University College London

The Development of a Musculoskeletal Profiling Tool to Guide Entry into Classical Ballet

Submitted for the degree of Doctor of Philosophy

by

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DECLARATION

I, Moira McCormack, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Presentations

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Abstract

The Development of a Musculoskeletal Profiling Tool to Guide Entry into Classical Ballet.

The classical ballet profession requires both athleticism and artistry in a professional dancer with a physique that satisfies the aesthetic demands of the artform. Intensive training starts very young in vocational schools, but injury rates and attrition are high.

Based on the consensus of a modified Delphi Survey sent out internationally to enquire about the most frequently selected attributes in the professional dancer, a battery of musculoskeletal assessment tests, some already in use, was selected. A focus group of experts was consulted to advise on suitability for inclusion in the audition profile prior to entry into vocational training. Fourteen range of movement (ROM) and functional movement control (FMC) tests were trialled on eighteen pre-professional ballet students (16 – 17 years) who had newly entered training. Three experienced physiotherapists conducted a repeated assessment, and reliability studies were carried out.

Intra- and inter-rater reliability was calculated. The intraclass correlation coefficient (Model 3,1), standard error of measurement and minimal detectable change were used to calculate the intra-rater reliability. The continuous measures were also divided into categories and the alpha coefficient was used. The filmed FMC tests were scored, and the Kappa coefficient was calculated.

Intra-rater reliability was moderate to excellent for ROM (ICC = .614 - .970) and substantial to excellent for the FMC (Cohen's kappa = .670 – 1.000). The inter-rater reliability for hip rotation reached moderate acceptability only on the right (ICC = .515 - .622) and spinal extension in the second round (ICC = .584). When continuous measurements were categorised and the Alpha Coefficient was used, hip rotation was acceptable on both sides and both rounds (.616 - .856). For spinal extension

the Alpha Coefficient was acceptable at .748. The inter-rater reliability of the three FMC tests was acceptable (.449 - .820) but the ballet technique-based tests resulted in low agreement with Raters 1 and 3 only, reaching moderate agreement (.410 - .654). The modified plank test was fair to moderate (.347 - .471) in spite of excellent intra-rater reliability (.838 – 1.000).

The use of categories when measuring ROM is recommended to improve agreement between raters. Scoring functional movement requires practise by therapists to improve reliability, and familiarity with technical movements in ballet requires physiotherapists to develop specialist skills.

Standardised, reliable tests are recommended to capture each physique and its particular combination of attributes, including spine, hip and plantarflexion. Decision making at audition can be supported and facilitated.

Impact Statement

Audiences for ballet are enthralled by the spectacle and moved by the drama, but few realise how relentlessly students are assessed throughout their schooling, by artistic managements.

This is the first ballet-specific musculoskeletal profiling tool, tested for reliability, to be proposed for use at vocational school auditions for 16-year-olds. The artistic panel observe the audition ballet class and select based on aesthetic appeal and physical capability. Clinicians assess each physique and the profile is referred to by the panel in order to support decision making. The tool is composed of range of movement and functional movement control tests. This is different to a pre-participation screen which is designed to identify, at the beginning of the season, those at risk of injury and in need of intervention. This musculoskeletal profile offers a brief global view of joint range and movement strategy. Any joint restriction or aberrant patterning may inform on potential injury risk considering the intensity of a dance training programme.

The passive range of movement tests include spinal extension, hip external rotation and foot and ankle plantarflexion which are omitted in other lower limb screens, but these joint measures in the dancer are vital for the clinician to understand, in order to evaluate future resilience in the light of technique demands. The functional movement tests reveal control of the measured range, and deficits are noted. Movement control compensations and technique errors can be observed revealing the possible impact to the young physique by frequently repeated dance vocabulary.

The young dancer-athlete must avoid injury which detracts from training time and instead build on technique and performance in order to compete in a crowded market, for few professional positions. Therefore, careful selection at audition before commitment to avoid attrition in ballet schools due to injury is required.

Tests which have been examined for reliability can be used with confidence, by the specialist clinician. As in sport, the selection of young dancers is a serious responsibility for vocational schools and academies, considering the commitment required from young aspirants. Teachers, trainers and parents need to be reassured that careful selection is based on well researched, reliable and recognised testing methods.

Dissemination is through the International Association of Dance Medicine & Science and prospective publication. An international focus on screening in dance will encourage further input, validation and sharing with those working with young dancers worldwide.

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Overview of Study

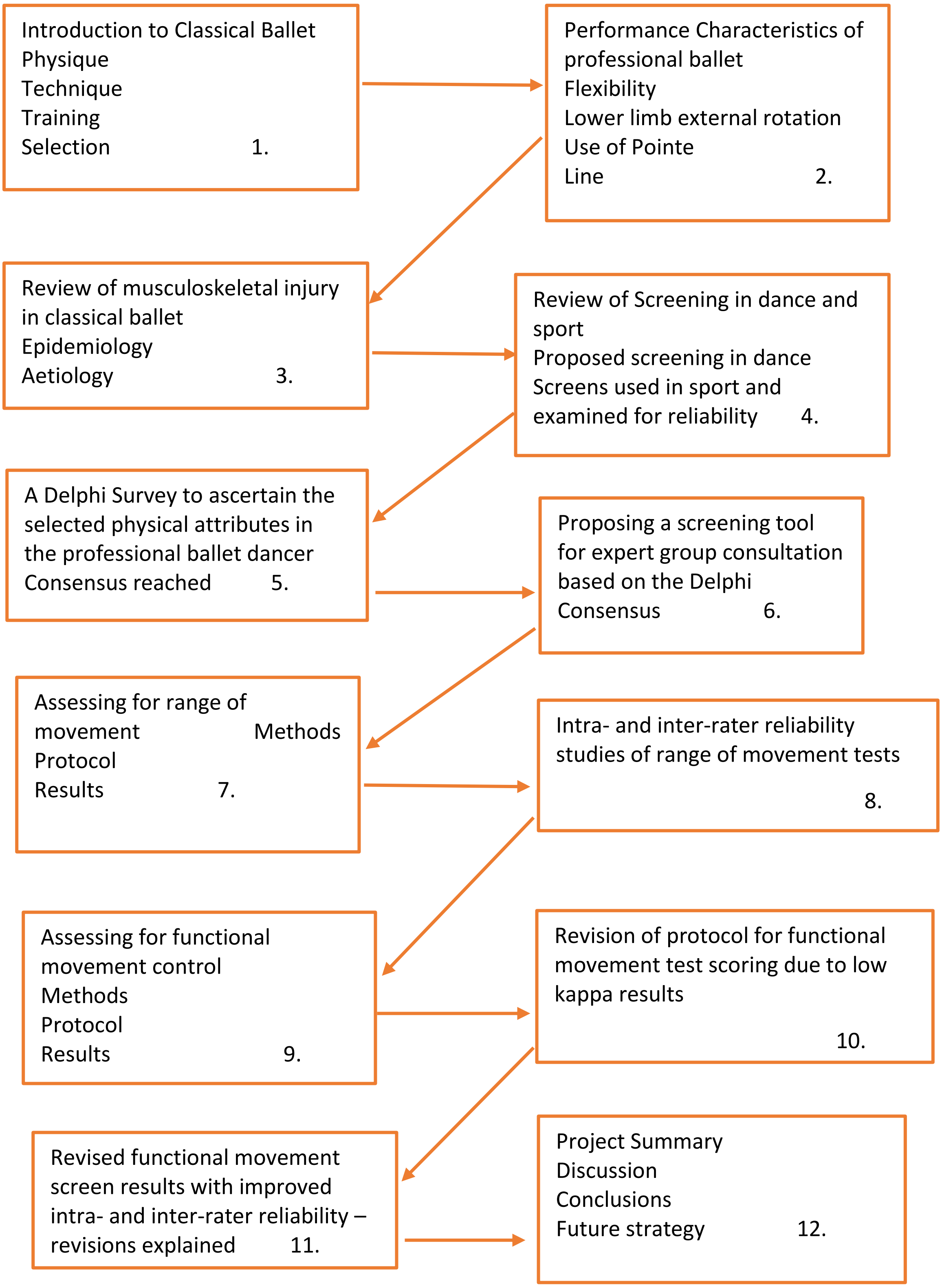


Figure 1.1 **Flow Chart for Sequence of Study**

Chapter 1. Introduction to Classical Ballet

A classical ballet dancer is a unique blend of artist and athlete. Ballet requires the physical characteristics of an elite athlete in terms of physiological oxygen uptake, muscular strength and endurance, although during performance, the focus is solely on artistic interpretation (Leanderson et al., 2011). The standard complement of athletic attributes is required in the dancer – comprising muscular strength and endurance, appropriate anaerobic and aerobic utilization, speed, agility, coordination and psychological readiness – all essential to dance performance (Russell, 2013). Dance can be seen as a highly physically demanding activity for the musculoskeletal system, matching high intensity sports (Moita et al, 2015), but it is not a sport. Professional ballet is unique in that it is not simply an athletic activity – it is a performing art (Hamilton et al, 1992). Classical ballet demands precision and power and while dance can be viewed from a sporting perspective, there is no question that it is truly an art using the possibilities of the body to speak to the audience about being human.

This physicality required is constrained by the confines of the technique and the visual aesthetic demands of the art form, and classical ballet choreography is highly dependent on the physique executing it. The steps, movement patterns and physique creating them are interdependent. Ballet uses the full range of joint movement and 'line' is the shape that the dancer's limbs make in dynamic and static positions. The dancer's physique has evolved throughout history with choreographic demands, and to understand where classical ballet stands today and how the 'artistic athlete' has arrived, it is important to appreciate the roots of the art form.

1.1. History

400 years ago, in the regal courts of Europe, grand court dances formed the origins of classical ballet. From Italy to France the elaborate and highly costumed practice spread and evolved into a more exacting technique with French terms to define positions and movements that make up the vocabulary that is still used today. In the

19th century Carlo Blasis set out his code of dance practise in 'The Code of Terpsichore' where movements and positions familiar in ballet technique today were analysed and codified both mechanically and artistically. He initiated the first 'science of moving figures' (Brandstetter, 2005). By the 19th century ballet had spread worldwide and the Russian school was highly developed. With the Russian revolution in 1917 dancers and teachers fled to Europe and the Ballet Russes, directed by Sergei Diaghilev, was established in Paris. From this company George Balanchine established himself in the United States founding New York City Ballet and Ninette de Valois in London, founding The Royal Ballet.

1.2. The Dancer's Physique

The body of the dancer has evolved from a stature that displayed ornate costumes that took the lead, to the physique itself and the dancer's technical skill being of prime importance. The technique has retained the jumps first initiated by Marie Camargo in the 1730s when she arrived on the male dominated scene to advance a powerful jumping technique, and later Marie Taglioni who started dancing en pointe without the support of today's pointe shoe. Haight (1998) described those dancers as powerful, expressive and able to bring off powerful feats on stage by virtue of their solid anatomy.

Today professional ballet dancers are the end result of a rigorous selection and training process. 'In addition to technique the dancer must have the right body shape and weight or be weeded out of the system' (Hamilton et al, 1992). While it is unclear whether ballet selects the perfect body, creates it, or both, it appears that certain dancers and physiques are at greater risk for injuries, eating disorders, and a foreshortened career (Hamilton et al., 1997).

1.3. Classical Ballet Technique

Classical ballet technique focuses on alignment, turnout (external rotation of the hips and lower extremity) of the four positions of the feet (Figure 1.), and an appearance of lightness, agility and strength. Globally, extremes of joint motion are used but the technique demands precision. The ankle and foot are plantarflexed ('pointed') as the foot leaves the floor and jumps articulate the whole foot with maximal shock absorption and a silent landing. The technique demands clean lines, geometric shapes and sweeping curves and complex movement at varied speeds. Frequent trunk extension is used and the upper body coordinates with, and echoes lower limb lines.

Ballet serves as the foundation for many forms of dance (Wilson et al, 2015) and professional ballet dancers are expected to constantly move between styles – classical, contemporary and neoclassical.

1st position  2nd position 

4th position  5th position 

Figure 1.2 Positions of the feet in Classical Ballet

1.4. Ballet Class

The ballet class is the daily class completed every day in a dancer's working life. It takes the form of a careful build-up of exercises at the *barre* (reassured by, but not supported by a *barre* at waist height). The exercises are brought into the centre and technical demands build from slow *adage* requiring strength, balance and control, to multiple turns (*pirouettes*) and jumps which rise in speed and power in the *allegro* section. Timing can be from 1.25 hours upwards depending on the aims of the class. All the basic elements of the vocabulary are covered in the class to maintain technique, or certain components are studied in detail to advance technique.

The ballet class can be used for training or for warm up and even psychological preparation for the day or for performance. Terminology is global and French terms are understood in studios worldwide

1.5. Selection for Training

Dancers are selected carefully for vocational classical ballet schools. The Royal Ballet School in London, UK, first invites prospective students to email photographs and video for the first part of the selection process. Chosen candidates are then invited to audition. A panel of senior teachers headed by the Artistic Director observes a ballet class which incorporates the full ballet vocabulary. The panel's task, using their collective artistic experience, is to select those with the most potential to join the next first year cohort of students. During the final audition a physical profile of each student is completed by the school physiotherapists and the information is made available to the panel to cross-check with their assessment. Not every school uses a physical screen, and many rely only on observed dance aptitude, technical training to date, musicality and agility. If prediction is mistaken those dancers add to the rate of attrition in vocational schools.

In the 1988 Howse and Hancock text, their 'Orthopaedic Assessment' of the young dancer prior to acceptance into the Royal Ballet School was designed exclusively to inform on the physique suited to ballet technique and those at risk of injury. The school has screened students at audition for over 50 years. Due to changes in management, healthcare staff and school site, records are not available, and any tracking of graduates has not been possible.

In St Petersburg, at the Vaganova Academy, the proportions of each physique are measured before the audition panel observes prospective students in a ballet class and if not conforming to the school prescription, the auditionee is not considered. Physique proportions are of primary importance to satisfy the aesthetic requirements in that institution (personal communication - Gillian Anthony, 2016).

In 1997, Hamilton and Hamilton presented their 'Dancers' Brief Orthopaedic Exam'. Although students already accepted into the School of American Ballet were used in this study, the school does not use an audition assessment. An annual screen is used to identify risk factors in students during their training at the school (Molnar and Esterson, 1997).

Careful selection at audition is important prior to acceptance and commitment and the audition assessment is different to the annual screen which is used to monitor and measure progress as well as trouble shoot, during training.

It is still unclear what physical attributes form the basis for selection into the profession today except observing the professional companies themselves. The Artistic Directors of professional companies and schools select at audition and choreographers cast their ballets, but there appear to be no clear criteria for selection. Aesthetic requirements take priority, but it is important that selected dancers have been assessed for suitability for intensive training. The greatest toll on dancers may occur among students who are ill-suited to the rigorous technique and training. Identifying the physical factors associated with the attrition rate in young dancers is key to their survival (Hamilton and Hamilton, 1997). The musculoskeletal requirements for the profession allow the dancer access to an exacting technique, but the aesthetic requirements are stringent and take precedence because of the visual art form. Clarity and evidence for selection criteria is required to inform and convince artistic and healthcare stakeholders.

1.6. Pre-professional Dancers and Training

Full-time pre-professional training is considered to be participation in more than 20 hours per week of training. Students are primarily exposed to class and rehearsal (with less of the performance components of professional dance) and the initial transition to full-time training represents a steep increase in demand. Students train for 3 years before the next transition to a professional role. Classes are designed for technical skill acquisition and different courses incorporate supplementary conditioning and health education. Dancers frequently begin specialized training from an early age, becoming full-time dancers from the age of

15 and over (Smith et al, 2016) when they enter vocational school. Vocational ballet schools in London train students for 6 days per week and in their study Ekegren, Quested and Brodrick (2013) reported that exposure time was in excess of the range recommended by the American Academy of Pediatrics Committee of Sports Medicine and Fitness (2000). It should also be kept in mind that the pre-professional dancer is often mid adolescent growth spurt when acquiring the increased technical expertise required for a company dancer. Interestingly, Fuller et al. (2019) reported that the mean weekly training loads in young ballet students is higher than observed in-season for Australian football. Pre-professional training is designed to replicate both the technical demands and intensity of the professional setting (Ekegren, Quested and Brodrick, 2013) and exposure times are associated with high training levels and reduced recovery time. However, Fuller et al. (2019) still found that the transition to professional dance involved an increase in performance demands with challenging schedules requiring heightened aerobic fitness. Performance requires higher oxygen uptake than class or rehearsal (Redding and Wyon, 2003) and some companies perform up to seven times per week with up to 145 performances per year across 15 different programmes (Allen et al. 2012). Young dancers, after further selection by Artistic Directors of companies, enter the corps de ballet. The work can be repetitive and continuous throughout the year, unlike in sport where workload is seasonal, and schedules and periodization are built around competitions. The professional dancer begins at the lowest level of the company hierarchy and the career progression is through first artist, soloist, first soloist and then principal. Successful progression is dependent on resilience, competing with peers, consistent technical enhancement and avoidance of injury. At pre-professional level time loss through injury means loss of skill acquirement. It should be emphasised here that ‘pre-professional’ means exactly that: student dancers who are carefully chosen at 16 years old for their distinct potential for entry into the profession. Collegiate dancers complete university degrees at a later stage in a variety of dance genres with basic ballet technique covered, and are not chosen or groomed for the profession. The term ‘dancer’ is used universally but the title, pre-professional classical ballet dancer, applies only to a very few in a competitive and challenging vocation. Differentiation

between amateur (recreational), pre-professional and professional in contemporary, modern or ballet requires careful delineation and understanding. The term ‘ballerina’ is not a casual term. It applies to a principal female classical ballet dancer of the highest rank (Kennedy et al., 2007).

Chapter 2 Performance Attributes – Classical Ballet

2.1 Introduction

Classical ballet is a highly stylized and, in many ways, artificial art form that requires a specific body type. The professional dancer is expected to be creative but also able to withstand the physical and psychological stress inherent in performance (Hamilton et al. 1992).

There is no competition, game or race to be won. Preparing the dancer is for a highly prescribed performance, not the chaotic nature of a sports game. The dancer performs within the constraints of the rehearsed choreography and the production. The performance is meticulously rehearsed but the dancer brings to the role his/her own expressivity. Challenging choreography is favoured by audiences and artistic directors, and concentration and focus are on interpretation of a role, with the emphasis also on a highly tuned technique. Physical prowess is seen as solely a foundation to the demonstration of complex skill sequences (Wyon et al., 2005).

2.2 Control, Motor Learning and Skill Acquisition

There are many texts documenting the training of classical ballet with a graded build-up of technical complexity. Training systems can start from 4 – 5 years of age up to advanced technique. The ballet vocabulary is wide and remains untampered with, except for slightly differing terminology between teaching systems.

Teaching ballet is a carefully ordered progression in motor control training. Ballet is taught in a generally reductionist manner. Ballet teachers give verbal instruction with demonstration. For the student the various stages include perception (attention and observation) of the demonstrated skill, replication and then feedback with additional explanation. Further practise encodes the movement in the dancer's mind (Krasnow and Wilmerding, 2015) and repetition embeds the skill in long term memory. Music accompanies classwork (training) with live pianist working with the teacher, regarded as the best situation, where the musician is adaptable and able to improvise, match music and movement and inspire dancers. The tempo drives the movement and like the music, movement has light and shade, *allegro* and *adagio.* Learned movement patterns or engrams are laid down by ballet teaching in progressively complex combinations within the motor cortex. The movements of the novice are gradually smoothed by practise and become more expert with economy of effort as the neuroplasticity of the Central Nervous System (CNS) allows for endless adaptation and refinement of sensorimotor mappings between variables. The dancer acquires more effective and efficient gathering and processing of sensory information relevant to action (Wolpert et al 2011). Complex and efficient movement function requires precise coordination of muscle action with heightened proprioceptive input supplying sensory afferent information from connective tissue, muscles and joints. This continuous flow of sensory information is processed at all levels of the CNS in order to achieve the desired motor strategies, and fine tune ongoing movements.

Teachers train based on their own experience, and so students receive knowledge through the prism of motor programs appropriate for their teacher's individual physicality (Karin, 2016). When demonstrating movements, teachers also transmit their own cultural background, personality, musicality and artistry. This is inevitable and it should be appreciated that this may restrict a young dancer's unique potential.

The above explanation of explicit learning describes a process through conscious verbal-analytical absorption of movement rules and mechanics. This conscious recollection of each element and its order in the sequence in explicit learning is the opposite of implicit learning which refers to subconscious mental subroutine establishing the correct combination, timing and muscle activation in a movement. The use of imagery to stimulate a quality of movement and alignment is discussed by Karin (2016) who refers to the teaching of an arabesque (Fig. 1) which could be a forceful co-contraction of the back and abdominal muscles (preventing natural coordination) or it could be a taught as a 'crescent moon', reconceptualising an arabesque as an embodiment of harmony and beauty. Teaching this way uses imagery and sensory cues to evoke motor responses that are difficult to convey technically. Karin (2016) suggests that kinaesthetic cues are embedded in metaphors and can assist in improving motor skills and optimal performance. Referring to Raab (2015), Karin explores motor learning in dance, suggesting a ‘hybrid’ learning where both implicit and explicit processes facilitate the learning of very complex skills. Explicit instruction can align bones in simple postures which is sometimes necessary, but dancers need efficient alignment throughout all positions and movements. By placing alignment in a sensory context with the use of imagery, the static and moving body can improve both alignment and expressivity. Implicitly learned skills require less working memory and are robust against disruption while explicit processes depend on working memory but are vulnerable to disruption by performance stressors or fatigue. Imagery appeals to the dancer because of their innate expressivity and artistic creativity. But dancers are accustomed to the analysis of steps which can facilitate mechanics and understanding. However, explicit learning can become implicit with practice (Lam et al., 2009) and implicit processes should dominate at the expert level.

2.3 Coordination

The neuroplasticity of the CNS allows for endless adaptation and refinement of sensorimotor mappings between variables as dancers acquire more effective and efficient gathering and processing of sensory information relevant to an action (Wolpert et al 2011). Sensorimotor control deals with a dynamic, real-time control system that turns sensations and memory into action and vice versa. Coordination is the optimisation of sensory feedback. Good coordination in ballet refers to enhanced precision and speed of motor control processes. Overlaying this is the temporal influence of music, directing rhythm and speed.

2.4 Stability

The stability of any system is the ability to limit displacement and maintain structural integrity (Willson et al., 2005). Efficient movement throughout joint range in dance depends on this, and is supported by a heightened proprioceptive system, efficient cortical programming and established movement strategy. Passive restraint is provided by tissue structures that surround joints (ligaments, capsule, fascia) while dynamic stability is provided by the interaction of deep muscles which limit joint shear and translation (Phillips, 2005). Dynamic and wide ranges of movement are made possible and more efficient by a precisely timed recruitment of local and global stabilisers. Locally, deep inner units producing low level continuous isometric forces stabilise joints. For example, the glenohumeral joint is stabilised by the rotator cuff as the upper limb is operated through range by more superficial muscles, creating smooth, efficient *ports de bras* (carriage of the arms). For functional efficiency the global stabilising system spanning several segments, integrates with the local system to protect joint congruity and synchronises smooth movement (based on Bergmark's theory of stability from 1989). Maximum stabilisation is required in the most demanding moves - leaping jumps and overhead lifts – and bracing takes over, providing stiffness against perturbation.

2.5 Balance

Balance requires the ability to integrate visual, vestibular and somatosensory systems. When compared to other athletes, dancers exhibit better balance strategies in some tests. Gerbino, Griffin and Zurakowski (2007) found sway index (ability to stand quietly) and centre acquisition time (ability to recover balance from perturbation) the most useful tests. Using centre of pressure variability data, dancers were found to have better standing balance than soccer players in only some tests. This was similar to the testing by Ambegaonkar et al. (2013). Dancers often perform anticipated choreographed movements as compared with the frequently unanticipated movements in athletics (Ambegaonkar et al., 2011; Liederbach et al., 2008). It appears that although dance participation results in dancers having better balance than that of nondancers in some areas, dance participation is not superior to athletics participation where balance is concerned (Ambegaonkar et al., 2013).

2.6 Strength

Considering the technical demand in ballet performance, high levels of strength are required in the lower limb for jumps and in the upper body for lifting and in the trunk to reinforce both. Developing strength within the musculoskeletal system requires overload to produce the power and torque required in highly challenging dance movements. Repetitive high forces lead to increased motor neuron excitability and efficacy of corticospinal-motoneuronal synapses (Nuzzo et al., 2016). The organization of movement representations within the motor cortex and supraspinal levels is sensitive to skill learning but not strength training which is regulated at spinal cord level (Remple et al., 2001). Initial strength gains are due to neural adaptation followed by intramuscular adaptation and hypertrophy. This regresses though, if the demand ceases.

The muscles responding to high load demand are more superficial and are responsible for movement and direction control, while stability control from deeper isometric forces provide intersegmental position and placement (Phillips, 2005), vital to smooth dynamic movement.

2.7 Agility

In sports science there is no universally accepted definition of agility, and the absence of effective training programmes appears to be the product of such uncertainty. 'A rapid whole-body movement with change of velocity or direction in response to a stimulus' is a currently recognised description (Young et al., 2015). No research in ballet specifically targets agility training but without a doubt, agility is intrinsic to the technique. Possibly, training in ballet class covers the movement complexity and speed variation such as demanded by small, fast jumps (*petit allegro*) in the allegro section. Dancers do not randomly change direction or velocity as in a game of sport. In class, movement combinations are set by the teacher and within the confines of the technique there are changes of directions to challenge the dancer and practised at different speeds, preparing the dancer for varied choreographic demands.

2.8 Stamina and Cardiovascular Endurance

Classical ballet is a high-intensity intermittent form of exercise which requires a substantial aerobic foundation (Allen and Wyon, 2008). When the aerobic system is trained, VO2max (maximal oxygen uptake) is improved such that all dance activity can then occur at a lower percentage of the maximum. If conditioning is sufficient, resistance to fatigue is high and proficiency scores for control and skill will also be high, allowing for concentration on coordination (Twitchett et al., 2011) and role interpretation. Dance can be a highly skilled form of movement and even mild fatigue has a major effect on the quality of movement, resulting in poor alignment of limbs and loss of form. If this is accompanied by low strength levels, risk of injury increases (Allen and Wyon, 2008). By increasing the anaerobic capacity, thereby allowing more work to be done prior to the anaerobic threshold, the dancer can prolong and possibly intensify activity levels before fatigue (Twitchett et al., 2011). Equipping a dancer with a good fitness base can allow improvements in artistry and aesthetics. Local endurance in constantly used muscle groups is essential. For example, because of the emphasis on lower extremity and particularly foot and ankle work in ballet, the calf complex requires local stamina for optimal lower leg function (Zeller et al., 2017).

2.9 The Dancer's Hip

The dancer's hip requires careful consideration in ballet function. Classical ballet 'turnout' works the lower limb externally rotated from the hip, and the feet placed pointing outwards. The fifth position (Figure 1.) is the functional position for the ballet dancer – feet turned outwards and crossed over heel-to-toe (Hamilton et at, 1997). Inevitably there is some distribution of rotation forces within the knee, ankle and foot but with a mobile hip and good control, safe biomechanics are facilitated. Working in external rotation also allows for greater triplanar hip range and aesthetic appeal (Cimelli and Curran, 2012). The external rotation of the hip joint allows increased range and the use of strong hip flexors in abducted positions. The hip joint range of motion is governed by both the shape of articular surfaces and the flexibility of connective tissue (Gannon and Bird, 1999). Both contribute to increased range and ease of movement. The height of raised positions used in technique requires strength of the prime mover and length in the antagonist muscles, and full turnout of the lower extremities requires joint facility, dynamic strength and stability control.

In any literature discussing turnout, the 180-degree (functional) angle of external rotation at the feet, is often quoted (Negus et al. 2005) in spite of the fact that average passive hip external rotation in their research proved to be 44.5 degrees on the right and 47.3 on the left, totalling 91.8^{o}. Total functional turnout was measured at 127 degrees in first position, well below the 180 degrees mentioned at the beginning of their paper assessing preprofessional ballet students. In professional ballet dancers, the mean passive measure was 50.2^{o} (totalling 100.4^{o})

by Washington et al. (2016). A functional foot angle of 66.8^0 (totalling 133.6) was measured in the same dancers.

Harris et al. (2015) found that in a classical ballet company of 47 dancers, 92% of females and 72% of males had dysplasia or borderline hip dysplasia. Mayes et al. (2020) found in a classical ballet company that the hypermobile hip may be an asset in the profession as cartilage defect prevalence was lower in their professional dancer cohort with generalised joint hypermobility (GJH) than those non-GJH dancers.

2.10 The Spine in Ballet

Dancers, gymnasts and figure skaters place their spines in extreme ranges of motion, with repetitive, high-impact manoeuvres. Aesthetic or artistic athletes involve extreme movements that are practiced repetitively from an early age, which can be in all six directions of motion (d'Hemecourt and Luke, 2012). In addition, many manoeuvres often involve simultaneous extreme hip and lumbar spine motion. There is an emphasis on spine hyperextension, flexibility, and axial loading (Quinn, 2014). Positions and movements involving end-range extension are an integral part of the dance aesthetic (Smith, 2009). The *cambré* (backbend) is a frequent move in the ballet vocabulary as is the *arabesque* and *attitude* positions which involve an upright trunk and hip extension (**Error! Reference source not found.**). When end-range hip extension is reached, the pelvis tilts anteriorly and global spinal extension with rotation completes the position. Moves into these ranges are frequent and repetitive in choreography, may need to be held motionless and are often ballistic where the lower limb is thrown to end of range. These positions are also associated with jumping and landing (Quinn, 2014) which will increase stress and demand. Hamilton et al. (1992) believe that increased flexibility is an asset in the selection process for dancers and this would seem a prerequisite in the lumbar spine. Swain et al. (2019) also observed that spinal mobility is required for progression in ballet and that a natural selection occurs. Bronner et al. (2018) also state that there is a positive selection on the grounds of hypermobility occurring early in a ballet career. Nilsson, Wykman and Leanderson (1993), using Debrunner's kyphometer and Myrin's inclinometer, found that young ballet students had increased spinal laxity and generalised hypermobility compared to controls. They suggest that any axial hypermobility is likely to be hereditary rather than the result of excessive training and that this is an asset in the profession.

Arabesque Attitude

Figure 2.1 Classical Ballet Hip/Spine Extension Positions

2.11 The Ankle and Foot in Ballet

Because of the use of pointe in female dancers and high demi pointe (3/4 pointe) in both male and female, the foot and ankle in a dancer require enough range in plantarflexion for aligned weight bearing through hip, knee and ankle through the tips of the toes *en pointe* and through the extended metatarsophalangeal joints and interphalangeal joints of the toes on ¾ pointe. This range is not just functional, but aesthetically adds to the lengthened, sweeping lines in ballet.

Furthermore because of the use of external rotation at the hip and turnout of the lower limb with the inevitable absorption of rotation forces, the medial structures of the foot are at more risk of injury.

Performing *en pointe* is facilitated by the supportive pointe shoe so characteristic of the genre. Pointework produces an appearance of lightness and lift which defines the 'weightless' nature of classical ballet (Wilson et al, 2015). Weight bearing *en pointe*, although regarded as unnatural and 'artificial', is nevertheless biomechanically possible in the foot and ankle with enough range. Skill and virtuosity (and also minimising risk of injury) are only possible with specific strength, stability and an enhanced proprioception. This requires a range of movement at the foot and ankle that allows weight-bearing through the plantarflexed metatarsophalangeal joints and extended toes meeting the firm end (box) of the pointe shoe to form a robust base of support. 90° to 100° of plantarflexion allows full equinus position (Hamilton et al, 1992) and Steinberg et al. (2016) found this facility primarily due to bone structure and less to soft tissue extensibility. The necessary range of plantarflexion is met by both the ankle and the midfoot (Russell et al, 2011). The position requires the balanced strength of ankle support and significant use of the intrinsic muscles of the foot. The skill of pointework takes many years to build and nurture and preparation starts around the age of 7 when specific exercises for the foot and ankle are started before embarking on full pointework around the age of 12-13 years.

Male dancers use a soft, malleable shoe which fits perfectly to move with the foot, encasing and not restricting it, but which supplies little support, leaving shock absorption to the dancer’s musculature. The use of the male foot in ballet, except for the use of pointe, is schooled in exactly the same way.

