

RISK FACTORS FOR OVERUSE INJURY IN ELITE ADOLESCENT BALLET DANCERS

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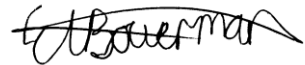
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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

Chapters 3 to 5 of this thesis represent three separate papers that have been submitted to peer-reviewed journals for consideration for publication. My contribution and the contribution by the various co-authors to each of these papers are outlined at the beginning of the thesis. All co-authors have approved the inclusion of the joint work in this Master's thesis.

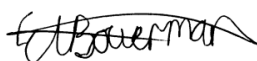
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Erin Bowerman

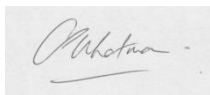
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CANDIDATE CONTRIBUTIONS TO CO-AUTHORED PAPERS

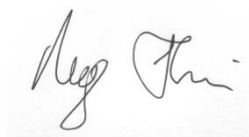
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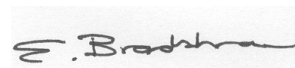
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Dr. Chris
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Dr. Nigel Harris



Dr. Elizabeth Bradshaw

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DEDICATION

For Grandy, my BFG – I wish you could be here to see what your generosity enabled me to do. I thank you for placing such emphasis on education and for always supporting me, and taking an interest in whichever endeavours I pursued. I dedicate this thesis to you.

ETHICAL APPROVAL

Ethical approval for this research was granted by the Auckland University of Technology Ethics Committee (AUTEC) and the Australian Catholic University ethics committee (ACUEC). The AUTEC reference was 12/175, with approval granted originally on 31st of July 2012. Registration of external ethics approval was granted by the ACUEC on the 13 December 2012 with a reference identification of 2012 320V.

ABSTRACT

Injuries are common among young elite ballet dancers, often leading to disruptions in training and in turn the development of talent. Anecdotally, the adolescent period of growth and maturation, and poor lower extremity alignment are thought to increase the risk of injury. Substantial evidence indicates that overuse lower extremity injuries are most common (lumbar spine, pelvis, legs and feet). Little research has been conducted into potential risk factors, and no studies have investigated the use of two-dimensional (2D) video to measure lower extremity alignment in young ballet dancers. The aims of this thesis were to investigate in young elite ballet dancers: 1) the reliability of 2D video assessment of dynamic lower extremity alignment during functional dance movement and 2) the associations between growth, maturation and alignment and lower extremity overuse injury.

A modified knee valgus angle and lateral pelvic tilt were measured during two dance movements (*fondue* and *temps levé*), using 2D video analysis. Reliability of the modified knee valgus angle in both the *fondue* (ICC = 0.88 to 0.89; TE = 3°) and *temps levé* (ICC = 0.80 to 0.87; TE = 6 to 8°) was high. Reliability of the pelvic angle in the *fondue* (ICC = 0.67 to 0.79; TE = 1°) was moderate to high, and moderate in the *temps levé* (ICC = 0.68 to 0.71; TE = 1°). Additionally, there was a significant difference in knee angle between the left and right legs during both the *fondue* ($p = 0.001$) and *temps levé* ($p = 0.001$). Finally, a strong correlation for the knee angle between the two movements on both the left ($r = 0.93$) and right ($r = 0.94$) legs was noted.

As well as knee and pelvic alignment, baseline maturation stage using the Tanner scale, and growth (based on change in foot length) were also recorded in all dancers. Overuse lower extremity dance injuries were diagnosed and recorded by a physiotherapist over a six month period. The injury rate ratio (RR) associated with each baseline variable was estimated using over-dispersed Poisson regression modelling. Changes in right foot length (RR = 1.41, CI = 0.93-2.13), right knee angles during the *fondue* (RR = 0.68, CI = 0.45-1.03) and *temps levé* (RR = 0.72, CI = 0.53-0.98), and pelvic angles during the *temps levé* on the left (RR = 0.52, CI = 0.30-0.90) and *fondue* on the right (RR = 1.28, CI = 0.91-1.80) were associated with clear changes in injury risk.

Simple 2D measures of knee and pelvic alignment during the *fondue* and *temps levé* movements in elite adolescent ballet dancers demonstrate moderate to high reliability. Improved right knee alignment is likely associated with a reduction in risk of right lower extremity overuse injury. Rate of growth is likely associated with an increase in risk of lower extremity overuse injury. Therefore, monitoring of growth and screening lower extremity alignment in elite adolescent dancers may assist with injury prevention.

CHAPTER 1

INTRODUCTION AND RATIONALE

Background

In order to achieve proficiency and reach an elite level of performance in dance, years of dedicated training are required often commencing at a young age. Similar to high performance sport, potential elite ballet dancers are now training for longer periods of time at increasingly young ages before being identified as talented for entrance into long term development programs or full-time training (Kadel, Teitz, & Kronmal, 1992). Despite the many positive attributes of dance, injuries are prevalent, with several studies indicating that injury incidence in the dance population lies between 0.6 and 4.4 injuries per 1000 dance hours (Allen, Nevill, Brooks, Koutedakis, & Wyon, 2012; Gamboa, Roberts, Maring, & Fergus, 2008; Leanderson et al., 2011; Nilsson, Leanderson, Wykman, & Strender, 2001). Injuries lead to disruptions in training and in turn the development of talent, while chronic overuse or severe injuries which occur during a dancer's adolescence can create a flow-on effect. The ongoing nature of some injuries may lead to missed performance opportunities, placing time and monetary costs on companies (Solomon, Micheli, Solomon, & Kelly, 1995), while some injuries may prevent a dancer from pursuing a career altogether.

Similar to many other aesthetic sports such as diving, gymnastics and figure skating, the intensity of dance training often begins to increase just as dancers are entering adolescence (Daniels et al., 2001). An association between increased intensity in training, the onset of puberty and increased injury incidence has been reported in the literature (Daniels et al., 2001; Fournier, Rizzoli, Slosman, Theintz, & Bonjour, 1997; Gamboa et al., 2008; Phillips, 1999a; Steinberg et al., 2011). During the pubertal years the body undergoes significant physical, physiological and psychological change (Robson, 2001), during which time young dancers are placing further demand on the body to hone and perfect technique and artistry. Anecdotally, the adolescent period of growth and maturation, and the onset of menarche are thought to increase injury incidence (Daniels et al., 2001; Gamboa et al., 2008; Phillips, 1999a; Poggini, Losasso, & Iannone, 1999; Steinberg et al., 2011). However, currently no studies have prospectively examined these key risk factors and provided evidence linking these to injury in elite adolescent dancer populations.

A further risk factor associated with lower extremity injury is poor lower extremity alignment (Poggini et al., 1999). In athletes, poor control of the pelvis, hip, knee and foot is considered a movement dysfunction, and it is thought that identifying this may help detect those athletes most at risk for injury (Stensrud, Myklebust, Kristianslund, Bahr, & Krosshaug, 2011; Whatman, Hume, & Hing, 2012). This pattern of lower extremity dynamic alignment is also considered

important in dancers. Assessment of lower extremity alignment is usually performed via visual observation of functional tests with increasing use of two-dimensional (2D) video analysis in athlete and dancer populations (Twitchett, Angioi, Koutedakis, & Wyon, 2009; Whatman et al., 2012). Currently no research has assessed elite ballet dancers for lower extremity alignment during functional dance movement. In particular the reliability of 2D video in the assessment of lower extremity alignment during functional dance movement requires investigation. The reliability of tests must be established if they are to be used in longitudinal studies investigating injury risk and the effects of training and/or rehabilitation in dancers.

Although it is impossible for dancers to completely avoid injury, many injuries may be preventable. Improving our understanding of the incidence and contributing factors to injuries will help the development of tools and strategies to enhance injury prevention. The identification of key injury risk factors in elite adolescent ballet dancers will provide valuable information to practitioners and allow improved management of the young elite dancer. This will also allow future studies to begin developing evidence-based guidelines for suitable workloads for dancers during this period of growth, ultimately leading to safer and more effective training systems for the dance industry.

Questions addressed in this thesis

Given limitations in the literature, the overall question of this thesis was “Do differences exist between injured and uninjured classical Australian Ballet School dancers in key risk factors including maturation, growth and lower extremity alignment?”

Specific questions were:

- I. Are maturation, growth and lower extremity alignment associated with overuse injury in elite adolescent ballet dancers?
- II. Are 2D lower extremity alignment measures reliable with elite adolescent ballet dancers?

Structure of the thesis

This thesis consists of six chapters that culminate in an overall discussion. Some of the study chapters have been submitted for publication in journals and each chapter is presented in the wording of the journal for which they were written. Consequently, there is some repetition in the introduction and methods between the review and experimental chapters. References are not included at the end of each chapter, rather as required by AUT University for thesis submission an overall reference list from the entire thesis has been collated at the end of the final chapter. Due to journal word limitations the literature review is separated into two chapters with one chapter submitted for potential publication. For the purpose of the thesis the term lower extremity is used to refer to the lumbar spine, pelvis, legs and feet.

Chapter 2 reviews the literature for the most common lower extremity overuse injuries and incidences among young elite ballet dancers. Chapter 3 reviews the evidence for risk factors for overuse lower extremity injury in young elite dancers. Several key risk factors are reviewed including growth and maturation, onset of menarche and lower extremity alignment. The evidence supporting these factors as increasing injury risk was minimal. Although the adolescent growth spurt and the period of maturation which follows are anecdotally considered to be associated with increased injury incidences among ballet dancers, a lack of prospective studies on young elite dancers make classifying cause and effect difficult. This chapter has been submitted for potential publication in the *Strength and Conditioning Journal*.

Chapter 4 examines the reliability of 2D video in the measurement of lower extremity alignment during functional dance movement. It was established that the reliability of 2D knee and pelvic angles during two dance movements in elite adolescent ballet dancers is moderate to high. Knee angles between the two movements are strongly associated and there is very likely to be a difference in knee angle between legs. This simple screening technique may be useful to dance practitioners and in longitudinal studies examining injury risk. This chapter has been submitted for potential publication in the *International Journal of Sports Medicine*.

Chapter 5 is a prospective study following injury in elite adolescent dancers over six months, while also assessing the association between key risk factors and injury. Key risk factors examined included maturation, onset of menarche, growth and lower extremity alignment. The incidence of injury was found to be 3.52 injuries per 1000 dance exposures and 2.40 injuries per 1000 dance hours. Findings indicate that rate of growth in elite adolescent ballet dancers is likely associated with a small to moderate increase in risk of lower extremity overuse injury. Furthermore, it was observed that improved right knee alignment is likely associated with a reduction in risk of right lower extremity overuse injury. This suggests that the monitoring of growth and screening of lower extremity alignment may be useful as injury prevention strategies in adolescent ballet dancers. This chapter has been submitted for potential publication in the journal of *Physical Therapy in Sport*.

Chapter 6 is an overall discussion of key findings of the thesis. It culminates with comments on implications and limitations of the previous chapters, areas for further research, and finally, with concluding statements on the key findings from the thesis.

CHAPTER 2

THE INCIDENCE OF LOWER EXTREMITY OVERUSE INJURIES IN YOUNG ELITE BALLET DANCERS: A REVIEW OF THE LITERATURE

Introduction

The risk of injury in classical ballet is considered similar to other non-combative sports, yet reported injury incidences among the dance population are higher than comparative activities (Leanderson et al., 2011; Poggini et al., 1999). Increased incidence of injury is reported in adolescent dance populations with the majority of these injuries classified as overuse (Gamboa et al., 2008; Garrick, 1999; Leanderson et al., 2011). However there is limited research examining injury incidence among adolescent ballet dancers at an elite level.

This review examines the available evidence for lower extremity overuse injury incidence in young elite ballet dancers while also assessing the literature for the most commonly reported injuries and locations. For the purposes of this review the term lower extremity has been used to refer to the lower quarter of the body including the lumbar spine, pelvis, legs and feet.

Methods

Literature search

An electronic search was conducted of the SportsDiscus, ProQuest Direct, and Google Scholar databases for articles from 1969 to July 2013 using keywords dancers, ballet, athletes, adolescent, adolescence, young, injury, injuries, overuse, lower limb, lower extremity, lower extremities and alignment. These keywords were used separately and in combination. Reference lists of all retrieved articles were manually checked for additional studies. Exclusion criteria included: (1) unavailable in English and in full text; (2) article was not in a peer reviewed journal or full conference proceeding; and (3) current concept papers.

Eleven published studies were retained for review after applying the exclusion criteria. Only five of these studies focused specifically on young elite ballet dancers. Due to the small number of studies in this age, group studies of young non-elite ballet dancers, professional ballet dancers and dancers of other genres such as contemporary were also included (a further six studies).

All 11 studies evaluated injury incidence in the dance population; five reporting on young elite ballet dancers; five on ballet dancers in professional companies; and one on young non-elite dancers of a variety of genres. Of the 11 studies reviewed, four were conducted with female participants only (one focused on age at onset of menarche and menstrual history). Six studies

included both genders and the remaining study did not specify the genders included. No studies were conducted on male-only samples.

Findings

The epidemiology of injuries in ballet is not well understood (Allen et al., 2012). Although there have been a large number of studies published looking at injury site and incidence, the lack of a standardised injury reporting system (Gamboa et al., 2008; Liederbach & Richardson, 2007), methodological differences, and other inconsistencies make comparisons across studies challenging (Allen et al., 2012).

Injury reporting

The main confounding factor in drawing comparisons between injury studies on dancers is the definition of injury. According to Liederbach & Richardson (2007) an injury surveillance system should capture information about how many injuries happened over a certain time period, to whom they occurred, when, where and with what outcome, as well as provide information about how and why injuries happened. It should further define an injury according to function or time lost. Discrepancies in injury definition were observed across the literature (Allen et al., 2012; Askling, Lund, Saartok, & Thorstensson, 2002; Ekegren, Quested, & Brodrick, 2011; Gamboa et al., 2008; Krasnow, Mainwaring, & Kerr, 1999), with several studies simply not defining injury at all (Bowling, 1989; Garrick, 1999; Steinberg et al., 2011), while others defined only the differences between injury type but did not provide a definition of an injury in and of itself (Leanderson et al., 2011; Nilsson et al., 2001).

Additionally it is common to define injury as occurring when the dancer seeks medical attention. Several authors (Ekegren et al., 2011; Gamboa et al., 2008; Leanderson et al., 2011) classified and recorded injuries only for which medical attention had been sought. Interestingly each definition specified a different type of care including orthopaedic, medical, and physical therapist interventions (Table 1). Sporting disciplines have also used the need for medical attention as part of injury definition. In a report outlining the International Olympic Committee approach to injury surveillance, injury was defined as “any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training” (Junge et al., 2008, p. 414). This definition is flexible in its ability to capture the majority of injuries, given most aspects of the definition can be adjusted, such as whether all injuries receive medical care, the inclusion of only new injuries, the time at which injuries occurred (training or performance), injuries occurring during the period of the tournament and the exclusion of illness and disease. Such a definition allows for a broad but detailed injury surveillance system and one which would be easily transferable to dance.

Adaptations of sporting definitions of injury are beginning to occur in dance literature and likely offer the most comprehensive definition of dance injury. Injury definitions from a combination of rugby, soccer and tennis were adapted for a study of injuries in a full-time professional English

ballet company focusing on a time loss definition (Table 1) (Allen et al., 2012). Some authors have however noted the limitations of focusing on time loss. Leiderbach & Richardson (2007) stated that non time-lost injuries can be more common than time lost injuries in dance so a definition by function lost may be a useful alternative. Furthermore, time lost to injuries can be difficult or impossible to quantify in dance due to dancers rarely refraining totally from practice or performance (Gamboa et al., 2008; Krasnow et al., 1999). However, Allen et al. (2012) stated the time loss injury definition makes it easier to objectively identify and report injuries that directly impact the dancers' ability to perform dance-related activities. International consensus within sports and the National Collegiate Athletic Association Injury Surveillance system have determined that a time-loss definition should be utilised in injury epidemiology studies.

Another important confounding factor in comparing injury studies on dancers is the lack of uniform standards for quantifying the number of injuries and the lack of standard methodology for expressing workload exposure (Gamboa et al., 2008). Injuries are either reported per 1000 hours of dance or per 1000 exposures of dance (i.e. one class, one rehearsal or one performance). Dance injuries are most commonly reported per 1000 hours of dance. Four studies reported dance injuries per 1000 hours of dance (Allen et al., 2012; Leanderson et al., 2011; Nilsson et al., 2001; Steinberg et al., 2011) in comparison to only two studies which reported injuries per 1000 dance exposures (Ekegren et al., 2011; Liederbach, Dilgen, & Rose, 2008). Only one study reported injury incidence using both methods (Gamboa et al., 2008), while two studies used neither method and simply reported total number of injuries over a given time period (Garrick, 1999; Krasnow et al., 1999). Although in the sports medicine context workload is most often considered by reporting injury rates per 1000 hours of athletic exposures such as one practice or one game, these exposures are not normalised for time spent actively participating in each event. This is problematic among dancers given that dance is considered a high intensity intermittent activity (Twitchett, Koutedakis, & Wyon, 2009), in which dancers can spend large periods of time at rest during class, rehearsal and performance. This may explain the preference for reporting dance injuries per 1000 hours instead of per 1000 dance exposures, given that dance exposures simply measure the number of 'events' a dancer takes part in during a given period (Gamboa et al., 2008).

Injury incidence

Anatomical structures are subjected to repetitive loading during sport participation, ultimately incurring microtrauma (DiFiori, 2010). Overuse injuries arise without a single identifiable event but instead from the inability of the loaded structure (e.g. bone, muscle) to adapt to the imposed stresses of this repetitive microtrauma (Allen et al., 2012; Macintyre & Joy, 2000). Within both classical and modern dance populations, 40% to 50% of injuries are classified as overuse (Allen et al., 2012; Gamboa et al., 2008; Geeves, 1997; Krasnow et al., 1999; Leanderson et al., 2011; Macintyre & Joy, 2000; Nilsson et al., 2001; Poggini et al., 1999; Steinberg et al., 2011).

