

Informal discussions with elite and amateur dancer, dance teachers and school physiotherapists highlighted significant factors which dancers considered were contributory to their injuries. There was no clear consensus among the amateur or elite dancers for types or number of injuries, although amateur dancers were fewer in number within this study and trained for shorter periods. Amateur sustained injuries which could be associated with foot type (pes planus), but without the advantage of muscular development to resist the demands placed on the musculoskeletal system a clear association is not possible. Although, these amateur dancers as evidenced in clinical practice sustained reoccurrence of injury which was

attributed to growth. Elite dancers attributed their injuries to a combination of fatigue brought on by hours of training and insufficient rest periods. While specific fatigue related injuries (shin splints) were attributed by some dancers to the effects of sprung flooring. The specific properties of these floors was not investigated, the assistance afforded in jumping and landing can only be interpreted in energy conservation effects on the musculoskeletal system. Fatigue is commonly associated with injuries among athletes, and where demands for muscular control are more critical to support and stability as in ballet a pattern of injury could be anticipated. The additional burden of foot posture (pes planus), ligamentous laxity (hypermobility) and resulting overpronation evidenced within this cohort combine to increase the risk of foot and ankle injuries reflected in these results. No conclusion is drawn on the benefit or otherwise provided by type of floor or lack of 'support' from the ballet shoe. Those individuals that exhibited a pes rectus foot posture were also subject to injuries all be it fewer in number. Given that other factors applied equally, sprung floors and ballet shoes, then a reasoned conclusion would point to the planus foot as being a principal factor for injury and recurrence of injuries with approaching twice the number occurring in this category for both genders.

8.2. Conceptual conclusions.

Theoretically, the high incidence of pes planus reported in this study, together with the levels and numbers of dancers who exhibited overpronation in dance positions of 1st and 5th position; are appropriately explained by the accumulative effects of intrinsic and extrinsic factors discussed. In these findings there was a clear association between a predominant pes planus and incidence of overpronation observed in both male and female dancers. This relationship was noted in the dance positions, en pointe, 1st and 5th position and dynamically

for male dancers with jumping and landing. Overpronation together with a biomechanical foot anomaly of pes planus places the foot, ankles and knees under strain due to uncontrolled perturbations and therefore instability and increases the likelihood of injury.

Identification of these factors together with the association or propensity to injury serves to promote the concept of an assessment model to be adopted for pre entry and continuous monitoring of individuals to identify ‘at risk’ performers. The conceptual process of a theoretical framework designed to monitor injuries is unique and combined with the application of proxy foot measures to identify foot type, aims to reduce the incidence and pattern of injury or identifies training needs to avoid reoccurrence and frequency of injury. My contribution fits into implication for practice outcomes for podiatry and dance schools.