The shape of the foot, the length of the digits, the angulation of the first metatarsal bone and the intrinsic strength of the foot all determine the wear and strain on the foot, ankle and first metatarsophalangeal joint in jumping, pointework, and utilising turnout throughout. Training and meticulous understanding of the mechanics of the foot also influence its ability to endure the rigours of the technique, alternately assuming the rigidity required for take-off and a shock absorbing structure on landing (Ahonen, 2008). The medial structures of the foot and ankle (Carter et al., 2017) and the stability of the medial aspect of the knee (Khoo-Summers et al., 1995; Hewitt et al., 2005; Nowaki, Air and Rietfeld, 2012) are all susceptible to strain in the externally rotated lower limb.

2.12 Jumping in Ballet

In sport, jumping is practised in order to contact the ball and score goals, but in ballet jumping is used to convey a dramatic story, express an emotion, or display technical virtuosity (Liederbach et al. 2008). The authors continue to explain that developing aesthetically precise balance and jumping skills is necessary for both male and females to advance into the professional.

A dancer’s jump is trained from early on to develop the upright stance of the spine without the hip and trunk flexion used in sport. In spite of greater torque generation possible in the hip extensors in greater degrees of hip flexion (Ward et al., 2010) the upright posture in dance is schooled in order to appear effortless and graceful.

Jump ability has been identified as one of the best predictors of dance performance (Escoban et al., 2020). In turn this aesthetic competence is related to lower extremity muscular power and upper body muscular endurance (Angioi et al., 2009). Muscular strength, neuromuscular control and segmental coordination are required to develop a powerful jumping technique and increased jump height required by male dancers to fulfil choreographic demands.

The agility of quick ‘*terre à terre*’ (low) jumps require enhanced agility, coordination and control and an economy of effort. The high, bravura leaps in ‘*grand allegro*,’ executed to extreme by male dancers are determined by maximal power output of the lower limbs. The height of a jump is not achieved by strength alone (Wyon et al., 2006). Instead, this is influenced by the relationship (perfect balance) between force and velocity mechanical capabilities (Jiménez-Reyes et al., 2017).

McPherson et al. (2019) demonstrated that both pointe shoes and flat technique shoe made no difference in ground reaction forces to barefoot jumps in the dancer with these forces absorbed by the dancer’s musculature. Lowering eccentrically through full articulation of foot, ankle, knee and hip (Bowerman et al., 2015), from toe strike followed by the ball of the foot and finally the heel (Arnwine and Powell, 2020), achieving a technically flawless and silent landing without the supplementary shock absorbing qualities of the sports training shoe.

Landing on to a single leg compared with two legs increases ground reaction force. Often more than 200 jumps can take place in a typical technique class (Liederbach et al. 2006, cited in Arnwine and Powell, 2020) with 50% of the time landing on a single limb. Ground reaction forces of 3.6 and 4.5 times the body weight of experienced dancers have been reported when landing from a *grand jeté* (travelling one to one jump), during which the greatest negative work was done by the knee extensors, followed by the ankle plantarflexors and hip flexors.

The number of repetitions completed during each training session imposes a significant loading volume, which suggests that correct landing biomechanics are necessary for dancers to avoid musculoskeletal injury. Antero-posterior and medial-lateral forces in jumping, as well as vertical ground reaction forces add to lower extremity stress in the dancer (Arnwine and Powell, 2020). These landing mechanics are unique to dancers and place substantial load magnitude on the lower extremities.

2.13 Pas de Deux

Classical ballet is also characterised by *pas de deux work* (partnering, lifting/being lifted and precise coordinating with another dancer). Traditionally the male dancer partners the female dancer, supporting her in multiple pirouettes (turns) and lifts, often overhead. This requires not only substantial strength but also coordination with the partner, teamwork and intuition. Partners need to be well matched. A male who is able to bench press his own weight should easily manage to lift a smaller female partner. However, it is not unusual for choreographers today to compose pieces for males partnering males in contemporary pieces and so challenges demanded of the male dancer appear to be increasing. Lifting technique and ergonomics require scrupulous attention in order to strengthen rather than strain and injure a young spine in training.

2.14 Flexibility

Flexibility in dancers is exploited by choreographers in greater measure than ever before (Newis, 2016). Research has shown that significantly more ballet dancers are hypermobile than non-dancers (Grahame and Jenkins, 1972; Klemp and Learmonth, 1984; McCormack et al., 2004, Leanderson et al., 2012; Chan et al., 2018). This increased range has allowed choreography to break away from the limits imposed by tradition and ballet has achieved breath-taking pinnacles of performance (Haight, 1995). Audiences demand more and more spectacular moves and consequently, society has a role in dictating the development of the art. Historically, high percentages of preprofessional and professional ballet dancers were found to have Generalised Joint Hypermobility when the Beighton Score of ≥ 4/9 was applied. McCormack et al. found 90% of their ballet cohort had ≥ 4 on the Beighton Score, and Chan et al. found 72%. Although the Beighton Score is widely used to measure generalised hypermobility it samples a small number of joints in the sagittal plane, and mostly upper limb with a point for each joint, totalling 9 points in all – fifth metacarpophalangeal joints, wrists/thumbs, elbows, knees and lumbar spine/hips.

Figure 2.2 The Beighton Score

Dancers require full lower limb assessment including the spine, hip joint rotation, knee extension, foot and ankle plantarflexion and metatarsophalangeal joint extension. In the hypermobile dancer there is a functional range which is necessary to perform classical ballet technique and a hypermobile range which requires further control if utilized by the choreographer for its extreme effect. Without a doubt, hypermobility is regarded as a prerequisite for a career in ballet and is seen as an asset for selection (McCormack et al., 2003; Leanderson et al., 2012; Foley and Bird, 2013; Chan et al., 2018).

2.15 The Importance of 'Line' in Ballet

'Line' is the shape that the dancer's limbs make in dynamic movement and static positions. In Islamic architecture the arabesque is a form of artistic decoration based on rhythmic, scrolling patterns and linear elements. As in design, the lines a dancer makes are unbroken and flow in a spiral. The line of the dancer's spine in an arabesque is both extended and rotated in a helix leading the eye to the extended and elongated limb. The spiral is balanced by the opposing upper limb to complete the image. These 'lines' are facilitated by the streamlined physique.

The hyperextended knee is often accompanied by hyper-plantarflexion of the foot and ankle inherent in the hypermobile physique. Functionally the weight-bearing limb *en pointe* requires extra range in foot and ankle. Aesthetically this is the desired line in classical ballet as demonstrated in the following figures.

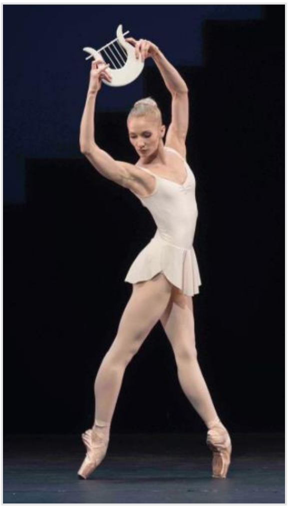


Figure 2.3 Hyperextended knee

Photo: Andrej Uspenski

Figure 2.4 'Line' in ballet (balletnews.co.uk)

The hyperextended knee is vulnerable in both sport and dance, but it still appears to be highly sought within the ballet profession as observed in any classical ballet company. Teachers find the hyperextended knee difficult to teach and technique modification is required, avoiding 'locking out' in weight bearing, to protect the posterior capsule and still generate sufficient strength and control. In sport it is regarded as an injury risk (Campbell et al, 2019; Myer et al, 2008; Söderman et al., 2001; Ostenberg and Roos, 2000). Nevertheless, the curvilinear sweep of the limb appears to be what is desired in the dancer's physique and is so prevalent in the profession.

The demand for clean lines and therefore leanness, appears to be a necessary attribute in classical ballet which favours linearity and long limbs. Dancers appear to be consistently leaner than age-matched controls (Kadel et al., 2005; Haight, 1998; Liiv et al, 2013). It has been suggested that dancers are predominantly ectomorphic individuals (Heath-Carter, 2002 in Twitchett, 2008) and aesthetically the ideal body type in many ballet companies is a mesomorphic- ectomorphic profile (Ryan and Stephens, 1987).

2.16 Physique Proportions

Very little has been studied on the measurement of proportions in the dancer's physique. Hamilton et al. measured trunk length, arm span, arm length and leg length but drew no conclusions (Hamilton et al., 1992). The Vaganova Academy in St Petersburg measures and compares lower limb length to trunk length at audition in order to attain physical conformity (G. Anthony, personal communication, July 17, 2016). Ideally, a small head, long neck, long arms, long legs and slender figure are required, as stated by the Artistic Director of the Vaganova Academy 2000-2013 (Asylmuratova, 2016). However, there is a debate as to whether this type of physique is necessarily the most robust.

Chapter 3. The Risk of Musculoskeletal Injury in Classical Ballet. A Review of the Literature.

In this chapter the early research in dance is represented, and the most appropriate work up to the present day is discussed in terms of epidemiology and aetiology. The path to more efficient injury surveillance, standardized reporting, identification of injury risk and ultimately the aim to prevent injury, is explained. Progression in dance research from early to the present day is encouraging, and prevalence and incidence of injury in vocational and professional can now be compared more easily, although further work is required to implement evidence-based prevention programmes. The results of the literature research are discussed in terms of each injury risk encountered.

Sport was well ahead of dance with standardized injury reporting instituted in the 1970s and researched over years by Meeuwisse, van Mechelen, Fuller, Bahr and Holme. This delay in research discipline shows the reluctance of this art form to recognise itself as an athletic pursuit based on science as well as a sophisticated form of artistic expression. Schon and Weinfeld (1996) stated that with all the concentration on the major sports players, the infrastructure, economically and socially, was miniscule for dance as a science and was overlooked and relatively underdeveloped. However, in 2012 the Standard Measure Consensus Initiative (SMCI) by the International Association of Dance Medicine & Science (IADMS) stated that the dance community was finding difficulty in achieving true understanding of dancers' injuries and developing meaningful risk reduction strategies. At that time the dance medicine and science community was not able to compare injury incidence among dancers because of different methods of collecting data, non-standardised injury definition and exposure data. In spite of over ten years of recommendations for better injury reporting, research papers still lacked clearly reported methods so as to be reproducible. A logical and systematic approach to injury surveillance tackles the enormous task of attempting to understand the cause of injuries. Standardising injury reporting methodology and measurement of intrinsic and extrinsic risk factors allows more robust comparison of results across research efforts. Standardisation also enhances the ability of the dance community to identify the most meaningful ways to reduce risk and prevent injury across dance genres (Liederbach et al, 2012).

The literature search strategy is explained (Figure 3.1) and the early studies are presented first in Table 3.1. The selected studies that followed are presented in Table 3.2. and selected reviews in Table 3.3.

An electronic search was conducted of five databases Pubmed, Web of Science, Scopus, Ovid and Sport Discus from inception to October 2021. Literature searches were conducted to obtain articles concerning ballet and injury. A combination of the following search terms was used: (danc* OR ballet) AND injur*, (danc* OR ballet) AND epidemiolog*, (danc* OR ballet) AND risk, (danc* OR ballet) AND screen*. Further refining used (danc* OR ballet) AND (professional OR pre-professional) AND epidemiolog*. Searches were limited to English language in peer reviewed journals. Studies were excluded that investigated other genres of dance or recreational ballet. No unpublished evidence was included. Only studies in ballet and at vocational and professional levels were included. Studies driven by cardiovascular, psychological, nutritional and bone mineral density issues were excluded. The studies identified were collected and duplicates removed. Titles and abstracts were searched. Those studies investigating injury incidence or prevalence in elite classical ballet were selected for full text review and their reference lists scanned for further possible inclusion. The PRISMA flowchart shows the search strategy and study selection.

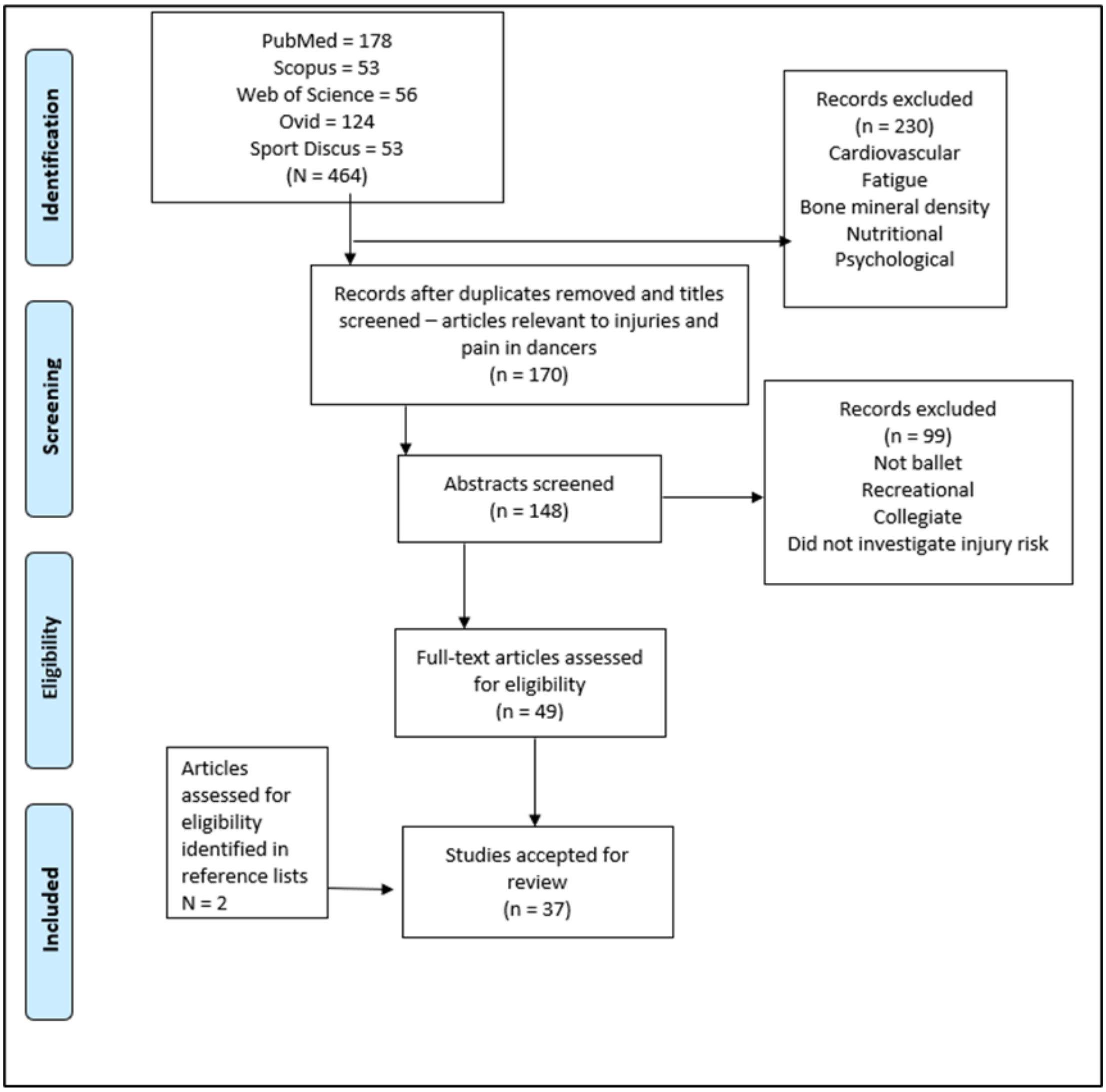


Figure 3.1 Prisma search strategy for risk of musculoskeletal injury in dance

Table 3.1 Early epidemiological research in dancer injuries.

Author/Study Year Country	**Population (N)**	**Age**	**Time period**	**Injury definition**	**Injury number**	**Injury Outcome**	**Injury rate/ preval**	**Expo-sure**	**Health professional diagnosis**	**Injury character**	**Injury Site Number/%**	**Cause/injury risk**
Quirk R Retrospective Australia 1983	Prof ballet Students 664		15 yrs	Medical attention	2113	N/S	N/S	N/S	Orthopaedic surgeon	Muscle 28.9% Tendon 17.1% Ligament 15% 123 surgeries	80% lower limb	N/S
Klemp and Learmonth Retrospective South Africa 1984	47 Prof ballet	19-47	10yrs	Medical attention	156	Preval-ence of hypermo-bility and injury	N/S (Low)	N/S	Orthopaedic surgeon	Severity reported Mild Mod Severe	Ankle sprain: 35 Knee:17 Calf:16 Tendon:32	N/S
Bowling Cross-sectional Retrospective UK 1989	141 Prof ballet 80F 61M	N/S	6months	N/S Self-report pain	123 42% injured	Injury prevalence	N/S (High)	N/S	SR	Chronic:48% 6 mth:60%	Spine:26% Ankle:20% Knee:12% Foot:16%	Perceived: Overworked Fatigue Cold environment Unsuitable floor Choreography Repetition Alignment Insufficient warmup
McNeal et al USA Retrospective Cross-sectional 1990	99 Prof ballet 49 F 50M	≥ 17	N/R Prevalence	Self-report (S/R) Time loss < wk lost > wk lost	99	Poor Alignment and injury to knees, foot and ankle	N/S high	N/S	Self-reported	Most overuse	Ankle:80% Knee:57% Foot:26%	Poor knee/foot alignment Injury rates increased with training but not correlated to alignment
Kadel USA 1992 Retrospective	54Prof ballet	N/S	Lifetime	Medical attention Stress fracture Time-loss	27 fractures	Risk of stress fracture	N/S	> 5 hrs dancing per day	Physician Bone scan Xray	N/A	2nd metatarsal 63% Tibia 22%	> 5hs/day Amenorrhea for > 6 mths
Hamilton et al 1992 USA Retrospective	28 elite prof ballet 14F 15M	22-41	Lifetime	Medical attention	N/S	Profile of MSK charact-eristics	N/S	N/S	Orthopedist	Overuse:79%F/40%M fracture:29%F/20%M Major:43%F/60%M Minor: 57%F/40%M	N/S	Older age No yrs dancing High flexibilityM Less plie F/Less TO F

Garrick and Requa 1993 USA	282 Prof ballet	N/S	3 yrs	Injury incurring Medical cost	309 in 104 dancers 1-12/dancer	Injury and financial outcome	2.97 injuries/ dancer	N/S	Physician	Lower extremity most frequently injured.	F/A:23.9% Lsp:23.9% Ankle13.%	The most frequently Injured will develop the most serious and costly injuries.
Ramel and Moritz Sweden 1994	128 Prof ballet	Mean: 27	12 mths	S/R: Time loss Nordic Questionn-aire	Total: 472 Time loss:168	N/S	N/S (High)	N/S	Self-reported Musculo-skeletal question-air	N/S	Lsp:70% F/A:65% Csp:54%	Suggested: Poor training Poor alignment Schedule planning Poor psychosocial work conditions
Lundon K et al. Canada 1999 retrospective	1023 Vocational ballet		25 yrs	Medical attention		N/S	Stress # twice as likely in females 70% 15-19yrs	N/S	Physician	Stress #	F=46% in 2nd MT M=40% F=23% in fibula M=40% F= 15% tibia F= 12% Lumbar F= 4% femoral neck M= 20% cuboid	Poor alignment Pronated foot Increased exposure
Solomon and Micheli USA 1999	70 Prof ballet	N/S	5 yrs	Self-reported dance medical problem	560	Injury and financial outcome	94-77% 1.7/dancer in 1 year	N/S	Physician	Overuse 29 surgeries on 22 dancers	Ankle 21% Foot 17% Hip/thigh 13% Spine 12%	More risk of injury after time off Age and rank not associated with injury

All these early studies used a retrospective research design, with six studies using medical attention as an injury definition. The remaining four used self-reported injury. One of the first investigations into injury in the dance profession in the UK was a survey carried out by Bowling in 1989 in which the author attempted to document the true prevalence of dance-related injury. This study was based on a postal survey of 188 professional dancers in the UK (response rate 75%). Most respondents (84%) had experienced an injury which affected their dancing at some time. About half reported a chronic injury that gave them continuing problems, and just over two-fifths had sustained at least one injury in the previous six months that had affected their dancing (Bowling, 1989). Sohl and Bowling (1990) in their follow-up paper state that 'most research on dance medicine, even that which is published in academic journals, lacks scientific rigour'. In particular, 'the failure to report sampling frames, sizes and response rates is common'. The study exposed the magnitude of the dance injury problem and injury risk in the profession in the UK but self-reporting by dancers and in sport in retrospective research design is subject to issues of recall bias with under or over reporting affecting the validity of results (van Mechelen et al., 1992). Ramel and Moritz (1994) followed with a similar study in Scandinavia, with comparable results using the recognized Nordic Questionnaire. Quirk (1983), an orthopaedic surgeon in Australia presented his epidemiological study of dance students based on retrospective medical attention records but the study did not allow dancers to 'have their say' as did the opinionated professional dancers in the UK and Scandinavian studies. Orthopaedic surgeons' studies will reveal a fraction of the prevalence because of the nature of medical attention definition of injury. Kadel (1992) recorded the prevalence of stress fractures in dance with increased exposure, Garrick and Requa (1998) the injuries reaching the doctor's office, as did Lundon et al. (1999) and Solomon and Micheli (1999). McNeal (1990) reported that 15 – 30% of dancers did not seek medical attention with Garrick and Requa reckoning that the true prevalence of dance injury is probably doubled, leaving reportage in those papers, in question. Garrick and Requa and Solomon and Micheli (1999) based theirs on injury and financial outcome which again can lead to under-reporting as only the more serious injuries become insurance claims. The study by Klemp and Learmonth (1984) investigated the incidence of hypermobility in a ballet company in Capetown and reported incidence of injury over 10 years based on insurance claims, with a low incidence again. However, in Australia the ‘Safe Dance Project’ survey (Geeves,1990) was underway reporting spinal injuries (34%), ankle (29%), knee (13%), foot (12%) and hip (4%). 37% were classical ballet dancers (Geeves, 1990). This report was not peer reviewed but contributed to our knowledge of dancers’ injury in different international regions. The other early papers still reported a high injury rate, but the most striking observation is the frequency of poor alignment reported as an important cause. This will warrant further consideration later in this study. These early studies suffered from inconsistency in study design and methodology and therefore it was not possible to fruitfully compare as the same definition of injury was not employed. Nevertheless, some of the larger research studies were instrumental in jumpstarting international participation and cooperation in dance research. Although early in the developing body of dance medicine research, they presented useful information to the clinician. Without a doubt, research in dance was lagging behind that in sport. Early on, researchers in sport recognized the need for injury surveillance systems to reveal incidence and severity and identify the aetiology or effectiveness of preventative measures (van Mechelen, 1997; Meeuwisse and Love, 1997). It was recognised early in the 1990s that there was a need for uniform injury definitions and appreciation of limitations in research design (van Mechelen et al., 1992; Meeuwisse, 1991). Meeuwisse was considering the multifactorial paradigm in sport injury in 1994, building towards his ‘dynamic model of etiology of sport injury’ in 2007. Understanding injury mechanisms, surveillance and risk factors were clarified (Bahr and Holme, 2003; Bahr and Krosshaug, 2005; Fuller et al., 2007).

The next twenty years yielded further fruitful but heterogeneous research, and it was not until the publication by the International Association of Dance Medicine & Science of its White Paper (Liederbach et al., 2012) that standardisation of dance injury epidemiology was outlined, and more disciplined research methods started to filter in.

The results of the literature search are seen in the following tables.

Table 3.2 Later research on injury in dance.

Study Year Country	**Dancers (N)**	**Age**	**Time Per-iod**	**Injury Definition**	**Injury N=**	**Study out-come**	**Injury rate/ prevalence**	**Exposure**	**Health Prof (HP) Diagn-osis**	**Injury character**	**Injury site**	**Injury risk**
Nilsson et al Retro-prospective 2001 Sweden	Prof Ballet 98	17-40 mean: 28.3	5 yrs	Not specified (N/S) Reported to onsite health prof	390	Injury incidence	0.62/1000 dance-hrs 1.00per dancer annum	48 hr/wk	HP	Traumatic: 43% Overuse: 57%	F/A:54% Lsp:18% Knee:11 %	> risk of ankle sprain in ≤ 26y
Liederbach and Compagno Prospective descriptive 2001 US	Ballet Prof and pre-prof 644	Pre-prof= 19±2 Prof= 24±4 27±8	2yrs	Time-loss	500 S/R to HP	Examine work conditions associated with injury	N/S	> injury in those dancing>5hrs/ day	HP	N/S	N/S	Injury with fatigue inadequate diet > 5hrs dancing/day
Luke et al Prospective US 2002	Pre-prof Ballet 39	15.8±1yr	9 mth	Self-report (SR) to PT	112 self report 71 HP assess ed	SRI RI Duration Severity	4.7/1000 SR 2.9	N/S	HP	58% SR New 44% Recurrent	Ankle: 22 Spine: 21	Underpowered
Askling et al Retrospecti ve cohort Sweden 2002	98 Pre-prof F:78% M:22%	17-25	No limit to recall and S/R	N/S	50 ham-string injurie s	Incidence of Hamstring injury	34% acute 17% hamstring	23hr/wk 35wk/yr	N/S	51% history of injury to rear thigh 66% acute 34%overuse	Rear thigh	Slow flexibility training (splits)
Byring and Bø Prospective Norway 2002	41Prof ballet 27F 14M	19-40	19 wks	Dance-related injury Time-loss	64 ≥31 dance injury	Injury incidence	N/S 'high' 3.2/dance	30-40hr/wk	HP	78% chronic 16% time loss Minor Moderate Severe	F/A Hip Back	Seasonal Training Planning ↓strength and preparation

Negus, Hopper and Briffa et al. Descriptive Correlation Australia 2005	29 Pre-prof Ballet F:24 M:5	15-22	2 yrs	Dance-Related Modify or time-loss	82	Correlation between TO and injury	Prevalence = 100%	N/S	N/S	History of 93.1% non-traumatic 41.4% traumatic injuries	Hip 25.6% Ankle 25.6% Lower leg 19.5% Knee 7.3% Thigh 1.2%	Non-traumatic injury correlated with decreased functional TO (active ER lag)
Gamboa Retrospective descriptive Cohort study US 2008	204 Preprof ballet	9-20	5 yrs	SR to PT	198 in 151 danc-ers	Risk characteristics/factor Utility of screening	1.09/1000 DE 0.77/1000hr 0.55/dancer in 5yrs	20h/wk	HP	Overuse	F/A:53.4 % Hip: 21.6% Knee: 16.1% Back: 9.4%	Increased injury in those with high disability screening scores and previous Lsp pain Increased injury with -foot pronation -reduced plantarflexion -lower strength in lower limb
Liederbach and Rose Prospective US 2008	298 183F 115M	18-41	5 yrs	Time-loss	1427	ACL Injury Rate:low	ACL injury in ballet .009/1000 exposures	Number of dance exposures (DE)	HP		F/A:57% Spine: 12% Hip:6%	ACL is low risk in ballet No sig risk factors

Hiller Australia Prospective cohort study 2008	115 pre-prof F:94 M:21		13m	Time-loss (>1day) ankle sprain	38 sprains to 33 dancers	Time to first ankle sprain	0.21/1000h	N/S	HP	Dance class:16	Inversion ankle sprain	Increased risk of sprain in younger, previous contralateral Increased inversion ROM Decreased balance ½ pointe
Campoy et al Retrospective Brazil 2011	258 Prof ballet	18±5	1yr	Dance-Related Interrupting routine	197 injured	Incidence	1.33/dancer 1.73/injured dancer	N/S	N/S	N/S	F/A:92 Thigh/ leg:88 Knee:71	Increased hr/wk dynamic overload height ↑exposure
Leanderson Open cohort Retrospective Sweden 2011	476 Pre-prof F:297 M:179	10-21	7yr	Overuse/ traumatic Influencing training	438 Trauma: 101 OU: 337	Incidence Site Type Most common	0.8/1000h	10.5-15h/wk	H/P	Overuse 76% LE Most common: ankle sprain Most common Δ: Foot tendinosis	Trauma F/A:69 OverUse F:102 Knee:81 Hip:41 Lsp:45	Increased Injury with increase in age
Drężewska and Śliwiński Prospective Poland 2013	71Pre-prof ballet F45 M26	15-18	Preval-ence Pilot study	Pain VAS	44	Prevalence of Lsp pain	Prevalence of Lsp pain in62% of 71 dancers	N/S	H/P	Overuse injury	Lower back	TO is associated with Lsp pain Sacral angle ≥ 30°. BMI<18.5 No sig between F/M
Allen et al UK 2013 Prospective	52 Prof ballet	25±6	1yr	Time-loss	183	Incidence Cause	4.4/1000 6.8/dancer	31.5-35.5hr/wk	HP	Overuse: 68%F 60%:M	Lower leg/F/A :75 Spine:48	Jumping Arabesque Lifting Pointe

Bowerman NZ 2014 Prospective	46 Pre-prof F:30 M:16	16±1.58	6m	Time loss	59 for 46 danc-ers	Growth Maturation LE align/ injury	3.52/1000DE 2.40/1000h	N/S records	HP	Overuse only monitored	F:31% Lsp: 24% A:15%	Growth (foot) associated with >injury Alignment
Ekegren UK 2014 Prospective	266 154F 112M Pre-prof	15-19	1yr	Time-loss	203	Injury rate Risk Exposure Character	1.38/1000h 1.87/1000DE	30.3h/ wk	HP	Overuse: 72% Traumatic:28 %	Ankle: 33% Low leg:22% Foot:20 % Knee: 13% Hip: 10% Thigh: 2%	Increase in age/ Increase in experience correlates to Increase in injury
Caine et al Cross-sectional Canada 2016	71 44F 27M	11-22 M=16.77	8.5m	Time-loss	114	Evaluate S/R injuries over 1 season	M=3.82/ 1000DE 3.06/1000h	12.5-20h/wk Individ records	HP	65.8% overuse 34.2% acute	F/A 30.7% Hip 20% Knee 17%	More injury in class Less injury at higher levels
Costa et al. Brazil 2016 Retrospective descriptive	53 Prof ballet	34±6.7	N/S	N/S			N/S	Survey/interview	N/S	N/S	Ankle sprain F:67.6% M:40.9 %	Pirouette Jump landing Increased risk in increased experience
Ramkumar et al US 2016 Retrospective	52 (153 in 10yrs)	Av:27	10yr	Med records	574	Most common diag. Injury sites	0.91/1000hr 1.10 per annum	N/S	HP	N/S	F/A:220 38% Lsp:117 20% Csp:55 10%	N/S

Lee et al Prospective NZ 2017	66 Pre- profession al F=40 M=26	Mean: 18.57 16-24	1 yr	Time loss	125	Injury incidence MCS score/ injury risk	2.27/1000hr 3.35/1000D E 2.11/1000D E – ballet majors 1.98/1000D E for time- loss	h/wk not stated	HP	Overuse 59.2% Acute 40.8%	Ankle Knee Foot 85 68% Trunk 25 20%	Rapid changes in load Increased load Reduced movement control
Yau et al USA 2017 Retrospect- ive	480 Pre-prof	12-25	6 yrs	Med records	1,014	Incidence	4.86/dancer days	15-20h/wk	HP	67.9% Overuse M/F no difference	Ankle 24.2% Foot 19.5% Hip 15.45 Spine 13.5% Knee 13%	Increased injury with ↑volume of extreme movement Lack of recovery
Sobrino and Guillen Spain 2017 Cross- sectional	N/S Prof ballet	19-33	6yrs	N/S	486	Incidence of overuse injury	0.239/1000 h	N/S	HP record	Overuse	Overuse Stress Fracture 2nd MT PFS Os trig Snappin g hip	Increased overuse injury in young prof ballet Less as skill improves
Bronner and Bauer Prospective US 2018	117 Pre-prof Modern with ballet training	18.14± 0.68	4yrs	Medical attention Injury (MAI) Time loss (TLI)	MAI: 167 TL: 288	Examine risk factors	MAI: 3.28/1000h TLI: 0.57/1000h	N/S	HP	2.3 times as many MAI as TLI	F/A: 21.72% Hip/ groin: 20.17% Knee: 12.29%	Low and high Beighton score Previous injury 2-4 tight muscle Technique error

Swain et al. Australia 2018 Prospective cohort study	Prof and pre-prof ballet 119 (F:100)	>17yrs	9 mths	Pain VAS= Chronic/ limiting/missed activity		SR	Prevalence 78% 1+ episode 52% limiting 29% chronic	49.9-85.3hrs/mth (no correlation)		LBP	Spine	Predictor = history of LBP
Jacobs et al Cross – sectional 2017 US	178 Prof ballet	26-30	Point Preval - ence	1.SRI 2.Scored severity of injury SEFIP	99	Self-report injury (SRI) SEFIP questionnaire	Prevalence: 9.6%injury 21.5%in recovery 24.9%pain 44.1%not injured 15% not reporting	N/S	N/S	Chronic: 24.9%	N/S	Rank was associated with SR injury Injury was associated with number of years dancing
Novosel et al 2019 Croatia Prospective	99 Prof ballet		1 yr	Injury Time-loss		Incidence Predictors	1.9 per dancer 1.4/1000hr	40 hr/wk	SR		F: Ankle Calf Foot/Knee M: LBP Knee Foot	Biopsycho-social association
Fuller et al. 2020 Australia Retrospect-ive cohort design	Pre-prof ballet/ contemp-orary 17	20.7 by end of training	3 yrs 6 sem esters	Medical attention	1=14 2=15 3=23 4=17 5=22 6=28		2.71/1000h 100% prev	HP notes	N/R			1=.85 2=.64 3=1.27 4=.81 5=1.14 6=1.36
Matiussi et al. 2020 UK	Prof ballet 123	F; 28±8.3 M;27.9±8.5	4 yrs	Medical attention(MA) Time-loss (TL) ≥24hrs off			MA F:3.9/1000 M:3.1/1000 TL F:1.2/1000 M:1.1/1000			65-69% MA: Overuse 50-51%TL: Overuse F/A:		1st Soloists Principal:2-2.2 additional MA injury/1000 9-1.1 additional TL injury M: Jump landing

Table 3.3 Literature Reviews

Literature Reviews	Year	Population	Conclusions
Hincapie et al.	2008	Cross section of dancers	Research methodology not consistent therefore 69% of studies not admissible. Musculoskeletal injury is very common at all skill levels. Recommendations for standardisations in future research.
Jacobs et al. Systematic.	2012		High prevalence and incidence of LE, hip and lower back injury. Psychosocial factors may increase injury risk. Ankle sprain can increase risk of contralateral sprain. Fatigue may be linked to ACL injury. Hamstring strain affects tendon > muscle in pre-professionals
Bowerman et al.	2015	Adolescent, elite ballet	High incidence of LE injury Growth and maturation Poor lower limb alignment (need for further evidence)
Smith et al. Systematic and meta-analysis	2015	Professional	Incidence: 1.06/1000hrs M 1.46/1000 F Overuse: 50% M 64% F Prevalence: 62% lower back 58% hip 66-91% lower extremity 14 – 57% foot and ankle
Kenny et al. Systematic	2016	Pre-professional	Previous injury Psychological factors Anthropometrics Poor aerobic capacity Poor LE alignment Faulty mechanics: Sacral angle > 30^{o} in turnout Poor jump landing technique
Smith et al. Systematic	2016	Professional and pre-prof	Highest prevalence of injury F/A Second highest is spinal Period prevalence of injury: Prof – 280% Pre-prof – 104% Link required between certain manoeuvres and specific injury patterns
Trentacosta et al. Systematic	2017	Professionals Students	3527 injuries seen in 1553 dancers 345 were hip/groin Incidence rate: 0.09/1000 hrs(27.7%) Of 462 professionals 128 hip/groin (27.7%) Of 1539 students 217 hip/groin 14.1% Older dancers have> hip injury Larger issue than previously thought
Biernacki et al. Systematic	2018	Ballet	Alignment is an important risk factor Poor lumbo-pelvic control Inappropriate transversus control Decreased lower extremity strength Poor aerobic fitness
Campbell et al.	2019	Ballet Pre-prof Professionals	Modifiable injury risks: Hypermobility/fatigue/overuse/neuromuscular dysfunction/core wakness/lower extremity weakness/range of movement limitations Screening tools: 7 identified to reveal injury risk and enable evidence-based preventative progeammes

Fuller et al. Systematic	2019	Pre-prof Professional	17-20 yrs have a 12% higher risk of injury compared to older dancers Increased injury risk with increased duration/intensity Possible increase of 3.03 injury rate for transition from final training year to 1st year in professional company (Ekegren et al., 2014; Allen et al., 2012) Possible increase of 42% transitioning to prof. Increased injury rate in first full-time training year Recommendation: Extend rehab to decrease reoccurrence Monitor training loads Increase cardiovascular fitness Increase strength training at these periods

Twenty-five studies representing twelve countries were included. Fourteen were prospective, six were retrospective, two were cross-sectional and one was retro prospective. Since 2008 there have been thirteen reviews in dance epidemiology. Nine of these were systematic reviews and one included meta-analysis.