Injury incidence within the dance population has been reported between 40% and 80% depending on the level of participation (Macintyre & Joy, 2000). However there is still some discrepancy in injury incidence between different populations. While Gamboa et al. (2008) and

Leanderson et al. (2011) report injury incidence for young female and male pre-professional ballet dancers at 0.77 and 0.80 injuries per 1000 dance hours respectively, Steinberg et al. (2011) found the injury incidence to be higher among this population at 1.25 injuries per 1000 dance hours. There are a number of possible reasons for this discrepancy. Firstly the dancers in the study conducted by Steinberg et al. (2011) were considered non-professional and therefore had not been selected to attend full time training, thus conceivably were somewhat physically distinctive from their professional counterparts. While the studies by Gamboa et al. (2008) and Leanderson et al. (2011) were conducted prospectively over periods of five and seven years respectively, the study by Nilsson et al. (2001) was carried out retrospectively over 15 years, thus there is the possibility for error in recalling injuries. It was further reported that young pre-professional ballet students exhibited a similar incidence of injury (1.9 per 1000 dance exposures) in comparison with other young athletic populations, although it is unclear as to who the comparative athletic populations were (Ekegren et al., 2011).

There is also discrepancy in injury incidence reporting in professional dancer populations. Prospectively studying a professional ballet company over one year, Allen et al. (2012) found an injury incidence of 4.4 injuries per 1000 dance hours in both male and female professional ballet dancers. Injuries were reported by one of three full-time, in-house physiotherapists on a standardised injury assessment form. In contrast, a professional Swedish Ballet company reported an injury rate of only 0.6 injuries per 1000 dance hours (Nilsson et al., 2001). The only injury definition provided by Nilsson et al. (2001) stipulated that only injuries for which the dancers had sought orthopaedic consultation were to be included in the data collection. No time lost or function lost definitions were provided, thus making it difficult to compare findings with the study carried out by Allen et al. (2012). Furthermore, the study by Nilsson et al. (2001) was larger, combining retrospective and prospective injury data for 98 dancers, conducted over five years. In contrast, the study by Allen et al. (2012) was carried out with only 52 dancers over a 12 month period. Given that the study carried out by Nilsson et al. (2001) was both retrospective and prospective, there is a possibility for error in the recall of injuries over the five year period.

Given the differences in injury definition, method of reporting, and population size and demographics between studies, the exact rate of injury for ballet dancers remains unclear. Evidence from the most well designed studies suggests it ranges from 1.09 to 1.9 injuries per 1000 exposures in elite, pre-professional ballet dancers, although true injury rates are likely higher as it has recently been acknowledged current methods fail to adequately report overuse injuries (Clarsen, Myklebust, & Bahr, 2012). The rate of injury is higher than in other activities that involve a similar training load (e.g. figure skating and gymnastics incidence = 1.4 injuries per 1000 hours; (Kiriakou et al., 2002; Kjaer & Larsson, 1990) and thus injury in dance is of significant concern.

Table 1. Studies reporting overuse injury incidence in dance populations

Study	Type of Study	Number, gender and age of participants	Dancer Participation	Injury Definition	Injury Incidence Proportion	Injury Incidence per 1000 hrs/per 1000 exposures	Injury Site
Bowling ⁽¹⁹⁸⁹⁾	Retrospective, cross-sectional	N=141, 80F, 61M 53% 18-25Y 33% 27-36Y 14% 37Y	Professional ballet & modern dancers	Not reported	47% of dancers with chronic injury (chronic injury not otherwise defined)	Not reported	Dancers with Chronic Injuries Back/neck 29% Hip/groin/ribs 6% Thigh/leg 16% Knee 17% Ankle 20% Foot/toes 6% Should/wrist/hand 6%
Garrick ⁽¹⁹⁹⁹⁾	Prospective, cross-sectional (20 months)	54F (13-18Y)	Non-elite ballet dancers	Not reported	Not reported	Not reported	53.6% Overuse Injuries Lumbar spine 4.6% Hip 8.2% Thigh 2.6% Knee 16.5% Leg 14.4% Ankle 15.5% Foot/toes 33% Other 5.1%
Krasnow et al. ⁽¹⁹⁹⁹⁾	Retrospective, cross-sectional	65F (15.5 ± 0.5Y) 30 artistic gymnasts 19 modern dancers 16 ballet dancers	Non-elite gymnasts, modern and ballet dancers	Pain during one class, rehearsal or performance that caused: <ul style="list-style-type: none"> • Cessation of activity • A need to modify activity • -Ve effects on training or performances • Sufficient distraction/distress to interfere with concentration 	Gymnasts: 100% ≥ 1 injury Modern: 79% ≥ 1 injury Ballet: 94% ≥ 1 injury	Not reported	Overuse Injuries Not Specified Ballet /Modern/ Gym Cervical/Thoracic 5%/8%/0 Lumbar Spine 12%/21%/18% Hips 30%/10%/17% Knee 22%/24%/5% Ankle/Foot 27%/26%/31% Wrist 0/0/19% Other 4%/11%/10%

Table 1 cont. Studies reporting overuse injury incidence in dance populations

Study	Type of Study	Number, gender and age of participants	Dancer Participation	Injury Definition	Injury Incidence Proportion	Injury Incidence per 1000 hrs/per 1000 exposures	Injury Site
Nilsson et al. (2001)	Retro- and prospective, longitudinal (5Y)	N=98, 43-48F, 29-34M (28.3Y)	Professional ballet dancers	Injuries were classified as either traumatic, i.e. dancer could define a specific sudden onset of pain with defined trauma, or as due to overuse	390 injuries to 98 dancers	0.6/not reported	57% Overuse Injuries F/M/Total Lower back/gluteal region 16.8%/19.2%/17.9% Thigh/groin 3.4%/4.4%/3.8% Knee 5.8%/18.7%/11% Lower leg 4.3%/1.1%/2.8% Ankle/foot 62%/46.2%/54% Upper extremity 4.8%/9.9%/7.2% Miscellaneous 2.9%/0.5%/1.9%
Gamboa et al. (2008)	Retrospective, descriptive cohort (5Y)	N=204, gender not specified (9-20Y)	Elite, pre-professional ballet dancers	At least 1 treatment session sought from a physical therapist	198 injuries in 151 dancers	0.77/1.09	75% Overuse Injuries Back 10% Hip 25% Knee 15% Foot/ankle 55%
Ekegren et al. (2011)	Prospective cohort (1Y)	N=266, 159F, 107M (15-19Y)	Elite, pre-professional ballet dancers	Needing medical attention and time lost from dance for more than 1 day	76% of dancers injured	Not reported/1.9	Not reported

Table 1 cont. Studies reporting overuse injury incidence in dance populations

Study	Type of Study	Number, gender and age of participants	Dancer Participation	Injury Definition	Injury Incidence Proportion	Injury Incidence per 1000 hrs/per 1000 exposures	Injury Site
Leanderson et al. ⁽²⁰¹¹⁾	Retrospective, longitudinal (5Y)	N=476, 297F, 179M (10-21Y)	Elite, pre-professional ballet dancers	Injuries were classified as traumatic in cases in which the dancer's pain arose as the result of a defined trauma. All other injuries were deemed to be caused by overuse.	44% of dancers injured	0.8/not reported	77% Overuse injuries Back 82% Thigh/hip 93% Knee 90% Foot/lower leg 70% Upper ext/misc. 29%
Steinberg et al. ⁽²⁰¹¹⁾	Cross-sectional, longitudinal (15Y)	1336F (8-16Y, Average 13.3Y)	Non-elite dancers (ballet, modern, jazz)	Not reported	43% of dancers injured	1.05 8Y 1.25 14Y/not reported	8-9Y/10-11Y/12-13Y/14-16Y Back 28.3%/15%/12.5%/18.9% Knee 10.9%/20.9%/35.6%/33.7% Ankle and foot 41.3%/25.2%/21.8%/23.1%
Allen et al. ⁽²⁰¹²⁾	Prospective, descriptive, single-cohort (1Y)	N=52, 27F (25 ± 6Y), 25M (23 ± 5Y)	Professional ballet dancers	<ul style="list-style-type: none"> Time loss definition preventing all dance activities for ≥24 hours Injury severity defined by number of days to return to full fitness Full fitness defined as the ability to take full part in the dance activities 	355 injuries in 52 dancers	4.4/not reported	66% Overuse Injuries F/M (Incidence per 1000h) Head and neck 0.55/0.45 Thoracic spine and rib 0.3/0.5 Lumbar spine 0.65/0.55 Pelvis and hip 0.3/0.2 Upper leg 0.35/0.38 Knee 0.2/0.45 Lower leg 0.7/0.9 Ankle 0.6/0.62 Foot 0.4/0.35 Shoulder 0.05/0.3 Arm and hand 0.05/0.0

Abbreviations: N=number of participants, F=female, M=male, Y=years, h=hour

Common lower extremity overuse injuries

Although the incidence of injury in dancers is unclear, the literature does highlight the most common injuries that occur in the dance population. Overuse injuries are the most commonly reported and will be the focus of this section. The injuries will be identified in order of prevalence as determined from the available literature.

The majority of overuse injuries in dancers occur in the lower extremities, with 50 to 70% of injuries occurring to the foot and ankle (Ahonen, 2008; Bowling, 1989; Conti & Wong, 2001; Gamboa et al., 2008; Garrick, 1999; Krasnow et al., 1999; Leanderson et al., 2011; Macintyre & Joy, 2000; Nilsson et al., 2001; Reid, Burnham, Saboe, & Kushner, 1987; Somogyi, 2001; Steinberg et al., 2011). The most common injuries in dance attributable to excessive loading are stress fractures. In both professional and young elite populations these most often occur in the metatarsals, but have also been found in the sesamoids, navicular, tibia and fibula (Allen et al., 2012; Conti & Wong, 2001; Poggini et al., 1999). Twenty-seven stress fractures were reported among 75 professional ballet dancers, with 26 of those 27 fractures occurring in the metatarsals (Warren, Brooks-Gunn, Hamilton, Warren, & Hamilton, 1986). The highest percentage of time lost due to injury in a professional ballet company was due to stress fractures of the tibia and metatarsals (Allen et al., 2012). While several studies agree that the foot and ankle are the most frequently injured sites in young elite ballet dancers (Gamboa et al., 2008; Garrick, 1999; Leanderson et al., 2011), no studies report the type of injury, such as stress fractures, which make up these overall figures.

The lumbar spine (frequently considered part of the lower extremity kinetic chain) is also an area at high risk for injury among classical ballet dancers (Alderson, Hopper, Elliott, & Ackland, 2009). Forty percent of all injuries sustained were reported as back injuries in 701 pre-professional dancers (Geeves, 1997), while 34% of all injuries sustained among professional dancers were also classified as back injuries (Geeves, 1990). Survey respondents were trained in a mixture of both classical ballet and modern styles but the level of the spinal injury was not specified.

Stress fractures of the lumbar spine are prevalent among the ballet population, perhaps not surprising given that activities involving repetitive lumbar hyperextension, axial loading, jumping and twisting carry a higher risk for lower back injuries (Dunn, Proctor, & Day, 2006). There is some discrepancy in the literature as to whether male or female dancers exhibit a higher injury incidence in the lumbar spine. A higher incidence of lumbar spine injuries was reported among the male ballet dancer population due to their lifting requirements (Alderson et al., 2009), a finding supported by Nilsson et al. (2001) in their study surveying injury incidence in a professional Swedish ballet company. Over a five year period 19.2% of males were diagnosed and treated for a variety of lower back injuries in contrast to only 16.8% of the female dancers. Conversely, a higher incidence of back injuries among female dancers was reported by Allen et al. (2012) with a total of 26 lower back injuries among females and only 21 lower back injuries among male dancers over a 12 month period. Regardless, these incidences appear high in comparison to lumbar spine injuries in team sport athletes. In a study of nearly 4800 college

athletes of different sporting codes, the incidence of a range of lumbar spine injuries was only 7% (Dunn et al., 2006). The lumbar spine injury rates for dancers have been reported within professional populations whose spines are arguably under much higher loads, given that one full press lift of a female dancer by a professional male dancer has been reported to exceed the National Institute of Occupational Safety and Health, Back Compression Design limit (3400N) (Alderson et al., 2009). Gymnasts are the only similar population to present with lumbar spine injury incidences higher than those observed with dancers, reported to be between 25% and 85% depending on the populations and definitions of injury used (Harringe, Nordgren, Arvidsson, & Werner, 2007; Kruse & Lemmen, 2009).

Incidences of lumbar spine or back injuries amongst the young dancer population appear slightly less than those found in the professional ballet population with numbers ranging from 4.6% to 12% (Gamboa et al., 2008; Garrick, 1999; Krasnow et al., 1999; Leanderson et al., 2011). Only two of five studies involving adolescents, specified lumbar spine in their injury classification with others citing only 'back injuries'. This makes it difficult to determine the contribution of injuries of different types or from different levels of the spine to the overall number reported. Only one study conducted with professional dancers classified injury incidence by specific site (Allen et al., 2012), while none of the research carried out on young dancers specified the type of back injury.

The hip is considered the most stressed joint in the dancer's body (Poggini et al., 1999), although it is not the most commonly injured site, presumably because it is anatomically well designed to take load. There is little information in the literature regarding hip injuries in adolescent dancers. The most commonly observed hip injuries in professional dancers include snapping hip syndrome, labral tears, stress fractures of the femoral neck and rectus femoris tendinitis (Bronner & Ojofeitimi, 2008; Stone, 2001). Injury incidence to the hip in professional dancers is reported as between 7% and 11% (Liederbach, 2000) with limited research indicating slightly higher incidences in young elite ballet dancers of 8% to 22% (Gamboa et al., 2008; Garrick, 1999; Leanderson et al., 2011). Higher rates (30%) for non elite dancers have been reported (Krasnow et al., 1999).

Tendonopathy is also a common injury reported among ballet dancers, and it has been stated that the majority of professional dancers will present with symptoms of Achilles tendonopathy during their career (Somogyi, 2001). An incidence of 18% for ankle and foot tendonopathy was reported in a population of 1336 dancers aged eight to 16 years (Steinberg et al., 2011). Tendonopathy is not only found in the Achilles but also various other sites around the foot including the peroneals and the flexor hallucis longus tendon (Poggini et al., 1999).

Elite pre-professional ballet dancers exhibit injury incidences for the knee of 16% to 17% (Gamboa et al., 2008; Garrick, 1999; Leanderson et al., 2011) with reports of slightly higher incidences for young non-elite dancers of 22% to 25% (Krasnow et al., 1999; Steinberg et al., 2011). The small amount of available literature suggests that both young elite and professional dancers present with a higher incidence of knee injuries than their athletic counterparts although

true incidences are difficult to gauge due to differences in populations and injury definitions. Approximately 15% of overuse injuries were knee injuries in elite female figure skaters aged between 13 and 20 years (Dubravcic-Simunjak, Pecina, Kuipers, Moran, & Haspl, 2003), while 14% of overuse injuries were prospectively observed to be knee injuries in male and female senior level basketball players (average age 23 years) during one season (Elke, Evert, & Romain, 2007). Only traumatic knee injuries were specified in Allen et al's (2012) overview of injuries in a ballet company. However Poggini et al. (1999) described the majority of knee injuries for adolescent dancers as falling into the category of patellar tendon disorders including Osgood-Schlatter disease, in which an osteochondritis of the epiphysis of the tibial tubercle occurs, typically in males during the adolescent growth spurt.

A number of limitations in the literature confound our ability to draw conclusions from studies in regard to injury sites and rates. Injury classification is important given that injury groupings are often combined without specifying the contribution from different body sites or injury types to the overall reported number. This is likely due to small sample sizes. Furthermore, discrepancies exist between the populations measured, with research citing a combination of young dancers and adults, elite and non-elite dancers, males and females from a combination of full time companies and schools or amateur private academies. Uneven sample sizes between comparative populations such as figure skaters and gymnasts are also cited, while some studies simply do not report basic information including age, gender and level of the dancers involved in the study. Finally, the age (up to 30 years) of a large proportion of the literature commenting on injury sites and incidences among dancers potentially limits the relevance of the information. This highlights a need for further quality research to be undertaken in this area given the paucity of information in the adolescent dance population in regard to injury incidence for specific overuse lower extremity injuries.

Conclusion

Overuse injuries in dance account for up to half of all injuries sustained, with injury incidence in dancers observed to be higher than those reported in sporting disciplines of similar training loads. The foot and ankle are the most commonly reported site of injury among dancers followed closely by the lumbar spine. Currently there is a paucity of information in regard to the key types of injuries reported at these sites. Finally it is clear from the literature that the lack of standardised injury definitions as well as a lack of standardisation in regard to the quantification and reporting of overuse injuries in dancers makes drawing comparisons between injury studies challenging.

CHAPTER 3

A REVIEW OF THE RISK FACTORS FOR LOWER EXTREMITY OVERUSE INJURIES IN YOUNG ELITE BALLET DANCERS

Overview

This review outlines the evidence for risk factors for lower extremity overuse injuries in young elite ballet dancers. Lower extremity overuse injuries in young elite ballet dancers have a reportedly high incidence. Maturation and the adolescent growth spurt occur just as the intensity of training increases for young dancers, and this, alongside poor lower extremity alignment is thought to contribute to an increased risk of injury. Strong evidence from well-designed studies indicates that young elite female ballet dancers suffer from delayed onset of growth, maturation, menarche, and menstrual irregularities. There is little evidence this increases the risk of overuse injury and likewise minimal evidence linking poor lower extremity alignment to increased injury risk. There is evidence that menstrual irregularities are linked with an increased risk of stress fractures in elite ballet dancers. Substantial evidence suggests that moderately intensive training has no impact on growth and maturation in young elite ballet dancers. Future prospective, longitudinal studies should focus on identifying the relationship between growth, late onset of maturation, menarche and lower extremity alignment on injury risk, specifically in young, elite male and female ballet dancers.