8.3 Practice conclusions and recommendations.

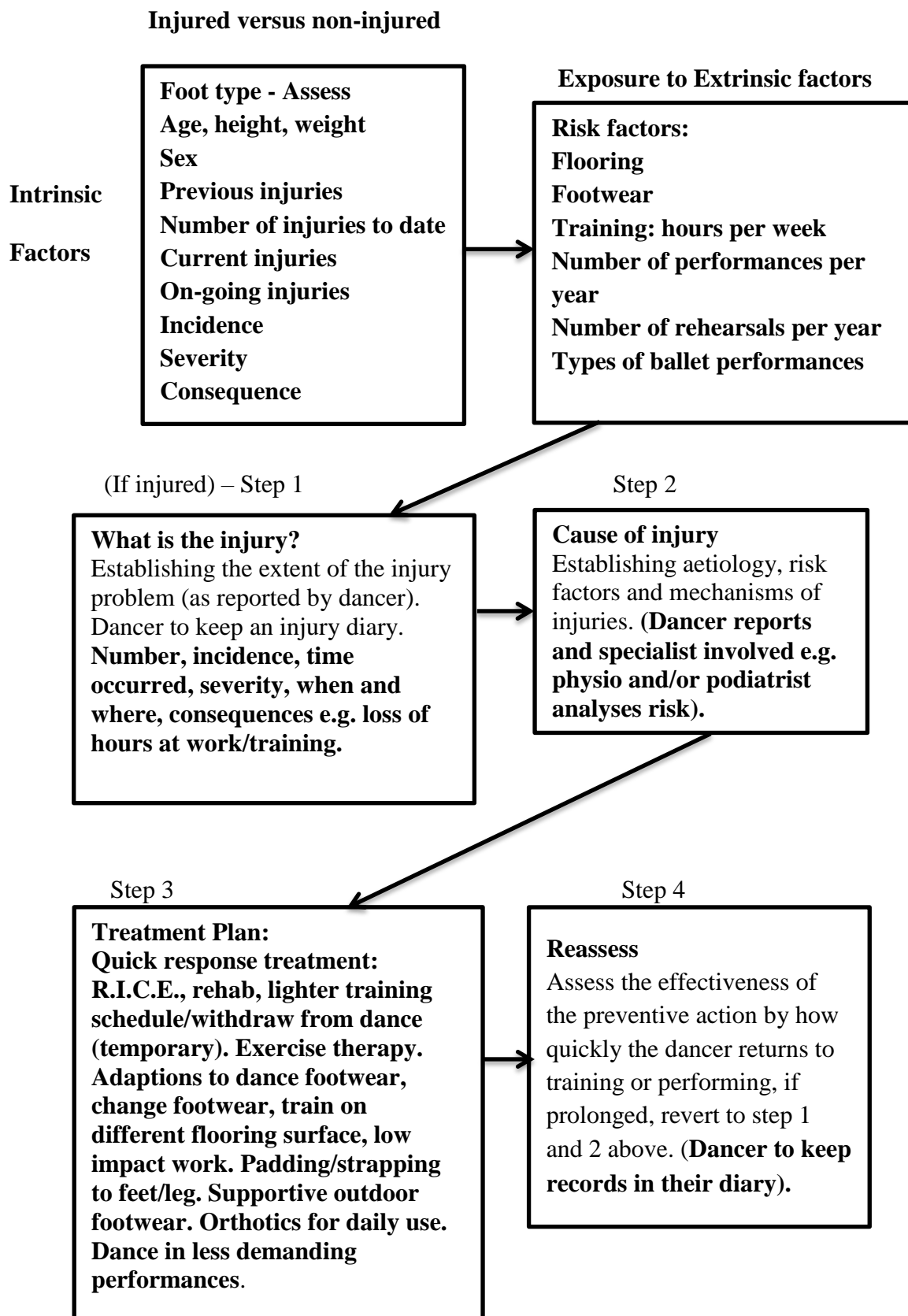
Ballet is an athletic as well as artistic activity, yet dancers face biomechanical challenges due to females dancing on pointe and males having to perform repeated high jumps as well as catching and holding the female dancers. The resulting biomechanical challenges imposed by this discipline need to maintain precise dance positions and pose are subject to external forces (GRF) which associated with the basic nature of the ballet shoe and the variability of floor structure combine, resulting in frequent and potentially unavoidable injuries.

Drawing on the model devised by Meeuwse (1991; Figure 4.1), which is non-specific to particular athletes, the current research will apply the model to dancers with some enlightened variations. Intrinsic factors would include pes cavus and pes planus foot types with pes rectus used as a cross reference since it is considered a normal foot type, as well as

age, sex, height and weight. Extrinsic factors would include hours of training, hours in performance, number of injuries sustained, current and on-going injuries, flooring, and characteristics of footwear, amateur and professional and injured and non-injured. Four steps are envisaged (below) however in context of these thesis only steps 1 and 2 were reported as the foundation and steps 3 and 4 were a future development which has now contributed to this Model (Figure 7.1).

Injury prediction could potentially, be addressed, early on in a dancer's career, as young as the pre-pointe years, where screening for foot type, flexibility, stiffness, or hypermobility, as indicators can be given to the dancer of the most likely injuries in the future. Hypermobility coupled with pes planus, the latter already the subject of excessive physiological stress to maintain a pointe position, intensifies the demands of having to keep the foot arched, and ankle stable. Dancers as young as 9 years of age would benefit from screening if they train for 4 hours plus a week. Screening by podiatrists who are involved in dance related injuries would be appropriate here as they can access for biomechanical anomalies, working in conjunction with dance specialist physiotherapists, and together would give a lower limb assessment for the novice dancer, parent and choreographer.