Leading the Standard Measures and Consensus Initiative, supported by the International Association for Dance Medicine & Science (IADMS) Liederbach et al. (2012) recommended that a definition of dance musculoskeletal injury should refer to 'an anatomic tissue-level impairment as diagnosed by a licensed healthcare practitioner that results in full time loss of activity for one or more days beyond the day of onset'.

The authors presented their White Paper in order to:

- Establish uniform methodology to assess dancer capacities and risk factors for injury

- Establish common protocols for reporting injuries

- Assist the dance community in applying these recommendations.

The authors adapted the Meeuwisse et al (2007) model of a 'dynamic, recursive model of etiology in sport injury', to create a model for dance. The intrinsic factors that can influence injury in dancers are many and complex. These can be divided into modifiable and non-modifiable (Bahr and Holme, 2003). It is important to study those that are potentially modifiable in order to design appropriate interventions. Extrinsic factors, modifiable and non-modifiable must be fully understood in order for interventions to be realistic. Dance injuries are multifactorial and Leiderbach et al. (2012) indicate the need for identifying how 'constellations of risk factors interact in ways that make dancers vulnerable to an injury event'. MacMahon and Pugh (1970), cited in Liederbach et al (2012), refer to a 'web of causation' when describing the influence and interplay of intrinsic and extrinsic variables in injury, which are dynamic in nature.

In the recursive model for sport of Meeuwisse et al (2007) and the adapted model for dance (Liederbach et al, 2012) it is suggested that researchers capture risk factor data during an aetiologically relevant time period looking back from the time of injury, in addition to looking forward from the beginning of the season. Combining injury prevalence and incidence allows a more complete picture of the true magnitude of dance injuries. They call for validity and reliability studies to be conducted prior to research and recommend that by focusing on specific risk factors found to be significant from higher levels of evidence, the direction of future research will be improved.

15% of injured dancers did not report their injuries to employers and/or medical staff due to expectations that pain is a normal part of dance (Jacobs, Hincapié and Cassidy, 2012).

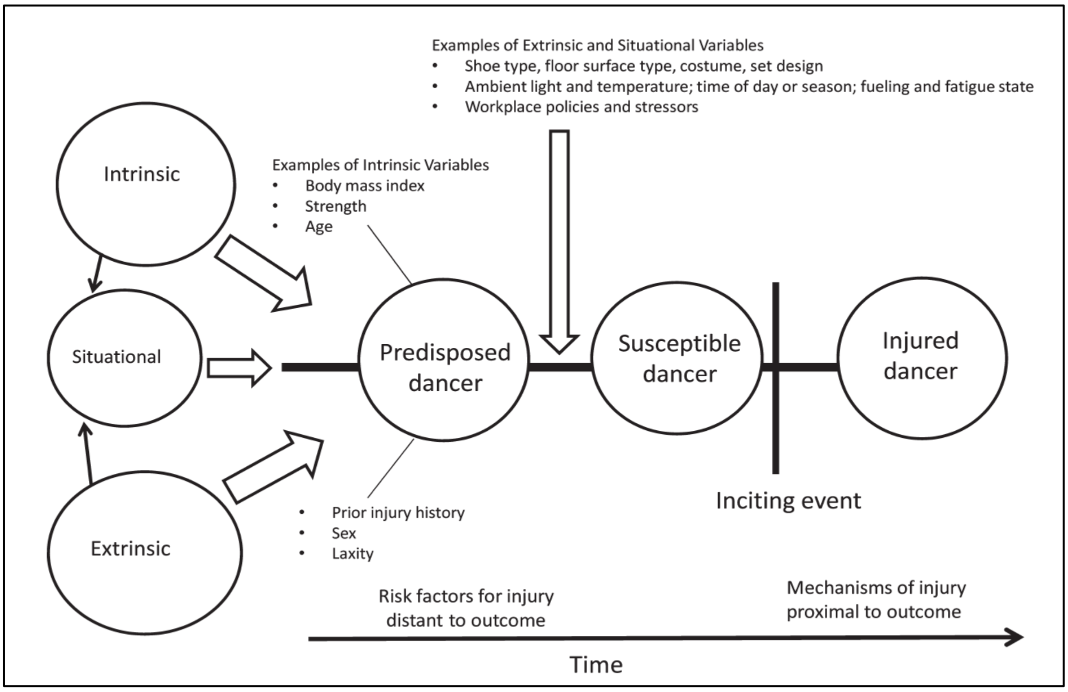


Figure 3.0.1 Interactions among intrinsic and extrinsic factors relative to the occurrence of injury (Meeuwisse, 1994). Modified by Liederbach et al. (2012).

3.1 Discussion of Injury Characteristics

3.1.1 Overuse Injuries

A traumatic injury refers to an injury resulting from a specific, identifiable event whereas an overuse injury is one caused by repeated micro-trauma without a single, identifiable event responsible for the repeated microtrauma (Fuller et al, 2006). Sobrino and Guillén (2017) in their retrospective cross-sectional study, investigated overuse injuries in professional dancers. The purpose of the study was to examine the prevalence of overuse injuries in four dance disciplines. Their results were again similar to other studies in that overuse injuries make up the majority of dance injuries. The occurrence in ballet, the authors concluded was a consequence of pathomechanics in technique.

Murgia (2013) stated that for many years, it has been axiomatic that the vast majority of dance injuries are the result of overuse, and that dancers frequently persist in movement activities in the presence of microscopic injury. Brenner (2007) describes an overuse injury as ‘microtraumatic damage to bone, muscle, or tendon that has been subjected to repetitive stress without sufficient time to heal or undergo the natural reparative process'. Sobrino and Guillén found there was a higher rate of overuse injury in classical ballet than other genres and more frequent in female dancers. The authors suggest that the highly repetitive dance movements are a likely reason for the far greater incidence of overuse injuries compared to traumatic. Smith et al. (2015) concluded that 75% of all injuries in ballet were from overuse with similar findings between male and females. This is consistent with many other studies (Nilsson et al. 2001, Luke et al. 2002; Bronner et al. 2003; Allen et al., 2012; Ekegren et al. 2013; Bowerman, 2015). Rehearsals and the repetition required were blamed for overuse injury (Kadel, 2006: Bronner et al., 2003). Allen et al. (2012) found that although the mechanism of injury was hard to identify with dancers often unable to recall the initiating event, 'training' and performance were more frequently attributed than rehearsals. Matiussi et al. (2020) also reported that more than two-thirds of their time-loss injuries were attributed to 'training' rather than performance. Training means morning class in dancer terms which in professional dancers is used to warm up and prepare for the day's rehearsals by executing the main ballet vocabulary. It is the repetition in rehearsals where tissue fatigue can set in, and fitness deficits become apparent. Pre-professionals, on the other hand, have mostly 'training' - classes throughout the day where they are taught to improve technique, with few performances. When considering pathomechanics in student dancers who come under the auspices and guidance of their teachers while training, inevitably the question is posed – why pathomechanics? Why deficient technique?

Overuse injuries can also be the result of extrinsic causes such as of poor planning of training sessions or rehearsals, floor surface, and footwear (Sobrino and Guillen, 2017; Ramel and Moritz, 1994). Intrinsic causes such as poor physical fitness and deficient technique were also reported. Traumatic injuries, for the most part, are thought to be freak accidents which are difficult to prevent (Garrick, 1999). However, Yau et al. (2017) advocate the further investigation of traumatic injury rates.

3.1.2 Lower Limb Injury

In all studies from early to the most recent, lower extremity (LE) injuries predominated. Only Ramel and Moritz reported slightly more injuries to the lower back (70%) than ankles and feet (65%). Smith (2015) in their review reported that lower extremity injury in the pre-professional category accounted for 75-91% of injuries with 39-53% of total injuries occurring in the foot and ankle. In professionals 66-78% of injuries occurred in the LE with 14-57% involving the foot and ankle. Smith et al. (2016) found their results also highlighted a high prevalence for foot and ankle. They added that no studies were found that identified why specific injuries occurred in relation to certain training or performance requirements and activities. Neither were any strategies investigated which were associated with reducing incidence of injury. Bowerman et al. (2015) concluded that while there is good evidence that lower extremity overuse injuries are the most common type of injury in young elite ballet dancers, there is a lack of quality evidence identifying these injuries. McNeal et al. (1990) drew attention to a high incidence of lower limb injury referring to the authors' prior enquiry into the use of turn out in ballet (Watkins et al., 1989) which clearly raises levels of suspicion as to the pathomechanics that result from less than judicious training. This was followed by several studies on turnout (Gilbert et al., 1998; Coplan, 2002; Negus et al., 2005). Lundon, Melcher and Bray (1999) also drew attention to foot pronation, increased angles of functional turnout, alignment issues and foot and ankle overuse injury. Askling et al. (2002) was the only research specifically concerning hamstring injury in dancers. This was a retrospective study over 10 years using a questionnaire regarding acute and overuse injury to the rear thigh. The research was carried out in a national ballet academy. One third of dancers appeared to have had acute injuries and one sixth developed overuse hamstring injuries. Many dancers appeared to have ignored their injuries. The mechanism of acute injury to the proximal hamstring was during prolonged stretching episodes. It has been suggested by Jacobs et al., (2012) that injury recall periods should be limited to up to 6 months to reduce recall bias.

3.1.3 Lower leg, ankle and foot

Allen et al. (2012) reported that in a classical ballet company the incidence of injury over one year revealed that the majority of injuries were in the lower leg (F: 17%, M: 19%), ankle (F: 15%, M: 13%) and foot (10%, M:8%). The latest study by Matiussi et al. (2020) concurred that over their four-year prospective study the distal lower extremity demonstrated the greatest burden across all dancers. Male and female dancers use the high half *pointe* position (3/4 *pointe*), with females dancing on full *pointe* which imposes excessive load on the joints of the foot (Nilsson et al. 2001). It should also be noted that this 'excessive load' takes place in external rotation of the lower limb, but no studies have referred to this added dimension. This higher incidence in lower leg, ankle and foot is borne out by the general epidemiological studies in dancers (Luke et al., 2002; Byring and Bø, 2002; Gamboa et al., 2008; Liederbach et al., 2008; Campoy et al., 2016; Ramkumar et al., 2016; Lee et al., 2017; Yau et al., 2017; Bronner and Bauer, 2018 and Novosel et al., 2019). Particularly regarding lateral ankle sprain, Hiller et al. (2008) found that this ankle injury was a predictor of future contralateral sprain in adolescent dancers. In 2001 Nilsson et al., based on their five-year retro- prospective study had reported that professional dancers had an increased risk of ankle sprain, and much later the higher incidence of ankle sprain in younger dancers was echoed by Leanderson et al. (2011) and Costa et al. (2016). Stress fractures were investigated early on by Kadel (1995) who correlated exposure to bone injury and by Lundon et al., (1999) who, after biomechanical analysis of jumping technique suggested the cause to be alignment faults and resulting stress reaction. Smith et al (2016) carried out a systematic review and meta-analysis of prevalence and profile of musculoskeletal injuries in ballet. They studied 7332 injuries in 2617 dancers from 19 studies they considered eligible. The findings of this review indicate that foot and ankle pathology appear to be the most common for professional and pre-professional ballet dancers. They report that the most common injuries in professional dancers are tibial and metatarsal stress fractures. This is a concern considering Kadel's report twenty-five years earlier.

3.1.4 Lower Back

Lower back injury has been reported as the third most common site of injury in pre-professional and professional dancers by Allen et al. (2012), Ekegren et al. (2014) and Smith (2015). Swain et al. (2018) cited the Australian Safe Dance Report by Crookshanks and Trotter (1999) reporting that it was the second most common injury in Australian dancers. Gamboa et al. (2008) found an association of past low back pain with future musculoskeletal injury in adolescent dancers. Swain et al. carried out a prospective study of 119 dancers (pre-professional, professional ballet and contemporary students) to consider the prevalence, impact and factors associated with low back pain. Although 52% of the dancers reported activity limiting lower back pain (LBP) over a nine-month period, the only associated factor was a history of LBP. Chronic LBP was reported by 24%, one third sought medical professional help and one fifth resorted to medication. In their 10-year retrospective Ramkumar et al. (2016) reported that lumbar spine strain made up 20% of dancers' injuries. Because of the repetitive nature of choreography and the use of extreme extension combined with rotation, place the ballet athlete at risk of spinal pathology. Male dancers lift repetitively to the point of fatigue with possible deterioration in technique, incurring further risk.

3.1.5 Alignment Concerns in Classical Ballet Technique

Several studies drew attention to incorrect alignment as a risk factor for ballet dancers. Dancers themselves identified alignment issues as an injury cause in Bowling's early study in 1989. McNeal et al. (1990), Ramel and Moritz (1994) and Lundon et al. (1999) all referred to training and alignment concerns. Negus et al. (2005) linked injury to lower extremity lack of control in turnout and Drewska and Śliwiński (2013) correlated LE external rotation to anterior tilt of the pelvis in compensation, and lower back injury. Bowerman identified LE misalignments and Lee et al. (2017) to reduced movement control. In Bronner and Bauer's screen in 2018, technical faults were linked to increased injury risk. Biernacki et al. (2018) concluded that peripelvic issues were an important injury risk for professional ballet dancers. This refers to the control of the pelvis and lumbar spine in the static posture and dynamic, end of range movement. Allen et al. (2013) attributed lower back injury to the arabesque line in professional dancers (Figure 2.1). Campbell et al. (2019) referred to impaired neuromuscular control, compensatory movement strategies and mistiming of muscle activation. Kenny et al. (2016) included faults in jumping technique in their resulting risk factors for dancers. Clearly these are important considerations which are reiterated over the years and will be discussed further in this study.

3.1.6 Core Stability

The definition of the term 'core stability' can depend on individual perspective. The term is often used loosely and requires careful consideration. In this study the perspective is from a specific dance point of view, considers postural and movement dance strategy, and seeks to improve performance. Rickman et al. (2012) states that more studies are needed to explore the role of core stability in performance enhancement and injury incidence and prevention in dancers. In the absence of appropriate research in the dance-athlete, published clinical and training experience can contribute to strategies to promote movement efficiency and injury prevention.

Classical ballet technique emphasizes proper alignment of the pelvis to optimise dancer performance and pelvic alignment is thought to facilitate efficient movement in general, and efficient specific action at the hip and lumbar spine (Deckert, 2007). A stable base for movement of the extremities is fundamental to the technique. Assaiante et al. (2005) referred to the pelvis as a reference frame allowing better control of the centre of gravity, but not omitting head placement which allows clear vision and better visual and vestibular processing. In challenging movement, they suggest both are reference frames contributing to postural control and facilitation of movement.

Low load conditions as well as highly dynamic movements in dance demand efficient motor control of the lumbopelvic segments. But the review of injury risk in dance by Biernacki et al. (2018) identified lumbopelvic misalignment and lack of strength of the deep abdominal muscles as an important risk of injury in professional ballet.

The review highlighted the prospective study by Roussel and co-workers (2009) who correlated lower extremity injury or back pain with insufficient activation of transversus abdominis (TA). The authors used two commonly used clinical tests. In 2013 Roussel et al. followed up with a second paper relating to insufficient pelvic stabilisation with a history of low back pain in dancers, using two tests for TA activation.

The deep stabilisers are numerous and activate not in isolation but in sequence. TA is one of the several local stabilisers in the active core musculature which along with the diaphragm and lumbar multifidus is proposed to have a stabilising effect on the lumbar spine, particularly in the neutral zone where the spine is at its most vulnerable to instability (Cholwicke and McGill, 1996). The horizontal fibres of TA and the internal oblique muscle attach to the deep fibres of the thoraco-lumbar fascia (Pool-Goudzwaard et al., 1995) and it is suggested that the stiffening of the hoop like structure raises intra-abdominal pressure and limits the translational and rotational motion of the spine. Hodges (1999) cited the work of Cresswell, Grundström and Thorstensson (1992) where the continued activation of TA during flexion and extension of the spine as opposed to the phasic activation of others, more superficial, suggested the stabilising role of TA rather than development of torque in orienting the spine. These claims have arisen from research over twenty years old and the subject remains contentious today. However, this action of narrowing the waist, similar to the 'draw-in' manoeuvre described by Hodges, Richardson and Jull (1996) and Gildea et al. (2013) is a routine component of ballet training and a fundamental in efficient ballet posture. In balletic terms it is called 'pull-up' (Smith, 2009). In modern dance it has even been speculated that the 'contraction' in Graham Technique develops strong abdominals (Bronner et al., 2003). O'Sullivan (2000) called it 'drawing-up and in' demonstrating the clinical effectiveness and importance of the integration of the deep stability muscle system into functional movements. In the same clinical paper O'Sullivan illustrated a transformed posture with deep stabilisation similar to the requirement in dance where the manoeuvre is believed to stabilise the pelvis and lumbar spine. The extensors of the thoracic spine reduce the thoracic kyphosis with the opening of the shoulder girdle, producing the dancer's distinctive upright stance. This is an observation in dance and no reliable qualification of the dancer's posture is available. The early work of Hodges, Gildea, Hides and Richardson was taken up by the Pilates movement and used extensively as the favoured exercise format to help stabilise the dancer's trunk and support dance technique. Their 'navel to spine' (Ahearn, 2006) adds to the different ways in which to describe the manoeuvre. Herrington and Davies (2005) found that training TA in the Pilates method did indeed produce improved stabilisation (prone abdominal 'hollowing' test), but in spite of its frequent practise the Pilates movement has not progressed in scientific evaluation of their exercise repertoire.

Suehiro et al. (2014) investigated the effect of TA activation on control of the pelvis in prone hip extension. They found that undesirable anterior tilt of the pelvis in hip extension could be effectively controlled with TA engagement. This is an important point considering the frequent hip and spine extension, often to end of range, in ballet. The work by Tsao and Hodges (2007) examining the effect of motor training and neuromuscular control suggests that the activation of TA through specific training, transfers to other tasks. These studies contribute to a body of work supporting the importance of deep abdominal activation to stabilisation in the dancer.

TA activation has been measured by EMG (Hodges et al., 1996; Hides et al., Tsao and Hodges, 2007; Suehiro et al., 2014) and MRI (Hides et al., 2006; Gildea et al., 2014). Under ultrasound imaging Streicher et al., (2014) demonstrated the tensioning of the thoracolumbar fascia and its stabilising effect on pelvis and spine and were investigated in their pilot study relating to recovery from low back pain, with positive results.

Referring to Panjabi's (1992) theory of the 'neutral zone', this is a region of laxity in the neutral position of a spinal segment. The size of the neutral zone is an important measure of stability and the larger it is, the less stable it is. The inherent laxity seen in dancers offers less passive structural restraint and therefore will require increased active control of the larger neutral zone. Therefore, it is logical that the dancer will need to prioritise this.

Stabilisation of the trunk with lower limbs moving into extreme ranges at speed requires control from the global stabilising muscles to manage load. Increased stiffness and bracing in the trunk is required to stabilise the lumbopelvic region when demand increases with extreme movements of the lower limbs. Jumps with twisting and bending movements can impose tremendous forces on the spine and pelvis (Roussel et al., 2013) and the challenge is met by these secondary stabilisers. Lifting a partner overhead will require further bracing - stiffening the torso such that all muscles become synergists.

Bronner and Bauer (2018) found that a lack of lumbopelvic stability was a common problem across all technique movements in their dancer screen, although they did not test this specifically as a risk factor. In powerful athletic movements the core is responsible for transferring ground reaction forces from lower to upper body (Rickman et al., 2012). Allen et al. (2013) in their 3-year injury audit programme on professional classical ballet dancers closely monitored the lumbopelvic region and the force closure of the sacroiliac joint, being the key link in the overall kinetic chain between lower limb, hip and trunk. Therefore, the impact of stabilization at the lumbopelvic region was closely monitored. Part of the stabilization of this region is through compressive force closure due to muscles, ligaments, and fascia. If these are weak or insufficient, they affect sacroiliac stability and load transfer through the pelvic girdle.

As far back as 1997 Molnar and Esterson identified deficits in abdominal activation in their dance-specific screen in the Journal of Dance Medicine & Science. They drew attention, with concern, to the lack of trunk strength apparent in preprofessional dancers. Moreover, on questioning the dancers during screening, they found that few recognised insufficient trunk strength as the key factor in their difficulties. Spinal alignment and pelvic alignment are the foundations of the technique and are the responsibility of the teacher. If training is poor quality, so is lower-extremity placement and proprioception. Efficient pelvic alignment, on the other hand, may facilitate efficient movement in general, and efficient specific action at the hip and lumbar spine (Deckert et al., 2007).

In sport, abdominal muscle fatigue was linked to hamstring injury, low-back injury was linked to delayed trunk muscle reflex responses and greater body sway was linked to subsequent ankle injury (Zazulac et al., 2007). Zazulac also correlated impaired core proprioception with knee injury in female athletes. This concurs with Willson et al. (2005) who explored the relationship of core stability to lower extremity function and injury. Deficits in abdominal activation and endurance can have far-reaching consequences.

3.1.7 The Use of External Rotation of the Lower Limb

A key component of classical ballet technique is being able to work the lower limbs in external rotation, retaining biomechanical integrity. The use of external rotation at the hip allows the positions illustrated in Fig. 1.2. and this alters the orientation of the joint, allows increased range of movement in abduction (the dancer's *2^nd^ position en l'air)* and its muscular control and use of the hip flexors to lift the lower limb. Bone morphology, connective tissue extensibility and muscle strength allow this necessary facility. Unfortunately, research papers still quote the use of the 180^{o} angle of the dancer's feet as the ideal (Di Tullio et al., 1989; Kadel et al., 2005; Negus et al., 2005; Sutton-Traina et al., 2015; Kaufmann et al., 2021). This needs further discussion in the next chapter on screening. The external rotation possible at the hip joint plays a significant part in attaining the rotated lower limb, and the remaining rotational forces are absorbed by the knee, tibial torsion, medial ankle, abduction of the foot and toe valgus. The functional angle of turnout is the angle the longitudinal axis of the foot (Inman et al., 1969 cited by Washington et al., 2016) forms with the frontal axis of the pelvis. Thirty years ago, Eivind Thomassen in Denmark and William Hamilton in New York both orthopaedic surgeons and dance specialists, stated that 60 - 70^{o} of external rotation at the hip was required for a professional dancer. The average passive hip measurement for professional dancers in research led by Washington et al. (2016) was 50.2^{o}. The functional angle of turnout was 66.8^{o}. This supports earlier research by Gilbert et al. (1998) where the dancer's functional angle was 13 - 17^{o} more than the passive external rotation of the hip. It appears that the dancer's ability to use the range within the hip and control the supplementary range available within the rest of the lower limb structures, is key to prevention of strain. Sutton Traina et al. (2015) concluded that the hip range of movement is the primary predictor of active standing turnout. Lack of control and lack of range put the dancer at risk, and this needs to be understood by teachers and clinicians. Baker-Jenkins and Wyon (2013) found that a risk of injury in contemporary dancers was increased with an increase in turnout angle compared to hip range (compensated turnout). This concurs with Coplan's earlier study (2002) finding that increases in functional turnout compared to passive hip rotation resulted in increase of injury risk. Assessing hip range and functional turnout poses further problems when it comes to the various measurement options, but this is discussed later in this study.

3.1.8 Repetition

Bronner and Bauer (2018) cite Daprati et al. (2009) stating that emphasis is placed on the aesthetics of flexibility in dance pushing lower extremity postures to increasing extremes in choreography and excelling in dance requires intensive practice. Yau et al. (2017) in a discussion of overuse injuries suggested reducing the number of repetitions in rehearsals in order to limit injury, especially those movements to end of range, in an attempt to modify an extrinsic risk factor. Moser (2014) warns of the threat of injury to the young hip in uncontrolled end of range repetitions, if the joint is lax or dysplastic. At the extremes of joint range, muscles are at the greatest mechanical disadvantage, theoretically putting the dancer at the greatest risk of injury. Wyon (2010) states that the quality of a training session is more important than the length of a session with quality being compromised by length and repetition. Complex choreography, however, demands repetition to develop the requisite refined motor control strategies and movement patterns (Yau et al., 2017). It is possibly the lack of stamina and control through range that fails the young dancer and deficits need to be recognized. High repetition of pathomechanics will hasten the strain on vulnerable structures and the development of overuse injury.

3.1.9 Jumping

Dance jumps are varied – vertical jumps and travelling (horizontal) jumps from two to two and one to two leg combinations. Repeated jumps require strength, stability, endurance and control in the trunk and lower limb. Age and stage of development should be taken into account when designing training regimes and rehearsal schedules. Jumping, especially larger jumps involve greater ground reaction forces and smaller jumps involve increased loading on the lower leg muscles, both of which may increase fatigue and risk of injury (Allen et al, 2012). Ambegaonkar et al. (2018) reported that in female collegiate dancers it was the horizontal work that predicted lower extremity injury rather than vertical power. Negus et al. (2005) found that jump landings (vertical) into a less turned-out foot position (implying less control) correlated with increased injury. In the case of repetitive jumping, the vertically aligned trunk of the ballet dancer increases the moments on the knee combined with the turned-out stance and may increase injury risk in the younger dancer (Bowerman et al, 2015). However, Yau et al., (2017) concede that repetition is required to perfect the aesthetic requirements of dance. However, repeated exposure to submaximal load without adequate recovery time leaves a dancer susceptible to injury (Ekegren, Quested and Brodrick, 2014). The same scenario using the faulty biomechanics suggested by Lundon et al. (1999) would surely incur further injury risk. Matiussi et al. (2021) attributed 21 stress fractures in professional male dancers over a four-year period, to jumping. When considering lower limb pathomechanics in ballet, the traumatic non-contact anterior cruciate ligament (ACL) injury requires consideration. Early and limited research into incidence of ACL injury did not concur. Leiderbach and Rose (2008) in the US examined prospectively, the specific incidence of ACL injury in four dance organizations, comparing the incidence in Ballet and Modern dancers. Considering that ballet dancers perform more than 200 jumps in a 1.5 hour technique class (Bowerman et al., 2014) with more than half of the landings involving a single leg, it was encouraging that their prospective epidemiological design found a low rate of anterior cruciate injury. Amongst intrinsic variables were knee hyperextension angles, thigh strength, passive hip joint range and navicular drop scores. The authors suggested the low ACL injury rate was due to the highly skilled balance ability in dance, the intricate footwork and the controlled neutrally aligned, toe-to-heel, landing techniques. In female ballet dancers the rate over a period of five years of ACL injury was 0.005 per 1000 exposures but higher in female modern dancers at 0.015 per 1000 exposures. The authors concluded that ballet with its upright, controlled moves accounted for this. The study recorded all other injuries where, to be expected, the majority were to the foot and ankle.

Meuffles and Verhaar (2008) in their 10-year study of Dutch dance companies found an incidence rate of 3.2 ACL ruptures per 100,000 working days – nearly as high as the rate in professional skiers. This injury was only found in the classical ballet dancers and all incidents involved the left leg when landing in a less exorotated, pronated foot position. This report is a serious concern, but has not been followed up.

3.1.10 Metabolic Fatigue, Tissue Fatigue and Lack of Recovery

The impact of fatigue on dancers' susceptibility to injury is widely reported in the literature. In 2001 Liederbach and Compagno found that those dancing more than 5 hours per day were more at risk and also those whose diet was inadequate leading to a tendency to disordered eating. Once fatigued, the ability to perform movements requiring complex skills is compromised. Wyon and Koutedakis (2013) reported that in a state of fatigue, muscle strength, power, jumps and lifts as well as highly intricate moves may be compromised with diminished accuracy. Murgia (2013) states that 'in a fatigue-induced state time to adapt to changes in forced load and direction is compromised' and 'motor control strategies are altered, putting ligaments and joints at risk for unexpected shear and torsion forces'. Twitchett et al, (2010) concur with this stating that subsequent faulty alignment, inefficient biomechanics, and stress placed on muscles and joints can only be tolerated a certain amount before injury. While physiological principles are routinely used in sport for performance optimization, fatigue management and injury prevention are less commonly used in dance (Wyon, 2010). After this statement was made 10 years ago, Fuller et al. (2019) reported that the imbalance between training load and recovery strategies leading to fatigue and injury is still not well understood and remains limited in dance (in spite of advances in sport). Wyon also observed that choreography is becoming more complex and arduous, the gender divide is being eroded (in technical challenges) and performance schedules are at least remaining the same or increasing in intensity. In addition, principles of periodisation that are routinely used in sport for performance optimisation, fatigue management and injury prevention, are less common in dance and warrant further consideration (Cunanan et al., 2018; Wyon, 2010). Liederbach, Schanfen and Kremenic (2013), in their study on ACL injuries explain that, in spite of fewer of these serious injuries in dance due to better lower extremity endurance compared to athletes, landing mechanics deteriorated with fatigue. They also observed that ACL injuries occurred most often late in the day (67%) and late in the season (75%), suggesting fatigue as a causal factor, though this was not statistically significant.