Introduction

Dance populations suffer a high incidence of lower extremity overuse injuries, particularly adolescent ballet dancers (Ekegren et al., 2011; Gamboa et al., 2008; Garrick, 1999; Leanderson et al., 2011; Poggini et al., 1999; Steinberg et al., 2011). Several potential risk factors for overuse injuries in the adolescent population have been identified including growth and maturation, the onset of menarche, and lower extremity alignment. As the adolescent growth spurt often occurs just as the intensity of training increases for young dancers, this short period of growth and maturation may amplify the risk for injuries (Daniels et al., 2001; Poggini et al., 1999). Young elite female dancers frequently exhibit delayed onset of maturation and menarche as well as menstrual irregularities (Brooks-Gunn, Burrow, & Warren, 1988; Kadel, Donaldson-Fletcher, Gerberg, & Micheli, 2005; Kadel et al., 1992; Matthews et al., 2006; Warren et al., 1986), and this may increase the risk of injury. Finally, as the majority of dance injuries occur in the ankle and foot (Conti & Wong, 2001), faulty lower extremity alignment is often proposed as an injury risk factor.

The purpose of this review was to examine the evidence for potential risk factors for lower extremity overuse injuries in young elite ballet dancers. Greater understanding of the risks associated with the most frequently reported injuries in this group will enhance our ability to provide evidence-based injury prevention. For the purposes of this review the term lower extremity has been used to refer to the lower half of the body including the lumbar spine, pelvis, legs and feet.

Methods

Literature search

An electronic search was conducted of the SportsDiscus, ProQuest Direct, and Google Scholar databases for articles from 1969 to July 2013 using keywords dancers, ballet dancers, athletes, adolescent, adolescence, young, injury, injuries, risk, overuse, lower limb, lower extremity, lower extremities, growth, maturation, menarche, alignment and biomechanics. These keywords were used separately and in combination. Reference lists of all retrieved articles were manually checked for additional studies. Exclusion criteria included: (1) unavailable in English and in full text; (2) article was not in a peer reviewed journal or full conference proceeding; and (3) current concept papers. Due to the small number of studies focused specifically on young elite ballet dancers, studies of young non-elite dancers and professional ballet dancers were also included. Thirteen published studies (two prospective) were retained for review after applying the exclusion criteria. Only five of these studies focused specifically on young elite ballet dancers, while four studies recruited young non-elite dancers of multiple genres, and the remaining four studies utilised professional ballet dancers. Nine of the 13 studies evaluated growth, maturation and onset of menarche in dancers (four included young elite ballet dancers, two young non-elite dancers and three adult professional dancers). The other four studies investigated lower extremity alignment in relation to injury incidence in dance populations. Two studies retrospectively examined the effect of turnout practices on lower extremity injury incidence in young elite and young non-elite ballet dancers. Another compared single leg landing biomechanics between male and female professional dancers of both ballet and contemporary genres while the final study investigated hip muscle strength in young novice female ballet dancers. Of the thirteen studies reviewed, eleven were conducted with female participants only.

Findings

Growth and maturation

There is currently little evidence-based research to support the theory that limiting load for young elite dancers reduces injury risk during the period of rapid growth. It has been suggested that high-impact and high risk components of class such as jumps, *pointe* work in the centre on one leg, challenging lifts, and movements that stress the knees such as *grand pliés* should be limited during periods of increased growth velocity (Daniels et al., 2001).

Growth refers to the increase in the size of the body both as a whole and of its parts, while maturation refers to progress towards the biologically mature state. Timing and tempo must both be considered with maturation given that various biological systems mature at different rates (Baxter-Jones & Maffulli, 2002). The adolescent growth spurt typically occurs between 11 to 14 years of age for both males and females within the general population, and takes on average, approximately three years from beginning to completion (Burckhardt, Wynn, Krieg, Bagutti, & Faouzi, 2011; Daniels et al., 2001; Krasnow et al., 1999; Marshall & Tanner, 1969; Phillips, 1999a; Stacey, 1999). During this time individuals will demonstrate substantial increases in height, increased body mass and increased arm and leg lengths (Daniels et al., 2001). Growth during adolescence is primarily measured by assessing changes in standing height. However, due to increased variability with this measure (Voss & Bailey, 1994; Voss, Bailey, Cumming, Wilkin, & Betts, 1990; Voss, Wilkin, Bailey, & Betts, 1991) change in foot length can also be used (Aml, Peker, Turgut, & Ulukent, 1997). During puberty an asynchrony between the rate of growth in stature and bone mass accumulation occurs (Burckhardt et al., 2011; Fournier et al., 1997). This lag in bone mineral mass accrual results in a transient state of low bone mass in adolescents and ultimately a decrease in the bone's resistance to mechanical stress. This temporary delay in bone maturation can last three to four years and is characterised by an increased risk of stress fractures, a problem present in young male and female ballet dancers (Burckhardt et al., 2011; Kadel et al., 1992; Warren et al., 1986). It is suggested that the incidence of fractures peaks at ages 12 and 14 years in females and males respectively (Fournier et al., 1997). Thus, monitoring the intensity and volume of training of young dancers is considered important, as overuse injuries present the greatest risk when a skeletally immature dancer is exposed to high training loads, especially during periods of rapid growth.

The literature agrees that the observed delay in growth and maturation is due to the selection of genetically late maturing individuals within specific sports, as opposed to resulting from specific training effects. Girls who mature later often self-select sports that require high relative strength and small stature, such as gymnastics, given that the late maturing, premenarcheal body type favours athletic success in this type of activity (Klentrrou & Plyley, 2003). It was reported that moderate to high amounts (up to 16 hours per week) of dance training does not affect growth across puberty (Matthews et al., 2006). Sixteen hours per week would be considered toward the low end of the elite training spectrum, given that most young dancers in full time training devote between 17 and 23 hours per week to training (Clarkson, Freedson, Skrinar, Keller, & Carney, 1989; Gamboa et al., 2008). Furthermore, the participants in Matthews' et al. (2006) study were classified as novice when the three year study began, thus the generalisation of their findings to an elite population is questionable. Growth has also been found to be independent of training activity. No significant differences in height were reported between 1482 non-elite female dancers and age-matched controls aged eight to 16 years (Steinberg et al., 2008). It should be noted that the control group was more than six times smaller than the dancer population in this study, potentially weakening the strength of the findings. Further, the non-elite nature of the participants again makes it difficult to generalise the findings to elite populations. While it has been observed that ballet dancers tend to have shortened statures during childhood and early

adolescence, they catch up with non-dancers in late adolescence, suggesting any delayed growth is transient (Damsgaard, Bencke, Matthiesen, Petersen, & Muller, 2000; Steinberg et al., 2008). The reported findings by both Matthews et al. (2006) and Steinberg et al. (2008) are supported in a review of the literature of the effect of intensive training on growth and maturation in artistic gymnasts (Malina et al., 2013). The review concluded that while secondary sex characteristics and age of peak height velocity indicated later maturation, despite intensive training, the gymnasts demonstrated growth and maturation patterns similar to individuals who were not athletes. Furthermore a normal range of variability in maturity status was observed in the gymnasts comparative with the general population (Malina et al., 2013). In contrast one study did report that in an elite group of 97 young female ballet dancers between the ages of nine and 15, 16% demonstrated a decrease in growth velocity during the prepuberty stage soon after beginning moderately intensive dance training (Pigeon, Oliver, Charlet, & Rochiccioli, 1997). It is unclear however as to what is considered 'moderately intensive' as no information was provided on the numbers of hours per week the dancers were in training. Furthermore it is difficult to know whether the decrease in growth velocity was caused specifically by the intensity of dance training or alternative extrinsic or intrinsic factors such as diet and genetics.

Maturation, or the development of secondary sexual characteristics, also occurs during the growth spurt. According to Phillips (1999b) it is not uncommon to observe a class of young dancers of the same chronological age who span the continuum between pre-pubescent child and mature adult. Currently there is no research examining the relationship between maturational age and injury occurrence at different stages of growth. The majority of research simply reports that it is during the pubertal years or the adolescent growth spurt that injuries begin to be reported more consistently among dancers (Fournier et al., 1997; Gamboa et al., 2008; Phillips, 1999b; Steinberg et al., 2011). In a study of 1336, non-elite female dancers, the prevalence of injury increased with age as well as with a corresponding increase in dance exposure (Steinberg et al., 2011). This represents a problem found in a number of studies with adolescent dancers, in that students are increasing the intensity of dance training just as the adolescent growth spurt is beginning (Daniels et al., 2001). It is then difficult to ascertain whether the reported increased injury incidence is due to age and/or growth, or is a result of increased hours spent in dance training, or a combination of all three. Steinberg et al., (2011) stated that the increase in injuries observed in the older dancers was due to an increased rate of bone growth in comparison to the ligaments and tendons, thereby exposing the soft tissue to a higher risk of injury. However there was no clear evidence for this being the cause of injury in the study as opposed to increased exposure. It has also been suggested that the increase in injury incidence often observed among young dancers can be attributed to the 'relearning' period in which previously learned technique must be reprogrammed due to new biomechanical challenges such as a decrease in strength and flexibility (Phillips, 1999a). The body grows first in size and then in strength, and while muscle size is a significant contributor to increases in strength, strength differences in adolescents may be due to neurological maturation and the ability to activate a greater number of motor units within a muscle (Phillips, 1999a). It is thought the decrease in flexibility is due to the muscles not lengthening as fast as the bones (Daniels et

al., 2001). To date, no prospective well designed studies have identified decreased strength or flexibility as increased risks for injury in adolescent dancers. Furthermore children of the same chronological age exhibit considerable variation in the timing and tempo of growth (Matthews et al., 2006), therefore chronological age is not necessarily an accurate indicator of the level of risk for a young dancer exposed to high levels of training. This variation in the relationship between age, growth and maturation creates challenges related to training, particularly when managing talented dancers during peak growth years (Helsen, Van Winckel, & Williams, 2005; Matthews et al., 2006). Hence, measures of maturation such as the Tanner scale may offer a more accurate guide to desirable training loads during certain growth and maturation phases for those working with young dancers. The Tanner scale (Leone & Comtois, 2007) is a series of images of both female and male reproductive organs depicting development at each of the five stages of sexual maturity from pre-pubescent child through to post-pubescent adult. The literature suggests a delay in the onset of puberty among the young elite and sub-elite dancer populations. Reduced or delayed growth has also been reported in other elite athletes involved in sports emphasising leanness such as ballet and gymnastics (Matthews et al., 2006). Pubertal development was demonstrated as being delayed among elite pre-pubescent and pubescent ballet dancers in comparison to age matched non-dancer controls (Kadel et al., 2005). The non-dancers had a significantly higher Tanner stage average of 1.95 ± 0.75 in comparison to the dancers' average of 1.44 ± 0.5 . This finding was supported by Matthews et al. (2006) in their study of young, non-elite ballet dancers and age matched controls. They found that age at peak height velocity was significantly earlier in controls (11.6 years) than dancers (11.9 years). This suggests non-dancers mature earlier than dancers while Matthews et al. (2006) further suggested that prolonged energy imbalances (often due to caloric restriction in dancers) may contribute to delayed maturation, ultimately resulting in a reduction in growth.

There appears to be a paucity of information in regard to growth and maturation as risk factors to lower extremity overuse injuries among young elite ballet dancers. The literature does suggest there is an increased likelihood of stress fractures between the ages of 12 to 14 due to an asynchrony in bone growth and bone mass accumulation, though this has yet to be shown in dancers (Burckhardt et al., 2011; Fournier et al., 1997). Currently there are no guidelines as to what the appropriate load thresholds may be for young elite ballet dancers to minimise injury risk during this time. The literature also reports that while young ballet dancers demonstrate delayed growth and onset of puberty in contrast to age-matched controls (Kadel et al., 2005; Klentrou & Plyley, 2003; Pigeon et al., 1997), moderate to high intensity training has no effect on growth and maturation in young dancers with a natural selection of genetically late maturing individuals occurring within specific sports (Malina et al., 2013). Finally, the literature suggests that chronological age is not a good indicator of injury risk for young elite dancers due to the variation in timing and tempo of growth (Helsen et al., 2005). For this reason studies using maturation measures such as the Tanner scale to assess injury risk are warranted and may provide a more accurate indicator of risk.

The lack of quality research in this particular area may be due to the difficulties associated with tracking growth and maturation in adolescents. Gaining access to large numbers of young dancers for an extended period of time is challenging, while there are also a number of confounding variables to growth and maturation which are difficult to monitor and control for, including diet and genetics, which may complicate findings. Further well designed prospective studies of young elite ballet dancers of both genders are required.

Onset of menarche

There is a general consensus among the literature that female ballet dancers and athletes of 'aesthetic' sports such as figure skating, diving and gymnastics reach menarche later than normal population females, as well as being at greater risk for menstrual dysfunction (Brooks-Gunn et al., 1988; Kadel et al., 2005; Kadel et al., 1992; Klentrou & Plyley, 2003; Torstveit & Sundgot-Borgen, 2005; Vadocz, Siegel, & Malina, 2002; Warren et al., 1986). While a number of studies link menstrual irregularity with high volume advanced level dancers (Brooks-Gunn et al., 1988; Kadel et al., 2005; Steinberg et al., 2008; Torstveit & Sundgot-Borgen, 2005), none have linked menstrual irregularity to injury, with the exception of stress fractures.

It has been suggested that intense physical activity combined with the pressure on performers to master the aesthetic and artistic components of dance, affects the onset of puberty and menarche in young dancers (Burckhardt et al., 2011; Steinberg et al., 2008). Furthermore, sports which emphasise low body weight for optimal performance are often associated with an increased prevalence of the interrelationship of menstrual function, energy availability, and bone strength (Burke & Deakin, 2006). If energy intake does not match caloric needs, this can lead to menstrual disturbances, low oestrogen and ultimately low bone mass (Burckhardt et al., 2011; Klentrou & Plyley, 2003). Research suggests that reduced energy availability may be the main cause of exercise associated amenorrhoea and menstrual dysfunction, possibly explaining why the highest prevalence of menstrual dysfunction is found in athletes competing in leanness or aesthetic sports (Torstveit & Sundgot-Borgen, 2005). Ballet dancers consistently weigh 10-12% below ideal body weight and these low weight ranges are commonly achieved by low energy intakes (Doyle-Lucas, Akers, & Davy, 2010). A number of authors suggest that ballet dancers with low body weight and relatively low bone mineral density are at increased risk of injury (Burckhardt et al., 2011; Doyle-Lucas et al., 2010; Kadel et al., 2005; Matthews et al., 2006; Torstveit & Sundgot-Borgen, 2005). The low body weight adolescent dancers exhibit at critical ages coupled with under-nutrition, low body fat, and a high ratio of lean mass to body weight is often related to the delay observed in onset of puberty and menarche (Kadel et al., 2005; Steinberg et al., 2008). Furthermore, athletes who begin sport specific training before menarche, such as ballet dancers, are likely to experience a significantly later onset than those who started sport specific training after menarche (Torstveit & Sundgot-Borgen, 2005). Both exercise and low body weight have yet to be conclusively shown to lead to delays in growth, maturation and the onset of menarche or menstrual disturbances (Burckhardt et al., 2011), although as stated earlier young ballet dancers did demonstrate delayed growth and onset of puberty in contrast to age-matched controls (Kadel et al., 2005). However it is thought this is

partially due to the natural selection of genetically late maturing individuals occurring within specific sports.

Abnormal menstrual patterns have been shown to have a negative effect on bone mineralisation and thus may have serious short and long term consequences, including an increased incidence of injury including stress fractures and osteoporosis. Abnormal menstrual patterns may include any one of primary amenorrhoea, or delayed menarche, being identified as the absence of menstruation by age 16 in a girl with secondary sex characteristics (Torstveit & Sundgot-Borgen, 2005; Warren et al., 1986). Amenorrhoea which is classified as the lack of spontaneous menses for greater than 90 days, while oligomenorrhoea is menses that occur at intervals of greater than 38 days but less than 90 days. One study reported that 18 of 75 dancers exhibited stress fractures, with the incidence of fractures higher among those experiencing delayed menarche as well as a rising incidence of stress fractures with increasing menarcheal age (Warren et al., 1986). Also, the incidence of secondary amenorrhoea was more than twice as high among dancers with stress fractures than among those without. Similarly, Kadel et al. (1992) found that a dancer who has been amenorrhoeic for greater than six months has an estimated risk for stress fracture that is 93 times greater than that of a dancer who is not amenorrhoeic. In this study surveying 54 professional ballet dancers, 17 exhibited stress fractures with 56% of these dancers presenting with amenorrhoea, and 100% of these being classified as amenorrhoeic for greater than 6 months.

The literature in regard to age at onset of menarche and menstrual dysfunction clearly outlines the fact that both pre-professional adolescent and professional adult female ballet dancers are at high risk for both delayed onset of menarche and menstrual dysfunction (Brooks-Gunn et al., 1988; Doyle-Lucas et al., 2010; Kadel et al., 2005; Kadel et al., 1992; Torstveit & Sundgot-Borgen, 2005; Warren et al., 1986). Two studies conducted with young elite dancer populations reported positive correlations between these populations and a delayed age at onset of menarche (Brooks-Gunn et al., 1988; Kadel et al., 2005). Both these studies reported findings in line with those in professional dancer populations, while in contrast two studies which recruited non-elite participants found neither a delay in age at onset of menarche or increased menstrual dysfunction in dancer populations in contrast to controls (Matthews et al., 2006; Steinberg et al., 2008). These findings demonstrate both the need for research to be conducted on specific populations as well as the danger in extrapolating findings to alternative populations.

The gap in the literature now lies in the link between delayed onset of menarche and menstrual dysfunction and injury occurrence. Only two studies identified a link between menstrual dysfunction – primarily secondary amenorrhoea – and injury with injury referring only to stress fractures (Kadel et al., 1992; Warren et al., 1986). Both studies were conducted on professional ballet dancers surveyed across two to four full time companies (Kadel et al., 1992; Warren et al., 1986). The studies were conducted retrospectively although the accuracy of recalled age at menarche has been shown to be fair in regard to reliability (Bergsten-Brucefors, 1976). While there appears to be a strong link between menstrual dysfunction and stress fractures within the

professional dancer population, more research of this nature is required with young elite dancers. In addition, research is needed to determine whether there is a relationship between delayed menarche and menstrual dysfunction and injuries other than stress fractures, given the high injury incidence found among the young elite ballet dancer population.