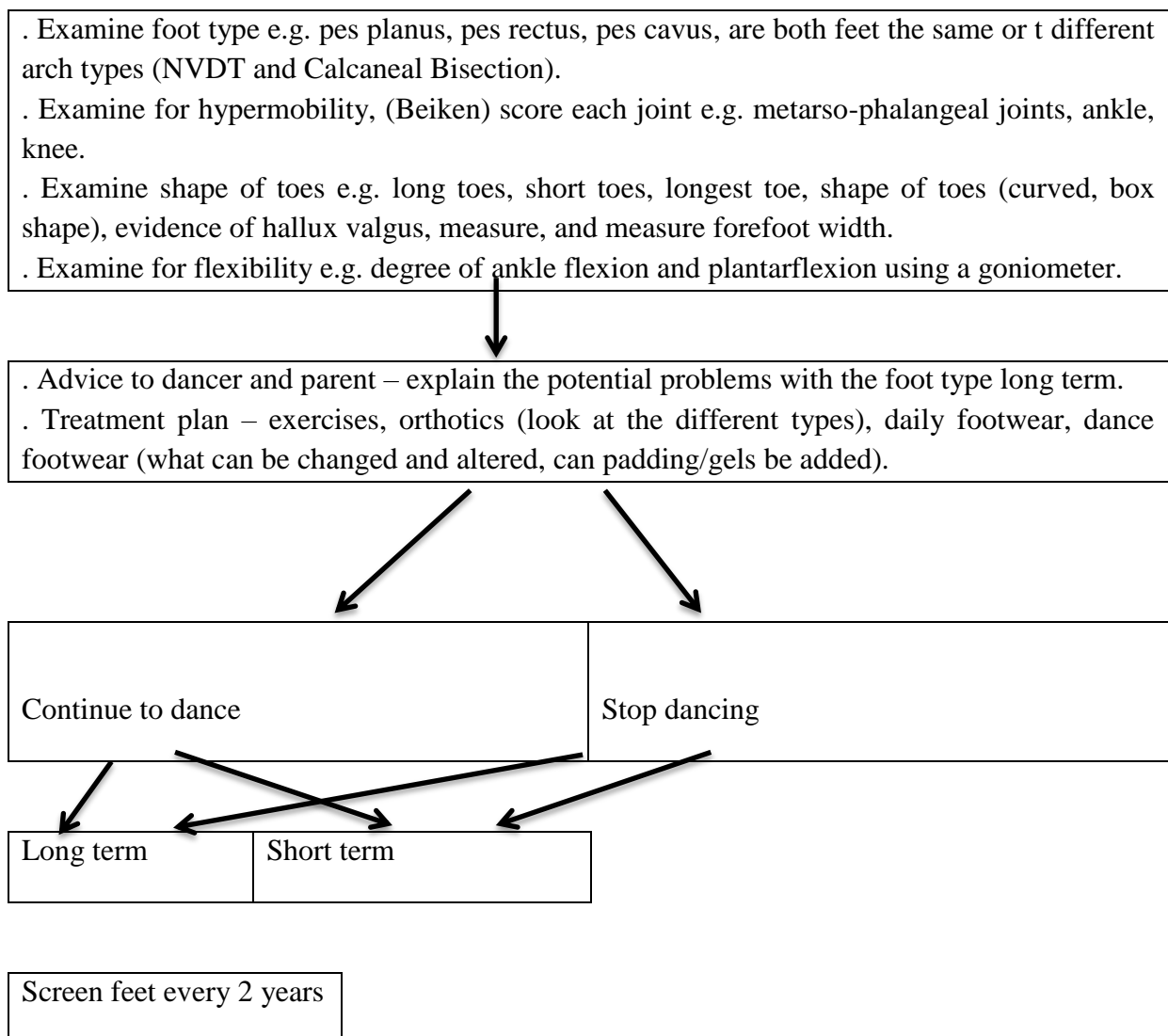
Figure 8.1 – Model of Injury Causation for Ballet Dancers (Patsy Parfitt, 2016).



The highlighted areas in the Model (Figure 8.1) are contributions made from this current thesis.

Screening should be addressed again if the dancer enters an elite dance school which could be at 11 years or 14 years of age no standardisation is apparent and upper schools (generally 16-19 years) see table 7.2. Again using a combination of specialist podiatrists and physiotherapists who work with the school and are present at dance auditions for potential students entering the schools. The aim is not to dissuade a dancer from their chosen career, but to educate them on their foot type, how this can impact on their career without monitoring i.e. the potential changes that can occur with that foot type, and also of the most likely injuries. A screening and education programme would help prevent some of the long term problems that dancers suffer from such as progressive bunions, broad forefeet and osteoarthritic changes, although some of these conditions have inherent factors. Photographic record of the foot posture, (NH) and width of the forefoot could be acquired at initial interview together with anthropometric data. This would provide a baseline assessment for future reappraisal of intrinsic changes at 2 year monitoring. The width measurement offers an approximation for the development of bunion (HAV) deformity. As part of the continuous monitoring for the dancers, they should be encouraged to diary their training periods to include day of injury, site of injury, ballet position, landing, type of shoes worn, and whether the injury occurred during training, rehearsals or performance. Although impractical to enforce such a record would assist the podiatrist, physiotherapist in their interventions, management and long-term treatment design. A logging of injuries will provide a repository of evidence for further study and incite to injury recognition and reduction.