Problems arise at tissue level when stresses accumulate without reciprocal rest time for recovery. Liederbach (2012) reported on the substantial number of injuries lost to surveillance due to lack of reporting even though performance is affected. Dancers do not report injuries for many reasons. They can be replaced, absence is regarded as a lack of commitment (Murgia, 2012) or they may simply not anticipate the tissue damage precipitating. The body adapts to stress but the applied stress is proportional to strain. ‘Stress’ refers to the internal forces experienced by a structure and can be defined as the force per unit of area (Kalkhoven et al., 2020). The authors defined ‘strain’ as the amount of deformation or length change in the direction of an applied force.

Twitchett et al. (2010) reported that some professional dancers can be working up to 18.5 hours a day. Kadel (1997) reported that more than 5 hours of dancing per day resulted in an increased risk of stress fracture in female professional dancers. Those dancers also had had significantly longer amenorrhoeic intervals, common in female dancers, indicating the hormonal influence on resorption. The ballet aesthetic of the female sylph makes the dancer particularly vulnerable to the female triad (Bronner et al., 2003). A recent study by Keay et al. (2020) found dancers to be a specific group of high-level artistic performers displaying indicators of Low Energy Availability and consequently at risk of developing adverse clinical health and performance consequences of relative energy deficiency in sport (RED-S). Extenuating health issues need to be taken into account when considering tissue stress in dancers. Solomon et al. (1997) reported that over a five-year period stress fractures comprised 8% of injuries. Matiussi et al. (2021) reported 21 stress fractures in male dancers over a 4-year period. The same establishment reported that it was rare for a ballet schedule to include meaningful recovery periods or facilitate progressions in load. Instead, training loads were highly variable due to factors such as studio, stage or choreographer availability and sudden cast changes owing to injury (Shaw et al., 2021). Slight overtraining can bring with it skill and strength gains but training to structural breakdown results in injury requiring medical attention. Clearly, without adequate recovery for tissue repair, bone resorption outpaces bone deposition. Edwards (2018) states that epidemiological studies into overuse injury have focused on activity intensity or loading exposure while ignoring the potential interaction of both on the mechanical fatigue process. Ground reaction forces of 3.6 and 4.5 times the body weight of experienced dancers have been reported when landing from a *grand jeté* (travelling one to one jump), during which the greatest negative work was done by the knee extensors, followed by the ankle plantarflexors and hip flexors. Repetition imposes a significant loading volume, which suggests that correct landing biomechanics are necessary for dancers to avoid undue tissue stress. Vertical ground reaction forces add to lower extremity stress in the dancer (Arnwine and Powell, 2020). These landing mechanics are unique to dancers and place substantial load magnitude and tissue stress on the lower extremities.

Articular cartilage is a highly hydrated fibre composite that provides a resilient, low friction bearing surface covering bones where they articulate. Like all connective tissue it is responsive to strain. It becomes increasingly elastic, less viscoelastic, as the loading rate increases, i.e. that hysteresis, the energy lost between loading and unloading, will decrease with increasing strain-rate (Edelsten et al. 2010). However, cartilage is designed to withstand compressive load within the congruence of the joint. Misalignment can cause shearing forces on chondral tissue that exceeds tissue tolerance (Kumar, 2010) with resulting degeneration, bearing in mind that articular cartilage is a relatively non-regenerative tissue.

Collagen fibres in tendons, arranged in close parallel alignment enables them to withstand high tensile loads. Tendon is load-response adaptive structure (Cook et al., 2009) as is all connective tissue. Stanley et al. (2017) reported on positive adaptation in Achilles tendon structural integrity over a collegiate season in long distance runners. Docking et al. (2016) reported on an improvement in Achilles tendon quality and structure over a 5-month pre-season in elite Australian football players. Kalkhoven et al. state that it is important to acknowledge the dynamic physiological environment in which tissue resides, incorporating tissue remodelling and recovery. Mechanical factors also provide important stimuli for positive physiological and mechanical adaptation if properly managed. A balance between training and load improves connective tissue quality but tendon overuse results in decreased exercise tolerance, reduction in function and a tendon that is less capable of sustaining repeated tensile load. Cook et al. described a continuum of pathology which requires understanding for effective management.

Bone and tendon cannot readily alter their mechanical properties and do so through chronic physiological adaptation, but muscle behaves more acutely, and activation can increase the stiffness of the muscle tendon unit subsequently increasing the stress tolerance of the musculature more readily. Kalkhoven et al. conclude that any factors that impair muscular functioning will reduce muscular resilience and therefore may increase the stress imposed on other tissues such as joints, cartilage and tendon. The authors suggest examples of physiological and mechanical changes which can cause acute effects, such as reduction in mechanical stiffness of the muscle tendon unit, acute fatigue, glycogen depletion, muscle acidification and reduced force production. Adequate recovery may provide long-term physiological and mechanical adaptation such as increases in strength and tendon and bone adaptation. Training muscle has a considerable impact on stiffness regulation so that muscle can better sustain high impact loads and subsequently maintain good recoil characteristics (Komi, 1986).

Alsiri et al. (2019) used an ultrasound system to measure tissue deformation in response to mild strain in participants with hypermobility spectrum disorder (HSD) and a group of controls, finding mean strain index in patellar and Achilles tendons to be significantly lower in those with HSD. Considering tissue fatigue in dancers, Scheper et al. (2013) stated that clinicians should be aware of the large variation of phenotype in connective tissue disorders and take this into account when assessing musculoskeletal injury. The authors reported that in spite of training, the dancers with general joint hypermobility (GJH) had lower muscle strength and lower submaximal exercise. This is an important concern when reviewing dancers, considering the laxity seen in so many. The dancer with HSD may be even more susceptible to tissue fatigue due to lowered muscle strength and connective tissue resilience.

The dancer does not have the advantage of a succinct ‘season’. Instead, the picture is of a continued level of work, with intermittent spikes, often unplanned. Volume (hours), frequency (sessions per day or week) and magnitude of load may be critical in the capacity of both normal and pathological tendons to tolerate load. Therefore, scheduling in dance companies and schools needs far more deliberation.

3.1.11 Exposure

It is during the pubertal years and the adolescent growth spurt that injuries begin to be reported more consistently alongside increased training of technique (Gamboa et al., 2008; Steinberg et al., 2013). Loads beyond an athlete’s capacity have been cited as potential risk factors for injury, (Lee et al., 2017). Kadel, Teitz and Kronmar (1992) also report that any sudden increase in training intensity will increase susceptibility to injury and that dancing for more than 5 hours per day is associated with stress fractures. Bowerman (2015) cites Matthews et al. (2006) reporting that up to 16 hours of moderate to high amounts of training per week do not affect growth during puberty. However, 16 hours would be considered towards the lower end of the elite spectrum and many young dancers are devoting between 17 and 23 hours to training. Ekegren, Quested and Brodrick (2014) report that the pre-professional dancers in their study trained in excess of the range recommended by the American Academy of Paediatrics Council on Sports Medicine and Fitness. Their young dancers trained 6 days a week instead of the recommended 5. They danced on average 30.3h per week with only gymnasts training at higher levels of 33.3h per week, (Steffen and Engebretson, 2010). Dancers can be training full time by as early as 15 years old and can be professional by 17 years old. Ekegren et al. also recommend further understanding and cooperation in the care of young dancers between healthcare and artistic staff, to monitor and modify training loads accordingly. Purnell et al. (2003) found that a training intensity of more than 8.5 hours per week was a significant injury risk factor for adolescent dancers. Increases in training load are reported as an injury risk in young dancers by McNeal et al. (1990), Lee et al. (2017) and Fuller et al. (2019) investigated the sudden increase of load and concomitant injury in young dancers as they take on full-time training at 16 years and as the pre-professional enters the professional company. Ekegren, Quested and Brodrick (2014) also observed that injury incidence rose as students progressed through training to the highest level just as they were graduating into the profession. This accords with the study by Caine et al. (2016) of a similar pre-professional population where the 'aspirants' about to move into the profession were the most injured.

A study in professional dance reported a weekly load of 31.5 to 35.5 hours per week (Allen et al., 2012). Wyon (2010) observed that workloads are often 6-8 hours per day increasing to 10 hours a day as the performance period approaches. Wyon also observed that choreography is becoming more complex and arduous, the gender divide is being eroded (in technical challenges) and performance schedules are at least remaining the same or increasing in intensity. It is clear there is an overload problem in ballet with lack of recovery time. In the Norwegian National Ballet Byhring and Bø (2002) reported up to 40 hours per week. Performance weeks may comprise of technique class, rehearsals and up to 8 performances per week, in a 6-day week and dancers maintain a year-round performance schedule requiring a constant 'peak' that allows little time for rest and recovery from minor injuries (Bronner et al., 2003). If exposure measurements are high, it follows that recovery time is low. Measuring exposure in a professional company is challenging as each dancer has individual commitments and each individual choreographer and teacher perceives their goals to be the most important. Wyon (2010) advocates for better communication between choreographers and rehearsal coaches in order to have more realistic demands. Dancers have reported that they perceive injuries to be caused by fatigue or overwork, repetitive movements, new or difficult choreography and demanding rehearsal schedules (Laws, 2005; Bowling, 1989; Ramel and Moritz, 1994).

3.1.12 Cardiorespiratory Fitness

Linked to the impact of fatigue, the relationship between fitness and injury in dancers requires attention. Twitchett et al. (2010) found a significant association between low levels of aerobic fitness and injuries sustained over a 15-week period in 13 pre-professional dancers in their final period of training. High levels of cardiovascular fitness are important to prevent the onset of fatigue and consequently the occurrence of fatigue-induced injuries (Clark and Redding, 2012) with the demands in performance higher than that during class or rehearsal. Koutedakis and Jamurtas (2004) state that there are two main anaerobic requirements for dance. The first is the large surge of power required for explosive jumps and high elevation and the second is when relatively high-power outputs are sustained for 30-60 seconds. The authors report that training in a ballet class elicited a mean blood lactate level of 3 mmol/l in female dancers, whereas a choreographed solo raised it to 10 mmol/l (peak), the same as in top-class football, squash and hockey. This indicates that there are deficiencies in daily training in relation to the demands of performance in ballet.

3.1.13 Strength

Out of the epidemiological studies, only Byring and Bø (2002) identified a deficit in strength parameters as an injury risk voiced by the dancers in the Norwegian National Ballet. They perceptively suggested that a lack of strength and endurance were occupational injury risks in their company. In the review by Campbell et al. (2019) lower extremity and core musculature weakness are cited as an important injury risk. Koutedakis and associates in 1997 investigated thigh strength in ballet dancers in relation to lower extremity injuries, finding that the poorer the thigh strength the greater degree of lower limb injury. Their body of work in this area started over twenty years ago and the subject has received renewed attention with continuing research. This is an important subject in ballet considering the mismatch between technical demand and the desired aesthetic and the accumulating risks identified regarding lack of fitness, overexposure and biomechanical deficits. Dowse (2017) found that a 9-week strength training programme in a group of adolescent ballet dancers produced improvements in dance ability and technique. This has been reported also by Angioi et al. (2009), Koutedakis et al. (2007) and Koutedakis and Sharp (1999). Parameters evaluated were maximum lower-body strength and power, dynamic balance, jump landing technique and dance performance in adolescent dancers. There was a 34.5% improvement measured in balance and jump landing technique. The claim that neuromuscular control is improved by a strength training regime should be questioned. With improved strength, perhaps concentration of technique can be enhanced but loading and strength improvements do not influence cortical mapping (Phillips, 2005). If ballet performance is a high-intensity form of exercise Twitchett et al (2009) question whether poor underlying physiology accounts for the high injury rates seen in classical ballet. The authors state that a dancer's highly developed economy of movement may offset neglected physical foundations but leaves them susceptible to fatigue. This in turn, has an effect on skill, causing poor alignment, especially during landing and lifting, and thereby exposing the body to inappropriate shear and rotational forces, increasing risk of injury. Lack of appropriate strength parameters are regarded as an injury risk, but as yet evidence is unavailable, although there may be association between strength deficits, the nature of which remains unclear (Moita et al., 2017).

3.1.14 Hypermobility

There are several terms that are used synonymously but it should be clearly understood that they are not interchangeable. Nicholson et al. (2022) explains that hypermobility refers to an objective measurement of passive or active range of motion beyond normal physiological limits. The proposed reasons are the shape of articulating bone surfaces (morphology), increased surface area for articulation, dysplasia and excessively compliant ligamentous restraint. Joint laxity is an objective measure of movement range beyond normal limits using accessory motion (manual testing).

Connective tissue laxity (fascia, ligaments and joint capsule) refers to abnormal or inadequate tissue composing the joint restraints which contribute to stability. Joint instability (functional) is a subjective self-report where there is loss of confidence that a joint will remain intact even under low loads. This confidence in joint integrity is measured through questionnaire (Nicholson et al., 2022).

Under adequate neuromuscular control a hypermobile dancer with joint laxity (excessive accessory range) may display excess physiological ranges of motion but report no instability or functional limitation. As Nicholson reports, in the presence of sufficient proprioception and kinesthesis, the active system compensates and disguises any inadequacy of the passive system.

One of the earliest studies on the incidence of hypermobility in dancers was by Grahame and Jenkins in 1978. They assessed student ballet dancers at the Royal Ballet School finding a high incidence of generalised hypermobility and asked the question whether hypermobility was an asset or a liability in vocational ballet students. The degree of hypermobility was measured by the Beighton Score, angle of dorsiflexion of the ankle and a quantitative test of passive extension of the 5th finger using a fixed force to test the tissues. The angle of deflection was greater in the dancers than the control group, as was the joint mobility score.

Following this, a study on injuries in professional ballet dancers was carried out in South Africa by Klemp and Learmonth in 1984 discussing the research carried out by Grahame and Jenkins (1978) on the incidence of hypermobility of joints in ballet and raised again the question of whether hypermobility was an asset or a liability in vocational ballet students. Klemp and Learmonth documented retrospectively the injuries sustained by 47 professional dancers over 10 years, recording site, characteristics and severity, reported by an orthopaedic specialist. The number of injuries over 10 years was surprisingly low and the authors attributed this to ‘great physical fitness and discipline of the dancer’. However, the definition of injury was not specifically stated, and neither was exposure or exact amount of time loss. Their data was based on injuries reported only to the orthopaedic specialist. Their data did not support the view that ballet dancers are hypermobile as, according to the Beighton criteria with cut-off of ≥4 (Beighton, Grahame and Bird, 1999) there were only two hypermobile dancers in their cohort. These researchers, with great foresight, also considered the forward flexion component of the Beighton score to be redundant in dancers as this is a trained prerequisite. Although this observation was published so long ago, researchers in dance have continued to use the Beighton score as a gold standard, although this may well not be the case.

Hamilton et al. (1992) suggested that increased hypermobility in male dancers may have contributed to increased injury. Nicholas' tests were used to score flexibility in this research. Consistency in assessing for hypermobility needs to be taken into account especially with earlier research.

Nilsson et al. (1993) found increased generalised joint hypermobility and spinal laxity in 10-year-old ballet students at the Royal Swedish Ballet School compared to controls. The researchers used a modified Contompasis score to differentiate the magnitude of joint mobility, finding the Beighton score of ≥ 4 too low for children. Following the Grahame and Jenkins research of 1978, McCormack et al. (2004) found significantly increased numbers of hypermobility in students in the Royal Ballet School and professional dancers in the Company compared to controls. Of more concern were the numbers diagnosed with Joint Hypermobility Syndrome (JHS) according to the Brighton Criteria (39%). The incidence appeared to decrease as the years of vocational ballet training progressed and also in the seniority within the professional company. The higher the professional rank, the fewer dancers with syndromic hypermobility, suggestive of an attrition rate due to hypermobility and injury.

At tissue level, in the skin the collagen fibre bundles are less tightly packed and have a disorderly arrangement with a whorled appearance on histologic examination (Black et al., 1980, cited in Joseph et al., 2018). This disorganization underlies the loss of skin biomechanical integrity. Numerous organ systems in which collagen is present, including the ligaments, tendons and joints are affected.

Briggs et al. (2009) found 50% of female ballet dancers with JHS had had at least one tendon injury and 61% had had to stop dancing for more than 6 weeks due to injury. 42% of male dancers with JHS had had at least one tendon injury and 83% of male dancers had had to stop dancing for more than 6 weeks due to injury suggesting that time lost to injury is high in this population. This may also be caused by longer healing times required in this population (Hardin et al., 1997; Grahame, 2000: Simmonds and Kear, 2007; Kim et al., 2010; Joseph et al., 2018). Defective connective tissue synthesis causes abnormal scarring with wide papyraceous scars so common in hypermobile tissue.

Hypermobility has been regarded as a risk factor for injury in dance by Ruemper and Watkins, (2012) who found 64% of injuries in a contemporary student cohort had generalised joint hypermobility (GJH) and 47% had JHS. Scheper et al. (2013) regarded JHS to be associated with vulnerability to injury, psychological complaints, reduced physical fitness and earlier fatigue. An increased incidence of injury has been reported in sport (Konopinski et al, 2012; Stewart and Burden, 2004; Pacey et al., 2010; Collinge and Simmonds, 2009). Kim et al. (2010) reported an increased injury risk for the hyperextended knee for anterior cruciate injuries, drawing attention to the efficacy of different grafts used in surgery in hyperlax tissues. The work of Ferrell et al. (2004 and 2007) drew attention to lack of proprioceptive acuity in Hypermobility Syndrome and abnormalities of musculoskeletal reflex function and Desfor (2003) drew attention to over stretching and altered reflex activity. Proprioception enhancement with exercise was the basis for the suggestion by Keer and Simmonds (2011) that hypermobile dancers may have a decreased proprioception placing them at greater risk of injury.

Bronner and Bauer (2018) included an analysis of flexibility in their 2018 study of risk factors for injury in elite pre-professional modern dancers. They found that dancers with low (≤ 2) and high (≥ 5) Beighton scores were more likely to sustain injury than dancers in the mid-range and were more likely to sustain joint-related injuries. The high Beighton score group accounted for the majority of diagnoses of joint instability.

Day, Koutedakis and Wyon (2011) question whether the Beighton score is appropriate to assess hypermobility in a dance population as the major joints used in dance are not included. However, the Beighton score, developed for the rapid epidemiological assessment of joint hypermobility in normal populations still remains the most commonly used assessment tool for joint hypermobility in non-specialist groups. The Beighton Score has since been re-evaluated as a score of generalised hypermobility in dancers. Chan et al. (2018) has recommended ≥ 6 for use in dancers and introduced the Lower Limb Assessment Score as a possible alternative. This was validated for adults by Meyer et al. (2017). The now redundant (Benign) Joint Hypermobility Syndrome (BJHS or JHS) employed the Beighton score of ≥ 4 as a major criterion and arthralgia, another. As a result, high numbers of dancers were diagnosed with syndromic hypermobility (McCormack et al., 2003; Chan et al, 2018).

In 2017 the terminology for the Ehlers Danlos Syndromes was revised and the hypermobility type is now described as a spectrum with Ehlers Danlos Syndrome (hEDS) at one end with severe symptoms, and asymptomatic hypermobility at the other (Malfait et al. 2017). In between lies a range of related conditions called Hypermobility Spectrum Disorders (HSD) or as reported by Nicholson, generalised HSD (G-HSD). Diagnosis adheres to stricter criteria but clinician experience and wider examination of joint mobility and the connective tissues, is recommended and taken into account and an individualised approach recommended. Discussion continues to define and refine criteria in the absence of a genetic marker.

In the ballet dancer it is important to assess the major joints, mostly lower limb, used to end of range remaining aware that the Beighton Score assesses mainly upper limb. The Beighton score is retained as part of the diagnosis of hEDS and higher cut-off scores are recommended for dancers. In a recent paper regarding contemporary dance students, van Rijn et al. (2021) ranked 0 - 3/9 as not hypermobile, 4 - 6/9 as hypermobile and 7 - 9/9 as extremely hypermobile. Expectation that high percentages of dancers, as a group, fall into the 4 - 6 category is realistic. It is the syndromic hypermobility that is the concern, but with stricter criteria fewer dancers are diagnosed. In this same research, hypermobility was not found to be associated with injury in contemporary dance students. Neither was this association found in research regarding the professional ballet dancer’s hip (Mayes et al., 2020). In establishments generating research on this subject there will be heightened awareness and therefore it is expected to see less association between hypermobility and injury. As mentioned by Chan et al. (2018), training, comprehensive health management and support can benefit particularly those most at risk of hypermobility related injury. This is not always available, and clinicians need to be vigilant when working in the field as Hypermobility Spectrum Disorders remain an injury risk if undetected.

3.1.15 Motor Control and Training Errors

Faulty dance technique involving poor alignment and motor control are frequently cited as possible risk factors for injury. Bowerman et al. (2015) measured pelvis and knee alignment in adolescent dancers in two dance functional movements; a *fondu* (turned out single knee bend) and a *temps levé*, (turned out single leg hop). They found a relationship between poor alignment of hip, knee and foot and increased overuse injury risk in the lower extremity.

Based on their experience in injury clinics Bronner and Bauer found that correction of errors in technique frequently eliminated musculoskeletal problems and in their 2018 screening research they examined three movements common to both ballet and modern dance assessing each with a simple points system. They found lumbopelvic control to be a common problem across all technique movements. Their results correlated with an increased injury rate and they add 'long standing neuromuscular habits are difficult to change and similar technical deficits can be seen in both the student and professional and struggling with minor injuries can produce compensatory patterns of poor placement'. Sobrino et al. (2017) advocate biomechanically correct technique and technical deficit is cited as a possible injury risk (Ahonen, 2008; Steinberg et al., 2012). In their review of risk factors for injury in dance Biernacki et al. (2018) concluded that alignment was the common risk factor for both recreational dance and elite ballet. Molnar and Esterson (1997) both physiotherapists, included technical moves in their screen: *battement tendu* front, side and back, *développé to* second and *plié*. Gamboa et al. (2008) screened *développé* to the front, assessing lumbopelvic strategy and *plié* in first position. Bronner and Bauer assessed *plié* in second and *développé* to second. These researchers clearly placed importance on linking screening elements directly to dance technique, a logical progression stating, 'faulty dance technique involving poor alignment and motor control are frequently cited as possible risk factors for injury'. This is supported by Ahonen (2008) and Steinberg et al. (2012). Bronner et al. (2020) followed this up with an intra- and inter-rater reliability study to examine a dance technique screening instrument where dance specialist physiotherapists assessed four technique movements*:* *grand plié* in second, *développé* to second, single-limb *passé relevé* balance and jumps (*sauté*) in first position. All reliability was high, lending weight to the aim of relating faults in ballet technique to increased injury risk and the ideal goal of decreasing injury.

With skill acquisition and accumulation of experience, the overuse injury in the professional dancer appears to decrease (Sobrino and Guillen, 2017). The suggestion that the more experience a dancer has, the more skillful they become and the less injury they incur is worth considering. Nilsson et al. (2001) reported that ankle sprain was their most common diagnosis and was four times higher in the youngest dancers < 26 years. The youngest and lowest ranking dancers in the Allen et al. (2012) study also reported the highest injury incidence overall. The increased rate in young male and female dancers may be explained by the challenge of moving from a training establishment to the challenges presented by the profession in terms of the strength, fitness and technical expertise required at professional level (Fuller et al 2020).

Ramel, Moritz and Jarnlo (1999) in their six-year follow-up research, comment on the fact that in spite of the number of performances having risen in the intervening time since their 1989 survey and their participants being that much older, their results were similar. The authors explain this proposing that as dancers get older, they develop an awareness of their capabilities making them 'work smart' and more able to care for themselves. Allen et al. (2012) concluded that demands placed on dancers in their company appear to be a greater predictor of injury than age and Solomon and Micheli in 1999, found that age and rank were not associated with injury. However, Bronner and Bauer (2003) who report on modern dancers with ballet training, state that the association between age and injury has been found to be inconsistent.

3.1.16 Previous Injury

It is recognized that a previous injury may increase the risk of sustaining a similar injury in the future. Kenny et al. (2016) found that previous injury history was highly associated with future injury risk and Liederbach et al., (2012) established that few pre-professional dancers seek medical attention due to fear of having to discontinue dancing. Therefore, it is highly likely that dancers do not fully recover from their initial injury. It is suggested that inadequate rehabilitation from a previous injury is a risk factor (Kenny, Whittaker and Emery, 2016; Clark and Redding, 2012; Hiller et al., 2008; Askling et al., 2002) and Bronner et al. (2018) found in their study that dancers with two or more injuries in the past year were more likely to sustain further musculoskeletal injury.

Smith et al. (2015) in their review and meta-analysis of injuries in ballet, concluded from the data available that injury patterns of pre-professionals and professionals are largely similar and advise that it is important to understand the pattern of pre-professional injuries as professional dancers report the development of chronic problems before the age of 18. They quote Lewis, Dickerson and Davies (1997) who reported that early injury can lead to early retirement. Garrick in 1999 was advocating the early identification and treatment of seemingly mild complaints (that might not even register in an epidemiological study) in an effort to prevent them gradually escalating into time-loss injuries requiring insurance costs and indeed career 'costs'. Kenny et al. (2016) also drew attention to the young dancer's limited timeframe for achieving artistic and academic goals. Ekegren, Quested and Brodrick (2014) also reported that injuries sustained in training will often recur in a professional career adding that if dancers could avoid injury during their pre-professional training, they might potentially extend their professional longevity.

3.2 Summary

The multifactorial nature of dance injuries presents a challenge to the health professional managing the performing artist (Cambell et al., 2019), echoing the 'web of causation' cited in Liederbach et al. (2012). From the results of this review, it is apparent that the injury incidence in ballet is high and may be higher than appreciated due to the retrospective nature of much of the research and dancers' reluctance to report injury (Jacobs et al., 2018, McNeal, 1990).

Wyon (2010) claims that the high injury rate in dance 'is not replicated in the most strenuous of full contact sports'. It is clear there is an overload problem in ballet with lack of recovery time. From Kadel's report in 1992 and the review by Smith et al. in 2015, stress fractures in ballet remain high. Lack of pelvic stability was reported in ballet in 1997 by Molnar and Esterson but is a main injury risk in Biernacki's review in 2018. This review highlights the importance of identifying problems in the pre-professional dancer and fully detecting the injury risks at this stage. The frequency of overuse injuries dominates the injury scene in dance and the injury to the lower limb in the classical ballet dancer. It is of concern to see from Ekegren, Quested and Brodrick, (2013) that injury incidence rose as students progressed through training to the highest level just as they were graduating into the profession. This accords with the study by McNeal (1990), Caine et al. (2016) and Fuller et al. (2019) of a similar pre-professional population where the 'aspirants' about to move into the profession were the most injured. Allen et al. (2012) and Sobrino and Guilléen (2017) report that the youngest professionals have the highest injury incidence, illustrating how the injury outlook develops. Is it appropriate that entry into the profession has become a 'survival of the fittest' situation? Prevention models are slow in arriving due to an inability to establish clear combinations of risk factors.

Importantly, obtaining the cooperation of artistic managements is essential to inaugurating more proactive approaches to prevention. This would allow healthcare professionals to acquire more robust evidence supporting the causes of specific injuries and patterns of injury in order to lower the risks to dancers. It is important to look beyond isolated potential risk factors and explore patterns and interaction among multiple risk factors, both intrinsic and extrinsic, and to better understand the complex nature of dance injury (Kenny et al., 2015). Without a clear understanding of the interaction between intrinsic factors such as age, growth, physique, fitness, strength, motor control and flexibility and extrinsic factors such as exposure, training methods, and schedule planning, prevention or even the lowering of risks is likely to remain elusive.

To conclude, what we do know is:

- There is a high injury rate in ballet. Wyon (2010) claims that the high injury rate in dance 'is not replicated in the most strenuous of full contact sports.'
- The most common injuries in ballet dancers are to the lower extremity and especially the foot and ankle.
- Lower back problems are the second most frequently injured area in the classical ballet dancer.
- Sufficient core activation and peripelvic stability remains an issue in ballet.
- It appears that training is not addressing this and as a result, lower limb mechanics may deteriorate.
- Control deficits of the lower limb in turnout are an injury risk.
- Incorrect technique with training errors will increase risk of injury.
- High repetitions and lack of stamina and strength increase injury risk.
- Jumping can exacerbate the situation.
- Range of movement, whether too much (excessively hypermobile) or restricted can be detrimental for the ballet dancer.

Furthermore:

There is no standardized screening programme to identify at-risk ballet dancers (Biernacki et al., 2018). Screening is recommended in ballet, based on the research by Bronner and Bauer, (2018), Bowerman et al. (2014), Biernacki et al. (2018) and Campbell et al. (2019).

Chapter 4 - Musculoskeletal Screening in Dance and Sport

Introduction

According to the Van Mechelen model of injury prevention, the development of injury prevention programmes requires injury surveillance to identify best practice and possible interventions. The use of screening tests is an intervention to identify athletes who may be at risk of injury. Implementing screening tools may be effective in reducing injury in both dance and sport. Although ballet is different to other dance genres and very different to sport, with distinctive demands, there are injury risks common to both. It would therefore follow that some screening tests already validated in sport may be useful in dance, but the specificity of ballet requires tests suitable for professional ballet physique, refined technique and the inherent challenge of the profession. The previous chapter investigated the injury characteristics and possible risks to the ballet dancer. This chapter reports on screening tests used in dance to reveal deficits that may possibly lead to injury and considers those being used in sport. Similarities and different needs are considered. To this end a literature search was carried out to examine the screening tools available in dance, and those being used to screen the lower limb (the location of the majority of dance injuries) in sport were explored.

In sport the pre-season screen gathers baseline information about an uninjured athlete that, in the event of injury, provides goals for rehabilitation. The pre-season screen attempts to detect those at high, moderate or low risk of injury in order to allow appropriate interventions to prevent future injury. Tests have ideally been examined for inter- and intra-rater reliability and in the best scenario, also for validity. Tests are used annually or bi-annually to monitor athletes' fitness and health, identify incomplete recovery from a previous injury and prevent further problems. Pre-season screening is well established in sport and screens vary in their approach and content. They are less well established in dance (Bronner and Bauer, 2018, Kenny et al., 2018). However, they unanimously aim to identify intrinsic risk and guide appropriate interventions. The importance of pre-participation evaluation was recognized by the American Medical Association's Committee on Medical Aspects of Sports over 40 years ago (Best, 2004). However, screens in sport have combined medical, musculoskeletal and sports specific assessments with mixed results. The pre-season screen is used to compare gathered information on an athlete to normative data and to highlight side to side deficits which can inform on injury risk. Studies measuring strength, flexibility, range of movement and balance for example, to clearly identify potential risk factors depends on the accuracy with which the measurements are made (Bahr and Holme, 2003). If common clinical assessment tools are used it is vital that testing procedures are reliable, valid and simple to produce across a range of participants (Gabbe et al., 2004).

Bahr (2016) drew attention to the necessary steps in developing and validating a screening programme and argued that three steps were needed: (1) a strong relationship must be demonstrated in prospective studies between a marker from a screening test and injury risk; (2) the test properties of the marker must be validated in relevant populations using appropriate statistical tools; (3) an intervention programme targeting athletes identified as being at high risk using the marker must be more beneficial than the same intervention programme given to all athletes. The final step should be a randomized controlled trial, where the treatment group receives the combined screening and intervention programme. These steps are certainly difficult in dance due to the historical lack of methodological standardisation in research, and large numbers of participants of the same level and genre with the same exposure, are rarely available. In dance, screening is attempted in smaller, specific settings according to the needs of the school or company and information gleaned allows interventions believed to be appropriate for the particular population investigated. The possibilities appear to be greater in sport with larger cohorts accessed.