Lower extremity alignment

It is clear from the literature that there is a lack of agreement about the characterisation of abnormal alignment or the methods of measuring it (Murphy, Connolly, & Beynnon, 2003). However the theoretical underpinnings of biomechanics suggest that abnormal alignment of the hip, knee and ankle is considered a potential risk factor for lower extremity injury (Murphy et al., 2003), with poor alignment leading to the possibility of decreased function and increased discomfort (Ahonen, 2008; Murphy et al., 2003). Dancers with biomechanical abnormalities or technical faults such as poor turnout, pronation of the feet, incorrect weight bearing or improper jumping techniques have been reported as having an increased risk of developing injury (Poggini et al., 1999). Currently, however, there is little evidence-based research in dance to support this, with a paucity of research prospectively examining the effect of poor lower extremity alignment practices in turnout and during jumping on young pre-professional ballet dancers. There is also a lack of research assessing hip strength of elite ballet dancers in relation to lower limb alignment and injury risk.

A key component of ballet technique is adequate turnout, determined by several factors including muscle strength, soft tissue extensibility, and skeletal anatomy (Bennell et al., 1999b). Theoretically turnout involves 90 degrees of external rotation of each leg, made up of approximately 55 to 70 degrees from the hip, 10 degrees from the knee, 12 degrees of tibial torsion, and some degree of abduction at the mid-tarsal joint (Conti & Wong, 2001). For those dancers without the desired range of motion, compensatory strategies in the kinetic chain may occur due to an attempt to increase turnout by obtaining additional movement at other joints such as the knee or foot (Bennell et al., 1999b; Gupta et al., 2004). The resulting compensatory movement that occurs at anatomical sites other than the hip joint, such as increased lumbar lordosis, pronation of the feet, or abduction of the forefoot, may put the dancer at increased risk for various acute and chronic injuries (Bennell et al., 1999b; Conti & Wong, 2001). To date there is no research prospectively examining the effect of poor lower extremity alignment practices in turnout on young pre-professional ballet dancers, although two studies retrospectively analysed the relationship between passive and active external rotation and lower extremity injury in ballet dancers (Coplan, 2002; Negus, Hopper, & Briffa, 2005). It was identified that those dancers with increased compensatory turnout, that is increased tibial torsion or lumbar lordosis, exhibited increased injury incidences of the lower extremities (Coplan, 2002). The number and severity of non-traumatic injuries were also reported to be associated with reduced functional turnout (Negus et al., 2005). The studies utilised self-report and interview style mechanisms to gather injury history which may reduce the reliability of the data collected. The study conducted by Coplan et al., (Coplan, 2002) was conducted using non-elite adult dancers while the study carried out by Negus et al., (Negus et al., 2005) utilised young elite participants.

An explanation offered for the majority of injuries occurring at or below the knee in ballet dancers is diminished hip strength leading to faulty lower extremity alignment. Currently however, there is no research assessing hip strength of young elite, or adult professional ballet dancers of either gender in relation to lower limb alignment and injury risk. The theory suggests that a decrease in strength within the hip abductor and external rotator muscles may lead to faulty biomechanics of the lower extremity, particularly when placed under increased load such as during the landing phase of a jump (Stacey, 1999). For any individual participating in any form of activity which consists of high impact loading on a single limb, decreased hip abductor and external rotator strength may increase the risk of injury. This is thought to be due to the role these muscles play in preventing excessive hip adduction and internal rotation (Ireland, Willson, Ballantyne, & Davis, 2003; Leetun, Ireland, Willson, Ballantyne, & Davis, 2004; Nguyen, Shultz, Schmitz, Luecht, & Perrin, 2011; Patrek, Kernozek, Willson, Wright, & Doberstein, 2011). Results from a study by Ireland et al (2003) demonstrated that female subjects (non-dancers) with patellofemoral joint pain exhibited 26% less hip abduction strength, as well as 36% less hip external rotation strength than age-matched controls. As a variety of knee injuries are commonly reported among ballet dancers (11-22%) (Bowling, 1989; Gamboa et al., 2008; Garrick, 1999; Krasnow et al., 1999; Nilsson et al., 2001), such a finding may offer an insight into the contributing factors for this type of injury in dance.

Lower extremity alignment and hip muscle activation were also analysed during a single leg squat in 60 adult recreational athletes of both genders, and it was reported that decreased gluteus maximus activation predicted greater hip internal rotation excursion (Nguyen et al., 2011). This observation supports theories that decreased hip muscle activation affects dynamic stability in the hip, ultimately leading to the inability of an individual to maintain neutral alignment during single-limb weight-bearing activities. As dancers perform more than 200 jumps per 1.5 hour daily technique class, and more than half of these involve single leg landings (Liederbach et al., 2008), a dancer's ability to maintain neutral alignment during single leg landings seems important to minimise injury risk. Furthermore, not only are dancers exposed to the effects of repetitive jumping but they contend with aesthetic constraints. These include a vertically-aligned trunk during takeoff and landing, as well as performing the majority of landings on a single outstretched leg, resulting in increased stress placed on the knee extensor mechanism (Fietzer, Chang, & Kulig, 2012; Orishimo, Kremenec, Pappas, Hagins, & Liederbach, 2009). From a young age dancers are trained to land with the lower extremities near full extension, with a vertical spine, and with maximum use of plantar flexion at initial contact. The extension of the lower extremity at initial ground contact aims to provide increased use of the full range of lower extremity flexion in order to disperse landing forces and to achieve the desired aesthetic of a smooth and weightless landing. Emphasis is also placed on controlling the alignment of the lower extremities during landing such that the patella remains in line with the second toe (Orishimo et al., 2009). Due to an erect trunk increasing the moments on the knee by increasing the demand on the knee extensors, and decreased knee flexion angles at contact causing quadriceps contractions to generate significant anterior tibial shear forces facilitating high levels of ACL loading (Padua et al., 2009; Powers, 2010), this landing technique may increase injury

risk. One study did compare the strength between various hip muscles of novice eight to 11 year old ballet dancers and non-dancers, in which the controls presented as significantly stronger in the external rotators (2.8kg and 4.0kg respectively) when normalised for body weight (Bennell et al., 1999a). It is likely though, that due to the age of the participants the ballet dancers had not received enough ballet training for an increase in strength of the external rotators to be observed in comparison to the non-dancer controls.

Variability in landing patterns may also be linked to increased injury risk. In a study comparing landing biomechanics between male and female professional ballet and contemporary dancers, Orishimo et al. (2009) reported the dancers demonstrated only 33% variability in landing patterns in contrast to athletes who exhibit between 46% and 87% variability of full range of frontal plane hip motion. Athletes also typically have other motor demands such as less predictable or rehearsed movement which may contribute to the increased variability observed in the athletes (Orishimo et al., 2009). The reduced variability in dancers is likely due to extensive practice and training, theoretically resulting in more consistent landing patterns, avoiding unanticipated movements that may result in injury (Orishimo et al., 2009). The aesthetic requirements of dance promote finite movement patterns and the ability of the dancer to accurately replicate these specific movements is often used as an indicator of proficiency. However evidence is emerging in dancers that variability may be key for stable yet adaptable movement patterns (Hopper & Karin, 2012). Given performance environments for dancers are more controlled than those of athletes, it is possible that 33% movement variability is enough to reduce injuries in dancers. In elite athletes, increased variability may represent a greater movement repertoire that reduces repetitive loading on the musculoskeletal system ultimately reducing the risk of overuse injury (Stergiou & Decker, 2011). In light of this, the reduced movement variability in dancers observed by Orishimo et al. (2009) may provide a possible explanation as to the increased knee injury rates observed in dancers. Encouraging a certain degree of movement variability within dance training such as varying tempos and combinations of movements (Wilson, 2009) may result in a decrease in injury risk. However this is difficult to detect with the naked eye and requires motion analysis technology which is potentially limiting due to time and monetary constraints (Hopper & Karin, 2012). This is a newly developing area in dance science and currently little research exists, particularly with young elite ballet dancers.

Compounding the challenge of assessing injury risk in relation to lower extremity alignment is the lack of agreement about the characterisation of abnormal alignment or the methods of measuring it (Murphy et al., 2003). This is exacerbated in dancers due to aesthetic constraints stipulating an erect trunk on takeoff and landing with the lower extremities near full extension, a technique which research in athletes has demonstrated may increase injury risk (Padua et al., 2009; Powers, 2010). Movement variability also appears reduced in dancers, likely due to both aesthetic requirements and extensive practice, however this may further increase the risk of injury in dancers due to a decreased ability to adapt movement (Hopper & Karin, 2012). While jumping places great stress on the skeletal and muscular systems, it would be pertinent if future research could also be conducted which prospectively assesses the effect of poor alignment in

turnout and *pointe* work on injury risk in ballet dancers. Finally there appears to be a paucity of information in regard to lower extremity alignment and biomechanics of the lumbar spine and ankle joints during functional dance movement, perhaps important given that both anatomical sites are reported as two of the most frequently injured in young elite dancers. While there is reasonable biomechanical theory linking poor lower extremity alignment and injury risk, further well-designed prospective studies incorporating young elite ballet dancers are required.

Practical Implications

- Due to a lack of current evidence, practitioners should be cautioned not to over-emphasise the impact of the adolescent growth spurt on the risk of injuries aside from stress fractures. Due to the increased risk of stress fracture during increased periods of growth, high-impact movements such as jumps should be reduced. I.e. supplementary training should focus on reduced load and assisting functional dance movement. Regular measurements of height and/or foot length are suggested as assessment for establishing an increased period of growth.
- Dance teachers and medical practitioners should continue to screen/monitor lower extremity alignment as there is some evidence this is an important injury risk factor in other athletes and potentially dancers. Lower extremity screening should include functional dance movement such as double/single leg rises, *relevés* and hops and could include visual or video assessment ensuring correct alignment of the centre of the patella aligned with the second toe.

Limitations

There are several limitations in the reviewed studies. Due to the small number of studies available, results from studies incorporating adult professional as well as young amateur dancers of multiple genres had to be incorporated into the overall findings, limiting the strength of evidence for young elite dancers. Additionally the studies reviewed demonstrate a lack of standardisation for reporting study methodologies, while no studies on dancers are currently published which have utilised male-only participants.

Conclusion

The purpose of this review was to evaluate the evidence for risk factors associated with lower extremity overuse injuries in young elite ballet dancers. While there is considerable evidence that lower extremity overuse injuries are the most common in young elite ballet dancers, with the foot and ankle representing the most commonly injured site within this population, there is a lack of quality evidence identifying key risk factors for these injuries. Although the adolescent growth spurt and the period of maturation which follows are anecdotally considered to be associated with increased injury incidences among ballet dancers, a lack of prospective studies

on young elite dancers make classifying cause and effect difficult. The literature also suggests that chronological age is not a good indicator of injury risk, therefore studies utilising maturation measures such as the Tanner scale to assess injury risk in young elite dancers may be warranted. Several well-designed studies indicate that young elite female ballet dancers suffer from a later onset of maturation and menarche, with a link to an increased likelihood of stress fractures. However the risk of late onset of both maturation and menarche is yet to be linked to other injuries and additional well-controlled prospective studies are required.

Evidence for poor lower extremity alignment as a risk factor for injury is minimal in ballet dancers although some research in other fields suggests the techniques used by dancers during jumping, dictated by the aesthetic constraints of the activity, may increase injury risk. There is also emerging evidence to suggest ballet dancers demonstrate reduced movement variability which may further increase injury risk.

Overall there has been little research conducted into potential risk factors for lower extremity overuse injuries including growth and maturation, onset of menarche and lower extremity alignment. Further research into injury risk is indicated given the high incidences of lower extremity overuse injuries reported among young dancers. Without a clear understanding of the risk factors, little progress can be made in the way of injury prevention in this population.

CHAPTER 4

RELIABILITY OF TWO-DIMENSIONAL LOWER EXTREMITY ALIGNMENT MEASURES IN ELITE ADOLESCENT BALLET DANCERS

Overview

Objective: To investigate the reliability of two-dimensional (2D) analysis of knee and pelvic angles during lower extremity functional screening tests in elite adolescent ballet dancers. *Design:* Quantitative repeated measures experimental. *Methods:* Forty-five elite adolescent ballet dancers performed two dance movements (*fondue* and *temps levé*). A modified knee valgus angle, lateral pelvic tilt, and depth of movement were measured using 2D video analysis. Between-trial reliability was assessed using intraclass correlation coefficients (ICC) and the typical error (TE) of measurement. Paired sample t-tests were used to evaluate the difference in angles between the right and left legs, while Pearson correlation coefficients were used to assess the relationship between the *fondue* and *temps levé*. *Results:* The reliability of the modified knee valgus angle in both the *fondue* (ICC = 0.88 to 0.89; TE = 3°) and *temps levé* (ICC = 0.80 to 0.87; TE = 6 to 8°) was high. There was a significant difference in knee angle for both movements on the left ($p = 0.001$) and right legs ($p = 0.001$). There was also a strong correlation for the knee angle between the two tests on both the left ($r = 0.93$) and right ($r = 0.94$) legs. *Conclusions:* Measures of 2D knee and pelvic angles during the *fondue* and *temps levé* movements in elite adolescent ballet dancers demonstrate moderate to high reliability. Knee angles between the two movements are strongly associated and there is very likely to be a difference in knee angle between legs. This simple technique may be useful to screen movement in dancers.

Introduction

Injuries to the lower extremities are very common in dancers, with 16-17% of all injuries occurring at the knee joint (Gamboa et al., 2008; Garrick, 1999; Leanderson et al., 2011). The cause of these injuries is thought to be multifactorial, with poor alignment suggested as one factor contributing to injury risk at the knee (Poggini et al., 1999). In athletes, poor frontal and/or transverse plane control of the pelvis, hip, knee and foot is considered less than ideal, and it is thought that identifying this may help detect those athletes most at risk of injury (Stensrud et al., 2011; Whatman et al., 2012). This pattern of lower extremity dynamic alignment is also considered important in dancers (Clippinger, 2007), and there has been much recent interest in the development of simple, reliable screening methods. A number of studies have been conducted in athlete populations to assess for poor lower extremity alignment with several studies demonstrating a link between poor dynamic alignment and injury (Levinger, Gilleard, &

Coleman, 2007; Willson & Davis, 2008). Greater frontal plane projection angle (FPPA) of the knee during a single leg squat in subjects with patellofemoral pain was reported by both Levinger et al., (2007) and Willson et al., (2008). However currently, no research has assessed elite ballet dancers for lower extremity alignment during functional dance movement.

While three-dimensional (3D) motion analysis is recognised as the gold standard for assessing lower extremity movement, due to time and monetary costs it is unsuitable for large populations of athletes and small independent clinics. Therefore clinical assessment is usually performed via visual observation of functional tests, with increasing use of 2D video analysis both in athlete and dancer populations (Twitchett, Angioi, et al., 2009; Whatman et al., 2012). The majority of previous studies investigating the reliability of 2D video measures in athletic populations have used the single leg squat and drop jump (Stensrud et al., 2011; Whatman et al., 2012). All measurements were recorded at maximum knee flexion, using the FPPA of the knee as the key measure. Intra-rater reliability was reported as excellent for the vertical drop jump ($ICC \geq 0.95$) (Stensrud et al., 2011; Whatman et al., 2012), and the single leg squat ($ICC = 0.92$) (Stensrud et al., 2011). Within-day test-retest reliability has also been classified as very good for the drop jump ($ICC = 0.83 - 0.88$) (Munro, Herrington, & Carolan, 2012; Stensrud et al., 2011) and fair to moderate in the single leg squat (right leg $ICC = 0.57$, left leg $ICC = 0.84$) (Stensrud et al., 2011). Two functional dance movements closely linked to a single leg squat and/or drop jump, and thus with potential to be used as screening tests in a dance population, are the *fondue* and *temps levé*. Dance teachers routinely rate the position of the pelvis and lower extremity during these movements, with ideal dance technique requiring maintenance of the knee over the foot and a level pelvis (Clippinger, 2007).

The potential for a 2D video analysis approach to be used as a screening tool should be considered, as this measure may assist visual assessment as well as provide an indication of young dancers requiring intervention to reduce the risk of injury (McLean et al., 2005; Whatman et al., 2012). There is potential for this 2D method of analysis to be used when screening elite ballet dancers during specific dance movement tasks (McLean et al., 2005). However the reliability of 2D video in the assessment of lower extremity alignment during functional dance movement, (*fondue* and *temps levé*) requires investigation. If the reliability of this screening method in elite ballet dancers can be established, practitioners will be able to use the tests with confidence while also allowing the testing method to be used in longitudinal studies investigating injury risk and the effects of training and/or rehabilitation interventions in dancers. Therefore, the aim of this study was to investigate the reliability of 2D analysis of knee and pelvic angles during lower extremity functional screening tests in elite adolescent ballet dancers. In addition, comparisons between the right and left leg, as well as the association between the tests were investigated.

Methods

Forty-five (F=29, M=16) young ballet dancers (16.1 ± 1.6 years (mean \pm SD), 1.68 ± 0.89 m, 53.4 ± 9.5 kg) were recruited from the Australian Ballet School (ABS) in Melbourne. All participants were full-time ballet students at the school. In accordance with institutional requirements, ethical approval was granted for this study. The dancers and their guardians provided written assent/consent prior to participation.

Each of the dancers attended a dance studio on one occasion. Participants wore standard dance practice clothes for testing and were asked to remove all footwear. Tape was used to mark the Anterior Superior Iliac Spine (ASIS), centre of the patella and centre of the ankle joint bilaterally. All dancers performed two movements, a *fondue* (single knee bend in external rotation) and *temps levé* (single leg vertical jump in turnout) based on standardised verbal instructions. Participants performed three repetitions of each movement on both legs with the arms held in a classical position. As stipulated by ballet technique the *fondue* and *temps levé* movements require execution in external rotation (turnout). As a result, two digital cameras (Panasonic, U.S.A) were used, one parallel to the frontal plane of the body and a second perpendicular to the line of the foot. The second camera position was adjusted to ensure the camera was always perpendicular to the line of the dancer's foot irrespective of the dancer's turnout range (see Figure 1). Based on post-collection visual inspection, any *temps levé* trials where the dancer's foot was clearly out of line with the camera were omitted from the analysis of the modified knee valgus angle (12 trials, 6 left and 6 right). All cameras were positioned on tripods, level with the floor at a distance of 1-2 metres, and a height of 0.86 metres. The *fondue* movement was captured at a rate of 30 frames per second (fps) and the *temps levé* at a rate of 250fps.