Figure 8.2: Screening Pre-point – 9 years plus.



8.4: Final reflections.

This study was a long journey into discovering whether ballet dancers did indeed develop foot injuries due to their foot type and postural movement. Observations apparent in the clinics over the years provided only anecdotal evidence of an association therefore prompting the need for further evidence to either prove or disprove a causal relationship. Other factors surrounding the presentation of foot and lower limb injuries needed to be considered and scrutinised to see if there may be contributory extrinsic factors, footwear and or flooring structure. As for the injuries experienced, an enquiry was made as to where the dancers were seeking treatment if any in order to recommend best practice of injury rehabilitation.

The methodological rigor proved to be complex since there was no single measure for foot type complicated by the tri-plane motion of pronation and supination. However by adopting 3 proxy measures and applying them to interpret the arch height (NH) and postural movements (ND) and displacement of the heel (calcaneal eversion) has proved consistent with good and repeatable results.

This thesis has proved to be original since there are no other studies examining and comparing foot types of both feet in male and female ballet dancers and linkage to injury. Additionally, the measurement of postural movement of pronation in cross comparison with the foot type and injury has not been previously reported. Coupled with the measurement of postural movement of pronation in 1st and 5th ballet positions which is also original, in all has proved to be valuable in defining possible implications of lower limb kinematics linked with foot types which when combined, are apparent with these dance movements.

Podiatric practice has through the application of validated assessment methods been able to highlight foot type and posture as a factor in the injury and recurrence of injury in this cohort. The absence of bias in the selection process gives credence to the study as being representative of the ballet dance population as a whole. This thesis is unique in that it combines the 3 proxy measures together in assessing foot type which could be used by other podiatrists , health practitioners or researchers to assess foot types in not only ballet dancers but other sports or general population and therefore a valuable contribution. The second contribution is the design of an assessment model which assesses foot type, injuries sustained and short and long term treatment protocol. Thirdly, results from the findings and interpretation are of clinical significance giving an indication of the different foot types and their associated injuries. The engagement of podiatrists in the selection process together with the implementation of the assessment model are proposed as invaluable to empower ballet schools in selection and monitoring of dancers for susceptibility to injury and re-injury.

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Appendices

Glossary – Definitions

Subtalar joint. Articulation between the talus and calcaneus.

Ankle joint. Articulation between the tibia/fibula and the talus.

Frontal plane. A plane passing through the body that divides the body into front and back sections.

Sagittal plane. A plane passing through the body that divides the body into left and right sections.

Transverse plane. A plane passing through the body that divides the body into top and bottom sections.

XY plane. A horizontal plane defined by a measurement system.

XZ plane. A vertical plane defined by a measurement system that is at right angles to the direction of walking.

Inversion. A movement in the frontal plane, and therefore about an axis parallel to the sagittal and transverse planes, that moves the plantar aspect of the foot towards the midline of the body.

Eversion. A movement in the frontal plane, and therefore about an axis parallel to the sagittal and transverse planes, that moves the plantar aspect of the foot away from the midline of the body.

Dorsiflexion. A movement in the sagittal plane, and therefore about an axis lying parallel to the frontal and transverse planes, that moves the far end of the foot, or any segment thereof, towards the shin.

Plantarflexion. A movement in the sagittal plane, and therefore about an axis lying parallel to the frontal and transverse planes that moves the far end of the foot, or any segment thereof, away from the shin.

Pronation. A combination of eversion, dorsiflexion and abduction.

Supination. A combination of inversion, plantarflexion and adduction.

Ballet terminology

Assemblé. Assemble is a jump that lands on two feet. When initiated from two feet, the working leg performs a battement glissé/dégagé, brushing out. The dancer launches into a jump, with the second foot then meeting the first foot before landing.

Pointé. Supporting one's body weight on the tips of the toes, usually while wearing structurally reinforced pointe shoes, ankles are fully plantarflexed.

Demi-pointe. Supporting one's body weight on the balls of one or both feet, heels raised off the floor.

Relevé. Rising onto the balls (*demi-pointe*) or toes (*pointe*) of one or both feet.