In agreement with other researchers (Coogan et al., 2020; Bronner and Bauer, 2018; Kraus et al., 2014) the Functional Movement Screen has not been considered here as it has been widely used in sport with mixed results. The screen was trialled on 71 ballet students in an elite university ballet programme by McPherson et al. (2017). The seven FMS tests were used following a recognised grading protocol. Injury records were collected for a period of 6 months post testing. The authors did not find that the FMS total scores were associated with injury risk, with no significant difference between the injured and uninjured groups, warning that the FMSTM tests should be used cautiously in a ballet population. Only total scores were used in the conclusion, but individual subtests and injury were not examined as in Newton et al. (2017).

Allen et al. (2013) used the FMS to screen 52 professional classical ballet dancers. The 7 movement tests were scored on a 4-point scale. It was stated that ‘a notable aspect of the FMS in relation to other dance screening is the absence of any dance-specific testing’. The authors paid special attention to the stability of the lumbopelvic region and claimed that the FMS allowed the nature of pelvic–hip compensations to be identified, in particular with the “deep squat” and “in-line lunge” tests. When designing functional evaluation tests Davids et al. (2013) listed 3 important prerequisites to understand. Firstly, the expertise level of the performer on the task should be considered and many dancers are familiar with neither of these movements. Secondly, the intentions/goals of the task should be considered. The squat is a movement needed in many athletic events but not in ballet. It challenges total body mechanics when performed properly, and the goal is to assess movement strategy, but the question would be whether the movement strategy required in a squat is useful information for a dancer and clinician. Thirdly, the correspondence between task and performance is important. The transfer of strategies to dance movement would also appear doubtful.

In ecological terms, to use a sport movement screen to establish the nature of movement outside the skill and technique of a dancer to provide an accurate indication of risk, would seem debatable.

4.2 Literature Search Methods

In the previous chapter the injury characteristics in ballet were investigated. In this chapter the use of screening tools in dance and sport is explored. Similarities and different needs are considered. To this end literature searches were carried out to examine the screening tools available in dance. Musculoskeletal screening tools in sport are explored and their use in dance is considered.

An electronic search was conducted using five databases, Pubmed, Web of Science, Scopus, Medline and SPORTDiscus from inception to October 2021. Search terms for dance were danc* AND injur* AND screen*. Musculoskeletal screening tests were selected and those concerning cardiovascular, fatigue, nutritional, psychological, and bone mineral density were excluded. Screening tests created to assess dance genres other than ballet trained, of a high standard were excluded. Only peer reviewed articles, in English were considered. Those using the Functional Movement Screen were excluded as the FMSTM had been trialled by the lead researcher and found to be lacking in specificity in dance as explained above.

In sport, functional movement assessment has been further refined and is considered here. Field-based tests were favoured that use minimal equipment and were clinically convenient to use.

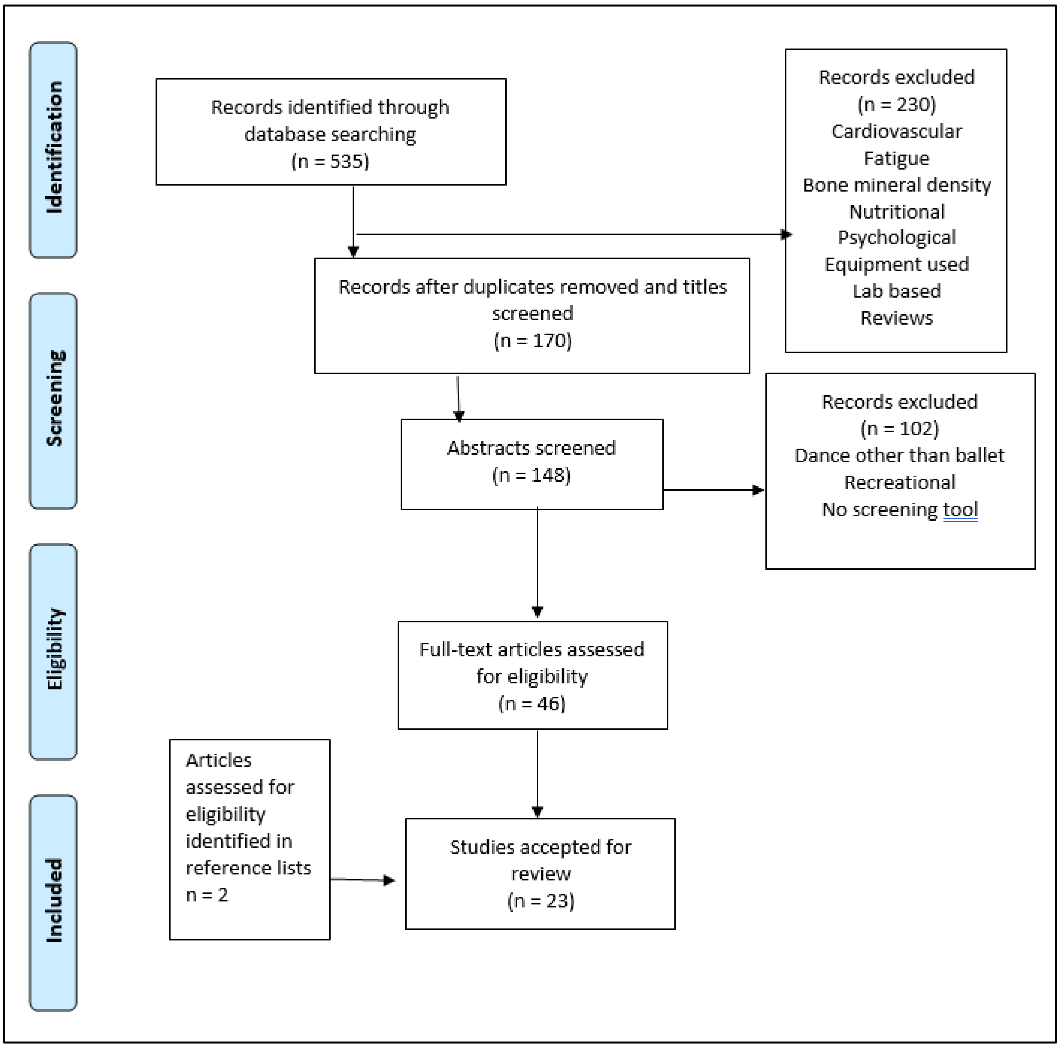


Figure 4.1 PRISMA diagram of search strategy for screening in dance.

Table 4.1 Screening Tools in Dance

Study	Screening Tool	Finding
Watkins et al. (1989)	Alignment of TO Deviation angle of knee in relation to foot	No significant relationship between deviation in alignment and injury rate for knee, ankle or foot.
McNeal et al. (1990)	Alignment of TO Deviation angle of knee in relation to foot	No significant relationship between deviation in alignment and injury rate for knee, ankle or foot.
Hamilton et al. (1992)	Flexibility of joints (Nicholas' tests) Strength Plantar/dorsiflexion ratio	Males with increased flexibility had ≥ 4 past injuries. Females with less turnout had more injury. Overuse injuries were related to less bilateral plié and decreased L ankle dorsiflexion.
Hamilton et al. (1996)	Leg length Lower limb alignment 1st position grand plié 2nd position demi pointe 5th position Sauté jump Lumbosacral (spondylolisthesis) Hip ROM ER (prone) Turnout (functional) Patellar alignment Knee hyperextension Posterior impingement sign Peroneal strength Foot type	Asymmetries of turnout, hip motion and pronation landing from jumps were noted.
Molnar and Esterson (1997)	Spinal screen – scoliosis Scapular position Pelvic kinetic tests Lower abdominal test – double leg lowering Hamstring/abductor/adductor length Thomas test Hip external rotation prone Gait Eyes closed single leg balance Intrinsic foot strength Plantar/dorsiflexion range Plié/relevé Posture Ports de bras – scapular/trunk stabilisation Passé développé in 2nd Tendu front/side/back	Significantly weak trunk strength and abdominal strength observed.
Weisler et al. (1996)	Ankle ROM (inversion/eversion) 1st metatarsophalangeal joint plantar/dorsiflexion Hallux valgus	Previous injury was predictive of a new injury. Previously injured dancers had lower dorsiflexion on the same limb.
Schon et al. (1996)	Postural alignment Spinal: scoliosis/kyphosis Hyperextension knees	Concentration on technical alignment assessment and correction to prevent injury.

	Ankle/foot/toe biomechanics (pronation, TO compensation) Range spine, hips, knees, ankles, feet measured Hip adduction/abduction/hamstring range Lower extremity alignment, balance, TO compensation Demi plié, grand plié, relevé to demi pointe, developé to 2nd	
Coplan (2002)	Passive hip external rotation (PER) /internal rotation 1st position functional TO 2nd/4th/5th functional positions Compensated TO PER - FTO	
Negus et al. (2005)	Passive ER (supine) Active ER (supine) FTO in 1st Active ER lag (active ER 1st - active ER supine) Static-dynamic TO: angle of landing in 1st/5th R and L.	Non-traumatic injuries were correlated with 6 of 7 TO variables Severity was correlated with 3 of 7. No correlation to traumatic injury.
Gamboa et al. (2008)	Posture: spinal curves/alignment Knee hyperextension Foot biomechanics Strength core/trunk Flexibility Orthopaedic testing hip/knee/ankle/foot Function: développé test/plié TO alignment/pelvic alignment/heel raise	Significant differences between injured and non-injured for R foot pronation, lower extremity strength and right ankle plantarflexion.
Wong et al. (2008)	Muscle strength Flexibility Alignment Posture Ankle/foot screening score	Recent F/A injury predicted risk Ankle sprain most common A score of ≥ 19 signified an injury risk
Angioi et al. (2009)	Passive and active développé to 2nd Muscle power: jump height Endurance: DAFT test	Vertical jump height was the strongest predictor of days off due to injury.
Twitchett et al. (2010)	Passive and active développé to 2nd (flexibility, strength) Muscle power: jump height (sauté) single/double leg Plank test Modified push-ups Endurance: DAFT test	Positive correlation between heart rate after DAFT Test and number of injuries.
Ruemper and Watkins (2012)	Beighton Score Brighton Criteria (JHS)	Time loss injuries were related to joint hypermobility syndrome.
Baker-Jenkins et al. (2013)	Total active TO (TAT) Total passive TO (TPT) Passive hip ER (pER) Compensated TO Active ER (supine) Compensated TO (TPT - pER)	For every 1% increase in compensated TO, 9% increase in the odds of being in the injury group. 1% increase in muscular TO= 8.4% increase in the odds of being in the 2+injury group.
Roussel et al. (2013)	Beighton Score Lumbopelvic movement control in 4 tests	Knee lift abdominal test and standing bow were significant predictors of injury.
Dręźewska and Śliwiński (2013)	Sacral inclination angle Measure with feet in parallel and in turnout	Statistically significant changes in sacral angle from parallel foot position to

		turned out ≥ 30º inclination caused higher pain scores.
Bowerman et al. (2014)	Maturation tanner scale Height Weight Foot length (growth) Lower extremity alignment in fondu and temps levé	Increase rate of growth is likely associated with increased LE injury rate. Better alignment is likely associated with a reduction in injury rate.
Kenny et al. (2018)	BMI%BMI BMD Foot Posture Index Ankle plantar/dorsiflexion range Passive hip ER Passive Supine TO Active standing TO Active straight leg raise Knee lift abdominal test Single leg standing (pelvis control) Unipedal dynamic balance Y Balance Test	Poor reliability of Foot Posture Index Poor reliability of passive hip ER. Moderate reliability for all other measures.
Lee et al. (2017)	Movement Competency Test (MCS)	MCS score < 23 increased risk of injury.
Bronner and Bauer 2018	Height, weight, blood pressure, postural analysis, turnout, joint range of motion (ROM), muscle strength, muscle flexibility, balance, GJL measured by the Beighton test, aerobic fitness, and dance technique analysis. For this study, we focused on four areas as possible risk factors: i) hypermobility (GJL); ii) dance technique; iii) muscle flexibility; and iv) past injury	Dancers with high Beighton Score were 1.5 times more likely to sustain injury. Better alignment correlated to less injury. 2 or more tight muscles correlated to more injury. 2-4 injuries in the last year meant 38% rise in injury risk.
Bronner et al. 2020	Dance technique testing instrument – ballet movements	Identification of technical deficits can guide injury prevention interventions
Van Seters et al. (2020)	Age Height Weight BMI Single Leg Squat Strength - countermovement jump (CMJ)	Significant association between limited dorsiflexion and lower limb injury.

Table 4.2 Screening Tools in Sport

Study	Screening Tool	Finding
Booysen et al. 2019	HLLMS 6 movement quality tests	High inter- and intra-rater reliability. Able to detect movement control impairments.
Frohm et al. 2012	Nine-test Screening Battery for Athletes	
Hewitt et al. 2005	Lab-based screen - vertical drop jump to detect knee/hip alignment in flexion/extension/ab- adduction	Knee abduction moment is 6.4 times greater in injured adolescent female athletes.
Luomajoki et al. 2007	Six lumbar spine movement control screening tests to detect stability deficits.	Movement control dysfunction was reliably scored in six lumbopelvic stability tests.
McCunn et al. 2017	Soccer Injury Movement Screen (SIMS) to detect movement dysfunction which may suggest future injury risk.	Five-test movement screen had acceptable intra- and inter-rater reliability.
Mischiati et al. 2015	Foundation Matrix Nine-test screen to assess movement control	Good intra- and inter-rater reliability in scoring the 9-test screen.
Padua et al. 2009	Landing Error Score System (LESS) to detect mechanics that may put the ACL at risk of non-contact injury	Field/Lab-based video recorded jumping task with good reliability
Reid et al. 2015	Netball Movement Screening Tool (NMST) to detect faulty movement patterns.	Good reliability in scoring movement faults in adolescent netball players.

The risk factors established in the previous chapter guide the discussion on screening in dance. Pre-participation screening is well established in the sports community and aims to enhance performance and reduce injury risk. Therefore, certain established screens in sport are considered here with some of the earlier papers influential in sports screening. Injury concerns common to both ballet and sport are explored.

4.3 Musculoskeletal Screening Elements

4.3.1 Hypermobility

The issue of joint hypermobility is raised in ballet and in sport. A degree of generalised hypermobility is required in ballet technique due to the range of movement required by the technique, but concern has also been raised that levels of hypermobility can lead to higher injury risk (Bronner and Bauer, 2018; Briggs et al., 2009). In the early screen by Hamilton et al. (1992) Nicholas' Tests were used, and males with more flexibility appeared to be more injury prone although the elite dancers were pronounced 'not hypermobile'. Őstentenberg and Roos (2000) tested elite female football players using the Beighton Score and found that ≥ 4/9 was a significant risk factor for injury. Söderman et al. (2001) also found this to be a concern, especially the hyperextended knee in soccer. The review by Pacey et al. (2010) found that generalised hypermobility was associated with knee joint injury in contact sports, but foot and ankle injuries were not associated. In contrast, Roussel et al. in 2013, with their stability tests, reported that lumbopelvic instability in dancers was more implicated in low back and lower extremity injury than a > 4/9 Beighton Score.

4.3.2 Pelvis, Hip and Knee Alignment

Screens in sport have concentrated on attempting to assess for risk of injury to the lower limb. Movement quality screening has come to the fore and is thought to challenge components of range of movement, strength, flexibility, coordination, proprioception and control of multiple body regions more thoroughly than isolated ROM and strength tests (Booysen et al., 2019). For example, instead of focusing on predicting injury risk (an impossible task according to Bahr, 2016), the Hip and Lower Limb Movement Screen (HLLMS) (Booysen et al., 2019) focuses on movement impairments in order to inform on exercise interventions. The six elements of the HLLMS cover hip mechanics and hip and knee alignment, hip muscle control, lumbo-pelvic dysfunction and restricted joint mobility with increased specificity.

The Functional Movement Screen (FMS) is used widely to screen in sporting environments and has been shown to be reliable and valid. The aim of the FMS is to be predictive of injury, but its predictive ability has been questioned in systematic reviews and meta-analyses. The FMS does not assess specifically enough for hip dysfunction as it has no unilateral weight bearing tests and is therefore less useful for assessing pelvis and lumbar spine and the likely compensations in the dancer or athlete. Lee et al. (2017) developed the Movement Competency Screen (MCS) to investigate the incidence of injury in pre-professional dancers, the relationship of injury and exposure and the relationship of risk factors (specifically the MCS outcome scores) and injury risk. The screen consists of 6 functional movements including a unilateral weightbearing test and a plyometric test. An MCS score of < 23 was associated with an increased risk of future injury. Benoît-Piau et al. (2021) showed that the MCS score correlated with deep abdominal activation and hip strength in dancers. The authors were also able to correlate the MCS with the FMS which supports the criterion validity of the MCS in dancers. Lumbopelvic control and lack of abdominal strength are specified as the main injury risks in professional ballet and as yet there were no screens in ballet to identify the 'at risk' ballet dancer (Biernacki et al. 2018). Trunk, lumbopelvic and hip stability are interdependent and Zazulac et al. (2007) found that impaired trunk proprioception was associated with knee injury in female athletes. For each degree increase in average proprioceptive repositioning error, a 2.9-fold increase of odds ratio of knee injury was observed, and a 3.3-fold increase in odds ratio of ligament/meniscal injury was observed (P≤.01).

4.3.3 The Knee

Östenberg and Roos (2000) reported that in female soccer players the knee was the most commonly injured (26%) followed by the foot (12%), ankle (11%), thigh (11%) and back (11%). The injury rate was not different for male soccer players, but knee injuries were the most common in females. Investigating lower extremity injury risk, the researchers measured isokinetic muscle strength at 60 and 100°/sec, one-leg-hop, vertical jump, square hop, aerobic capacity (VO2max), BMI and general joint laxity (Beighton, Grahame and Bird, 2012). General joint laxity and higher age were found to be the significant risks for injury along with a high-performance score (greater height) in the square-hop test. Dallinga et al. (2012) used a modified version of the Cochrane Methods and the Oxford Center for Evidence-Based Medicine (Devillé et al., 2002; Torpy et al., 2009) scoring this study highly for methodological quality in their systematic review of lower extremity screening for sports injury.

Anterior cruciate ligament rupture in otherwise healthy young individuals is a significant problem in sport and research efforts have been designed to identify those particular risk factors in non-contact conditions in order to target specific interventions (Smith et al., 2012). Hewett et al. (2005) using force platform and a high-speed motion analysis system (3D biomechanical measures) found significant correlation between knee abduction moment and angle and peak Ground Reaction Force in females with anterior cruciate ligament (ACL) injuries (R=0.74 and 0.67, respectively; $P < .05$). Significant leg-to-leg differences in knee load were observed in injured but not uninjured females. Side-to-side knee abduction moment difference was 6.4 times greater in ACL injured versus the uninjured females. From these results linking valgus motion/loading and ACL injury, more effective prevention strategies aimed at improving muscle contributions to dynamic knee stability in coronal plane control and neuromuscular training, can be developed (Hewett et al., 2005). 3D analysis of movement and use of force platform however, come at high financial and time costs and are impractical in field work. The authors advocated for further trials of the simpler 2D measurements in large scale screening to monitor neuromuscular profiles and also changing profiles over several seasons. Smith et al. (2012) attempted to follow this recommendation by screening the drop vertical jump in 5047 participants using commercial video cameras. The participants were followed for ACL injury during their sports season and video data was assessed using the Landing Error Scoring System (LESS). This is a reliable clinical screening tool that was developed (Padua et al., 2009) to identify individuals at increased risk of suffering noncontact ACL injury through evaluation of landing biomechanics associated with the drop vertical jump test. The Landing Error Scoring System (LESS) 17-point scale (Smith et al., 2012) assesses lower extremity and trunk positioning at the point of initial ground contact through analysis of frontal and sagittal plane video data. The study, however, was unable to demonstrate that the screening tool has predictive value for identifying those at increased risk of suffering non-contact ACL injuries. While trying to bridge the gap between laboratory studies of ACL strain with clinically identifiable movement patterns during sports by scoring jump mechanics, the tool did not prove sensitive enough in this study of a drop jump. Conversely, in 2019 Ṡiupṡinskas et al. found in their study (field-based) of elite female basketball players that a higher total LESS score ($p = 0.028$) was associated with the end of season injured group.

Considering ACL injury, Myer, Ford and Patterno (2008) found that future ACL status was predicted by measures of knee hyperextension and side-to-side differences in antero-posterior (AP) tibiofemoral translation (measured with a knee arthrometer). These findings indicate that increased knee-laxity measures are potentially related to increased risk of ACL injury. By highlighting this risk, the authors recommend determining the relationship between active and passive stability with a possible indication of neuromuscular control intervention. Engebretson et al. (2010) advise that static tests should not be confused with the dynamic valgus pattern associated with non-contact ACL injuries in female athletes, identified by Hewitt et al (2005).

Prevention of ACL injuries occupies a large part of screening in sport while landing strategies in dance are examined in relation to lower limb biomechanics and the development of faulty movement patterns and overuse injuries (Bowerman, 2015). Jumping in ballet does not only challenge normal functional mechanics, but the lower extremity operates in turnout, landing in a forwards trajectory, mid rotatory leap as well as vertically and on single leg most of the time with up to 200 jumps per 1.5 hours. Bowerman et al. examined the turned-out knee bend in ballet (*fondu*). Movement was captured by video and angles calculated. The researchers found that a moderate decrease in right leg injury risk was associated with a 10^{o} reduction in modified knee valgus angle. A small decrease in right leg injury risk was also observed with a 10^{o} improvement in a modified knee valgus angle on the right side during a *temps levé* movement (single leg hop in external rotation). The young dancers were monitored over 6 months, technique correction resulted with a reduction in lower limb injury.

Figure 4.2 Jump Landing Mechanics in Turnout. Bowerman et al. (2015)

Leiderbach (2008) in the US found that compared to sport there was a lower incidence of acute ACL injury in dance, but Meuffles et al. (2009) in the Netherlands around the same time, found an incidence rate of ACL rupture in dancers nearly that of skiers. This is surprisingly high (and has not been followed up). The risk was higher in the classical company rather than the contemporary and there was a 7% risk of ACL rupture in a 10-year career.

Instead of an internal rotation of the hip found in faulty mechanics in sport, in dance there is external rotation with a relatively more pronounced external rotation of the lower leg and foot.

Figure 4.3 Faulty landing mechanics in classical ballet. Meuffles et al. (2009)

4.3.4 Assessing Turnout in Ballet

Because of the use of turnout and the wide range used in ballet technique, the hip requires specific screening in classical ballet. Washington et al. (2016) explored passive, active and functional external rotation of the hip in dancers of different levels in a professional ballet company, showing that across a professional company hierarchy the measurements were similar. The purpose of their study was not to calculate injury risk but rather to enhance precision of assessment and to define measurements of healthy professional dancers in the light of past claims that to be professional, ballet dancers should have a greater range of external rotation than non-dancers and that greater range makes a better dancer. Washington et al. measured passive external rotation in supine position with results similar to those in the study by Hamilton et al. (1992) who measured hip external rotation in prone position, finding both male and female to be similar at 52 degrees. Washington et al. questioned the conventional assertion that classical ballet dancers need at least 60 degrees of external rotation (Hamilton, 1992; Liederbach, 1997, Thomasen, 1982). Functional turnout was measured at a mean of 56.8 degrees in each side. The deficit between passive and functional measurements has been shown to correlate with injury risk in collegiate dancers (Coplan, 2002) but this research illustrates that higher measurements of passive external rotation are not required in the evaluation of the professional dancer. However, this suggests that many aspects of technique, control, strength, experience and teaching methods are all involved here. Coplan found that based on self-reported injury to the lower extremity and lower back, working at a functional turnout greater than available passive hip external rotation increased injury risk. Passive external rotation minus functional turnout angle equals the amount of rotation absorbed below the hip at the knee, ankle and foot which bear the strain. Washington et al. postulate that less of a difference between passive and functional turnout values may contribute to their dancers' success but do not report on injury risk. Turnout is assessed by approximately 95% of practitioners during initial screens and injury evaluations, and it is one of the most frequently researched subjects in dance medicine and science (Lowrie, Champion and Chatfield, 2008). According to the screening the results of the Washington et al. research do illustrate realistic measurements and the importance of absolute precision and reliability in any screen. In a descriptive correlational study of 29 pre-professional classical ballet dancers, Neegus, Hopper and Briffa (2005) evaluated static, dynamic and static-dynamic turnout discrepancies. Static-dynamic turnout was the angle at landing in 3 functional turned-out positions. Injury history over the past two years was self-reported but no injury definition was stated. Adding to this limitation, the sample size was small, and injury was not professionally diagnosed though measurement reliability was calculated and excellent. The statistical analysis was also explained in detail. Their study found that both the number and severity of non-traumatic injuries were associated with reduced functional turnout in classical dancers (highlighting reduced control). In contrast, the number and severity of traumatic dance injuries were not associated with reduced turnout. Injury prevalence was not associated with passive hip external range of movement so is consistent with Coplan (2002).

Before measuring turnout in further musculoskeletal screens, methods require standardizing and testing for validity and reliability (Lowrie, Champion and Chatfield, 2008). Ten years later Kenny et al. (2018) examined the reliability of measuring range of motion, suggesting that measurements of passive external rotation can be unreliable. This is a measurement invariably incorporated in musculoskeletal screens for ballet using varied methods, hence perhaps varied results. This measurement requires an accurate set up and should be regarded with reservation if included. Kenny et al. (2018) reported poor reproducibility of this measurement in their reliability study of screening components. Until there is more clarity, prioritisation and standardisation of measuring set-up, screening results of hip range in ballet will remain questionable.

4.3.5 Posture

Good standing posture improves movement efficiency and is mechanically functional and economical. Screening the initial posture in a dancer before observing the dancer in the turned-out position reveals structure, asymmetries and muscular control. The externally rotated position will expose deficits and compensations. Dręźewska and Śliwiński, (2013) found that compensation in the turnout position by increased anterior tilt of the pelvis may increase the risk of low back pain. The angle of sacral bone inclination was measured using a mechanical inclinometer. The comparison of sacral angulation in parallel and in the balletic turned-out position, if increased to above or equal to 30 degrees, correlated significantly with increased pain reported using the visual analogue scale. Schon and Weinfeld (1996) emphasise the need to consider the dancer's posture in terms of scoliosis and kyphosis, genu varum and valgum, recurvatum, procurvatum and ankle and foot biomechanics before observing movement.

4.3.6 Technique and Control

Several researchers have considered it important to screen specific dance movements (Schon and Weinfeld, 1996; Hamilton et al., 1996; Molnar and Esterson, 1997; Gamboa et al., 2008; Bronner and Bauer, 2018; Bronner et al. 2020). This assumes that raters are conversant, if not specialists in ballet technique. Bronner et al., (2020) performed reliability studies on their Ballet-based Dance Technique Screening Instrument with excellent results. The authors state that screening for dance technique errors has been described as a primary prevention strategy for screening in a dance population.

4.3.7 Spinal Screening

As in dance, athletes consistently recruit or transfer high levels of repetitive force through the spine. The trunk muscles are multifunctional. They are designed to stabilise, co-contract and brace when required in lifting tasks or contribute to the generation of torque at the shoulder utilising the stretch-shortening cycle in rotation, as a boxer throws a powerful punch (Ruddock et al., 2016). Chaudari, McKenzie and Borchers (2011) showed that professional baseball pitchers who had greater lumbo-pelvic control had greater velocity, control and endurance. Golfers suffer from spinal injuries most of all with loss of spinal stabilization leading to load transmission away from the muscular components, towards ligaments, disc and bony structures of the spine (Donatelli, 2012).

In lower limb moves Kibler, Press and Sciascia (2006) described the role of the core to provide proximal stability for distal mobility. Donatelli, Dimmond and Holland (2012) suggest that the push up test and the single-leg bridge test are efficient tests to determine torsional trunk control. Trunk muscular endurance tests include the side plank, the flexor endurance test and the back extension test. Poor back endurance rather than isometric strength was more indicative of future pain (Biering and Sorenson, 1984).

Spondylolysis and spondylolisthesis are more prevalent in activities that involve hyperextension of the lumbar spine like diving, volleyball, gymnastics, football, tennis, and dance. Spondylolisthesis in American football players was found not to reduce the chance of high-level play, but spondylolysis in the lower spine was a serious threat to a running back. Sakai, Sairyo and Suzue (2010) reported a 30% incidence of spondylolysis in soccer-playing population which was 5 times that of the normal population.

Only 4 out of 23 dance screens included the spine. Scoliosis or kyphosis were identified only. Only 5 out of 23 screens examined posture. No assessment of axial range was undertaken. Whereas extreme spinal extension is frequently used in the dancer's vocabulary and if uncontrolled, can prove to be an injury risk (Gottlich and Young, 2011). Only Nilsson et al. (1993), in early research, measured spinal range in children at the Swedish National Ballet School suggesting that axial hypermobility is hereditary and a selection asset in ballet. Surprisingly, none of the dance screens examined spinal extension and none of the assessments of technique explored movements involving extension. Only Molnar and Esterson (1997) assessed pelvic stability and lower abdominals with a double leg lowering test.

The lumbar hyperlordosis in the ‘aesthetic athlete’ can contribute to spinal injuries and can emanate from poor technique and compensation for inadequate turnout in dance (Quinn, 2014). The pelvis tilts anteriorly allowing for increased external rotation due to the relaxation of the iliofemoral ligament. While the dancer may have achieved enhanced turnout, the resultant lordotic posture increases the compression on the posterior structures of the lumbar spine. The abdominals are slack, and the thoracolumbar fascia tightens. The hip flexors tighten and the gluteals weaken (Quinn, 2014, Khan et al., 1995). Experienced dancers can often overcorrect this, and the ‘flat back’ causes decreased shock attenuation and may contribute to lumbar risk disc injury. Initial assessment of balletic posture would seem essential.

4.3.8 Specific Movement Screens in Sport

Injuries are common in team sports such as soccer, basketball, volleyball, football and hockey (Dallinga, Benjaminse and Lemminke, 2012) and the disabling consequences incur high costs. Apart from good reliability and validation, screening tools also need to be simple, low-cost and convenient for large scale testing in the clinic or the field (Dennis et al., 2008). The emphasis of many sports screens is to identify risk factors for traumatic injury. The development of screening tools is thought to be a crucial component in lowering the risk of injury with the information obtained valuable for the adjustment of training programmes and the designing of appropriate interventions. The specific needs of different sports has led researchers to design specialised screens.

McCunn et al. (2017) presented their soccer-specific screen (SIMS) composed of five tests designed to functionally challenge the athlete. The in-line lunge from the FMS is used, an anterior reach from the Star Excursion Balance Test (SEBT) to test ankle dorsiflexion and an explosive jump specific to soccer with unilateral landing involving horizontal displacements. The screen demonstrated good to excellent inter- and intra-rater reliability.

Reid et al. (2015) performed reliability studies on their Netball Movement Screening Tool (NMST) composed of tests drawn from the MCS, SEBT and the FMS considered to impose similar challenge to netball moves. Reliability was moderate to excellent, and the screen is convenient and easily administered in a practical setting and an example of customised screen design.

Frohm et al. (2012) set out their 9-test screening battery for soccer players. They chose 7 tests from two different test batteries (FMS and United States Tennis Association High Performance Profile) and two tests were added to challenge dynamic performance of the trunk. Two tests were common to the FMS and MCS. Again, good inter- and intra-rater reliability was shown. No video was used as the screen was designed to be employed in the clinic for large numbers of athletes. (It uses minimal equipment and is not time consuming.) As yet no studies have tested validity or the responsiveness of the test battery in injury prevention, rehabilitation or performance enhancement.

Mischiati et al. (2015) carried out an intra and inter-rater reliability study of the Performance Matrix (TPM) which incorporates a selection of movement tests from the Foundation Matrix, finding good inter-rater reliability and excellent intra-reliability for two experienced physiotherapists for this nine-test screen. These include five low threshold tests of alignment and coordination control and four high threshold tests of strength and speed control. Intraclass-correlation coefficients were excellent between raters (0.81) and within raters (Rater 1, 0.96; Rater 2, 0.88) but poor for real-time versus video (0.23). Studies as yet have not correlated TPM results with identifying injury risk, but the recent Hip and Lower Limb Movement Screen (HLLMS) has researchers in common showing that the work continues to advance in observing movement dysfunction.