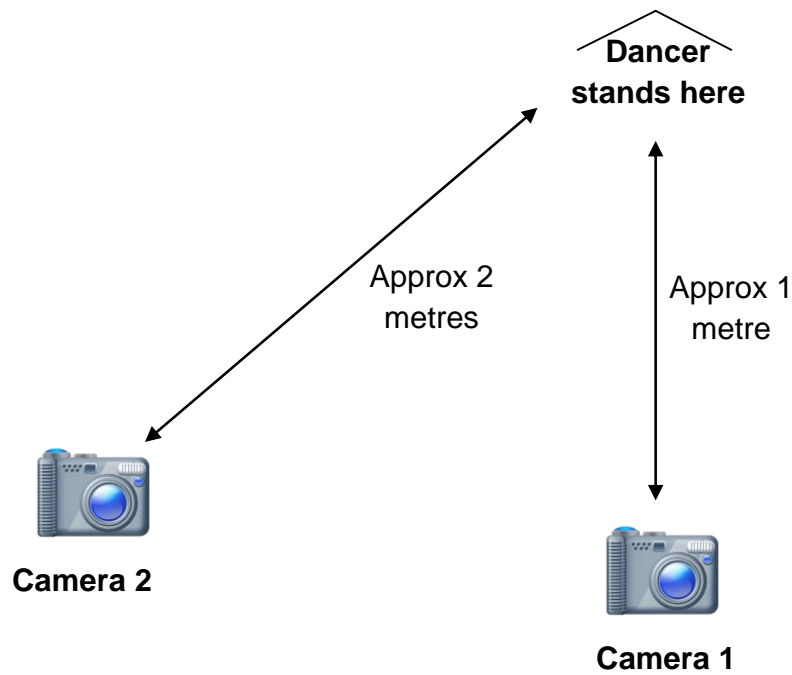


Figure 1: Camera set-up – Camera 1 positioned parallel to the frontal plane of the dancer and Camera 2 positioned perpendicular to the line of the foot of each dancer in their functional turnout positions.

Using Kinovea video analysis software (v 8.15) a modified knee valgus angle, (Camera 2), depth of movement (Camera 1), and lateral tilt of the pelvis (Camera 1) were measured for all three trials performed by each dancer (Figure 2). These are the most commonly reported 2D frontal plane alignment measures in athletes (Whatman et al., 2012). The modified knee valgus angles were measured at the point when the patella was observed to be most medially positioned relative to the second toe. The pelvic angle was measured at maximal knee flexion which was visually estimated. Depth of movement was measured by assessing the distance of the ASIS relative to the floor at the lowest point of the movement in centimetres. Pilot testing assessing intra-rater reliability for the 2D angle measures was conducted using nine semi-elite female ballet dancers (age 13.3 ± 2.1) from Auckland, New Zealand. A single, experienced dance teacher measured 2D angles from the same video on two occasions, separated by a period of seven days. Reliability was very high to extremely high for both knee and pelvic measures (ICC = 0.96 – 0.99, TE = 1-2 degrees).

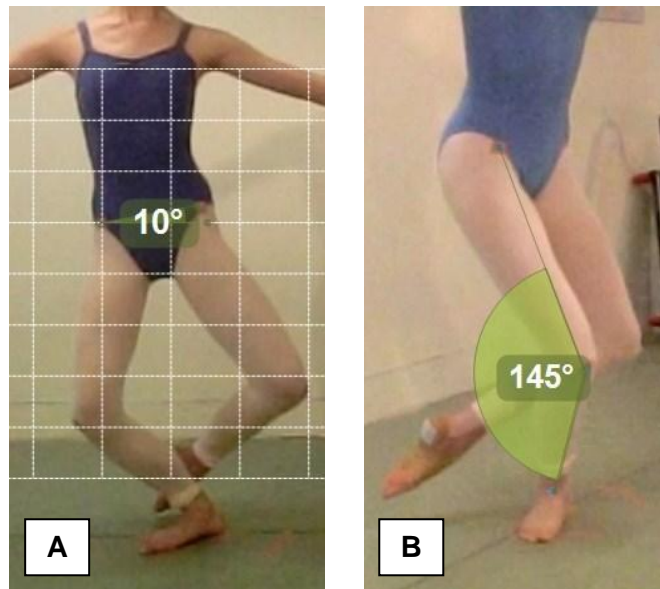


Figure 2: 2D knee and pelvic measures. A: The pelvic angle was measured by assessing the line of the ASIS's relative to the horizontal. B: The modified knee valgus angle was calculated by connecting the bony landmarks of the ASIS, centre of patella and centre of the ankle joint.

Descriptive statistics including overall group mean and standard deviations were calculated for all angles. Using an excel spreadsheet by Hopkins (2011) for analysis of between-trial reliability, intraclass correlation coefficients (ICC) and the typical error of the measurement (TE) were calculated using the original (raw) data. The magnitude of the ICC values were described as ≥ 0.99 = extremely high, $0.90-0.99$ = very high, $0.75-0.90$ = high, $0.50-0.75$ = moderate, $0.20-0.50$ = low, ≤ 0.20 = very low (Hinckson, Hopkins, Aminian, & Ross) (unpublished observations). Using IBM SPSS Statistics for Windows, version 21 (IBM Corp, Armonk, NY) the difference in means between the right and left limbs were compared using a paired sample t-test and qualitative magnitude based inferences were added using an excel spreadsheet (Hopkins, 2007). Pearson correlation coefficients were also calculated to assess the magnitude of the associations between knee valgus angle for both movements on both the right and left legs. An alpha level of 0.05 was set as the significance level for all statistical tests.

Results

Peak mean angles and standard deviations for the knee and pelvis during both the *fondue* and *temps levé* are presented in table 3. Between-trial reliability for knee and pelvic angles during three repetitions of the *fondue* and *temps levé* movements are presented in Table 2.

The between-trial reliability of the modified knee valgus angle in both the *fondue* (ICC = 0.88 to 0.89) and *temps levé* (ICC = 0.80 to 0.87) movements were high. Between-trial reliability of the depth of *fondue* and *temps levé* was high to extremely high (ICC = 0.85 to 0.99). Reliability of the pelvic angle in the *fondue* ranged from moderate to high (ICC = 0.67 – 0.79) while the *temps levé*

showed only moderate reliability (ICC = 0.68 to 0.71). There was little difference in reliability between limbs.

The typical error of measurement (TE) for the modified knee valgus angle in the *fondue* was 3°, but was higher in the *temps levé* ranging from 7–8°. Pelvic angle TE ranged from 1°–2° for both movements.

There was a significant difference in the knee valgus angle between the right and left legs for both the *fondue* (mean = 10°; $p = 0.001$) and *temps levé* (mean = 14.7°; $p = 0.001$) movements (Table 3). There was also a significant difference in pelvic angle between sides for both the *fondue* (mean = 1°; $p = 0.005$) and *temps levé* (mean = 1°; $p = 0.03$). For the knee valgus angle there was a strong, statistically significant correlation between the *fondue* and *temps levé* tests on both the left ($r = 0.93$, $p = 0.01$) and right ($r = 0.94$, $p = 0.01$) limbs.

Table 2. Between-trial reliability during the *fondue* and *temps levé*

		TE (°) (90% CL)	ICC (90% CL)	RELIABILITY*
FONDUE	Knee (R)	3 (3-4)	0.88 (0.81-0.92)	High
	Knee (L)	3 (3-4)	0.89 (0.82-0.93)	High
	Pelvis (R)	1 (1-1)	0.79 (0.67-0.87)	High
	Pelvis (L)	1 (1-1)	0.67 (0.50-0.78)	Moderate
TEMPS LEVÉ	Knee (R)	6 (5-8)	0.87 (0.78-0.92)	High
	Knee (L)	8 (6-10)	0.80 (0.67-0.88)	High
	Pelvis (R)	1 (1-1)	0.71 (0.55-0.82)	Moderate
	Pelvis (L)	1 (1-2)	0.68 (0.44-0.76)	Moderate

*TE = typical error, ICC = intraclass correlation coefficient, R=right leg, L=left leg, *Terms for ICC magnitudes: 0.75-0.90 = high, 0.50-0.75 = moderate.*

Table 3. Peak mean angle (°) ±SD, mean difference in angle between right and left leg (90% CL), p value, inference

		PEAK ANGLE ±SD	Difference between right and left sides		
			MEAN (90% CL)	P-value	INFERENCE*
FONDU	Knee (R)	175 ±3			
	Knee (L)	186 ±3	10 (6-14)	0.001**	96%, very likely
	Pelvis (R)	3 ±1			
	Pelvis (L)	2 ±1	1 (1-2)	0.005**	0%, most unlikely
TEMPS LEVÉ	Knee (R)	161 ±7			
	Knee (L)	176 ±6	15 (9-20)	0.001**	99%, very likely
	Pelvis (R)	3 ±1			
	Pelvis (L)	2 ±1	1 (0-2)	0.03**	0%, most unlikely

*=likelihood difference is practically important (knee >5°, pelvis >2°), **=statistically significant (p≤0.05)

Discussion

Poor lower extremity alignment has been proposed as an injury risk factor for ballet dancers, particularly for knee injury (Poggini et al., 1999). Dynamic lower extremity alignment has been assessed in athletic populations for injury risk, using a number of different screening tests (Levinger et al., 2007; McLean et al., 2005; Munro et al., 2012; Stensrud et al., 2011; Whatman et al., 2012; Willson & Davis, 2008). No research has examined the dynamic lower extremity alignment of dancers using dance-specific movement.

The primary aim of this study was to assess between-trial reliability of simple 2D alignment measures in elite adolescent ballet dancers performing a *fondue* and *temps levé*. The excellent ICC values indicate that 2D video analysis of the modified knee valgus angle for both the *fondue* and *temps levé* movements is reliable between-trials on the same day. The ICC values for the knee were higher than the ICC values for the pelvic angles, however a contributing factor to the lower pelvic ICC's is the lack of variability between participants (range = 0 to 10° for both *fondue* and *temps levé*). The low TE values for the pelvis still suggest this is a reliable measurement. The excellent ICC values for the depth of movement for both the *fondue* (ICC = 0.98-0.99) and *temps levé* (ICC = 0.85-0.88) indicate that elite adolescent dancers execute both movements with high repeatability. This is important for comparing movements on two separate occasions. Previous studies of similar lower extremity functional tests in athletes have suggested the maximum frontal and transverse plane deviations need to be assessed across the same range of sagittal plane motion for the test to be valid (Whatman, Hing, & Hume, 2011a). This idea is supported by studies reporting increased frontal plane motion with increases in sagittal plane motion during lower extremity functional tests (Kernozek, Torry, van Hoof, Cowley, & Tanner, 2005; Zeller, McCrory, Kibler, & Uhl, 2003). Thus, the standardisation of depth is not required for screening within dancer populations, resulting in a simple screening test without the requirement for additional monitoring that adds to time and equipment needs.

The low TE values for both the knee and pelvic angles (TE = 1° – 4°) measured during the *fondue* further support the reliability of the measure between-trials. The TE values for the knee angles during the *temps levés* are higher (TE = 6° – 8°) suggesting greater variability with this movement. Based on these error values, practitioners should be able to establish if changes observed between-trials are true changes in individual performance or a result of measurement error (Munro et al., 2012). They also provide an indication to practitioners as to the uncertainty in a single screening measure if using this test. The TE values for the *temps levés* are higher than those reported in similar studies for the drop jump and single-leg landing (Munro et al., 2012). This is most likely due to differences in the camera position, related to the dancers' external hip rotation, which resulted in greater variability in each dancer's orientation relative to the camera. The higher values could also be explained by the increased pace and load of the jump in comparison to the *fondue*. Practitioners need to be aware if using the *temps levé* that there is increased variability with this movement in comparison to other tests. No feedback was

provided to the dancers in regard to their turnout or foot position relative to the camera during testing and this could be provided to reduce the variability observed during testing.

The significant correlation between the *fondue* and *temps levé* movements on both the right ($r = 0.94$) and left ($r = 0.93$) legs indicates that good execution of the *fondue* transfers successfully to a higher load *temps levé* movement. This may be useful for practitioners due to the simpler and slower nature of the *fondue*, making it easier to visualize, while also providing a reliable option for screening injured dancers who are unable to perform higher load movements. The significant difference in knee angle between the left and right legs for both the *fondue* and *temps levé* tests indicates that both legs should be tested during the screening of dancers for lower extremity dynamic alignment. While there was also a significant difference in pelvic angle between sides, the difference was small and suggests it is of little practical importance.

There are several limitations in this study readers should be aware of. Firstly, within-day reliability only was assessed thus future studies should evaluate between-day reliability of the *fondue* and *temps levé* tests, while inter-rater reliability of the measures should also be considered. Secondly, while some practitioners may use 2D video to screen lower extremity alignment in dancers, many teachers visually rate movement without video assistance. Thus visual rating requires investigation, as well as the use of visual rating in comparison to 2D video analysis. Furthermore, feedback could be provided on the maintenance of turnout and the dancer's foot position perpendicular to the camera during the *temps levé*, with repeat tests if required, to maximise the reliability of the measurement technique. The use of these measures in comparative investigations between injured and uninjured ballet dancers and dancers of other ages warrants investigation. Finally, using cameras in only two positions does not replicate clinical or teaching strategies in which practitioners or teachers would view a dancer or movement from multiple angles.

Conclusion

The reliability of 2D knee and pelvic angles during the *fondue* and *temps levé* movements in elite adolescent ballet dancers is moderate to high. Knee angles between the two movements are strongly associated and there is very likely to be a difference in knee angle between legs. This simple screening technique may be useful to dance practitioners and in longitudinal studies examining injury risk.

CHAPTER 5

ARE MATURATION, GROWTH AND LOWER EXTREMITY ALIGNMENT ASSOCIATED WITH OVERUSE INJURY IN ELITE ADOLESCENT BALLET DANCERS?

Overview

Objective: To identify growth, maturation and biomechanical risk factors for overuse injury in elite adolescent ballet dancers. **Methods:** Maturation, growth, height and body mass were recorded in 46 elite adolescent ballet dancers. Growth was based on change in foot length and stage of maturation using the Tanner scale. Age at onset of menarche for the female dancers was also assessed. A modified knee valgus angle and lateral tilt of the pelvis were measured using two-dimensional (2D) video during two functional dance movements (*fondue* and *temps levé*) to quantify lower extremity alignment. Overuse dance injuries were diagnosed and recorded by a physiotherapist for the duration of this six month study. The injury rate ratio (RR) associated with each baseline variable was estimated using over-dispersed Poisson regression modelling. **Results:** Fifty-nine injuries were recorded with an overall injury incidence of 3.52 injuries per 1000 dance exposures and 2.40 injuries per 1000 dance hours. Changes in right foot length (RR = 1.41, CI = 0.93-2.13), right knee angles during the *fondue* (RR = 0.68, CI = 0.45-1.03) and *temps levé* (RR = 0.72, CI = 0.53-0.98), and pelvic angles during the *temps levé* on the left (RR = 0.52, CI = 0.30-0.90) and *fondue* on the right (RR = 1.28, CI = 0.91-1.80) were associated with clear changes in injury risk that were likely to be substantial. **Conclusions:** Rate of growth in elite adolescent ballet dancers is likely associated with an increase in risk of lower extremity overuse injury. Better right lower extremity alignment is likely associated with a reduction in risk of right lower extremity overuse injury. Observed changes in risk were associated with several other factors, although the effects were unclear and these warrant further investigation.

Introduction

It is well documented that there is a high incidence of injury among elite adolescent and professional ballet dancers. Overuse injuries of the spine and lower extremities are particularly common in this population (Allen et al., 2012; Bowling, 1989; Ekegren et al., 2011; Gamboa et al., 2008; Garrick, 1999; Krasnow et al., 1999; Leanderson et al., 2011; Nilsson et al., 2001; Steinberg et al., 2011). Recent research has begun to highlight key risk factors for these injuries with particular reference to adolescent dancer populations (Fournier et al., 1997; Gamboa et al., 2008; Phillips, 1999b; Steinberg et al., 2011) due to a sharp increase in the incidence of injuries observed at the onset of, and during pubertal development. The adolescent growth spurt and the period of maturation that follows, including the age at onset of menarche in females, have

been suggested as two key risk factors for injury in elite adolescent dancers and athletes (Ford, Shapiro, Myer, Van den Bogert, & Hewett, 2010; Hewett, Myer, & Ford, 2004; Matthews et al., 2006; Poggini et al., 1999; Steinberg et al., 2008).

Maturation, or the development of secondary sexual characteristics, occurs during adolescence with significant variation between individuals in the timing and tempo of growth (Matthews et al., 2006; Phillips, 1999b). Several studies of female athletes have highlighted how maturation can lead to an increased risk of injury. Following the onset of maturation, female athletes demonstrated increased peak knee abduction angles when landing from a vertical drop jump (Ford et al., 2010; Hewett et al., 2004). A number of studies have also demonstrated a relationship between increased knee valgus on landing (inwardly rotated knee alignment) and increased risk of lower extremity injury (Levinger et al., 2007; Willson & Davis, 2008). Currently however, no research has examined the effects of maturation on dance performance, nor on the level of risk associated with the incidence of injury at different stages of maturation in elite adolescent ballet dancers.