Demi-plié. A smooth and continuous bending of the knees outward with the upper body held upright.

Plié. The knees must bend directly above the line of the toes without releasing the heels from the floor.

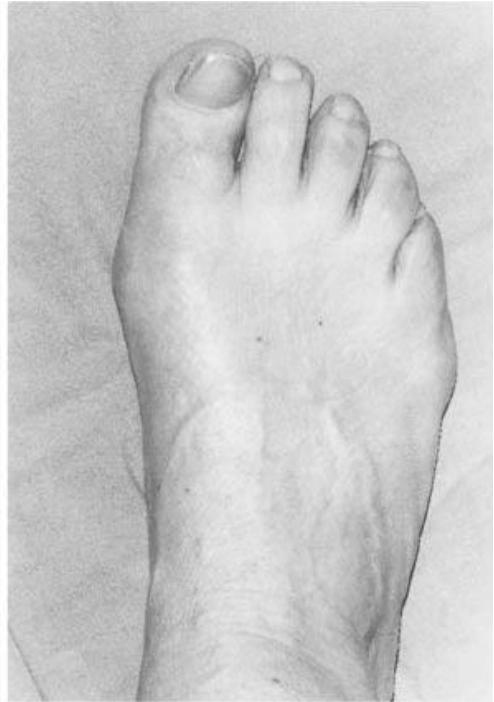
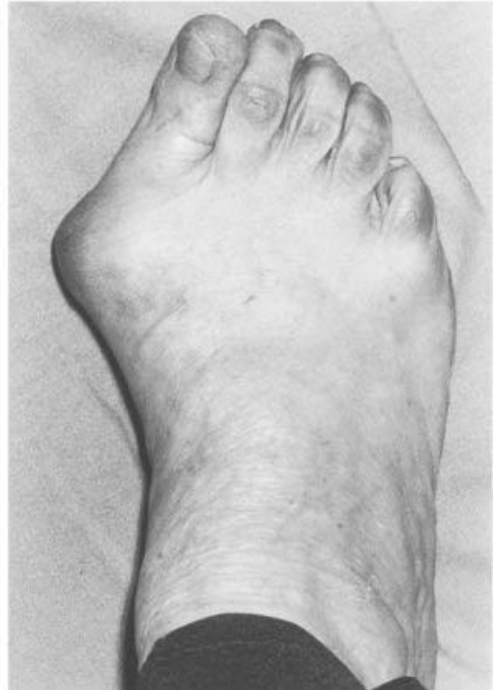
First position. First position should be turned out legs with the feet pointing in opposite directions, heels touching.

Fifth position. Fifth position should form two parallel lines with your feet. The heel of the front foot should be in contact with the big toe of the other, and the heel of the back foot should be in contact with the last toe of the front foot.

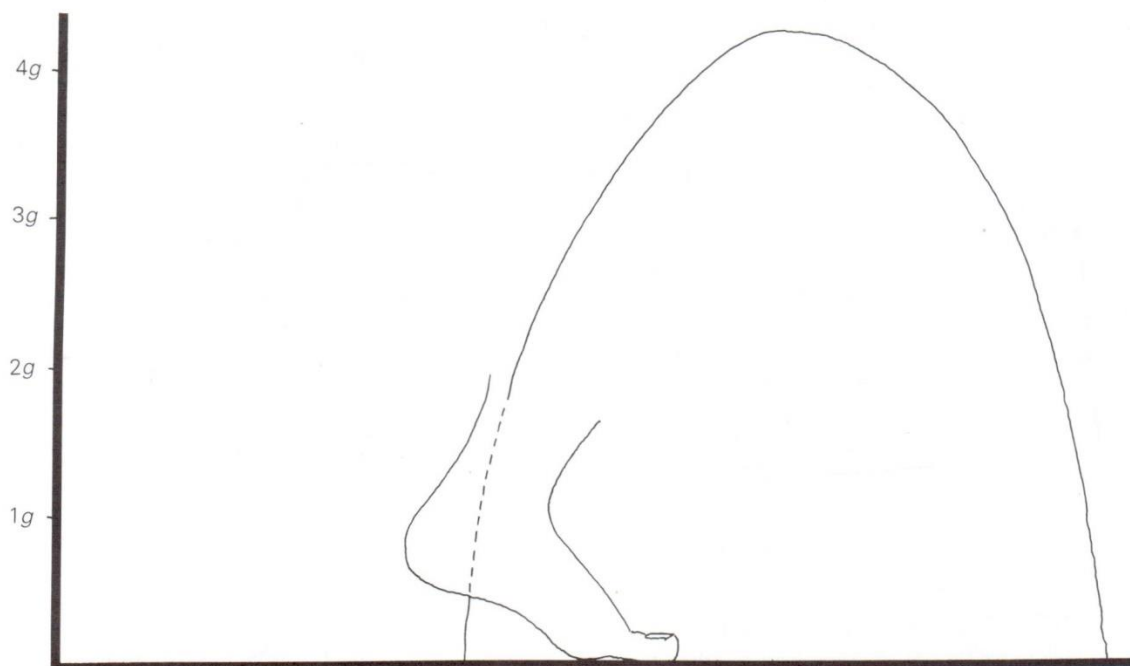
Pulling Up. To pull up, a dancer must lift the ribcage and sternum but keep the shoulders down, relaxed and centered over the hips, which requires use of the abdominal muscles. In addition, the dancer must stabilize the pelvis, maintaining a neutral position, and keep the back straight to avoid arching and going off balance.