4.3.9 Ankle Injuries and Screening

Engebretson et al. (2011) carried out one of the largest prospective cohort studies on 508 soccer players, examining single leg balance on Airex mat and floor and clinical examination of the ankle. The authors found that only previous ankle injury was a significant factor in predicting ankle injury. Even with 56 acute ankle injuries, the statistical power was limited for multivariate tests indicating that none of the screening tools would be helpful. Research results require the appropriate statistical approaches for reliable interpretation as advised by Bahr and Holme (2003).

In a different approach Hadzic et al. (2009), in a prospective study of 38 professional volleyball players, examined plantarflexor and dorsiflexor isokinetic strength, postural sway (equipment based rather than field based) and active dorsiflexion/plantarflexion range of movement. The significant factors for ankle injury were increased plantarflexion strength and decreased dorsiflexion range. This was an encouraging preliminary analysis. The same authors, however, suggest that the Star Excursion Balance Test (SEBT) (Hertel, Miller and Denegar, 2000) may provide more reliable results. Plisky et al. (2006) identified a composite score for lower limb difference less than 94% and an anterior reach difference of 4cm or greater as a risk factor for lower limb injuries.

The SEBT has been found to be reliable in predicting knee and ankle injuries in collegiate athletes in the anterior direction (Stiffler et al., 2017). This was a retrospective study and so limited by direct exposure calculation but demonstrated 82% accuracy in diagnosing the athlete’s injury status. Regarding ankle sprain Attenborough et al. (2016) found that in the SEBT a reach distance in the posterior-medial direction of less than or equal to 77.5% of leg length increased the odds of sustaining an ankle sprain. The SEBT and its simplified version the Y Balance test have a high intra-tester (0.85-0.89) and intertester (0.97-1.00) reliability, are far less costly and more convenient in field testing but Grassi et al. (2018) recommend further research to confirm its ability to predict ankle injuries. Van Seters et al. (2020) concluded that limited dorsiflexion in the single leg squat in dancers was the most significant risk factor for lower extremity injury in their screen of contemporary dancers (also trained in ballet).

Zellers et al. (2017) found that dancers had significantly less plantarflexor endurance than non-dancers and considering the high incidence of foot and ankle injuries in dance, recommended that screening for endurance may reveal those at risk and direct appropriate interventions. Zellers tested the dancers in the same neutral position (appropriate to assure correct biomechanics) as non-dancers and instructed the participants to rise to maximum height. Testing and any endurance exercise is carried out in neutral hip rotation in order to use the hip muscles in a balanced way rather than in dancers' functional rotation. The hip is generally believed to benefit from control in neutral rotation and not always worked in turnout. Classical ballet dancers do not only work in turn-out and are multi-genre and are accustomed to this. Results suggest that since dancers have a greater range of plantarflexion and use full range *en pointe*, there is decreased muscular demand compared to the more restricted 'normal' range, explaining the lowered calf capacity. The test set-up can be used for increasing repetitions and endurance, with attention to activation of gluteal muscles and intrinsic muscles of the foot. Prospective, interventional studies are required to determine the efficacy of a preventative calf-strengthening programme.

4.4 Conclusions

Bahr and Holme (2003) have pointed out that for small to moderate associations some 200 injured subjects are needed. For a risk factor to be clinically relevant with sufficient sensitivity and specificity, strong associations are needed (Engebretson et al., 2011). Research on risk factors for injury is advocated for two reasons: to help understand why injuries happen (causal mechanisms) and to predict who is at risk. If a screening test identifies a statistically significant association between the result and increased injury risk this is just the first step in validating a screening programme, but Bahr (2016) also states that there is no screening test available to predict sports injuries with adequate test properties and there is no intervention study providing evidence in support of screening for injury risk. However, Bahr admits while predicting future injury risk through screening tests is unrealistic, a 'periodic health evaluation' of an elite athlete can serve several other purposes. It can build a comprehensive assessment of the athlete's current health status, introduces the athlete to the medical team and establishes a rapport. It also establishes a performance baseline for the athlete.

Assessing athletes this way allows familiarisation with individual profiles and prompt interventions. Sport or dance specificity allows for the use of the appropriate combination of targeted tests to supply enough information with simplicity, speed and convenience but also accuracy, in a practical setting. Furthermore, ‘pre-participation screening’ or ‘periodic health evaluation’ allows not only a gathering of information for the clinician but needs to be useful for the athletes themselves and creates a cooperation with healthcare team. This is especially important in the dance setting considering the reticence of young dancers to report injuries and their willingness to work through pain (Jacobs et al., 2017). In doing so, asymmetries are created, and neuromuscular compensations require retraining. Armstrong and Relph, (2018) observed the positive physical and psychological impact on dancers, of screening implementation and intervention. This cannot be underestimated.

Observing movement quality, defined as optimal motor control and joint alignment (Sahrman et al., 2017) is used to detect altered kinematics that are believed to be linked to injury risk and detrimental to peak performance (Booysen et al., 2019). Whole body tasks are considered better than traditional measurements such as ROM and strength and functional movement analysis can be sport or dance specific.

Gamboa et al. (2008) reported fifteen years ago that substantial efforts were underway in the dance medicine and arts management communities to create a universal screening tool that could be administered to elite and sub-elite, professional and preprofessional dancers by a broad cross-section of testers. The efforts were to provide individual dancers with their own personal musculoskeletal profiles and contribute to a larger normative database. The authors conceded that significant financial and personnel resources required to conduct screenings, and the limited predictive value of the measurements, made such efforts questionable. Attempts to investigate more focused relationships between specific intrinsic characteristics and injury may have more predictive and risk management value.

Chapter 5. Injury risk factors, Risk Mitigation and Injury Reduction

The multifactorial nature of dance injuries presents a challenge to the health professional managing the performing artist (Campbell et al. 2019), considering the 'web of causation' cited in Liederbach et al. (2012). From the results of the preceding reviews, it is apparent that the injury incidence in ballet is high and may be higher than appreciated due to the retrospective nature of much of the research, and dancers' reluctance to report injury (Jacobs et al., 2018; McNeal, 1990). Wyon (2010) claims that the high injury rate in dance 'is not replicated in the most strenuous of full contact sports'. Bronner et al. (2003) reported that dancers sustain a higher incidence of work-related musculoskeletal disorders than workers in high-risk jobs such as construction, based on US statistics.

Many studies in dance are small. Authors explain the difficulty in recruiting professional and preprofessional dancers due to their availability and time restriction (Cimelli and Curran, 2012; Bowerman et al., 2014). As yet, dance lacks the epidemiological and screening studies from which interventional strategies can be evaluated (Allen et al., 2013). In the absence of these, to tackle the problem of high injury rates, Bronner et al. (2003) set out the primary, secondary, and tertiary strategies employed in a modern dance company to reduce the cost and the high injury rates. Primary intervention requires surveillance of injuries to provide a global picture, exposes patterns and characteristics, rates, and severity of injury and analyses an individual's injuries against the rest of the cohort. Dance screens are required to provide individual healthy baseline data, uncover pathology, and flag individual concerns. They reveal intrinsic risk factors allowing primary prevention strategies to educate dancers generally in warm up/cool down, protective equipment, general cross training needs, hydration etc. Individual intrinsic factors such as errors in dance training and alignment, joint laxity, deficits in cardiovascular fitness and strength, footwear, and more specific cross training needs are identified

Early detection of injury allows secondary prevention, intended to reverse, prevent, or slow progression of an injury. This necessitates immediate triage to ascertain timely intervention or referral, modification of or removal from specific work roles, and treatment to minimise further musculoskeletal complaints (Bronner et al., 2003). This is where reliable medical assistance through trusted in-house health care providers and availability of a company physician can limit the impact of injuries when they occur (Solomon et al., 1997) and persuade those dancers who are naturally reluctant, to report mild disorders before they become time-loss.

Tertiary prevention seeks to minimise the effects of injury on the individual through rehabilitation, modified dance workload to retain integration, education, minimising of risk and promote cross-training where possible. Inefficient secondary prevention means more time-loss and an overuse of medical services.

At the primary intervention stage many of the potential injury risks to the lower extremity with poor alignment of the hip, knee, ankle and foot can be identified if alignment is assessed in relation to hip external rotation range and control. Forced turn out (foot abduction) in demi-plié leads to excessive internal rotation of the tibia, dropping of the medial arch, and lateral deviation of the great toe, leading to hallux valgus (Ahonen, 2008). Turnout affects foot posture and is associated with injury (Cimelli and Curran, 2012). Excessive subtalar joint pronation is associated with increased strain on the medial longitudinal arch, the plantar fascia, and the plantar musculature of the foot. Posterior tibial tendinopathy, flexor hallucis longus tendon problems and hallux valgus are also related to this misalignment. Bowerman et al. (2014) found that that greater knee alignment can result in a small to moderate decrease in risk of lower extremity overuse injury in elite adolescent ballet dancers. The argument for continued focus on sound training is strong, and emphasis on correct lower extremity alignment is believed to be a priority.

Dancers who are found to have increased levels of hypermobility can be shown at primary intervention level how to protect their joints. Dancers with hip dysplasia can avoid extremes of ballistic range and be directed to motor control methods to improve neuromuscular activation throughout range. The hyperextended knee can be schooled to develop control at 0^{o} extension in weight bearing (Bronner et al., 2012) rather than the hyperextended default which further stretches the posterior capsule and interferes with the muscular balance and control of the lower limb in turnout. The dancer with increased levels of hypermobility can be initiated in an appropriate loading regime to increase strength levels. Empirical evidence shows that the hypermobile dancer can strengthen significantly. Komi's study in 1986 suggested that the increase in size of the individual muscle fibre is associated with parallel increases in connective tissue between the fibres but as yet, it is unknown whether 'fragile connective tissue' becomes any more resilient with loading. Strength and control can be targeted here.

Assessing technical moves allows the clinician insight into the movement patterns used by the dancer repeatedly in the studio and on stage and may reveal potential risk. Without that, insight into causation links is missed. Gamboa et al. (2008) included *plié* in first position and *développé devant.* Bronner and Bauer (2018) included a *développé* to second, a grand plié in second and a *sauté* in first. Those dancers with a medium and low score of faults were 37% and 13% less likely to develop injury. The authors noted that lumbo-pelvic stability was a common problem across all movements. In their 2020 paper Bronner et al. performed reliability studies on these technical moves adding a *relevé* balance in *passé*. Inter-rater reliability was high, and the researchers concluded that identification of dance technique movement faults allows healthcare professionals to quickly address them following pre-season screening, with appropriate corrective intervention and therefore, potentially prevent dance-related injuries.

Traditionally the Pilates Method has been employed in ballet to promote improved movement patterns and the chosen method of cross-training to support ballet technique. There is little evidence to support this, other than empirical, but it is widely used. When specifically applied to ballet, and designed to transfer directly to technique, dancers appear to feel the benefit. Unloaded postures that replicate functional activities, like jumping, can be carried out on a Pilates reformer (a supine spring-based exercise machine on which a series of exercises can be performed, and resistance varied according to the number of springs engaged). Allen et al. (2013) used this in the early stages of 'functional integration' to check neuromuscular control.

Fifteen years ago, the movement to reduce injury incidence generated research into cardiovascular fitness and the reduction of fatigue in dancers (Redding and Wyon, 2003; Koutedakis and Jamurtas, 2004; Twitchett et al., 2009; Twitchett et al., 2010; Rodrigues-Kraus et al., 2015). Improvements were made but no studies were directly linked to reduced incidence of injury.

In the last few years, the approach to injury reduction, is directed at improvement in strength through resistance training, in spite of the fact that Stalder et al., although a small study, promoted task specific weight training for female dancers in their 1990 research paper. Koutedakis et al. followed with several papers (1997, 2005, 2007, 2009, Koutedakis and Sharp, 2004 and Koutedakis and Jamurtas, 2004) advocating for improved strength parameters in dancers. The return to strength training in recent years has yet to prove a relationship to reduction of injury in classical ballet.

Low calf endurance in spite of dancers' occupational requirements, was tackled with heel-rise endurance exercise and is now practised widely in vocational training and professional companies. This was initiated because of the high incidence of foot and ankle injury in dance. As yet, no studies have been carried out to measure results of this intervention.

Mistiaen et al. (2012) evaluated musculoskeletal injury rate and physical fitness before and six months after a supplementary endurance, strength, and motor control exercise programme in preprofessional dancers. The study was uncontrolled in order to preserve the power of the study and 40 dancers were employed in the trial. All parameters improved but a relatively high injury rate was observed during the intervention period. Without the control group it was difficult to explain the injury rate – except the unpredictable nature of dance training over a prolonged trial. Other limitations were lack of standardised timing of testing and a drop-out rate, illustrating the challenges of recruiting enough participants in dance of the same stage and exposure rates. Also, the significant injury rate in preprofessional dance may not respond to physiological improvements, and other influences need to be explored.

The combination of motor control work (Pilates), technical coaching, cardiovascular fitness programmes, strength accrual through strength and conditioning and focus on local endurance have equipped clinicians with tools to target deficits in dancers. A multidisciplinary team is necessary to provide this amount of support and provide a thorough service to professional dancers and vocational dance students in large organisations. Regular surveillance measures incidence and tracks patterns of injury in the cohort. Individual assessment requires a significant amount of time and manpower. Then, interventions need to put in place immediately after assessment. After a period of time the process is repeated, and progress is measured. Few organisations can afford a multidisciplinary team and smaller organisations will employ a single clinician who will attempt to educate and support dancers. Surveillance and screening require a significant investment and Gamboa et al. (2008) reports the financial and personnel resources required are substantial. Smaller organisations often find the outlay prohibitive and the time the dancers are out of the studio, impossible to accommodate.

Surveillance and screening offer a certain amount of information but without exposure data an important element in the 'web of causation' is missing and may be the key to the incidence of injury.

These procedures are possible within a vocational school where exposure will be high but the schedule relatively predictable. In a professional company where exposure for each individual will be different depending on rank, particular circumstances and changing repertoire, measurement is possible but successful interventional strategies may be difficult to install and reduction in injury rate difficult to achieve.

The most recent research paper from a classical ballet company (Shaw et al., 2021) to examine exposure, rank and injury risk concluded that the ballet company should distribute the workload uniformly across the company, periodize the repertoire, progress loads gradually before congested periods of performances and consider recovery when planning rehearsal and performance schedules. The authors reported that while sports people typically taper their training before competition, a ballet company will instead increase rehearsal load in the build-up to the opening night of a production. The authors appear not to have considered how a ballet company operates and the involvement and coordination of choreographer, artistic management, dancers, costumes, scenery, lighting, stage management, orchestra and conductor. The repertoire is planned at least two years in advance and new productions are unknown until they take shape in the studio. Dancers are in competition with each other for more prestigious roles and may over-rehearse themselves rather than appear on stage unprepared. It is perhaps unwise to compare a new 3-hour stage production to sport. There may be other ways in which to protect performers but tapering and periodisation needs to be part of a tentative discussion between healthcare and artistic management in order to understand different professional demands. The authors have not included the amount of overtime incurred regularly in dance. The number of hours dancers work per week is legalised by Equity, the union that professional dancers belong to. If companies do not belong to the union, workload is not regulated. Exposure in ballet may be the injury risk that is most difficult to tackle.

Modifying dance workload can also be an anathema in the professional dance workplace. It may be suggested that a dancer with a history of anterior tibial stress fracture should jump on alternate days. Young dancers undergoing growth spurts may be advised to do the same, but this advice is often accepted reluctantly, and the benefit of recovery time not clearly understood by artistic management. However, the modified workload may be the element that prevents re- injury or allows a level of work appropriate for a changing physiology. To avoid misunderstanding, all parties involved need to be fully informed, communicate extensively and approve protocols to support the dancer.

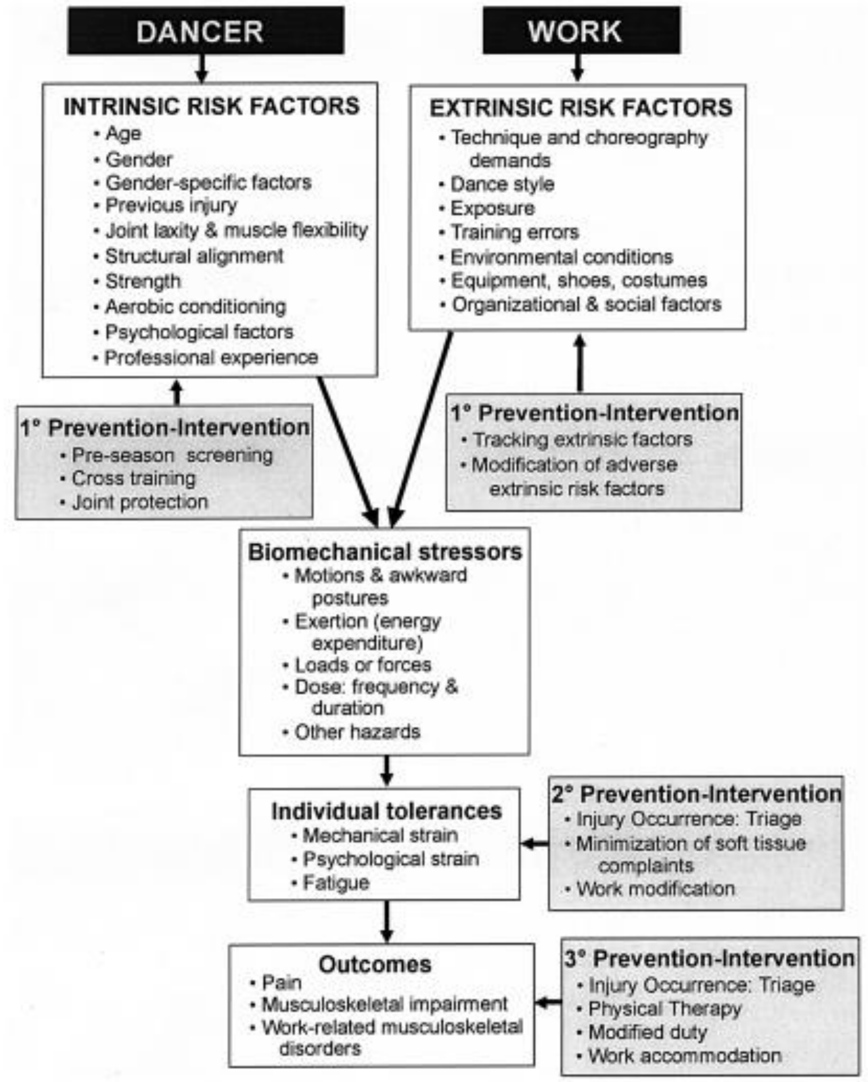


Figure 5.1 Conceptual paradigm: A multi-factorial model of dance injury and prevention-intervention (Bronner, Ojofeitimi and Mayers, 2017)

Individual dance companies, both modern dance and ballet, have made progress in decreasing their injury rates by providing specialised healthcare services on-site to meet the specific needs of these elite artist-athletes. The positive impact of moving from an insurance-based funded system to an 'in-house' medical care system for a professional ballet company was reported over a period of 5 years by Solomon et al. (1999). The decrease in injury rate and financial saving to the company was encouraging to all concerned, increasing company morale. Bronner et al. (2018)

also emphasised that trust between dancers and healthcare staff was critical for an effective in-house programme. The authors published the results of their customised occupational medicine approach to reduce human and financial costs of work-related musculoskeletal disorders in dancers. 64% reduction of new Workers' Compensation cases was achieved over 3 years and time-loss savings of 60%. The prospective cohort study over 15 years was subsequently published by Bronner and co-workers in 2018 showing time-loss injuries averaging 0.16 injuries/1000- hrs, lower than rates in ballet and sports. These results came from a modern dance company and few companies will operate under the same circumstances, but these decreased injury rates and changed injury patterns demonstrate efficient injury management and prevention programming.

Solomon et al. (1999) mentioned a noticeable improvement in company morale during the years of the study. There was an increased awareness among the dancers that the company was making a concerted effort to prevent injuries, and to limit the impact of injuries when they did occur by providing reliable medical assistance. Bronner et al. (2003) mentioned that company administrators believed that the intervention program made the responsibility of health care less burdensome, and dancers believed that the administration cared about their well-being. From these statements there appears to be a lack of understanding and united purpose – even a lack of trust between dancers and management. There appears to be a need to clarify the requirements of each party and Bronner concluded with a call to arms 'we must go into their arena: the dance studio, dance department, and theatre, to develop an ongoing dialogue with dancers, choreographers, artistic directors, and dance educators to prevent and reduce injury'.

Teaching methods and style will understandably, not be ideal for every dancer. Choreographers will have diverse styles and methods of rehearsal. Discipline in the ballet studio is strict and there is an understanding that the dancer is the obliging instrument through which the choreographer expresses his creativity and in class, the teacher is not questioned. In a university setting lecturers are given regular feedback. In business there are annual reviews. In ballet the dancer rarely has a voice, the choreographer is omnipotent, and teachers are unregulated, with no enforced in-service training. Clinicians are ethically obligated to their patients but employed by artistic management. To unite each of these stakeholders requires an ongoing effort to understand each other, to converse with and learn from each other in order to protect, support and promote the performer.

Chapter 6. A Delphi Consensus Exercise on the Physical Attributes that Make the Elite Ballet Dancer.

6.1 Introduction

Classical ballet dancers are selected for their physical attributes (Chapter 1.4.). Musicality, artistry and expressiveness are important, but physique appears to take precedence. Young dancers are selected for their potential into vocational schools based on their talent and physical characteristics (Walker, Nordin-Bates and Redding, 2010). They are selected by audition and according to the institution, with differing degrees of physical scrutiny. We know that dancers are selected into professional companies for many qualities – the technical standard they have achieved, dramatic talent and possibly their already established reputations as well as their particular physiques. They are the result of a relentless and highly selective process (Haight, 1998). Haight claims that while most athletes are selected for their genetically endowed tendency to perform well in a certain event or genre, ballet dancers are selected overwhelmingly for aesthetic reasons. We can also assume that dancers in professional companies set the trend for selection into vocational schools because there is nothing reported in the literature.

The subject of this study focussed on the physical attributes desired in the elite ballet dancer today, in spite of being only a part of what goes into being dancer as it is unclear how vital a part the physique has played in the past and plays today, it is important to determine from experts, which physical attributes are preferred as this has implications for both the artistic team and the healthcare team in the selection of young dancers into the profession.

The relationship between competitive success and physique traits has been identified in an array of sports, including football (Olds, 2000) and track and field (O'Connor et al, 2007). A study on lightweight rowers' physiques concluded that certain anthropometric measurements correlated with success (Slater et al, 2005) and O'Conner et al (2007) state that 'physique and morphological characteristics play one of the most critical roles in competition success in athletics.' Talent identification in aesthetic sports such as gymnastics has also been investigated by Vandorpe et al. (2011) who stated that "the importance of an appropriate physique in gymnastics for both aesthetic reasons and biomechanical advantages is well known." Vandorpe and co-workers carried out a multi-dimensional battery of tests on young gymnasts to explore elite-level potential in an exhaustive research study.

In 1958 Celia Sparger, a British physiotherapist working with the Royal Ballet School in London, attempted to analyse classical ballet technique, technical faults, physique and related injury. She commented on 'few carefully selected, physically perfect and gifted children' but did little to describe the 'ballet physique' or identify a correlation between physique, form and performance (Sparger, 1970). The text was ground-breaking in its time and stood alone in its observations of dancers and injuries in ballet (Sparger, 1970). Films of Royal Ballet dancers in the 1950s (New York Library of the Performing Arts) reveal strength, speed and stability. An athletic tautness lent itself to the demanding choreography of the day by Frederic Ashton, a major choreographer from 1935 to 1976 and known for his quickness, footwork and use of the upper body.

Towards the 1970s the ballet physique began to be influenced by the Russian choreographer George Balanchine who was artistic director of New York City Ballet (1948-1983). Balanchine exploited the physique he favoured in his choreography: flexible feet, slim straight legs, strong back, fine bones, long neck, perfect turnout (Kirkland and Lawrence, 1986). Although there is much controversy over what is sometimes referred to as the 'Balanchine Body', he favoured tall and slim to the extent of having no figure, with long necks, long legs and short torsos. Legs went higher and neoclassicism took hold and Balanchine's technique became the 'American' technique and with it went his favoured physique.

In England Kenneth MacMillan (principal choreographer for the Royal Ballet from 1977 to 1992) was creating his own style and choreographic content. His last muse was the ballerina Darcey Bussell, a tall dancer with the proportions and thinness of the Americans. Bussell remained a principal dancer with the Royal Ballet until 2005.

From these observations the desired physical characteristics of the classical ballet dancer appear to be dictated by directors and choreographers who use the body of the dancer as an instrument. Wainwright et al. (2005) alluded to the growing aesthetic for almost skeletal, hyperflexible, ephemeral bodies that may be more prone to injury. The audience approves when they are fed material they appreciate or otherwise. The directors of professional companies choose dancers to fill the ranks that they themselves prefer, just as Balanchine did, and choreographers of the moment select and promote their own ideals, inspired by particular dancers (Wainright et al., 2005).

Twenty-five years ago, Hamilton et al. (1992) reported a profile of the musculoskeletal characteristics of elite professional ballet dancers based on dancers in New York City Ballet – the physique harking back to the Balanchine era. Kadel et al. (2005) reported anthropometric measurements of young ballet dancers observing that the characteristics of professional dancers – increased joint range of motion and flexibility can be seen in children from 8 to 13 years of age in vocational training. Researchers (Liiv et al., 2013) have conducted anthropometric investigations in ballet, contemporary and dance sport concluding that the three genres differ in anthropometric variables – somatotype, weight and aerobic fitness. Again, there is little enlightenment as to the recommended classical ballet ideal. There is a paucity of information available explaining the body type preferred today in ballet, but certain choreographers have definite requirements and that is obvious from the dancers they choose and to whom they present choreographic challenges.

No enquiry as to what physical attributes are sought after by the ballet profession today has been carried out. There are no clear guidelines as to the physiques favoured by vocational schools today, choreographers or professional company directors. There are texts explaining the merits of certain physiques in classical ballet related to injury prevention (Howse and McCormack, 2009) but it is the artistic community that selects dancers, not those in healthcare. Therefore, there are two different issues involved – those desired by the directors and choreographers for aesthetic reasons and those physiques that may be more desirable from an injury prevention/performance enhancement perspective.

6.2 Research Aims and Rationale

This research sets out to explore underlying assumptions regarding the classical ballet physique and to obtain information from an expert group which might lead to consensus. There is a need to explore the desired attributes from both artistic and healthcare professionals involved in the selection of elite dancers, the hypothesis being that the artistic team will look for aesthetics and the healthcare team will look for performance indicators while considering injury risk.

The Delphi method was considered to be the most appropriate tool with which to investigate and gain consensus from a broad range of ballet professionals as to the body type currently being selected. By reaching consensus, this should inform the screening at audition to bring all sides together. Hasson, Keeney and McKenna (2000) describe the Delphi method as an iterative multistage process designed to transform opinion into group consensus. The aim of this study was to reach a consensus of expert opinion internationally. Where there is little and uncertain information, this method is thought to be of particular value (Mead and Mosely, 2001; Hardy et al., 2004).

The research objectives were:

- to explore underlying assumptions about the attributes selected into the profession by those in artistic management (respondent group).
- to seek out information which may generate a consensus on the part of the artistic directors (respondent group).
- To gather informed judgements on the topic.
- To educate the respondent group about the diverse and interrelated features of the topic.

6.3 Methodology

6.3.1 The Delphi Technique

The term ‘Delphi’ was derived from Ancient Greece. It was so named in deference to the legend of the Greek oracle at Delphi. The ancient Greeks would consult the oracle who had a network of informants and was considered the most truthful. The classic Delphi is used for gathering opinions for structured decision-making and forecasting. It is regarded by many as quasi-experimental, bridging the gap between qualitative and quantitative methods (Procter and Hunt, 1994, reported in Walker and Selfe, 1996). A classic structure requires the panel to both generate ideas and then in the rounds following, rate or rank in some way to arrive at consensus. The terms Delphi method, approach, study, technique, survey, exercise and process have all been used interchangeably but refer to the same research approach.

The Delphi Technique is a structured process that uses a series of questionnaires or ‘rounds’ to gather information which are continued until ‘group’ consensus is reached (Keeney et al., 2006). The technique involves presenting a questionnaire to a preselected panel of informed individuals or experts and seeking their opinion on a particular subject. Ludwig (1994) and Custer, Scarcella and Stewart (1999) advise that three iterations are often enough to collect enough information to reach consensus. The first round is usually qualitative in nature beginning with an open-ended questionnaire to specific solicit information.

When the replies are returned and the data are summarized, a new questionnaire is designed based on the responses from the first round. The second-round questionnaire is then returned to each participant showing the overall group response from round one. Respondents are asked to reconsider their initial response in the light of the first round’s overall results. The initial qualitative data forms the basis for close-ended questionnaires in subsequent rounds. Repeat rounds can be carried out until consensus is reached. (Keeney et al., 2006). It is a repetitive process where experts are consulted at least twice on the same question and can reconsider their answers aided by information they receive from the rest of the panel (Landeta, 2006). Anonymity of the panel is maintained and also their responses. The experts do not coincide in time or space and the any negative influence of personality or hierarchy/status is avoided. Feedback is controlled and the exchange of information is carried out by the coordinator, in this case, the researcher. The final answer (consensus) is formed of all opinions and the questions are formulated so that the answers can be processed quantitatively and statistically.

A minimum score is set as cut off for retention in the survey and a consensus score is used to denote the amount of agreement conveyed by the panel.

The aim in this study is to follow a Delphi process in order to establish a consensus of opinion from the profession as to the physique currently being selected into classical ballet. The leaders in the profession – artistic directors, choreographers and teachers are responsible for selection of the future ballet dancers, as managers and coaches are in football. Unlike football, dancers are chosen for their aesthetic attributes as well as their skills but the attributes required are not stated. Using the Delphi method, the authors aim to reach consensus with expert opinions, on the attributes that are currently being favoured in the profession. By reaching consensus it is anticipated that a better understanding of the physique will ensue, and a better understanding of performance enhancement and reduction in injury which is an aim in all elite sports.

6.3.2 The Delphi Process

Turoff (1970) suggested additional guidelines:

- There should be at least two professionals acting as the design-monitor team in order to check procedures. Ideally, one should be knowledgeable in the problem at hand (but not precommitted) and the other should have editorial talents.
- A month or more is needed to develop the first-round questionnaire.

- Each questionnaire should be tested on co-workers who have not been involved in the design in order to eliminate anything stated in a confusing manner.
- Care should be taken to avoid compound statements to be voted upon. The question 'if A and B are true' should be broken into two separate items.
- Ease of the respondents in providing answers and understanding is always favoured.
- The procedure should ensure anonymity is preserved throughout.
- Respondents must be convinced that they are participating in an exercise which involves a peer group.

Turoff also advises to keep track of certain subgroups making up the respondent group as a whole. This provides a mechanism to check whether polarized views reflect the affiliations or backgrounds of the respondents.

Theoretically, the Delphi process of iterated rounds can be continued until consensus is determined to have been achieved. However, many researchers advise that three iterations are often sufficient to collect the required information and to reach consensus in most cases (Hsu and Sandford, 2007).

The Delphi process traditionally begins with an open-ended round one questionnaire which serves as the foundation for gathering specific information about a target area (Custer, Scarcella and Stewart, 1999). A thorough introduction in round one explaining the process and exactly what is expected when inviting the participant to join the study, ensures commitment to the task. Understanding the study's aims and the process, helps to build a research relationship, which is important as the ongoing response from the second and third rounds is based on the premise of self-selection (Hasson, Keeney and McKenna, 2000).

A vast number of inter-related items may be produced, and the researcher needs to condense these for round two. Following round one, analysis is usually undertaken using descriptive statistics and the responses are then themed by the researcher/coordinator and the collected information arranged into a well-structured questionnaire which serves as the survey instrument for the second round. The participants can then see their own response in relation to the panel's view.

In the second round each participant is asked to review the summarized information to which they contributed, in the form of the second questionnaire. They may be asked to rank or rate items to prioritize in order of importance. A rating scale however, provides more flexibility.

Walker and Selfe (1996) suggest that the respondent has three options:

1. To ignore feedback and maintain the previous position.
2. To try to sway others' opinion by voting strongly in the direction opposing the mean view.
3. To be swayed by others' opinions (Goodman, 1987).

Choosing the third will aid progress towards consensus, while the second will tend to lead to increasing divergence.