Due to the variation in timing of maturation, chronological age is not necessarily an accurate indicator of the level of injury risk for a young dancer exposed to high levels of training (Helsen et al., 2005; Matthews et al., 2006). Instead, measures of maturation such as the Tanner scale (Marshall & Tanner, 1969) may offer a more accurate guide, and therefore provide guidance when determining desirable training loads during certain growth and maturation phases. Although the use of Tanner scales may improve specificity in training loads and assist in reducing injuries, few studies with adolescent dancers have used them. Age at onset of menarche is further associated with the period of maturation, although there is general consensus among the literature that this milestone is often delayed among female ballet dancers putting them at greater risk for injury (Brooks-Gunn et al., 1988; Kadel et al., 2005; Kadel et al., 1992; Klentrou & Plyley, 2003; Torstveit & Sundgot-Borgen, 2005; Vadocz et al., 2002; Warren et al., 1986). While numerous studies have demonstrated a link between delayed onset of menarche or menstrual irregularity with high volume advanced dancers (Brooks-Gunn et al., 1988; Kadel et al., 2005; Steinberg et al., 2008; Torstveit & Sundgot-Borgen, 2005), this delay has not been successfully demonstrated to coincide with an increase in injuries aside from stress fractures, specifically in elite adolescent populations.

An increase in injury incidence has reportedly been observed in dancers both at the beginning, and throughout the adolescent growth spurt (Burckhardt et al., 2011; Daniels et al., 2001; Krasnow et al., 1999; Leanderson et al., 2011; Phillips, 1999a; Stacey, 1999; Steinberg et al., 2011). However it is difficult to ascertain the exact cause for this observed increase given adolescence is often when students also begin to increase the intensity of dance training (Daniels et al., 2001). Several studies assessing injury incidence have reported a higher injury frequency in older dancers (Leanderson et al., 2011; Steinberg et al., 2011), noting that the observed increase was due to an amplified rate of bone growth in comparison to the ligaments and tendons, thereby exposing the soft tissue to a higher risk of injury. However, there was no

clear evidence for this being the cause of injury as opposed to increased exposure. Although there are some biomechanical and physiological underpinnings suggesting a rapid increase in growth may lead to an increased risk of injury (Daniels et al., 2001; Phillips, 1999a; Stacey, 1999), there is currently a lack of evidence supporting this cause-effect relationship, specifically in elite adolescent dancers.

Abnormal alignment of the hip, knee and ankle has been identified as a further risk factor for lower extremity injury (Murphy et al., 2003; Poggini et al., 1999; Whatman et al., 2012; Willson, Ireland, & Davis, 2006). In athletes, poor frontal and/or transverse plane control of the pelvis, hip, knee and foot is considered less than ideal, and it is thought that identifying this may help detect those athletes most at risk for injury (Stensrud et al., 2011; Whatman et al., 2012). This pattern of lower extremity dynamic alignment is also considered important in dancers (Clippinger, 2007). A number of studies have been conducted in athlete populations to assess for poor lower extremity alignment with several studies demonstrating a link between poor dynamic alignment and injury (Levinger et al., 2007; Willson & Davis, 2008). However, to date no research has assessed elite adolescent ballet dancers for lower extremity alignment during functional dance movement with regard to injury risk.

The aim of this study was to identify growth, maturation and biomechanical risk factors for overuse injury in elite adolescent ballet dancers.

Methods

Forty-six (Female = 30, Male = 16) adolescent ballet dancers (mean \pm SD, age 16 \pm 1.58 years) were recruited from the Australian Ballet School (ABS) in Melbourne and prospectively followed over six months. All dancers were full-time ballet students at the school. Ethical consent was granted for the study by the AUT University Ethics Committee (AUTEC) and the Australian Catholic University Ethics Committee. The dancers and their guardians provided written assent/consent prior to participation. Due to leaving the school, a total of four participants (Female = 1, Male = 3) dropped out of the study over the six month period.

Maturation, growth, height and body mass were recorded in all dancers. All dancers also completed a survey to assess their stage of maturation using the Tanner scale. The Tanner scale consisted of a series of images of female and male reproductive organs depicting development at each of the five stages of sexual maturity from a pre-pubescent child through to post-pubescent adult (Kadel et al., 2005). Age at onset of menarche was also included in the survey for female participants. Growth was assessed by change in foot length (reliability during pilot testing on five dancers ICC = 0.54; typical error = 0.09 cm). Kinovea video analysis software (v 8.15) was used to measure foot length at baseline and six months (Figure 3). Foot length was defined as the distance between the tip of the longest toe (first or second distal phalanx) to the most posterior point on the heel (calcaneus). The dancer stood with full body weight on the foot being assessed during all photographs. All height and body mass data were

collected by the ABS physician. The timetables for each year level at ABS were used to calculate injury rates both per 1000 dance hours and per 1000 dance exposures.

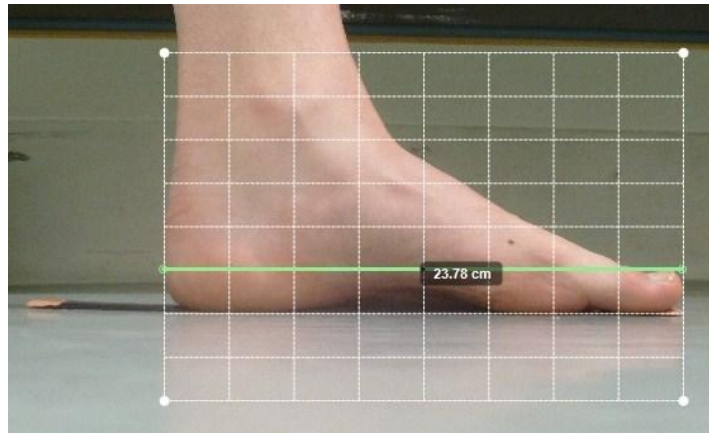


Figure 3: Foot length measure

Lower extremity alignment was also measured in all dancers. Each dancer was asked to perform two functional dance movements, a *fondue* (single knee bend in external rotation) and *temps levé* (single leg vertical jump in turnout). Tape was used to mark the Anterior Superior Iliac Spine (ASIS), centre of the patella and centre of the ankle joint bilaterally. Participants performed three repetitions of each movement on both legs with the arms held in a classical ballet position. Two digital cameras (Panasonic, U.S.A.) were used, the first parallel to the frontal plane of the body and the second perpendicular to the line of the foot. The second camera position was adjustable to ensure the camera was always perpendicular to the line of the dancer's foot irrespective of the dancer's turnout range (Figure 4). All cameras were positioned on tripods, level with the floor at a height of 0.86 metres and a distance of 1-2 metres from the dancer. The *fondue* movement was captured at a rate of 30 frames per second (fps) and the *temps levé* at a rate of 250 fps.

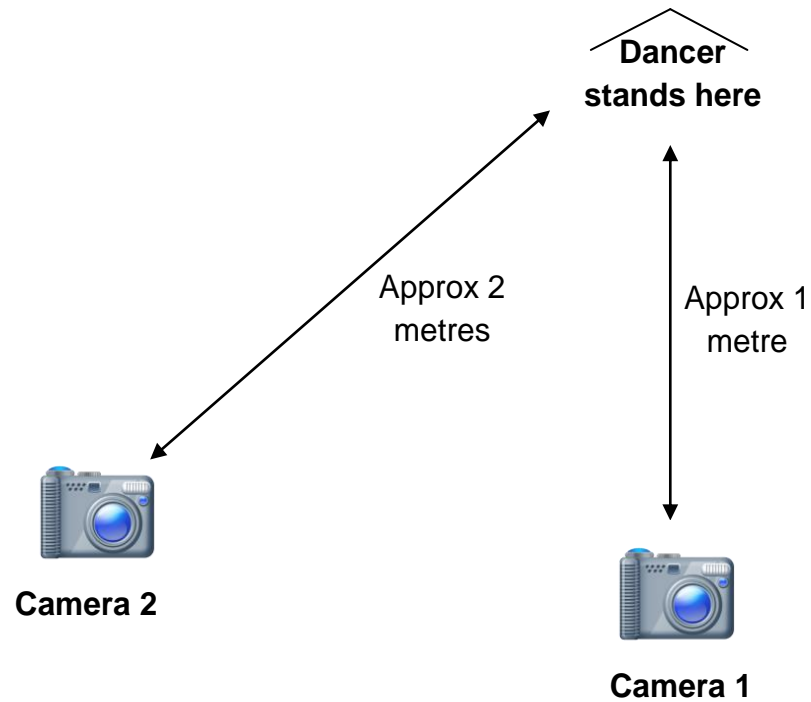


Figure 4: Camera set-up – Camera 1 positioned parallel to the frontal plane of the dancer and Camera 2 positioned perpendicular to the line of the foot of each dancer in their functional turnout position.

Using Kinovea video analysis software (v 8.15) a modified knee valgus angle, (Camera 2) and lateral tilt of the pelvis (Camera 1) were measured (Figure 5) for both the *fondue* and *temps levé* movements. These are the most commonly reported 2D frontal plane, lower extremity alignment measures in athletes (Whatman et al., 2012). The modified knee valgus angles were measured at the point when the patella was observed to be most medially positioned relative to the second toe. The pelvic angle was measured at maximal knee flexion which was visually estimated.

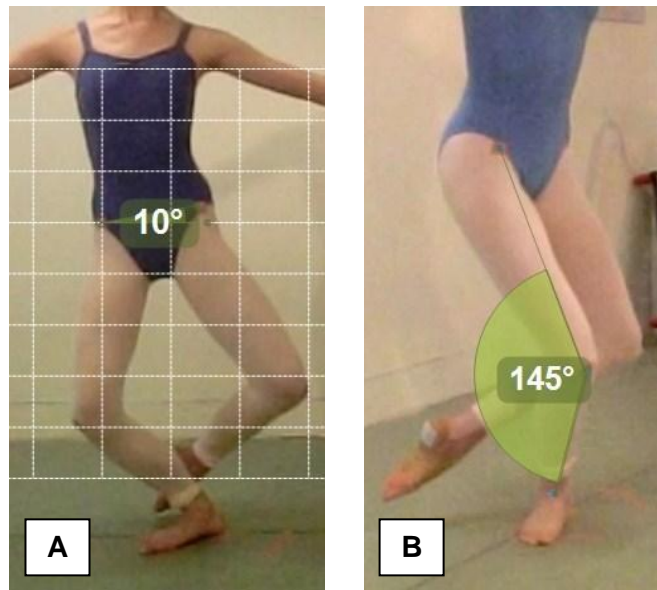


Figure 5: 2D knee and pelvic measures. A: The pelvic angle was measured by assessing the line of the ASIS's relative to the horizontal. B: The modified knee valgus angle was calculated by connecting the bony landmarks of the ASIS, centre of patella and centre of the ankle joint.

For the purpose of this study the definition of injury was modified from Krasnow et al. (1999). Injury was defined as any physical harm resulting in pain or discomfort that required a dancer to modify their dance activity during one or more classes, or which required a dancer to cease all dance related activity. Injuries were diagnosed and recorded by the ABS physiotherapist for the duration of the six month study. Only injuries which occurred as a result of dance training, were located in the lumbar spine and/or lower extremities of the body, and were of an overuse nature were included in the data collection. Information recorded included the injury diagnosis and location, whether the injury was new or ongoing, and the severity of the injury. Injury severity was coded as S1 (modified class), S2 (off class less than seven days), or S3 (off class more than seven days). Dependent variables in the analysis were (i) total count of injuries, and (ii) total count of injuries on the right or left legs (severity was not considered in the injury counts). Overall injury incidence rates were calculated both as the number of injuries per 1000 dance hours and per 1000 dance exposures.

All analyses were conducted using IBM SPSS Statistics for Windows, version 21 (IBM Corp, Armonk, NY). Descriptive statistics were calculated for all variables including means and standard deviations (SD). The overall injury rate ratio (RR) associated with each risk factor was estimated using over-dispersed Poisson regression modelling. For each risk factor, separate Poisson regression models were used to estimate the RR associated with different levels of the risk factor. Factors included in the models for total injury count were gender, age, height, body mass, Tanner stage, occurrence of menarche, and change in foot length. The RRs represent

the change in injury rate associated with a one unit change in the risk factors or a change considered substantial based on the standard deviation of the between subject baseline measures: foot length (0.5 cm); height (9 cm); body mass (10 kg).

Right and left leg injury RRs associated with the lower extremity alignment measures were also estimated using over-dispersed Poisson regression modelling. In this model the RRs represent the average change in injury rate associated with a 10° increase in knee angle, and a two degree increase in pelvic angle having accounted for gender. These changes in angles represent substantial changes based on the between subject standard deviations of the baseline knee and pelvic angles.

A spreadsheet for deriving magnitude based inferences from p values (Hopkins, 2007) was used to make a qualitative inference about the true value of the RR relative to thresholds for a substantial decrease in injury risk (RR = 0.90) or substantial increase in injury risk (RR = 1.11) (Hopkins, Batterham, Marshall, & Hanin, 2009). Qualitative inferences were unclear if there was >5% chance the true value of the rate ratio could both substantially increase and decrease injury risk. Otherwise the outcome was clear and the inference was based on the likelihood the true value of the RR was less than 0.90 or greater than 1.11 using the following scale: 25-75% (possibly); >75% likely; >95% very likely; >99.5% most likely (Hopkins et al., 2009). Magnitudes of observed RR's were interpreted based on the following scale: 1.11 (small), 1.4 (moderate), 2.0 (large), 3.0 (very large), 10.0 (extremely large) and their inverse (Hopkins et al., 2009).

Results

A summary of baseline dancer characteristics are presented in Table 4. Tanner stages one to five were recoded to create a dichotomous classification of maturation for subsequent analysis. No dancers identified themselves as Tanner stage one. Tanner stages two and three were re-classified as maturation level one, and Tanner stages four and five as maturation level two. Over the six month follow-up period change in foot length (cm) was; mean \pm SD, left foot 0.34 \pm 0.25; right foot 0.34 \pm 0.32 (based on 42 dancers).

A total of 59 injuries were reported for 29 dancers over the follow-up period of six months. Sixteen of those 29 dancers suffered from multiple injuries. Table 5 presents the injury counts and injury rates for all dancers, males and females, right and left legs, and lumbar spine. The rates of injuries are expressed both per 1000 dance exposures and per 1000 dance hours. The feet were the site of the highest number of injuries and the majority of injuries were severity S1 (Figure 6).

Right knee angles, pelvic angles and changes in right foot length were associated with clear changes in injury risk that were likely to be substantial (Table 6). A difference of 0.5 cm in right foot length growth was linked to a moderate increase in injury risk (RR = 1.41, CI = 0.93-2.13). A 10° greater right knee angle (improved alignment) in both the *fondue* and *temps levé* resulted

in a moderate decrease in injury risk for the *fondue* (RR = 0.68, CI = 0.45-1.03) and a small decrease in injury risk for the *temps levé* (RR = 0.72, CI = 0.53-0.98). A two degree greater pelvic angle for the *temps levé* on the left leg was associated with a moderate decrease in injury risk (RR = 0.52, CI = 0.30-0.90). In contrast a two degree greater pelvic angle for the *fondue* on the right leg was associated with a small increase in injury risk (RR = 1.28, CI = 0.91-1.80). Gender, the knee and pelvic angles during the *fondue* on the left leg, and the pelvic angles during the *fondue* and *temps levé* on the right leg were associated with small observed increases in injury risk, however these effects were unclear. Age, height, body mass, maturation level, and menstruation were all linked to trivial observed changes in injury risk however these effects were again unclear.

Table 4. Baseline descriptors of dancer characteristics, peak knee and pelvic angles (mean \pm SD)

Height (cm)	168.7 \pm 8.8
Body Mass (kg)	53.4 \pm 9.5
Maturation Level 1 (%)	41
Maturation Level 2 (%)	59
Menstruated (%)	70
Right Knee Fondue (°)	175 \pm 3
Left Knee Fondue (°)	186 \pm 3
Right Pelvis Fondue (°)	3 \pm 1
Left Pelvis Fondue (°)	2 \pm 1
Right Knee Temps Levé (°)	161 \pm 7
Left Knee Temps Levé (°)	176 \pm 6
Right Pelvis Temps Levé (°)	3 \pm 1
Left Pelvis Temps Levé (°)	2 \pm 1

Table 5. Injury rates per 1000 dance exposures and 1000 dance hours

	Injury Count	Injuries per 1000 Dance Exposures	Injuries per 1000 Hours
All dancers	59	3.52	2.40
Female	35	3.21	2.19
Male	24	4.12	2.81
Right Leg	19	1.13	0.77
Left Leg	27	1.61	1.11
Lumbar Spine	13	0.78	0.53

Table 6. Effect of risk factors on rate of lower extremity overuse injury

	Risk Factor	Rate Ratio (90% CI)	Inference*
All Injuries	Gender (female)	1.16 (0.68-1.97)	Unclear
	Age	1.03 (0.88-1.21)	Unclear
	Height (9 cm)	1.03 (0.85-1.25)	Unclear
	Body Mass (10 kg)	1.08 (0.85-1.37)	Unclear
	Maturation Level	1.06 (0.59-1.90)	Unclear
	Menstruation	1.03 (0.10-8.95)	Unclear
	R Foot Length change (0.5 cm)	1.41 (0.93-2.13)	Likely increased risk
	L Foot Length change (0.5 cm)	1.37 (0.77-2.44)	Unclear
Injuries (R)	F Knee angle (10°)	0.68 (0.45-1.03)	Likely decreased risk
	TL Knee angle (10°)	0.72 (0.53-0.98)	Likely decreased risk
	F Pelvic angle (2°)	1.28 (0.91-1.80)	Likely increased risk
	TL Pelvic angle (2°)	1.13 (0.77-1.66)	Unclear
Injuries (L)	F Knee angle (10°)	1.19 (0.85-1.67)	Unclear
	TL Knee angle (10°)	1.02 (0.81-1.29)	Unclear
	F Pelvic angle (2°)	1.28 (0.88-1.86)	Unclear
	TL Pelvic angle (2°)	0.52 (0.30-0.90)	Likely decreased risk

*R=right, L=left, F=fondue, TL=temps levé, *=likelihood the change in injury risk is substantial (rate ratio <0.90 or >1.11)*