Grand jeté. A long horizontal jump, starting from one leg and landing on the other. Known as a split in the air.

Corps de ballet. The ensemble of a ballet company, especially the ensemble apart from the featured dancers. Being a part of the corps means one is neither a soloist nor a principal dancer

A**B****C****D**

The Manchester scale. (A) No deformity (grade 1); (B) mild deformity (grade 2); (C) moderate deformity (grade 3); (D) severe deformity (grade 4). Diagram adapted from Garrow AP. Papageorgiou A. Silman AJ. Thomas E. Jayson MI. Macfarlane GJ. (2001) The grading of hallux valgus. The Manchester Scale. *Journal of the American Podiatric Medical Association* 91:74.



Ground Reaction Force with forefoot contact. Copyright, Subotnick, 1989.

PARFITT PODIATRY

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Email: patsy.parfitt@ntlworld.com

21st October, 2014.

Date:

Study Title: Exploration of the contributing factors to lower limb injury in ballet dancers.

Purpose and value of the study:

The aim is to study foot/lower limb injuries in ballet dancers, the frequency of certain injuries, and to observe any linkage to particular biomechanical foot type e.g. pes planus (flat feet) or pes cavus (very high arches), or to physical factors such as shoe composition, and floor type.

Invitation to participate:

Dear Dancer,

I am a Podiatrist who specialises in lower limb/foot injuries particularly in sports injuries. I am seeing an increase in numbers of dancers to the clinic and feel that I need to gain more of an understanding of dance moves/positions as well as to see if there are any particular foot shapes that are more susceptible to injuries. I am collecting data of injuries to see if there is any common theme. I also want to look at the dance shoes for wear marks and support on the feet, as well as shoe and dance floor composition. Learning about the frequency of certain injuries helps to improve the treatment plan.

I am therefore undertaking research at Anglia Ruskin University, Cambridge. I would like to interview by questionnaire 50 professional ballet dancers.

I would like to invite you to attend an interview lasting approximately 30 minutes. The first part of the interview will involve asking questions about your dance training, years of dance, stage work, level achieved, performance work, injuries and dance shoes. Also any treatment received, success of treatment and repeated injuries or on-going.

The second part of the interview would involve measuring the back of the heel by pen, height of the arch as part of an assessment of foot type, Foot Posture Index/Navicular Drop test. I will also be measuring the feet when you are standing in 1st and 5th positions.

For confidentiality purposes, I will not put your name or address/telephone number on the interview schedule, but will give you a candidate number,

This research might be of interest to you in the future as it will give insight of different foot types and any potential links to injury.

Yours sincerely,

Patsy Parfitt Podiatrist MSc, M.Pod.A.

Who is organising the research:

Patsy Parfitt, a qualified Podiatrist

What will happen to the results of the study:

The information will be collated and analysed using appropriate software. The foot measurements will be charted. Photos of the lower limb (knee to foot) will be added in to the Thesis as part of the analysis.

Source of funding:

The study is entirely self-funded.

Contact for further information:

Patsy Parfitt on 0208 207 2655 or 077911 04311. Email: patsy.parfitt@ntlworld.com

Why you have been invited to take part:

Four dance schools have given me permission to locate the study in their centre.

Participants are identified at random from membership lists but also stratified according to age category and previous/current injury. You have been invited to take part as a dancer in one of those centres.