If the items generated in the first round are ranked, participants can demonstrate a clear priority but cannot show the interval distance between items. A rating scale provides flexibility but reduces the need for comparison of items (Walker and Selfe, 1996). A Likert scale of six forces the panellist to decide and choose a positive or negative response and grade with a priority.

The number of Delphi iterations (rounds) depends largely on the degree of consensus sought by the investigators and can vary from three to five.

A further round of rating/ranking may be required, or this may be the final round where participants are asked whether they agree with the concluding list of items showing those that have achieved consensus. This is their final opportunity for them to revise their decisions and provide closure for the study.

6.3.3 Consensus

The fundamental aim of the Delphi is to progress toward consensus. The dictionary definition states that consensus is a generally accepted opinion or decision among a group of people (Cambridge Dictionary, 2019). The Collins English dictionary states that consensus means 'general or widespread agreement'. The cut-off for consensus is not standardized. In Walker and Selfe (1996) consensus was set at 66% but McKenna suggests a level of 51%. Van Zolingen and Klassen (2003) advises that the starting point is usually an arbitrary criterion such as: if 60% of the respondents agree that this is an event that will occur with a probability of 50-90% (Hill and Fowles, 1975, reported in Van Zolingen and Klassen, 2003).

In the current study the consensus level of 60% was decided after consultation with other experienced researchers.

6.3.4 Rationale for using Delphi

The Delphi process is used where precise analytical methods are not suitable for studying the problem, but subjective judgement on a collective basis can provide beneficial information relative to the problem (Linstone and Turoff, 1975). It also has the advantage of enabling each participant to express views impersonally, while ultimately providing information generated by an entire group (Fink et al., 1984). The number of rounds can be adjusted to meet the investigator's needs.

Classical ballet and its off-shoots – neoclassical and experimental choreography – are global and therefore it is necessary to seek international opinion.

In the present study the use of an exploratory Delphi study lends itself to gathering opinions from an international sample of experts who are geographically dispersed, and the aim is not to implement an action, it is to gather information about a trend and arrive at a consensus, providing the basis for further study. Research has been carried out considering the dancer as athlete, but there is no information about the physique currently being selected into classical ballet, current preferences and the implications of these. The dancer-athlete has been tested physiologically, biomechanics have been examined widely but the main physical attributes that influence these have not been fully understood. There are uncertainties in areas that need investigation, and the Delphi can help to clarify these areas that are not fully understood.

Hsu and Sandford (2007) state that Delphi has been applied in various fields such as program planning, needs assessment, policy determination, and resource utilization. In the current study it is used to gather current opinions, to understand motives for physique selection, to clarify the implications of these and to provide a basis for further study of the classical ballet physique, injury prevention and performance enhancement.

In an often time-pressured profession answering a survey can be fitted into a busy schedule whereas an extra meeting or interview cannot. The technique can give voice to those who are more reticent in expressing views. Also, with assured anonymity those high-profile individuals who are careful of airing views, can share ideas more freely. The anonymity here should be regarded as partial as the lead researcher sent invitations to the panellists and reminders where necessary. However, all snowball participants were entirely anonymous as were the actual responses across the board.

Opinio software (7.6.4.) was used in this study to create and manage the survey. The method is cost effective and inexpensive to use. With the use of Opinio online software (https://opinio.ucl.ac.uk) large volumes of data can be handled and survey responses manipulated with timed release and closing of surveys and the sending out of reminders.

6.4 Considerations when using Delphi

6.4.1 Expert Panel and Participants

Regarding the criteria used to guide the selection of Delphi subjects Hsu and Sandford, (2007) state (citing Pill, 1971; Oh, 1974) that individuals are considered eligible to be invited to participate in a Delphi study if they have somewhat related backgrounds and experiences concerning the target issue, are capable of contributing helpful inputs, and are willing to revise their initial or previous judgements for the purpose of reaching or attaining consensus. 'Experts' are selected in the Delphi technique on the premise that they will yield significantly better and substantially different responses from ‘non-experts’ (Goodman, 1987). Fundamental to the credibility of the consensus panel is the careful selection of the “expert” participants with similar backgrounds.

Purposive sampling involves non-probability sampling techniques (Joffe, 2007). In the present study they are selected for a purpose ‘based on the assumption that the researcher’s knowledge about a population can be used to handpick the cases to be included in the sample’ (Polit and Hungler, 1997, reported in Hasson, Keeney and McKenna, 2000). There is therefore a responsibility to prove and justify the selection procedures used. In this study what distinguishes expert opinion from that of anyone else is the fact that these ‘experts’ are making decisions and are responsible for selection of dancers into the profession. It could be argued that their positions of authority have been achieved by proven artistic success. Sackman (1975) claimed that any group of informed individuals can provide good feedback and he also stated that he could not find any studies where ‘professional training’ or ‘scaled experience levels’ are reported to qualify panellists as possessing the skills required to meet an objective criterion as an ‘expert’. He states that this ‘very desirable’ standard is effectively neglected in Delphi practice. Sackman’s criticism of the Delphi method is well-known and while well-founded criticism is to be respected, there are varied contexts where his opinion cannot apply. There are many experienced specialists in the field of classical ballet, but the core group of directors is responsible for selection, supported by artistic staff.

Snowball sampling can also be used. The snowball technique is one of the most common approaches of sequential sampling (Habibi, Sarafrazi and Izadyar, 2014). This method was used to access potential well-informed participants not known to the researcher, introducing further experts. This additional sampling by non-probability method can be used when further potential members of a group cannot be easily identified. In the current study the method greatly enhanced numbers in both the artistic and healthcare groups. The use of snowball sampling also introduces a further element of anonymity. The participants recruited through this type of sampling are unfamiliar to the researcher and vice versa. By completing the survey, they commit to it out of interest in the subject but not out of any professional obligation. This could be seen as a positive contribution to the reliability of the study.

6.4.2 Possible Bias

The anonymity and controlled feedback in electronic communication in a Delphi study are advantages in reducing bias and distortion which are possibilities in group dynamics where individual interests can dominate and detract from the purposes of the study. Through the controlled feedback process a well-organized summary of the prior iteration intentionally distributed to the participants, allows each to generate additional insights and more thoroughly clarify information developed by previous iterations (Hsu and Sandford, 2007). Researcher-bias must be avoided after the first round when it is the researcher's task to condense and theme the often vast number of suggested items from round one without moulding opinions or omitting under-represented entries (Walker and Selfe, 1996). Naturally as in the present study, the researcher is an interested party, not an impartial facilitator and so care must be taken to avoid any prejudice.

The participants are expected to become more problem-solving and offer their opinions more insightfully as iterations progress. However, Sackman (1975) again criticizes the process of controlled feedback. He draws attention to an explicit distinction between independent and dependent expert judgement. 'The first round is basically designed to secure independent expert judgement. The second and successive rounds produce strictly correlated, or biased, judgments.' He states that 'all rationalization about reconsidering, incorporating new information, and converging toward consensus, cannot hide the fact that independent judgment is destroyed once the participant knows how others have responded to each item'. Hassan, Keeney and McKenna (2000), in contrast, argue that as the participants know the group response, and may change their views as a result, this is what brings panellists towards group consensus and is seen as an advantage. While Sackman's observations are valid and require consideration, it should be noted that Sackman was writing in 1974 when Delphi was used for financial, military and commercial applications. Awareness of the potential for double bias (participant and researcher) is important in order to minimize risk where possible. However, since Sackman's day the Delphi Method has been used in many different contexts and extensively and positively in the health environment. Further commentary on this important point ensues in this chapter.

6.4.3 Anonymity

One of the advantages of using the Delphi method is the security of anonymity for the panellists. While the panel is known to the researcher, the opinions are anonymous therefore the term 'quasi-anonymity' was used by McKenna (1994).

Goodman (1987) states that guaranteed anonymity encourages true opinions, not influenced by peer pressure or other extrinsic factors but counteracts this by suggesting that it could also lead to a lack of accountability. Sackman also suggests that anonymity could also encourage snap judgements. However, in most studies a willingness to participate means that instant unconsidered responses are less likely to occur (Goodman, 1987). In the present study, due to participants with a high public profile, reassurance of anonymity was important. In an artistic profession, with a lack of familiarity with survey and research techniques, there may have been an element of reserve and therefore required careful explanation. Although it is necessary to request demographic information, in order to analyse views possibly reflected by background and experience, the responses of the panel cannot be linked to any individual. Sackman (1975) stated that anonymity can still be honoured if patient characteristics are presented as statistical aggregates.

6.4.4 Panellist Drop-out

Sackman (1975) stated that 'panellist dropout is one of the well-known hazards of Delphi experimentation stating that 'Delphi dropout rates are probably quite high.' Duncan (2004) states that poor recruitment and retention of participants significantly impacts on the credibility of research findings.

Delphi is heavily dependent on the sample having the time to commit to seeing the process through to completion. If the questionnaire is too time consuming, this is also a demotivation concern. Ludwig (1997) recommended a thirty-minute completion time but in the current study this was thought to be too long for any of the iterations. Panellists were asked for no more than ten minutes of their time for each survey. Participant motivation and interest wanes if the process is too slow as several days or weeks may pass between rounds (Ludwig, 1997) and so interest must be sustained with reminders if necessary. Clear explanation introducing each survey iteration makes a survey straightforward and thus more inviting. Sackman stated that the first round is basically designed to secure independent expert judgement. However, in doing so it is necessary to engage interest and therefore adherence to the process. Initial, independent expert judgement is extremely interesting, in itself. Panellists become fatigued after repeated rounds (Fink et al. 1984; Whitman, 1990; cited in Walker and Selfe, 1996) and so iterations need to be kept to the minimum required to reach agreement. Greatorex and Dexter (2000) states that results can be skewed by panellists drop out and reasons are: low motivation; disagreeing with design and content of the study; minority opinions not explored and lack of faith in the initial results (Sackman,1975).

6.4.5 Time

Williams and Webb (1994) drew attention to the fact that Delphi can be time consuming. The process can stretch over months and if the expert panel is large, the administration can become unwieldy and lengthy. In professional and vocational ballet access to respondents is restricted by differing 'seasons', school terms and holidays especially considering Western Europe and Australasia. In the current study the first round was sent March 14th, 2016, and the panel was given one month to respond. The second was sent in June 2016 and was open for one month. The third and final round was sent December 8th, 2016, and closed February 2017 when consensus was reached.

6.4.6 Reliability

Reliability is the certainty with which an instrument reflects true scores and not random errors. Reliability also increases with the size of the group and the number of rounds (Fink et al, 1984) and indicates the reproducibility of an instrument (Woudenberg, 1991). Hasson, Keeney and McKenna (2000) state that there is no evidence of the reliability of the Delphi method. Sackman (1975) warns that the reliability of the method is not nearly as great as several authors claim. Woudenberg (1991) established that because of person-specific and situation-specific factors it is difficult to standardize Delphi and evaluate its reliability and states that a new measuring instrument is created with every new application of the method. These person- and situation-specific biases inevitably arise as every new set of questions is accompanied by a new group of experts giving judgements.

As reported in Van Zolingen and Klaassen (2003) Jillson (1975) proposed more optimistically to increase the reliability of the Delphi method by establishing guidelines:

- the applicability of the method to a specific problem.
- the selection of the respondents and their expertise: the panel.
- the design and administration of the questionnaire.
- the feedback.
- the consensus.
- the group meeting.

6.4.7 Validity

Van Zolingen and Klaassen (2003) discuss internal and external validity. The authors refer to Woudenberg's conclusion that the external validity is determined by the skills of the group leader or researcher, the motivation of the participants and the quality of the instruction in each questionnaire. The use of successive rounds also strengthens decision making. Having a larger sample size may make it easier to generalize across a population (Sivo et al., 2006) but increasing the sample size may not lead to higher external validity if the sample is biased. The internal validity is whether the design of the Delphi method leads to the results desired. Attention must be paid to ethical responsibility throughout the data collection process respecting issues of reliability and validity (Hasson, Keeney and McKenna, 2000). If used correctly and rigorously, the Delphi can contribute significantly to research and broaden knowledge. However, Sackman (1975) concluded that the Delphi's liabilities outweighed its assets but researchers following Sackman have disagreed and found the method has contributed widely to research in the healthcare field.

6.4.8 Participant Recruitment

The terms experts, expert panel, consensus panel, panellists, participants or respondents have been used interchangeably. Large numbers of respondents generate many items making categorization difficult (Ludwig, 1994) but larger numbers of respondents increase reliability (Fink et al, 1994) and smaller non-response error (Sivo et al., 2006). Delbecq, Van de Ven and Gustafson (1975) recommend that the minimally sufficient number of subjects should be used. They suggest that ten to fifteen could be sufficient if the background of the Delphi subjects is homogenous. Hsu and Sandford (2007) advise that what constitutes an optimal number of subjects in a Delphi study never reaches a consensus in the literature. Williams and Webb (1994) also state that there is no agreement regarding the panel size and that in several studies the size seemed to vary arbitrarily according to the researcher. The authors refer to Reid (1988) who listed 13 published studies where the panel varied from 10 to 1685.

In the present study two reference groups were involved and so numbers were higher. Furthermore, a truly international cross-section of professionals was sought, requiring larger numbers.

Delbecq, Van de Ven and Gustafson (1975) state that three groups of people are well qualified to be participants of a Delphi study. The authors recommend:

(1) the top management decision makers who will utilize the outcomes of the Delphi study.

(2) the professional staff members together with their support team.

(3) the respondents to the Delphi questionnaires whose judgements are being sought.

In this study the expert panel was made up of directors of professional ballet companies, directors of vocational ballet schools, senior teachers of classical ballet (with many years of experience), professional choreographers of classical ballet and principal dancers (the directors of the future). Included in this panel were therapists who work for ballet companies or vocational schools (physiotherapists/chiropractors/osteopaths), exercise specialists (Pilates trainers, Sports Scientists) and doctors attached to companies and schools.

Healthcare professionals were included in order to integrate the ideas of another informed discipline involved with performers and who help to keep them in the profession. Only in some centres are health professionals consulted as to the suitability for vocational training, but it was decided that input from those approaching the investigation from a different standpoint would add interest and depth. Opinions were sought worldwide. Both the artistic professions and the healthcare professions were represented here for the broadest possible views. These two groups have interests in common but mostly differing backgrounds. These panel members were chosen because they are indeed involved in selection of dancers at each step of the way, into the profession. Having said that, it is the artistic choice that dictates, advised in times of doubt by healthcare support. Selection of dancers by the artistic panel is based on aesthetics and artistic performance. Sympathetic to these requirements in an artistic environment, the concerns of the Healthcare Team are principally injury reduction, rapid rehabilitation and performance enhancement. There are two stakeholder groups involved in one panel here. In each iteration the participant's profession is recorded and so the panel's opinions could be divided into two groups and compared. Therefore, the researcher was interested to find out what the current perception of artistic management was concerning the balletic physique and the views held by the healthcare team. Healthcare professionals known by the principal researcher, working with vocational and professional dancers, were sourced by email. Snowballing sampling was used to further increase the size of the panel. Trusted colleagues in the profession, familiar with the strict criteria for panel inclusion were requested to distribute the survey.

Baker, Lovell and Harris (2006) state that experts provide an accessible source of information that can be quickly harnessed to gain opinion and that they can often provide knowledge when more traditional research has not been undertaken. There are, however, some reservations about the expertise of the experts. Landeta (2006) suggests that it may not be about who they are but what attributes they possess but Fink et al. (1984) states that an expert should be representative of their professional group, with either sufficient expertise not to be disputed or the power required to instigate the findings. Duncan, Nicol and Ager (2004) advise that too narrow a definition of expert reduces the potential sample size.

Concerns about whether a panel should be unidisciplinary or multidisciplinary is questioned by Cantrill, Sibbald and Beutow (1996) who state that this will depend, in part, on the nature of the research question. In the present study the aim is not to implement an action, it is to gather information about a trend and arrive at a consensus using opinions from different professionals, all stakeholders in the professional classical ballet.

In this study the 'expert panel' is broad, covering those leaders in the art form who wield influence in the selection of dancers into the profession or which dancers are put on stage.

6.4.9 Participant motivation

Questionnaire research is notorious for its low response rates and the Delphi technique asks much more of respondents than a simple survey. The potential for low responses increases exponentially (Keeney et al, 2006). Hsu (2006) states that because of the multiple feedback inherent and integral to the concept and use of Delphi, there is always a potential for low response rates.

Some people who participate in early rounds will drop out in subsequent rounds.

Cantrill et al. (1996) suggest that "the most important factors governing a response rate are the perceived importance of the study to the respondent and the number of approaches made by the investigator".

Electronic Delphi studies provide an efficient method for gathering data from a widespread sample and communication between participants and researcher (Duncan, Nicol and Ager, 2004). Respondents need stimulation and with repeated gentle and respectful electronic reminders attrition can be reduced. Ludwig (1994) states that successful implementation depends on the active role of the investigators to ensure as high a response rate as possible._Duncan et al. state that poor recruitment and retention of participants significantly impacts on the credibility of research findings.

In this study it was found that participant motivation was higher with personal communication where the participant knew the researcher and felt valued for their own standing in the profession. Confirming this, McKenna (1994) suggested that the 'personal touch' could help enhance return rates. One-to-one interviews in the first round can develop a rapport which can be used in subsequent questionnaires to psychologically oblige participants to complete the study. However, due to the international nature of the present study, this was not possible due to geography, time, and the need for anonymity.

The artistic community in classical ballet is unused to research and relatively unaware of the potential benefits. Artistic directors and well-known choreographers are wary of being quoted as there has, in the past, been negative press about injury, low weight and body shape in ballet and it is not a subject openly discussed. Even the anonymous nature of the present study appeared suspect to some, and reassurance was needed.

Those in the artistic community respond more readily to others in the relatively closed world of ballet but not to those removed in academic research. The lead researcher was able to take advantage of this.

6.4.10 Exploration of Opinions

In this study it was decided to simply ask for the ten most sought physical attributes in the classical ballet profession, in an open-ended request, but respondents were free to express themselves fully so given free rein. Asking for a finite number pushes the panellist to express more rather than less and allow those who wish, to add more thoughts. It allows freedom and imagination. No pre-exploration was done for the panellists for fear of 'leading' or influencing what was meant to be a spontaneous, 'uncontaminated' response from professionals who have firm opinions.

6.5 Methods Delphi Round 1

Ethical Approval for the study was obtained from the Ethical Committee of University College London (reference number: 7693/001).

Once the initial survey enquiry was decided and the survey design agreed upon by a Clinical Specialist Physiotherapist, a Professor of Rheumatology and the lead researcher, a Senior Physiotherapist with extensive expertise in treating dancers, the online tool was tested prior to use, for clarity of language, face validity and ease of electronic management. It was tested three times on a lay person, a dancer and a physiotherapist not involved in a vocational school. Feedback was positive with only minor modification, and once familiarity with electronic management was established, the first invitation and link to the questionnaire were sent out.

An initial email introduction to the subject of the study was sent to the selected participants explaining the aims and requesting participation. This reassured the invitees of anonymity and confidentiality and that very little of their time was expected. A link to the online questionnaire concluded the message.

It is at this stage that snowballing was employed as previously discussed.

Round 1 survey was comprised of 3 questions.

1. the panellist's professional role.
2. the panellist's geographical location.
3. an open-ended question requesting up to 10 attributes that make a classical ballet dancer.

It was important to explain to the panellists that the researchers were aware that there is far more to the dance-artist than only the physique type, but this was the sole aspect being investigated in the study.

6.5.1 Data Management and Analysis

Using Opinio Software the results from the third question were downloaded into Excel for analysis. Question 3 was printed for clarity. Content analysis was undertaken on the results and thematic coding was carried out (Joffe, 2012). After agreement on coding method with the Clinical Specialist Physiotherapist and a Consultant Rheumatologist, each of these suggested attributes were colour coded by the principal researcher. Common terms used in ballet are not always understood by those not working in the profession. For example, 'plié facility' means weight bearing dorsiflexion range of the ankle and *'ballon'* means ability to jump. The various attributes recommended by the respondents were expressed in many different ways. Respondents assumed the researcher was familiar with the vocabulary and expressions used frequently by dance professionals. All the attributes suggested were considered and a comprehensive list with the selection frequency of each attribute was reported – Figure 6.1. Once coded, the results were thematically analysed. Joffe (2012) states that the end result of the thematic analysis should highlight the most salient constellations of meanings present in the data set. Round 1 Table 6.1 displays the themed attributes ranked by frequency of selection and percentage.

6.6 Results Delphi Round 1

148 respondents returned completed questionnaires. Demographic details can be seen in Table 6.1 and Table 6.2. Twenty-eight (20%) of the respondents were artistic directors and forty-four (30%) were senior ballet teachers reflecting an expected ratio. Eighty-three (56%) of panel were artistic professionals. Sixty-five (44%) of the panel comprising of therapists, exercise specialists and doctors made up the healthcare subgroup. Forty-five (30%) were physical therapists representing the majority in healthcare. 6 continents were represented, with the majority of the respondents coming from Western Europe and North America. Eastern Europe, South America, Australasia and Asia were also represented.

Table 6.1 Round 1. Profession and number of respondents

Profession	**Number**	**%**
Artistic Director Company	14	9.4%
Artistic Director School	14	9.4%
Senior Ballet Teacher	44	28.3%
Choreographer	3	2.7%
Principal Dancer	8	5.4%
Exercise Specialist	11	7.4%
Physical Therapist	45	31.7%
Doctor	9	13.8%

Table 6.2 Round 1. Geographical location and number of respondents

Location	**Number**
Western Europe	83
North America	34
Australasia	18
South America	7
Eastern Europe	3
Africa	2
Asia	3

After coding was undertaken by the lead researcher, 34 attributes resulted from the selection reported by the consensus panel. Overall flexibility and hip turn out (external rotation) were the most frequently reported attributes with 50% or more of the respondents making these selections. Ankle plantarflexion was also favoured. Other common attributes included strength, coordination, proportions and aesthetics. The attributes were then themed to further highlight meanings present in the data.

The consensus panel was then divided into two subgroups. The artistic group was defined as artistic directors, principal teachers, principal dancers and choreographers. The healthcare group was defined as therapists, exercise specialists and doctors. The selections made by each group illustrated the preferences of each subgroup and highlighted the preferences of the different professions, shown in Table 6.4. Both groups considered flexibility to be an important attribute, followed by strength but the artistic group consistently chose proportions and aesthetics over all other attributes.

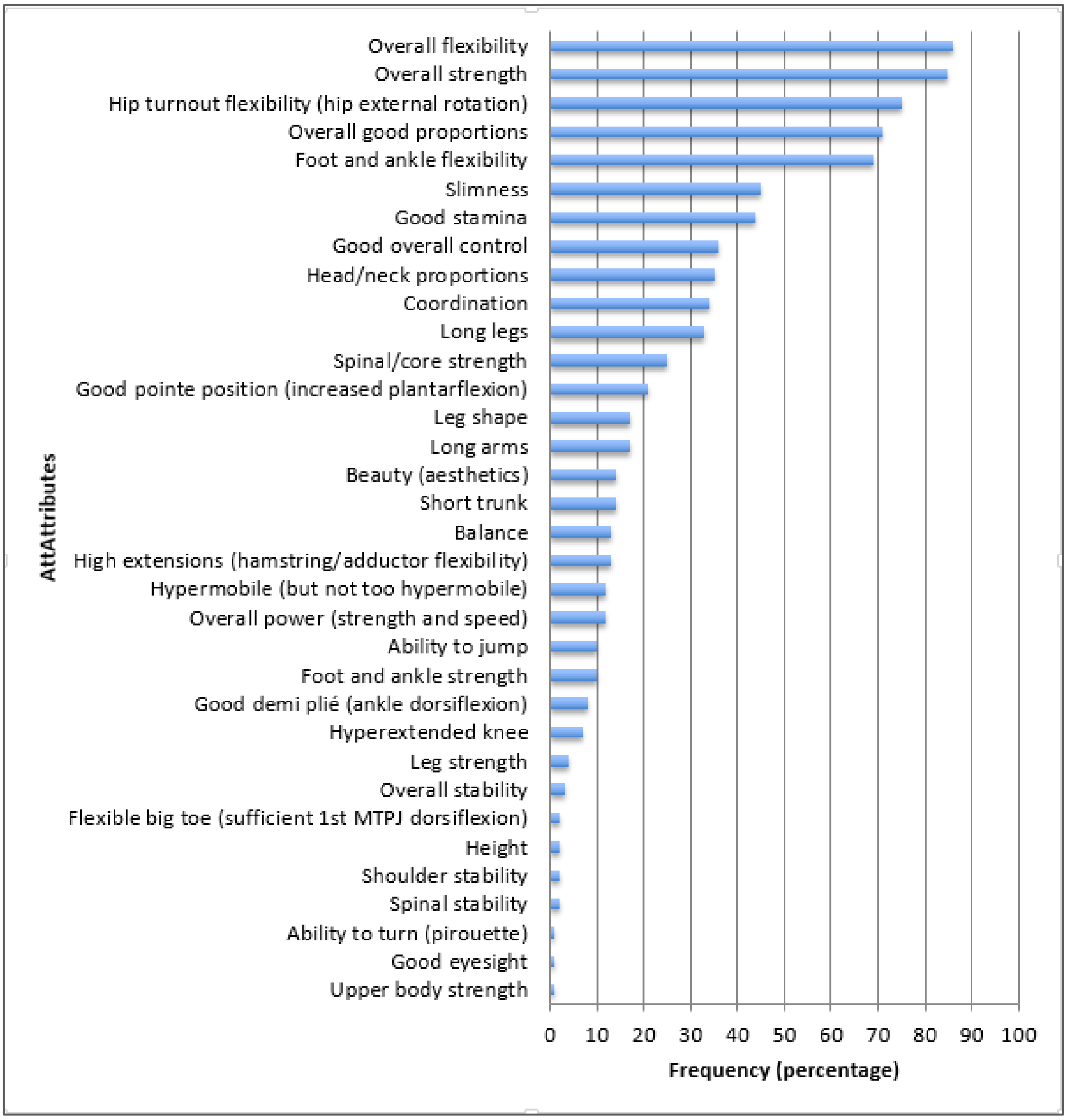


Figure 6.1 Round 1. Reported physical attributes ranked by frequency

Table 6.3 Round 1. Reported physical attributes grouped into each of the conventional broad dance specific themes

Theme		Attribute	Frequency (n)	%
Flexibility	1.	Overall flexibility	86	57.7
	2.	Hip turnout flexibility	75	50
	3.	Foot and ankle flexibility	69	46
	4.	Good pointe position (plantarflexion)	21	14
	5.	High extensions	13	8.7
	6.	Not too hypermobile	12	8
	7.	Good demi plié (dorsiflexion)	8	5
	8.	Hyperextended knee	7	4.6
	9.	Flexible big toe	2	1
Strength	10.	Overall strength	85	57
	11.	Spinal/core strength	25	16.7
	12.	Foot and ankle strength	10	6.7
	13.	Power	12	8
	14.	Ability to jump	10	6.7
	15.	Leg strength	4	2.6
	16.	Upper body strength	1	0.6
Coordin - ation	17.	Coordination	34	22.8
	18.	Balance	13	8.7
	19.	Ability to turn (pirouette)	1	0.6
Stability	20.	Overall stability	3	2
	21.	Spinal stability	2	1
	22.	Shoulder stability	2	1
	23.	Control	36	24
Proportions	24.	Overall good proportions	71	47.6
	25.	Head/neck	35	23
	26.	Long legs	33	22
	27.	Long arms	17	11
	28.	Short trunk	14	9
	29.	Height	2	1
Aesthetics	30.	Slimness	45	30
	31.	Leg shape	17	11
	32.	Beauty	14	9
Fitness	33.	Stamina	44	29.5
Miscellaneous	34.	Good eyesight	1	0.6

Table 6.4 illustrates how the two subgroups selected. Based on their different backgrounds, interests and experience they have selected differently. The artistic professionals have been driven by aesthetics and proportions. They also regarded foot and ankle and hip flexibility as extremely important. Both groups highly selected flexibility as necessary in the classical ballet dancer but the healthcare group favoured strength, control and stamina – the attributes that protect from injury and enhance performance.

Table 6.4 Round 1. Number and percentage of each profession which selected the same themed attributes.

Physical Attribute	Artistic professionals N=83	%	Healthcare professionals N=65	%
Flexibility	61	73.4	45	69
Strength	53	63.8	45	69
Control	8	9.6	27	41.5
Stamina	13	15.6	18	27.6
Balance	2	2.4	14	21.5
Coordination	25	30	8	12
Hip turnout	53	63.8	21	32
Foot and Ankle flexibility	64	77	21	32
Aesthetics	66	79.5	16	24.6
Proportions	67	80.7	11	16.9

In Round 1. each panel member responds to a request for up to 10 attributes required in the professional dancer. In the first round the panellists are not influenced by each other. They identify the attributes in their own language. Table 6.4. illustrates the priority the healthcare group gave to the motor control attributes – control, balance and coordination compared to the artistic group. Perhaps the healthcare group regarded motor control as the key to excellent technique and biomechanics and therefore the successful dancer. It is surprising that coordination was identified so differently by the two groups but many in healthcare had already selected control which incorporates coordination. Whereas the artistic group prioritised aesthetics twice as highly. It appears that healthcare professionals see the dancer through a different prism.

6.7 Terminology Used by Respondents

In deciphering the responses of each group, the terminology used was faithfully reported so as not to interpret and in doing so, alter. ‘Overall control’ (was understood to mean general technical control. At no point was technique mentioned and it was understood that a dancer’s control is synonymous with technique and precision. Coordination and stability belong to the same concept as (motor) control. When control, stability, coordination and balance are selected in differing totals, they are understood to represents different areas of technical control or motor control. While the artistic group may relate more easily to ‘coordination’, the healthcare may use ‘control’. Meeting in a common language needs to be accepted with tolerance and understanding.

6.8 Method Delphi Round 2

In the second round of the Delphi exercise all 34 chosen attributes were returned to the original panel for their consideration using Opinio online survey software. The panelists’ demographic information was again sought, to enable subgroup analysis. The panel were requested to consider the 34 attributes and to rate each one on a scale of importance from 1 to 6 using a Likert Scale. A 6 level Likert rating was used so that either a positive or negative answers could be ascertained. 1-3 passed selection and a preselected level of consensus at 60% was used (frequency of responses between 1-3). 60% or more of panelists placing their vote in 1-3 on the Likert scale retained the attribute for future consideration. 60% or more of panelists placing their vote from 4-6 on the Likert scale discarded the attribute. Attributes not gaining a 60% vote did not reach consensus. Survey returns in this round were accepted if 70% of the Likert questions were answered.

6.9 Results Delphi Round 2

Out of the 34 attributes, 2 were de-selected. Joint flexibility remained highly preferred with strength, control, stability and coordination gaining awareness. Panelists returned 123 completed questionnaires through Opinio. The return rate was 83% and the attrition rate was 16% at this stage. The attrition rate was 24% in the artistic group and 9% in the healthcare group.

Demographic information showed that a substantial number of representatives from each profession still engaged in the second round –Table 6.5. Numbers depleted in all professions except the doctors who remained involved. The numbers of respondents from Asia, Australasia and South America rose –Table 6.6. This was either due to renewed interest in the second round or due to snowballing.

Survey returns in this round were accepted if 70% of the Likert questions were answered. This is reflected in Table 6.7. where there is a small amount of missing data. The raw data was cleaned and any respondent with completely absent data was removed. The Likert results are shown in Chart 2 with approved attributes and those thought not important, in a stacked bar chart – (Figure 6.2). The 60% cutoff was inserted to indicate consensus. Two out of the thirty-four attributes did not reach consensus. Those were the hyperextended knee from the flexibility category and the short trunk from the proportions category. As some of the Likert scores were omitted in some of the attributes, the bar chart shows the missing data.

Flexibility remained highly preferred with strength, control, stability, stamina and coordination gaining awareness.

The panel were then divided into their two subgroups of artistic and healthcare and their preferences compared. To allow this the raw data was further cleaned to remove any incomplete demographic information. A mean score was calculated for each question answered by the respondents in each subgroup. The mean score for each question translated into level of agreement. The lower the score reflected, the higher the importance accorded to the attribute – (Figure 6.3). In the majority of attributes both groups are in agreement, but in the proportions category the artistic group selected significantly higher importance than the healthcare group. This was similar to the selection differences in Round One.