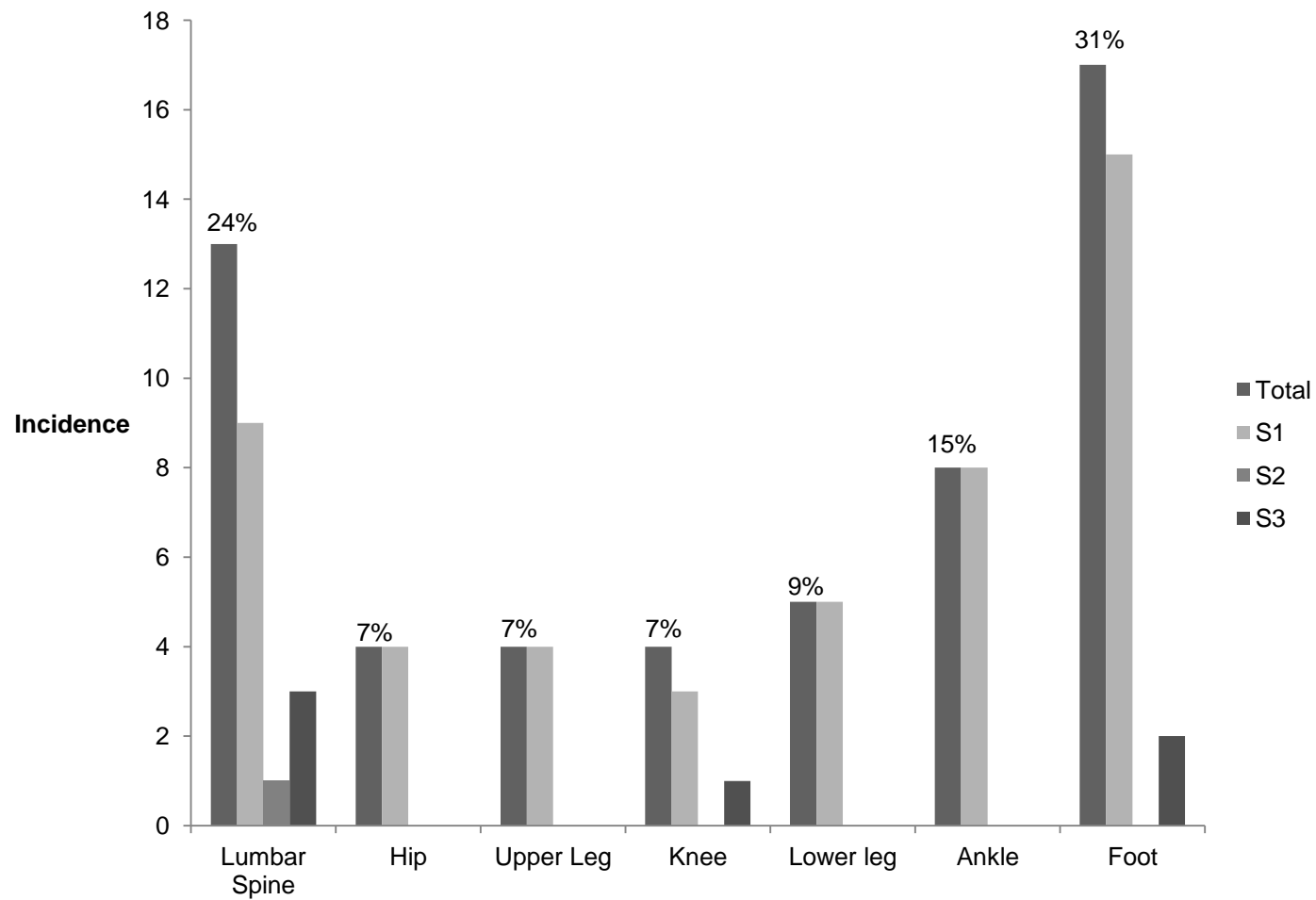


Figure 6: Incidence and severity of injury by body region. S1=modified class, S2=off class less than seven days, S3=off class more than seven days

Discussion

Several factors have been proposed as increasing the risk of overuse injuries in elite adolescent ballet dancers and athletes. These factors include the rapid growth that occurs during adolescence, the associated period of maturation that includes onset of menarche for females and poor lower extremity alignment (Ford et al., 2010; Hewett et al., 2004; Matthews et al., 2006; Murphy et al., 2003; Poggini et al., 1999; Steinberg et al., 2008; Whatman et al., 2012; Willson et al., 2006). Currently no research has prospectively examined the effect of these risk factors on injury occurrence in elite adolescent ballet dancers.

The purpose of this study was to determine whether growth, stage of maturation, and lower extremity alignment were associated with overuse injury risk in elite adolescent ballet dancers. A total of 59 injuries were recorded for 46 dancers over a six month period with an injury rate of 3.52 injuries per 1000 dance exposures and 2.40 injuries per 1000 dance hours. These injury rates are higher than those reported in previous studies of elite adolescent dancers but lower than rates reported for professional adult dancer populations. An injury rate of 1.9 injuries per 1000 dance exposures was reported for elite adolescent ballet students studied prospectively over a 12 month period, however the participant numbers were significantly higher at 266 (Ekegren et al., 2011). A further study of 204 elite adolescent dancers also reported injury rates lower than those in the current study with 1.09 injuries reported per 1000 exposures and 0.77 injuries per 1000 hours, although the data was collected retrospectively over a five year period (Gamboa et al., 2008). In contrast, an injury incidence of 4.4 injuries per 1000 hours was reported by Allen et al. (2012) in a 12 month prospective study of 52 professional adult ballet dancers. This is considerably higher than the injury rate of 2.24 injuries per 1000 hours in the current study.

Knee angle, pelvic angle and changes in foot length were all likely to have substantial effects on injury risk. Several authors have proposed a theoretical link between rate of bone growth and increased risk of injury due to an increased load on soft tissues (Poggini et al., 1999). However there is little previous evidence to support growth as a risk factor in elite adolescent athletes or dancers (Leanderson et al., 2011; Steinberg et al., 2011). This is one of the first studies to link growth (as measured by change in foot length) to an increase in injury risk. A moderate increase in risk was associated with differences in right foot length growth and although unclear due to greater uncertainty, a small increase in injury risk was also observed with differences in left foot length growth. These findings suggest there may be a small to moderate increase in risk of overuse lower extremity injury associated with growth in elite adolescent ballet dancers. In contrast, the height of the dancers was not a risk factor for injury, although the measure of height was not a change variable, but simply an association of risk between differing heights at baseline. The observation of no change in injury risk associated with height may also be due to greater variability in the measurement of standing height, noted as a concern by several authors (Voss & Bailey, 1994; Voss et al., 1990; Voss et al., 1991). Change in foot length was preferred as a measure of growth in the current study as several studies have suggested its use as an

indicator of growth (Aml et al., 1997; Dimeglio, 2001). Although not commonly used, the simple measure of photographing and measuring foot length was shown to be moderately reliable in our own pilot testing (ICC = 0.54; typical error = 0.09 cm). Due to the increase in injury risk observed with an increase in growth, the tracking of growth using a combination of both change in foot length and standing height may be useful for health professionals or instructors involved in the training of elite adolescent dancers.

Poor alignment of the lower extremities is thought to increase the risk of injury in athletes (Nguyen et al., 2011; Patrek et al., 2011) and biomechanical theories suggest that poor lower extremity alignment would also increase the risk of injury for dancers. This is supported by findings in the current study which identified a moderate decrease in right leg injury risk associated with a 10° reduction in knee valgus angle on the right leg during a *fondue* movement (single knee bend in external rotation). A small decrease in right leg injury risk was also observed with a 10° improvement in knee valgus angle on the right side during a *temps levé* movement (single leg hop in external rotation). This finding supports previous research which has reported a relationship between poor knee alignment in female athletes and an increased likelihood of lower leg injury (Patrek et al., 2011; Powers, 2010). There was no change in injury risk observed for the knee angle during the *fondue* and *temps levé* on the left side; however, this observation may be explained by the dancers' limb dominance. It has been stated that a dancer will have anatomical asymmetries and exhibit lateral preferences for certain dance skills (Kimmerle, 2010). During testing, participants were given the option of choosing the leg on which they would prefer to initially perform each movement with 82% of dancers indicating the right leg as their preference, potentially indicating right side dominance. It is possible that given the preference for the right side, this leg is used preferentially during training resulting in greater load including increased repetitions of take-offs and landings. Thus the observed relationship between injury and alignment on the right side may be due to this increased exposure. Findings from the current study indicate that greater knee alignment can result in a small to moderate decrease in risk of lower extremity overuse injury in elite adolescent ballet dancers. Thus, a continued focus on training and emphasising correct lower extremity alignment in dancers is recommended for all teachers involved with adolescent ballet dancers.

A further finding of the current study indicated that when measured during the *temps levé* movement on the left leg, an increase of two degrees in pelvic angle (right side higher) was likely linked to a moderate decrease in left leg injury risk. Previous authors have suggested a link between improved hip abductor muscle function and reduced injury risk (Jacobs, Uhl, Mattacola, Shapiro, & Rayens, 2007) which could be an explanation for the observed reduction in injury with an increase in pelvic angle. Increased pelvic angle has also been shown to improve dissipation of impact forces on landing (Myer, Ford, McLean, & Hewett, 2006) and this may also decrease injury risk. Pelvic obliquity is thought to play a role in shock absorption by controlling the descent and ascent of the body's centre of gravity, particularly during running (Schache, Bennell, Blanch, & Wrigley, 1999). Additionally, too little or too much pelvic obliquity can result in either stiffness or excess mobility in the pelvis and lower back, leading to the possibility of increased risk of injury (Schache et al., 1999; Schache, Blanch, Rath, Wrigley, &

Bennell, 2002). In contrast to the *temps levé* which has impact load, an increase in pelvic angle during the *fondue*, which has no impact load, was linked to a likely small increase in injury risk and this could be as a result of increased stiffness in the pelvis and lower back. It should be noted that a difference in pelvic angle of two degrees may be difficult to reliably measure and the effect of pelvic angle on injury risk was not consistent across all tests.

Previous research has suggested that due to the variation observed in growth and maturation between adolescents, chronological age may be an inaccurate indicator for the level of risk for injury for an adolescent athlete (Helsen et al., 2005). This is supported by the current research with no substantial association between injury risk and age. Furthermore, although the result was unclear, there was a 70% likelihood the effect of age on injury risk was trivial. This is in contrast to findings from both Leanderson et al. (2011) and Steinberg et al. (2011) who reported an increase in injury incidence with an increase in age. However, the observed increase in injury incidence in these studies coincided not only with an increase in age but also with an increase in dance exposure (Steinberg et al., 2011); a factor which was not examined in the current study but which may warrant further investigation.

The effect of maturational level on injury risk was also unclear with no observed change in injury risk, however this may be due to limited numbers of participants and a short follow-up period. Although unclear, the observed finding in the current study is supported by previous studies that suggest the period of maturation has a limited impact on injury risk in elite adolescent dancers (Matthews et al., 2006; Steinberg et al., 2008). Risk associated with maturational level needs to be clarified with further studies of larger numbers of dancers over an increased time period. Also associated with the adolescent period of maturation is the onset of menarche. Several studies have reported associations between delayed onset of menarche and secondary amenorrhoea, and increased incidences of injuries, in particular stress fractures (Kadel et al., 1992; Warren et al., 1986). This study served only to identify whether the presence or absence of the onset of menarche was a contributing risk factor to injury in elite adolescent ballet dancers. Again this finding was unclear although there was no substantial observed increase in risk. It should be noted that data was collected only in regard to whether the females had experienced onset of menarche and the age at which this occurred. No further information concerning primary or secondary amenorrhoea, or in regard to the presence of any abnormal menstrual patterns were recorded. In addition, due to only being applicable to female dancers, numbers were further reduced.

The main limitation of this study was the number of dancers tested which was primarily based on the number of dancers available at the Australian Ballet School. Due to the low sample size, a number of findings related to injury risk factors were unclear. Small to moderate increases in injury risk were however observed for a number of these factors and this provides evidence these risk factors are worthy of further investigation. An additional limitation was the loss of four dancers during the study which may have affected the observed risk ratios.

Conclusion

Rate of growth in elite adolescent ballet dancers is likely associated with a small to moderate increase in risk of lumbar and lower extremity overuse injury. Conversely, greater right lower extremity alignment is likely associated with a reduction in risk of right lower extremity overuse injury. While the effects were unclear, there were observed changes in risk associated with several other factors and these warrant further investigation. Monitoring growth and screening lower extremity alignment may be useful as injury prevention strategies in adolescent ballet dancers.

CHAPTER 6

DISCUSSION AND CONCLUSIONS

Potential elite ballet dancers are being identified as talented for entrance into long term development programs or full-time training at increasingly young ages. However injuries, particularly of an overuse nature in the lower extremities, are prevalent among young elite dancers, leading to disruptions in both training and talent development. Furthermore, for those dancers identified as talented, an increase in training intensity often occurs just as dancers begin to enter adolescence and a link between increased training, the onset of puberty and increased injury incidence has been reported.

The epidemiology of lower extremity overuse injuries is considered multifactorial, however on the basis of the literature review several key risk factors for injury in adolescent dancers have been proposed. The key factors identified included the adolescent growth spurt, the associated period of maturation including onset of menarche for females, and the dynamic alignment of the lower extremity. Thus this Master's thesis sought to analyse the effect of key factors on the risk of overuse lower extremity injury in elite adolescent ballet dancers.

While poor dynamic lower extremity alignment has been identified as a key risk factor for injury in athletes, the effect of poor alignment in elite adolescent dancers had not been considered. In order to assess lower extremity alignment as a risk factor for injury, the reliability of lower extremity alignment measures in ballet dancers first had to be established. Therefore, the primary aim of chapter four was to investigate the reliability of two-dimensional (2D) measures of knee and pelvic alignment during two lower extremity functional dance movements (*fondue* and *temps levé*). A modified knee valgus angle and lateral pelvic tilt were measured using 2D video which is ideal for use by dance practitioners as it is simple and inexpensive. Excellent ICC values (*fondue* ICC = 0.88 to 0.89; *temps levé* ICC = 0.80 to 0.87) indicated that 2D video analysis of a modified knee valgus angle for both movements was reliable between trials. The frontal plane pelvic measure was also reliable (*fondue* ICC = 0.67 to 0.79; *temps levé* ICC = 0.68 to 0.71). Excellent ICC values were also observed for the depth of movement for the *fondue* and *temps levé* indicating high repeatability of the movements by adolescent dancers. Greater variability was observed in the knee angles during the *temps levés* which may be explained by the increased speed and load of the *temps levé* jump in comparison to the *fondue*. A strong correlation was noted between the movements for the *fondue* and *temps levé* on both legs indicating that good execution of the *fondue* transfers to a higher load *temps levé*. As high speed movement is difficult to rate visually, dance practitioners may be able to infer alignment based on the slower (more easily observed) *fondue*. The study identified that this simple, inexpensive screening technique using 2D video may be useful to dance practitioners.

Given the limited research available on key risk factors for injury in adolescent dancers, the main aim of chapter five was to identify the effect of growth, maturation and dynamic lower extremity alignment on overuse injury in elite adolescent ballet dancers. Knee angle, pelvic angle and changes in foot length were all observed to have substantial effects on injury risk. The key findings suggested there may be a small to moderate increase in risk of overuse lower extremity injury associated with growth in elite adolescent ballet dancers. An improvement in knee valgus angle on the right leg during the *fondue* and *temps levé* demonstrated moderate and small decreases in right leg injury risk respectively. No change in injury risk was observed for the knee angle during the *fondue* and *temps levé* on the left leg. An increase in pelvic angle was likely linked to a moderate decrease in left leg injury risk when measured during the *temps levé*. In contrast, a small increase in injury risk was linked to an increase in pelvic angle during the *fondue*. The increased angle during the *temps levé* may help dissipate landing forces (decreasing risk) while the increased angle in the *fondue* may increase lumbopelvic stiffness (increasing risk). Given the inconsistency of the findings across all tests, interpretation of pelvic angle in relation to injury risk requires further investigation.

No substantial association was observed between injury risk and age, height, body mass or maturation level, although these findings were unclear due to the associated uncertainty in these estimates of risk. Also associated with the adolescent period of maturation is the onset of menarche. This study only identified whether the presence or absence of the onset of menarche was a contributing risk factor to injury in elite adolescent ballet dancers. This finding was again unclear, although there was no substantial observed increase in risk. Monitoring growth and screening lower extremity alignment may be useful as injury prevention strategies in this population.

Thesis Limitations

The studies presented in the thesis were, at times, limited by methodological constraints and these should be taken into account when interpreting the results.

- The principal limitation of the study was the number of dancers, which was primarily based on the number of dancers available at the Australian Ballet School (ABS). Due to the small sample size, a number of findings relating to injury risk factors were unclear although the results are representative of the target population. Four dancers also left the ABS during the six month period of the study and therefore were unable to be included in the final results of chapter five.
- The second limitation was the length of the follow-up period. In monitoring key variables of growth and maturity, six months provides a limited window of opportunity to observe substantial change. The combination of a limited time period and small sample size also resulted in a low number of injuries being recorded over the six month period, causing further limitations in regard to unclear injury risk factors. For this reason it is appropriate

that the ABS have committed to the continuation of this study for a further two years and they are currently in the process of recruiting more dancers to the study.

- The student researcher based in Auckland, New Zealand had limited time at the ABS in Melbourne to collect data, resulting in the analysis of only intra-rater and within-day reliability of the 2D knee and pelvic angles assessed in chapter four.
- Female participants were required to provide information as to whether they had achieved menarche and if so the age at which this had occurred. No further information was required, however this resulted in a gap in information with regard to any menstrual irregularities which had occurred or were occurring. This in turn limited the analysis of the effect of menarche on injury risk.
- Workload information such as the intensity or difficulty of class work was also not included in the study analysis. This would have been difficult to quantify, but nevertheless could be considered another critical factor contributing to the risk of lower extremity overuse injuries in elite adolescent dancers.

Recommendations for Future Research

Key areas identified for future research from chapter four include evaluating between-day reliability of the *fondue* and *temps levé* tests, along with inter-rater reliability of these measures. Although the use of 2D video to screen lower extremity alignment in dancers is increasing in popularity, many teachers visually rate movement without video assistance. Therefore, visual rating of lower extremity alignment in dancers requires investigation, as well as the use of visual rating in comparison to 2D video analysis. The use of these measures in comparative investigations between injured and uninjured ballet dancers and dancers of other ages and genres also warrants investigation.