Whether you can refuse to take part:

Participation is entirely voluntary. You can choose to withdraw at any time and giving a reason is not necessary. You can advise me at any time at the interview or contact me by email at patsy.parfitt@ntlworld.com. You can also contact me on 077911 04311

What will happen if you agree to take part:

I would like to interview you for 30 minutes in the dance studio or if more convenient, you are welcome to attend one of my three clinics at Elstree, St. Albans or Harpenden. There is no charge or fee if you attend the clinic since it is part of a study.

Firstly, I will ask you questions about years of dance training, performance work, point work, injuries, level of training, dance shoes (which you will need to bring with you - all pairs, no matter how worn), and the type of dance floor that you have danced upon. Agreement to participate in this research does not compromise your legal rights should something go wrong. However there are no likely risks or side effects should you attend.

All information is strictly confidential and no names will be attached to worksheets. All personal identifiers will be kept secure in a locked cabinet to which only I will have access. Worksheets will instead have a candidate number and your date of birth. Information will be collated with that from other participants and data assessed using a software package. Your foot arch heights will be charted and the measurements of your foot will be analysed and information added to the written research. Datasheets for analysis will also contain only a code. Again the identifier to that code will be held secure in the locked cabinet.

There are no given benefits from taking part but at the same time you may find it very interesting to discover biomechanical foot types and precautions to take to help avoid any further injury when this research is completed. The research will be disseminated and hopefully will inform developments for future dancers.

Thank you for reading this Information Sheet. If you decide to take part in this study then please complete the attached Consent form and return it to Patsy Parfitt at the contact address above.

Kind Regards,

Patsy Parfitt, MSc, MPodA
Podiatrist.

PARFITT PODIATRY

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Mobile 07791-104311

Email: patsy.parfitt@ntlworld.com

Dear Participant,

1st May 2014

As a candidate you can refuse to take part at any time if you feel it is unsuitable.

You can choose to withdraw at any time, preferably before the interview date so that I can offer that time to another dancer. Please contact me by email at patsy.parfitt@ntlworld.com. You can also contact me on 077911 04311

What will happen if you agree to take part:

I would like to interview you for 30 minutes in the dance studio or if more convenient, you are welcome to attend one of my three clinics at Elstree, St. Albans or Harpenden. There is no charge or fee if you attend the clinic since it is part of a study.

I will ask you questions about years of dance training, performance work, point work, injuries, level of training, dance shoes (which you will need to bring with you - all pairs, no matter how worn). After the questionnaire, I will measure the height of foot arch (barefoot), then I will take a photo of you standing barefoot from the knee down to the foot. I would also like a photo of the foot on point in the point shoes.

There are no risks or side effects. Although if you are under 16 years, you must have a parent present or nominated teacher.

Agreement to participate in this research should not compromise your legal rights should something go wrong. There are no special precautions to take before, during or after taking part in the study.

All data is strictly confidential and will not have your name, address or telephone number. It will instead have a candidate number and your date of birth. The questionnaires will be collated and assessed by a statistical package. The foot arch heights equally will be charted. The photos of the

foot and knee will be analysed and added to the written research. There are no given benefits from taking part but at the same time it will be information on foot types which may be useful in the future when the research has been completed. Your participation will be kept confidential since a candidate number will be used instead of your name.

Patsy Parfitt, MSc, D Pod M. Podiatrist

QUESTIONNAIRE: SUBJECT NO:

NAME:	DATE OF BIRTH	AGE
CURRENT BALLET SCHOOL:		YEAR STARTED
YEARS OF DANCE	AGE STARTED	

1.CURRENT INJURIES

DATE OCCURRED: State number on each body site

WHERE IN BODY: Foot (1)
Ankle (2)
Lower leg (3)
Upper leg (4)
Hip (5)
Upper body (6)

State injury

1a. When did this injury happen?

Training (1)
Rehearsals (2)
Performance (3)
Other (State) (4)

1b. How did you recognise that you had been injured?

Difficulty in performing a dance move (1)
Difficulty in dancing (2)
Unable to dance (3)
Other (state) (4)

1c. How soon after suffering the injury did you receive diagnosis or treatment for it?

Immediately (1)
Same day (2)
Same week (3)
Same month (4)
Not at all (5)
Later date (state month and year)

1d. Where did you get treatment or diagnosis?

At the school (1)
Physiotherapist (2) School (3) Outside school (4)
Specialist (state) (5)
Self-treated (6)

1e. What was the injury diagnosed as?

State

1f. What causes were ascribed to the injury?

- Overtraining (1)
- Flooring (2)
- Dance shoe (state type) (3)
- Increase of hours of training (4)
- Performance (5)
- Other (state) (6)

1g. How did you respond to the injury ?

- Stop dancing (1)
- Restrict certain dance movements (2)
- Restrict training (3)
- Restrict performance (4)

1h. Has the injury been entirely healed? I

- Yes (1)
- No (2)

1i. If no, then what are its continuing consequences?

- Restricted training (1)
- Restricted performances (2)
- No performances (3)
- Time out to heal (4)
- Usual training (5)

1j. What if any have been the financial or lifestyle implications?

- Financial loss (1)
- Not being chosen to perform (2)
- Neither (3)

1. CURRENT INJURIES

DATE OCCURRED:

State number on body site

- WHERE IN BODY:
- Foot (1)
 - Ankle (2)
 - Lower leg (3)
 - Upper leg (4)
 - Hip (5)
 - Upper body (6)

State injury

1a. When did this injury happen?

- Training (1)

Rehearsals (2)
Performance (3)
Other (4)

1b.How did you recognise that you had been injured?

Difficulty in performing a dance move (1)
Difficulty in dancing (2)
Unable to dance (3)
Other (state) (4)

1c.How soon after suffering the injury did you receive diagnosis or treatment for it?

Immediately (1)
Same day (2)
Same week (3)
Same month (4)
Not at all (5)
Later date (state month and year)

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Physiotherapist (2) School (3) Outside school (4)
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1e.What was the injury diagnosed as?

State

1f.What causes were ascribed to the injury?

Overtraining (1)
Flooring (2)
Dance shoe (state type) (3)
Increase of hours of training (4)
Performance (5)
Other (state) (6)

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- No performances (3)
- Time out to heal (4)
- Usual training (5)

1j. What if any have been the financial or lifestyle implications?

- Financial loss (1)
- Not being chosen to perform (2)
- Neither (3)

2. TRAINING:

2a. How many hours a week do you train?

- 10 hours (1)
- 11-20 hours (2)
- 20-30 hours (3)
- 31-40 hours (4)
- 40 hours plus (5)

2b. How many hours a week do you perform?

(If specific months, state the month (s) 1 -12) Month(s)

Hours for each month:

- 1-5 (1)
- 6-10 (2)
- 11-15 (3)
- 16-20 (4)
- 20 hours plus (5)

2c. If previous injury, how much time have you taken off from training?

- 1st injury Day () Month () Year ()
- 2nd injury Day () Month () Year ()
- 3rd injury Day () Month () Year ()
- 4th injury Day () Month () Year ()

3. FOOTWEAR:

How many pointe or flat shoes (character shoes and flats for males) do you wear through in a month? State shoe type

0-5 (1)
6-10 (2)
11-15 (3)
16-20 (4)
21-25 (5)
26-30 (6)
31 plus (7)

0-5 (1)
6-10 (2)
11-15 (3)
16-20 (4)
21-25 (5)
26-30 (6)
31 plus (7)

Month

0-5 (1)
6-10 (2)
11-15 (3)
16-20 (4)
21-25 (5)
26-30 (6)
31 plus (7)

0-5 (1)
6-10 (2)
11-15 (3)
16-20 (4)
21-25 (5)
26-30 (6)
31 plus (7)

Performance

0-5 (1)
6-10 (2)
11-15 (3)
16-20 (4)
21-25 (5)
26-30 (6)
31 plus (7)

- 0-5 (1)
- 6-10 (2)
- 11-15 (3)
- 16-20 (4)
- 21-25 (5)
- 26-30 (6)
- 31 plus (7)

3. Are certain ballet positions/moves more challenging for you than others?

State:

4. What is your ambition as a student – what level do you want to achieve in your dance career?

- Leisure only (1)
- Performance (2)
- Professional level/career (3)

6. What do you consider to be the overall cause of your injuries. Rate: (0) – Strongly disagree, (1) somewhat agree, (2) Agree (3) Very likely, (4) Strongly agree.

- Overtraining (1) (0) (1) (2) (3) (4)
- Insufficient rest (2) (0) (1) (2) (3) (4)
- Competition (3) (0) (1) (2) (3) (4)
- Tiredness (4) (0) (1) (2) (3) (4)
- Other? Please state

7. What flooring do you use in training?

Hardfloor

Sprung Floor State type if known.

8. what flooring do you use in performance?

Hardfloor

Sprung Floor State type if known.

The Navicular Drop Test

RCSP (Right) (Left)
Corrected (Right) (Left)

FPI

Right Left

The Calcaneal Bisection

Right Left

First Position

Right Left

Fifth Position

Right Left