The use of cameras in only two positions does not replicate clinical or teaching strategies in which practitioners or teachers view a dancer or movement from multiple angles. Future studies could evaluate the reliability of video and/or visual assessment of dance movement in comparison to three-dimensional (3D) techniques.

Several areas requiring further clarification arose from the assessment of key factors to injury risk in chapter five. While small to moderate increases in injury risk were observed for a number of factors including gender, right and left pelvic angles during the *fondue* and *temps levé*, and the left knee angle during the *fondue*, the inferences for these factors were unclear. However, the observed changes provide evidence these risk factors are worthy of further investigation.

The use of the Tanner scales should also be utilised in future research to determine the risk of injury associated with maturational levels, while also allowing for the potential identification of a pattern of injuries occurring with different maturation stages. Future studies need to be

conducted with an increased number of dancers over a longer time period. This will also allow future studies to begin developing evidence-based guidelines for suitable workloads for dancers during the period of growth and at different stages of maturity, ultimately leading to safer and more effective training systems for the dance industry.

A key factor which requires further investigation with regard to injury risk in adolescent dancers is workload. The effect of the intensity and difficulty of workload as a factor in injury risk should be considered in future studies.

The literature review also highlighted other areas for future research. There is a paucity of research conducted on male-only dancer populations. The review further highlighted limited information in regard to the key types of injuries observed at the most commonly reported injury sites. Finally, it was clear from the literature that the lack of standardised injury definitions as well as a lack of standardisation in regard to the quantification and reporting of overuse injuries in dancers makes drawing comparisons between injury studies challenging. Continuing development of standardisation of both injury definition and reporting would enhance the quality of research on injuries in dancers.

Conclusion

This thesis consists of two studies, the first evaluating the reliability of 2D video in measuring dynamic lower extremity alignment in dancers, the second investigating the effect of several factors on lower quarter overuse injury risk in elite adolescent dancers. This study is the first to demonstrate the reliability of 2D video in the assessment of lower extremity alignment during functional dance movement and one of the first to link growth and lower extremity alignment to injury risk in elite adolescent dancers.

While it is conceivably highly unlikely that the dance industry can be completely devoid of injury, many injuries may be preventable, particularly among adolescents. Monitoring of growth and lower extremity alignment in elite adolescent dancers may assist with injury prevention.

PRACTITIONERS SUMMARY PAGE

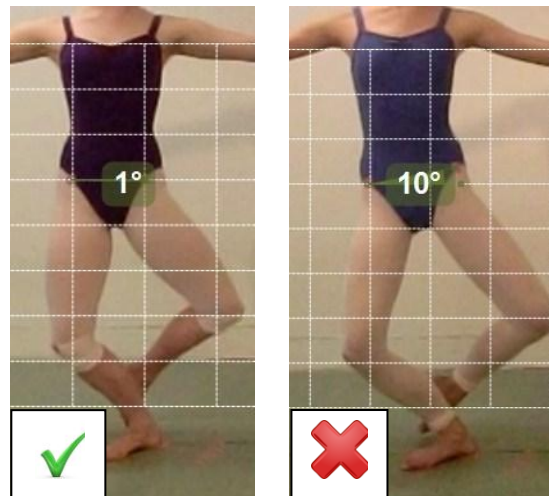
Lower extremity overuse injuries are common among adolescent ballet dancers. Poor dynamic alignment of the lower extremity and periods of fast growth rates are potential risk factor for these injuries. Visual and/or video assessment of simple dance movements may assist in the identification of poor alignment in young dancers and rate of growth can be assessed by a simple foot photograph.

For the alignment measures, sports tape is used to mark the position of the anterior superior iliac spine (ASIS) and centre of the patella of the dancer prior to video capture. All measures were made using KINOVEA video analysis software (free download from www.kinovea.com).

Lower extremity alignment measures

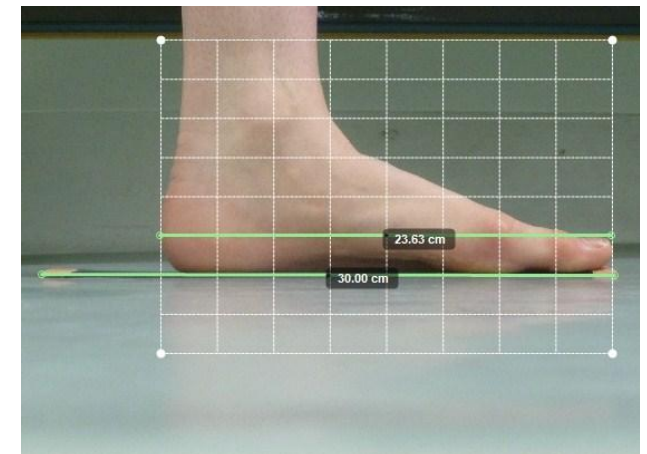


Modified knee valgus angle Camera positioned perpendicular to the line of the foot in the dancer's functional turnout position. Three repetitions of a *fondue* and *temps levé* are performed. The angle is measured by connecting the ASIS, centre of the patella, and centre of the ankle joint. An average from the three repetitions is recorded.



Pelvic angle Camera positioned parallel to the frontal plane of the dancer. The dancer performs three repetitions of a *fondue* and *temps levé*. The pelvic angle is measured by assessing the line of the ASIS's relative to the horizontal (ASIS of the weight bearing limb to the ASIS of the non-weight bearing limb). An average from the three repetitions is recorded.

Rate of growth measure



Foot length The dancer stands on a standard 30 centimetre ruler with full body weight on the foot being measured. Foot length is measured from the tip of the longest toe (first or second) to the most posterior point on the heel. The ruler provides a scale reference for the video analysis.

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Participant Information Sheet



Date Information Sheet Produced: 9 July 2012

Project Title: Differences in maturation, growth, and lower extremity alignment between injured and uninjured classical Australian Ballet School dancers

An Invitation

My name is Erin Bowerman and I am completing a Master of Sport and Exercise at AUT University in Auckland, New Zealand. As part of my qualification I am required to carry out a research project and I would like to invite you to take part in my study.

The study is investigating causes of injury in adolescent pre-professional dancers such as yourself. The study will include growth, maturation, landing alignment and injury measures collected every 6 months for three years.

Together, you and your parents should decide whether or not you would like to be involved. You don't have to be involved, it won't affect your role at ABS, and you can

stop being involved in the study at any time. You can also discuss the project with Janet Karin at the ABS.

What is the purpose of this research?

The purpose of this research is to help develop knowledge around preventing injuries in elite pre-professional ballet dancers like you. Right now we do not know if physical maturity and growth affect the injuries teenage dancers suffer from. The results of this research could help us find out if there are certain stages when you are growing that it is more likely you might get a certain type of injury. Also, the research might help your teachers and conditioning instructors give you the right amount of work for your body based on your growth instead of based on your age which could help to stop you getting injured in the future.

The completed research will result in a published thesis as part of the requirements of the Master of Sport and Exercise at AUT University.

How was I identified and why am I being invited to participate in this research?

You have been identified and invited to take part in this study because you are enrolled as a full time student at the Australian Ballet School and you are either between the ages of 13 and 18 or are currently dancing at level 4, 5, 6, 7 or 8 under the Australian Ballet School training system.

What will happen in this research?

We will ask you to complete a private self-assessment of your physical growth every six months for three years, using the Tanner scales of assessment. The Tanner scales are a series of diagrams of the female and male body that show usual growth during

the teenage years. You will be asked to tick which diagram best matches the way your body looks. Female dancers, you will be asked an extra question about if and when you had your first period. You will fill the form out by yourself at home. You will be given your own unique identification code which you will put on the form instead of your name, and you will use a reply-paid envelope to return it to Dr Elizabeth Bradshaw at Australian Catholic University (ACU) in Melbourne. To help us monitor your growth even more we will also take a digital photograph of one of your feet every six months.

We will also require your consent to allow the Medical Practitioner to send us your records of date of birth, height and body mass every six months along with your injury records. Your records will also only have your unique identification code on them and not your name.

We will also take a video recording of you doing three hops in a row on both legs and from the video recordings your leg line will be rated. Your unique identification code will also be used for the video. You will only have to do the jump test at the very beginning of the study and this will not be repeated every six months.

What are the discomforts and risks?

The level of risk will be no more than what you experience as part of your usual training. You might feel a little bit embarrassed about identifying which body you look most like from the different diagrams we will give you, and girls about identifying when you had your first period.

How will these discomforts and risks be alleviated?

This embarrassment will be removed by ensuring the process remains anonymous. You will be asked to complete the form by yourself in your own home using a unique identification code which you will be given. You will then post the form in a reply-paid envelope back to additional supervisor of the study, Dr. Elizabeth Bradshaw at Australian Catholic University. For the duration of the study you will be provided with a unique identification code which will be used on all your individual data collected instead of your name. The only people who will know your unique identification code and your name will be the physiotherapist and the Kinetic Educator at the Australian Ballet School.

What are the benefits?

Your contribution to the study will result in helping to develop greater knowledge around adolescent dancers and injury prevention, hopefully lowering the risk of injury for both yourself and others in the future.

The completion of this research also contributes to a Masters qualification and upon completion you will be provided the results of the study.

How will my privacy be protected?

All data collected will remain completely anonymous to the researchers throughout the study and at no stage will any individuals be identifiable in any way in any published documents.

What are the costs of participating in this research?

There is no monetary cost to you to be involved in this research, the only cost is time. Every six months for the next three years you will need to give up approximately 5 - 10 minutes of your time to fill out the sheet about your physical maturity and post it to Dr. Elizabeth Bradshaw, and to have a photograph taken of one of your feet.
How do I agree to participate in this research?

If you agree to take part in the research you will need to fill out a consent form if you are over 16 years of age. If you are under 16 years of age you will need to fill out an assent form while a parent or guardian will need to fill out a consent form agreeing to let you take part.

You will be given a copy of the consent and/or assent forms with this information sheet. If you do not return a signed consent and assent form you will not be allowed to participate in the study.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor Chris Whatman, chris.whatman@aut.ac.nz, (09) 921 9999 ext 7037

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTECH, Dr Rosemary Godbold, rosemary.godbold@aut.ac.nz, 921 9999 ext 6902.

Whom do I contact for further information about this research?

Researcher contact details:

If you would like any further information about the study at any stage please feel free to contact Primary researcher, Erin Bowerman at erin@westmerepilates.co.nz, or Janet Karin at ABS.

Project Supervisor Contact Details:

Primary Supervisor Chris Whatman

Faculty of Health and Environmental Sciences

AUT University

(09) 921 9999, Ext. 7037

chris.whatman@aut.ac.nz

Additional Supervisor Dr. Elizabeth Bradshaw

Faculty of Health Sciences

Australian Catholic University

(03) 9953 3030

Thank you for considering whether to take part in this research.

Parent/Guardian Consent Form



Project title: *Differences in maturation, growth, and lower extremity alignment between injured and uninjured classical Australian Ballet School dancers*

Project Supervisor: *Chris Whatman*

Researcher: *Erin Bowerman*

- ☐ I have read and understood the information provided about this research project designed to investigate differences in maturation, growth, alignment and injury in dancers at the Australian Ballet School in the Information Sheet dated 09 July 2012.
- ☐ I understand that the duration of this study is three years.
- ☐ I have had an opportunity to ask questions and am happy with the answers I have received.
- ☐ I understand that taking part in the study is entirely my choice and that I may withdraw my child/children and/or myself or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ☐ I permit the researcher to use the videos that are part of this project and/or any photographs from them and any other reproductions or adaptations from them, either complete or in part, alone or in conjunction with any wording and/or drawings solely and exclusively for research or educational purposes
- ☐ I understand that the videos will be used for academic purposes only and will not be published in any form outside of this project without my written permission.
- ☐ I understand that any copyright material created by the video is deemed to be owned by the researcher and that I do not own copyright of any of the video.
- ☐ If my child/children and/or I withdraw, I understand that all relevant information including photographs, video footage, or parts thereof, will be destroyed.
- ☐ I understand that any information my child/I give during this study will be confidential and my child's/my name will not be recorded on any collected data at any time.
- ☐ I agree to my child/children taking part in this research.
- ☐ I wish to receive a copy of the report from the research (please tick one): Yes ☐ No ☐

Child/children's name/s :

.....

Parent/Guardian's signature:

.....

Parent/Guardian's name:

.....

Parent/Guardian's Contact Details (if appropriate):

.....

Date:

Approved by the Auckland University of Technology Ethics Committee on 23 July 2012 AUTEC Reference number 12/175

Note: The Participant should retain a copy of this form

Participant Assent Form



*Project title: **Differences in maturation, growth, and lower extremity alignment between injured and uninjured classical Australian Ballet School dancers***

*Project Supervisor: **Chris Whatman***

*Researcher: **Erin Bowerman***

- ☐ I have read and understood the sheet telling me what will happen in this study about injuries and alignment and growth in dancers at the Australian Ballet School and why it is important.
- ☐ I understand that this study lasts for three years.
- ☐ I have been able to ask questions and am happy with how they have been answered.
- ☐ I understand that being part of this study is entirely my choice and that while the information is being collected I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.
- ☐ I will allow the researcher to use the videos and photographs that are part of this project exclusively for research or educational purposes
- ☐ I understand that the videos will be used for academic purposes only and will not be published in any form outside of this project without my written permission.
- ☐ I understand that any copyright material created by the video is deemed to be owned by the researcher and that I do not own copyright of any of the video.
- ☐ If I stop being part of the study, I understand that all information about me, including the photographs and video recordings or any part of them that include me, will be destroyed.
- ☐ I understand that any information I give during this study will not have my name on it and my name will not be recorded on any collected data at any time.
- ☐ I agree to take part in this research.

Participant's
signature:.....

Participant's
name:.....

Participant Contact Details (if appropriate):

.....

Date:

***Approved by the Auckland University of Technology Ethics Committee on 23
July 2012 AUTEC Reference number 12/175***

Note: The Participant should retain a copy of this form.

Participant Consent Form



Project title: *Differences in maturation, growth, and lower extremity alignment between injured and uninjured classical Australian Ballet School dancers*

Project Supervisor: *Chris Whatman*

Researcher: *Erin Bowerman*

- ☐ I have read and understood the information provided about this research project designed to investigate differences in maturation, growth, alignment and injury in dancers at the Australian Ballet School in the Information Sheet dated 09 July 2012.
- ☐ I understand that the duration of this study is three years.
- ☐ I have had an opportunity to ask questions and am happy with the answers I have received.
- ☐ I understand that taking part in the study is entirely my choice and that I may withdraw any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ☐ I permit the researcher to use the videos that are part of this project and/or any photographs from them and any other reproductions or adaptations from them, either complete or in part, alone or in conjunction with any wording and/or drawings solely and exclusively for research or educational purposes
- ☐ I understand that the videos will be used for academic purposes only and will not be published in any form outside of this project without my written permission.
- ☐ I understand that any copyright material created by the video is deemed to be owned by the researcher and that I do not own copyright of any of the video.
- ☐ If I withdraw, I understand that all relevant information including photographs, video footage, or parts thereof, will be destroyed.
- ☐ I understand that any information I give during this study will be confidential and my name will not be recorded on any collected data at any time.
- ☐ I agree to taking part in this research.
- ☐ I wish to receive a copy of the report from the research (please tick one): Yes ☐ No ☐

Participant name :

.....

.....

.....

Participant signature:

.....

Participant Contact Details (if appropriate):

.....

Date:

Approved by the Auckland University of Technology Ethics Committee on 23 July 2012 AUTEC Reference number 12/175

Note: The Participant should retain a copy of this form.

APPENDIX 5

QUESTIONNAIRE

Girls

TITLE OF PROJECT: **Maturation and Injury Patterns in Elite Ballet Training**

PRINCIPAL INVESTIGATORS: **Elizabeth Bradshaw and Janet Karin**

Dear Participant,

Please look at the diagrams below and place a tick next to the picture that best matches your body. Then add today's date and your unique identification code for this study to the form. We would also like to know if, and when, you had your first period.

Afterwards, please fold up the questionnaire and place it in the envelope provided. Please place the envelope in your nearest post box.

Thank-you for your time.

Kind Regards,

Liz Bradshaw and Janet Karin

Date: _____. ____ (day/month/year)

Identification Code: _____

Have you had your first period? Yes / No (please circle)

If you answered Yes, how old were you when you had your first period?

_____ years _____ months (if known)

Please place a tick next to the diagram that best matches your body ✓

I			
II			
III			
IV			
V			

APPENDIX 6

QUESTIONNAIRE

Boys

TITLE OF PROJECT: **Maturation and Injury Patterns in Elite Ballet Training**

PRINCIPAL INVESTIGATORS: **Elizabeth Bradshaw and Janet Karin**

Dear Participant,

Please look at the diagrams below and place a tick next to the picture that best matches your body. Then add today's date and your unique identification code for this study to the form.

Afterwards, please fold up the questionnaire and place it in the envelope provided.
Please place the envelope in your nearest post box.

Thank-you for your time.






Kind Regards,

Liz Bradshaw and Janet Karin

Date: _____ (day/month/year)

Identification Code: _____

Please place a tick next to the diagram that best matches your body ✓

I		3 ≤2,5
II		4 2,5-3,2
III		10 3,6
IV		16 4,1-4,5
V		25 >4,5

APPENDIX 7



MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Chris Whatman
From: Rosemary Godbold, Executive Secretary, AUTEC
Date: 31 July 2012
Subject: Ethics Application Number **12/175 Differences in maturation, growth, and lower extremity alignment between injured and uninjured classical Australian Ballet School dancers.**

Dear Chris

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 23 July 2012 and I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement by AUTEC at its meeting on 13 August 2012.

Your ethics application is approved for a period of three years until 31 July 2015.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 31 July 2015;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/research/research-ethics/ethics>. This report is to be submitted either when the approval expires on 31 July 2015 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this. Also, if your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all written and verbal correspondence with us. Should you have any further enquiries

regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 6902. Alternatively you may contact your AUTECH Faculty Representative (a list with contact details may be found in the Ethics Knowledge Base at <http://www.aut.ac.nz/research/research-ethics/ethics>).

On behalf of AUTECH and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Erin Bowerman erin@westmerepilates.co.nz, Nigel Harris, Patria Hume