Table 6.5 Round 2. Profession and number of respondents

Profession	Number	%
Artistic Director Company	6	4.9
Artistic Director School	10	8.1
Senior Ballet teacher	31	25.2
Choreographer	4	3.2
Principal Dancer	11	8.9
Exercise Specialist	11	8.9
Physical Therapist	41	33.3
Doctor	9	7.3

Table 6.6 Round 2 Geographical location and number of respondents

Location	Number
Western Europe	67
North America	17
Australasia	19
South America	13
Eastern Europe	2
Africa	0
Asia	5

Table 6.7 Round 2. Attrition rate between Round 1 and 2

Panel subgroups	Round 1 numbers	Round 2 numbers	Attrition rate
Artistic	82	62	24.4%
Healthcare	67	61	9%

In Round 1 the artistic group outweighed the healthcare group in number but by Round 2 they were almost equal.

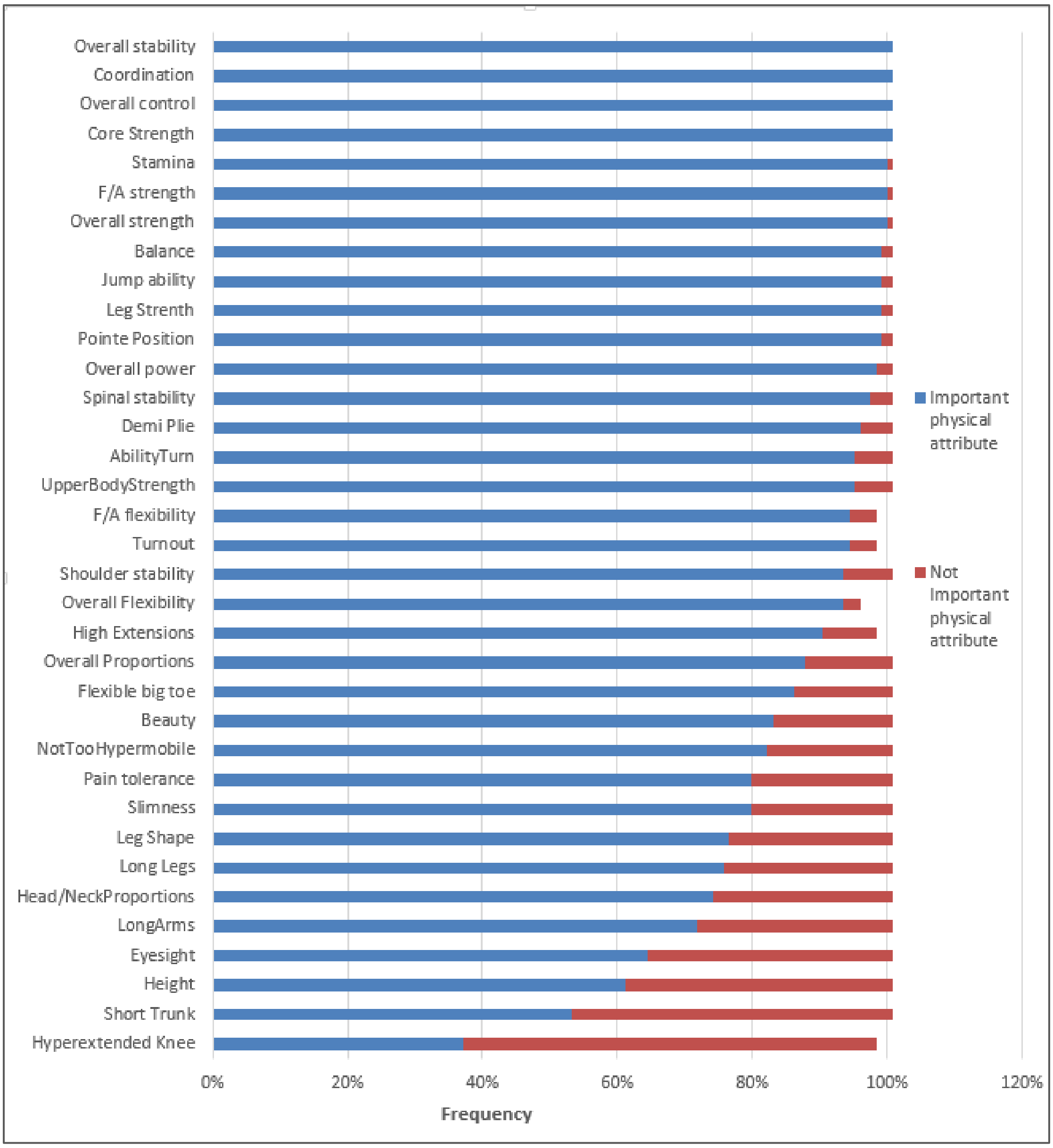


Figure 6.2 Round 2. Selection of attributes ranked in importance (frequency of selection).

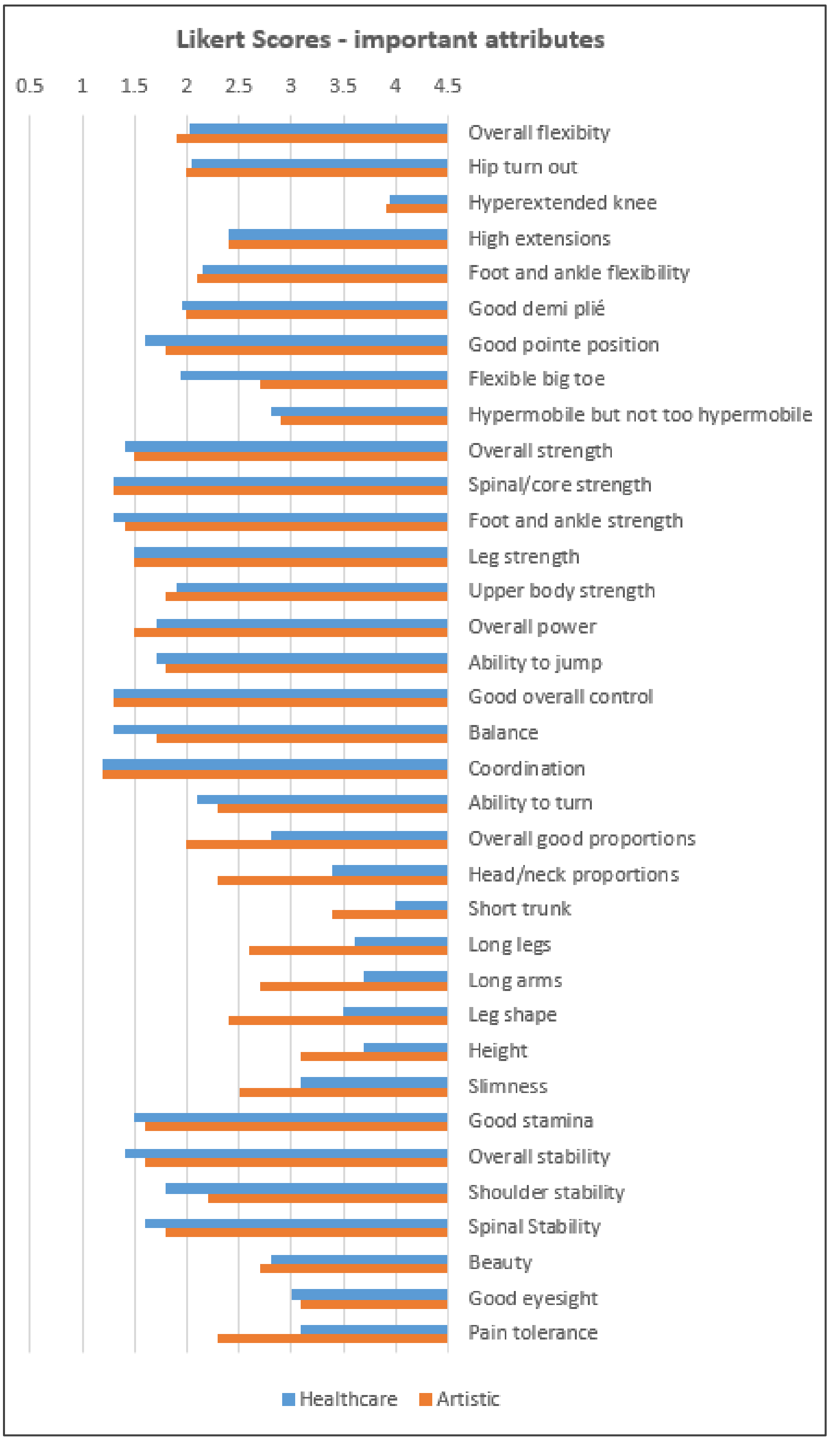


Figure 6.3 Round 2. Selected attributes by artistic and healthcare groups, based on Likert Score, showing contrast in preference.

6.10 Method Delphi Round 3

The Round 3 questionnaire was emailed to the same respondents as Round 2 using Opinio software. The respondents were asked the same demographic questions as Round 1 and 2. A chart showing the attribute selection frequency from Round 2 was included to illustrate the panel choices and encourage engagement in the next round. The respondents were asked to approve each of the attributes that had reached consensus in Round 2, and they were also asked to approve the deselection of the two attributes that did not reach consensus. Approval required the respondent to tick the box beside the attribute.

6.11 Results Delphi Round 3

Tables 6.8. and 6.9. illustrate the demographics of Round 3 respondents.

Table 6.8 Round 3. Profession and number of respondents

Profession	Number	%
Artistic Director Company	3	4
Artistic Director School	4	5
Senior Ballet teacher	25	30
Choreographer	3	4
Principal Dancer	6	7
Exercise Specialist	5	6
Physical Therapist	27	33
Doctor	9	11
Total	82	

Table 6.9 Round 3. Geographical location and number of respondents.

Location	Number
Western Europe	33
North America	8
Australasia	26
South America	7
Eastern Europe	3
Asia	4
Africa	2
Total	83

Eighty-four of the panel returned the third survey round. Attributes were either approved or deselected. Twenty-five reached 60% consensus with one borderline and ten were rejected – (Figure 6.4). Two respondents omitted their profession and one respondent omitted their geographical location – Round 3 Table 6.8 and Table 6.9. The attrition rate at this concluding stage was 30%.

23 attributes reached consensus for the elite dancer. Coordination was highly selected, followed by strength, control, flexibility and stamina. Plantarflexion range of the foot and ankle was also considered extremely important. Flexibility which was the highest in Round 1 lost some ground by Round 3, although it remained a highly sought-after physical attribute throughout the exercise.

The respondents were then divided into their subgroups of Artistic and Healthcare in order to compare responses. Those without demographic detail (2) were omitted and the selections made by each group were examined – (Figure 6.5).

Both groups agreed on the selection of thirteen of the attributes, but their opinions differed significantly on nine of the attributes. The artistic group rated aesthetic qualities and proportions more highly, indicating their importance to the art form. They also selected pain tolerance more highly than the healthcare group. The healthcare group consistently selected the athletic qualities of strength, stability, stamina and control.

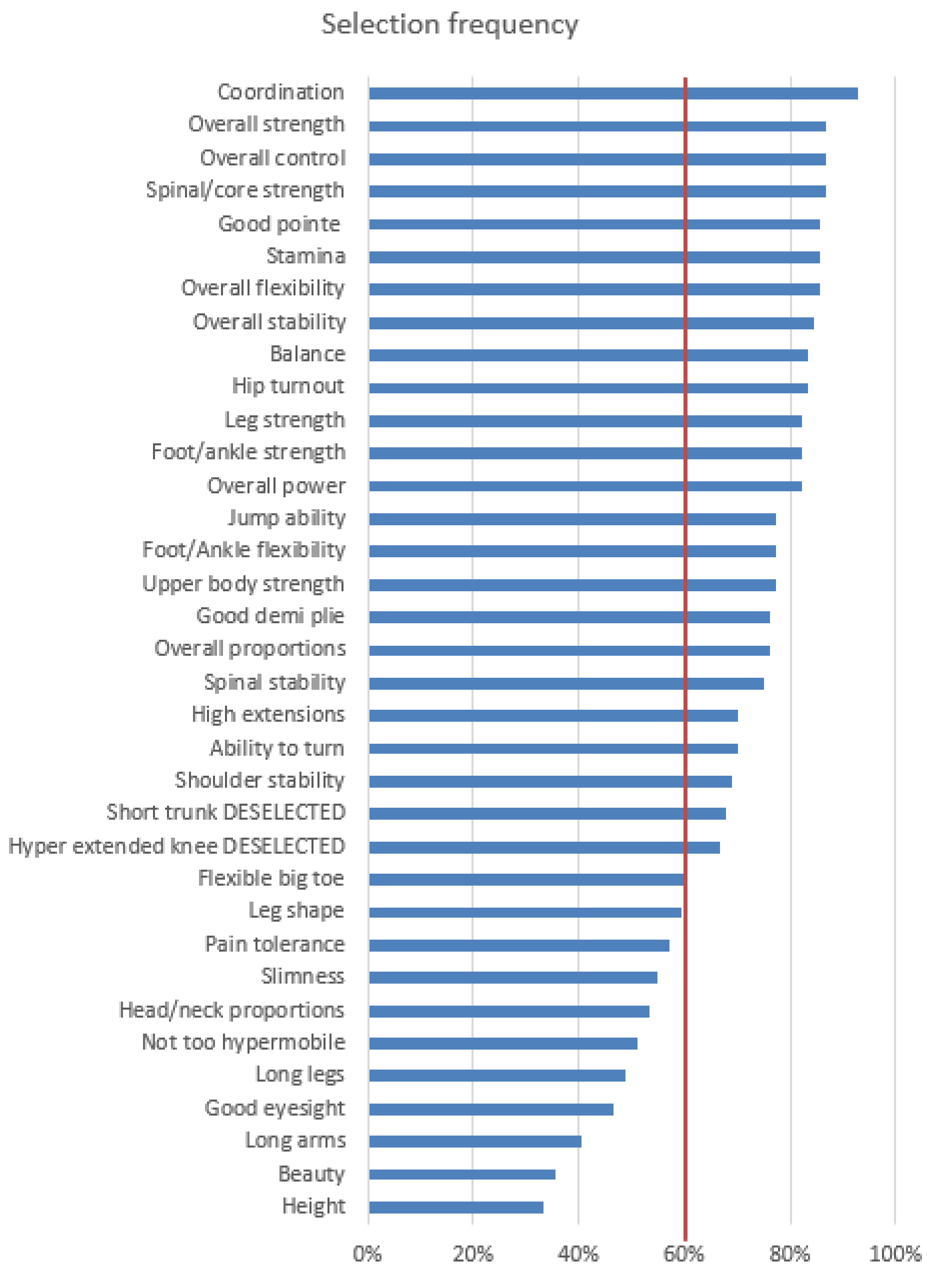


Figure 6.4 Round 3. Consensus of selected attributes ranked by percentage (n=23)

Table 6.10 Round 3. Attrition rate between rounds.

Panel	Round 1 n=	Round 2 n=	Attrition rate %	Round 3 n=	Attrition rate %	1-3 Attrition rate %
Artistic	82	62	24.4%	41	33.9%	50%
Healthcare	67	61	9%	41	32%	38.8%

Table 6.11 Round 3. Attributes reaching consensus

	Attribute	Number selected
1	Coordination	78/84
2	Overall strength	73
3	Spinal strength	73
4	Overall control	73
5	Overall flexibility	72
6	Stamina	72
7	Good pointe position	72
8	Overall stability	71
9	Hip turnout flexibility	70
10	Balance	70
11	Overall Power	69
12	Ankle & Foot Strength	69
13	Leg strength	69
14	Ankle & Foot Flexibility	65
15	Upper Body Strength	65
16	Jump Ability	65
17	Overall Good Proportions	64
18	Good demi plié	64
19	Spinal Stability	63
20	High Extensions	59
21	Ability to turn	59
22	Shoulder stability	58
23	Flexibility of big Toe	51

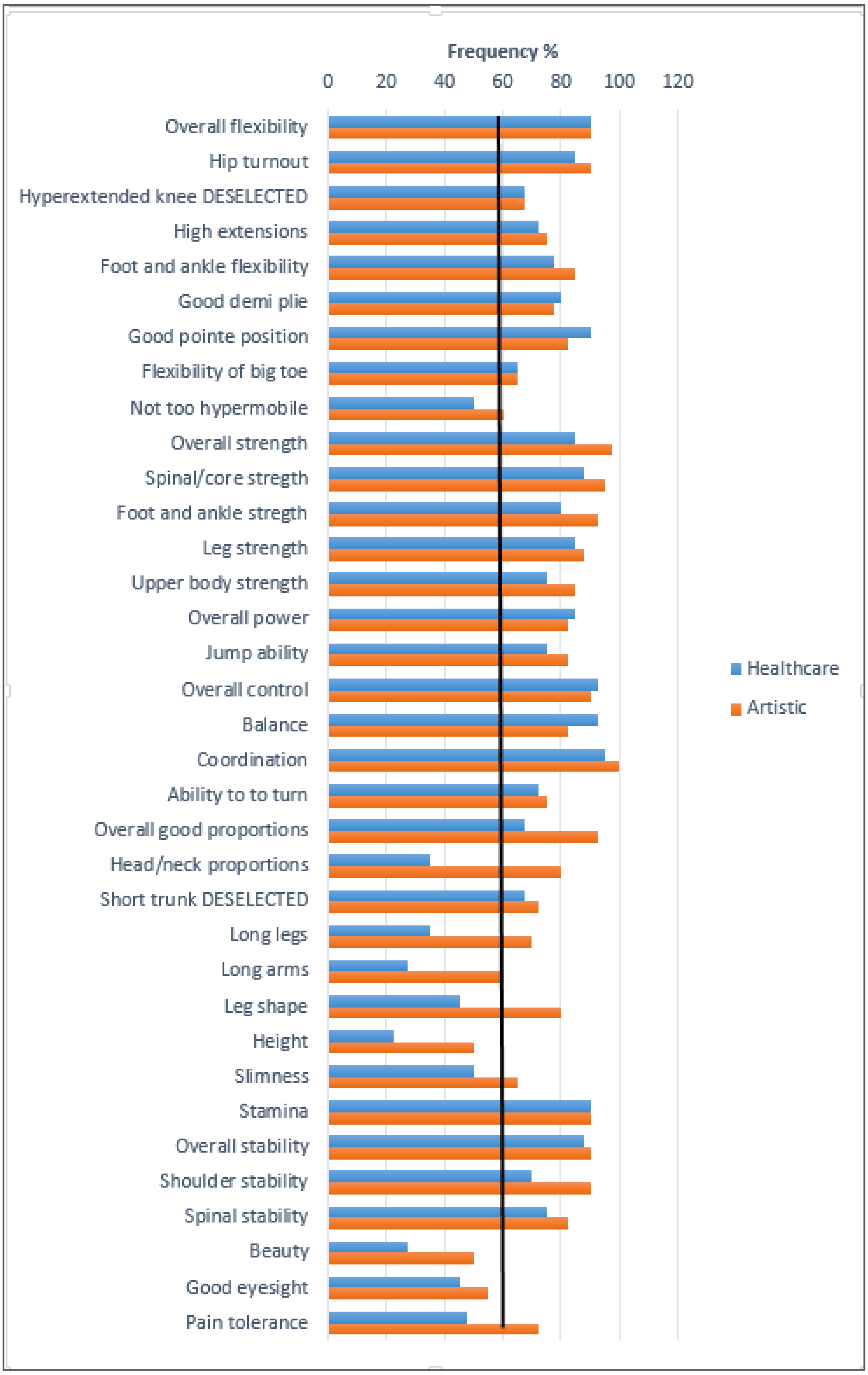


Figure 6.5 Round 3. Artistic and healthcare subgroup attribute selection preferences.

6.12 Summary of Delphi Results

The multidisciplinary panel arrived at consensus, agreeing on a selection of attributes considered most important in the elite dancer reported in Table 6.11.

Round 3 resulted in a consensus of 23 physical attributes for the elite dancer.

The panel agreed most highly on coordination, strength, control, flexibility, stamina, pointe position, stability, turnout, balance and power.

Overall flexibility was most highly selected in Round 1 and although it was superseded by other attributes, the flexibility category remained an important attribute in elite ballet.

The initial response rate in the exercise was good and each round retained representatives from all professions and each continent. The attrition rate between rounds 1 and 2 was 16% and between 2 and 3 it was 30% which was high but still considered acceptable in survey research. This was attributed to panel fatigue and the time between Rounds 2 and 3 which could have been shortened.

Close observation of subgroup selections allowed the researcher to examine the themes that most interested the different professions involved in classical ballet.

6.13 Discussion

This is the first study to explore and gain consensus on the physical attributes regarded necessary in the professional classical ballet dancer. It is the first study to explore the opinions of an international cohort of artistic directors, senior ballet teachers, principal dancers and choreographers. It is also the first time that healthcare teams working within the profession have been consulted. Representatives from each continent took part in the exercise and although there was an expected attrition rate, each profession and geographical location remained involved. As these attributes were generated by the panel, they possess high face and content validity (Baker et al., 2006). Artistic professionals from international classical ballet and allied health teams provided a unique perspective on the subject in question. The fact that the panel was multi-professional allowed a revealing view of each panellist's opinion and each subgroup's opinion. It is clear from the consensus list that it takes many specific and interrelated attributes to build the elite dancer, but each survey round was interesting and valuable in its own right.

The two subgroups agreed on the necessity of overall flexibility, flexibility of the hip, foot and ankle and high extensions. This category was given a high priority throughout the exercise. Round 1 results revealed two stake-holder groups with different priorities. The artistic group clearly prioritised the aesthetic attributes and flexibility, with physical proportions and foot and ankle flexibility amongst them, often not considering the attributes required for robustness and resilience of the physique, considering that these are dance-athletes. The prioritising of flexibility is what is seen on professional stages today. However, by Round 3 the artistic group had increasingly selected stamina, strength, control and coordination by over 80%. Coordination is part of motor control and should not be seen as a different entity. The fact that in Round 3. it rose to over 80% is part of the Delphi process where respondents are influenced by ideas and terminology. These were their decisions as experts.

The healthcare group, on the other hand, consistently selected those physical attributes believed to be required to protect the athlete from injury – strength, stability and control. Those are the qualities also required to enhance performance, but they had overlooked the qualities intrinsic to the art form – aesthetics, 'line' and proportions of the body and even by Round 3 still regarded these as less important.

The fact that the two do not always understand each other is not openly aired but revealed here in the first round of the Delphi and this study draws attention to a concern in the profession and provides a basis for on-going enquiry and resolution of this mismatch in the profession.

It must be remembered that it is the artistic group who ultimately take the responsibility for selecting into the profession and therefore the onus should be taken on by those in healthcare to resolve this gap in understanding with discussion and exchange of ideas and experience.

It is evident that the dancer is an aesthetic athlete and both approaches require equal attention. A third round was required to obtain consensus where all parties agreed on a combination of attributes. Clinicians are employed in ballet not only to care for dancers but to support artistic staff in the training of the young dancer, in prevention of injury and ultimately in performance enhancement. There are many stakeholders in the operation and mutual understanding, communication and support are essential.

6.13.1 Deselected Attributes

The hyperextended knee was selected initially by six in the artistic group but was subsequently deselected in Round 2. While the hyperextended knee is not a prerequisite, it is frequently seen in ballet as part of the hypermobile 'picture' along with the hyperplantarflexed foot and ankle which is highly selected and appears in the consensus. It is said to create an attractive line in open chain movement. The hyperextended knee is regarded as an injury risk in sport (Soderman et al. 2001; Ostenberg and Roos, 2000) and it is difficult to strengthen and train in classical ballet.

Although it has been deselected here, it will remain a frequently accepted attribute in the profession and needs to be taken into consideration when healthcare teams screen dancers (Chapter 2.3). A recent study by Chan et al. (2018) found, in a cohort of 85 student ballet dancers and professionals in classical ballet, that 72% measured 4/9 on the Beighton scale for hypermobility. The authors found a high prevalence of generalized and syndromic hypermobility in this population. Their results concur with the opinions expressed in Round 1 of this study with selection preferences for flexibility taking first place.

In the current study, 'hypermobility' was selected in the first round but was deselected by round three.

The 'short trunk' was also deselected from Round 2. It should be noted that the short trunk is part of the proportions attribute and may mean the same as 'long legs' as it conveys ratio of trunk to lower limb. These proportions, indicative of the ectomorphic physique are selected into ballet as shown by Liiv et al. (2013) and also by Twitchett et al. (2008) who also linked the somatotype to injury.

One of the criticisms of the Delphi is that there is, as rounds progress, a 'strong group pressure towards conformity' (Woudenberg, 1991). Sackman (1975) sees this as negative arguing that the Delphi system militates against independent judgement because it is destroyed once panellists know how others have responded to each item (Goodman, 1987). Hsu (2007) however, defines 'experts' as those 'capable of contributing helpful inputs, and who are willing to revise their initial or previous judgements for the purpose of reaching or attaining consensus'. This converging towards consensus is seen here and the 'education' observed in this Delphi exercise with converging views typifies the edification required in the profession to reduce the incidence of injury in ballet.

Sackman (1975) stated that 'panellist dropout is one of the well-known hazards of Delphi experimentation. Mullen and Spurgeon (2000) stated that the larger the panel, the larger the drop-out rate. Duncan (2004) stated that poor recruitment and retention of participants significantly impacts on the credibility of research findings. In this study recruitment was good but retention suffered. While those in healthcare remained engaged, those in the artistic group lost interest and the drop-out rate was higher in the artistic group. This should not come as a surprise, as research is often seen as unnecessarily time consuming by dance management (author experience only), but in retrospect it is possible that the wait time between rounds should have been shorter and the reminders more pressing. Round 1. was weighted more on the artistic side in numbers, Round 2. became equal and Round 3. was equally weighted regarding the two groups. As an exercise, although the attrition rate was high, the imbalance was not unreasonable. Over 50% of the panel was retained and Round 3 was made up of equal artistic and healthcare numbers. A consensus was reached, and the process revealed interesting mind-sets and viewpoints that can promote better understanding, if pursued, in the attempt to provide better stakeholder coordination in the profession, and ultimately better care for the performer.

6.13.2 Limitations to the Study

The study was restricted to the English language and so countries such as Japan, China and Korea where classical ballet is widespread in vocational training to the profession, were unrepresented. Russia, although the seat of a sophisticated ballet culture, was unrepresented for the same reason. We do however, see frequent traffic between these countries, Europe and the United States with a global sharing of choreography and teaching.

If initial participants had been fully informed as to the iterated rounds necessary in a Delphi exercise, perhaps attrition would have been less. Conversely, this might have resulted in less initial commitment due to apprehension.

The follow-up response rate decreases in inverse proportion to the size of the panel. Therefore, the validity of the result is subject to response bias (Williams and Webb, 1994). This could be the case in the current study as the attrition rate between Rounds 2 and 3 was 33%.

The respondents had some opportunity in the first survey to comment on the exercise if they had reservations or criticisms. On reflection, if this had been available in subsequent rounds the respondents may have appreciated the enhanced autonomy and been more engaged in the exercise to the final round. The period between round 1 and round 2 could have been shorter and this may have resulted in less attrition at this stage.

6.13.3 The Implications of the Delphi results for the profession

The study contributes further towards an understanding of the factors that are regarded as important in dancer selection and the priorities for each group. In the efforts to understand the physical attributes that are being selected, the study has revealed an important divide between the artistic and healthcare professions involved in dance. The professions are interdependent but are divided in understanding, and even the language used. It provides a basis for further understanding the challenges of working in healthcare, caring for the aesthetic athlete and cooperating with artistic management.

The researcher fully appreciates that it takes far more than just physique, to make an elite classical ballet dancer, but without the advantageous physical attributes considered in this exercise, the young dancer will find it difficult to succeed in today's intense professional climate.

'Screening' is advocated for athletes and dancers, particularly concerning injury prevention (Liederbach et al., 1997; Gamboa et al., 2008; Allen et al., 2013; Bronner and Bauer, 2018; Southwick, 2017; Kenny et al., 2018). Although advocated, few reliability studies have been carried out. In training and within the profession an annual screen aims to identify intrinsic risk and potential injury. A brief but specific 'screen' has been used traditionally to screen young dancers at audition before entering full time, rigorous vocational training in order to gauge potential talent and also to choose the physiques with the facility required for the profession and exclude those judged to be an injury risk (Royal Ballet School, personal communication). The physical screen is carried out by a physiotherapist who assesses the major joints to evaluate the physical profile for risk factors.

Good coordination, an element of motor control, which scored highest in the consensus is observed in the dance part of the audition where young dancers perform for the panel of artistic experts. Proportions and aesthetics are also noted at that stage. Strength and control are observed through technical ability and age and stage of maturity are taken into account.

Vandorpe et al. (2011) showed that in gymnastics it was possible to predict elite-level gymnasts at a young age, through flexibility, strength, speed, endurance and motor coordination tests. Testing was exhaustive. The authors used 4 coordination sub-tests and 9 locomotion skill tests. Interestingly, it was the coordination results that appeared to define elite and sub-elite and these were not sport-specific tests. However, the deciding factor for these young gymnasts was competition success. In classical ballet, the deciding factors are entry into vocational training, a subsequent career and advancement in career, and these require longitudinal studies.

Flexibility was regarded as highly important in the Delphi consensus and artistic and healthcare subgroups selected in equal measure. Range of movement dimensions of all the major joints assesses the full range of movement from hypomobility through to hypermobility. Active range in a young dancer will be less than passive range of movement and the greater the difference between active and passive, the greater the risk of injury due to control and strength deficits. Hypermobility whether global or localized is an important feature in the young dancer’s profile, both representing an injury risk unless accompanied by strength and control. It is important to note the range at each major joint and establish whether there is sufficient range, too little or too much.

Strength, control and power were prioritised in the Delphi consensus, but these are the attributes to be developed during vocational training and maintained during a professional career. Stamina is also an attribute to be built and maintained. Jump ability and ability to turn are both attributes that can be improved.

The consensus from the Delphi prioritised the aesthetics of pointe position, turnout and stability. A less than aesthetically pleasing pointe position can be caused by lack of strength and control of the foot. If plantarflexion is however truly restricted structurally, this can be an injury risk to the posterior ankle. External rotation of the hip (turnout) needs accurate measurement of the classical ballet student in training.

Teachers need to understand the passive potential and the active capability when teaching, but the truly restricted hip is an injury risk to the rest of the kinetic chain in a technique dependent on facility. A flexible big toe (first metatarsophalangeal joint) was also prioritised and as ballet dancers suffer a high incidence of first metatarsophalangeal joint wear and tear and joint injury, at the start of a career a weightbearing dorsiflexion angle of 90 degrees or more is favoured (Rietfeld, 2013).

Deficits in stability can be hidden by flexibility and familiarity with movement patterns in dance and therefore requires careful functional testing. Stability can also be compromised by hyperlax joints that lack acute proprioception (Desfor, 2003; Hall et al., 1995; Bird et al., 1978) required in precision work and speed. Therefore, an accurate and informative test can add to the dancer's profile.

Having completed the Delphi study, the next step was to assemble a screening tool informed by the Delphi findings.

Chapter 7. Proposing a screening tool for expert group consultation

7.1 Introduction

The aims of this chapter are to devise a baseline screen and consult with an expert group in order to arrive at the best possible selection of tests to thoroughly and efficiently supply the necessary information to support an audition panel's decision to proceed or otherwise, with intensive training.

The selection of young dancers into vocational classical ballet is a challenging process and the format varies between different ballet schools and companies. Usually, decisions at audition have to be made with a tightly proscribed timetable and this has implications for the acceptability of a screening tool offered in support of selection. Aspects of the audition process therefore need to be understood for the design of a tool that is hoped will prove practical and popular with good take-up.

In several prominent vocational schools, dancers are first viewed by an artistic panel who observe a 'class' made up of the steps and movement patterns suitable for the age group. The dancer's aesthetic qualities and physique are marked along with technical ability and musicality. The dancer is then assessed by the physiotherapist who screens the physique for the desired qualities, with injury risk in mind. The process involves the artistic and aesthetic needs of the art form as well as the healthcare support and advice, considering that the aims of full-time training are to build the dancer-athlete capable of taking on a career in professional dance. At many auditions 30 students may be seen in a day, therefore each audition screen is given 15 minutes. A screen that is possible for a single physiotherapist to employ is required because the lone professional is often the case and one who has no access to equipment and expertise needed for measurement of range or biomechanical analysis of movement. The screen that can be used 'in the field', independent of assistance and without costly tools is essential. A screen that is based on selection findings but also respects the research that has gone before, is the aim in this next part of the study with reliance on visual analysis of the movement control elements with an acceptable degree of reliability.

Liederbach (1997) stated that there were six reasons to screen dancers:

1. To establish normative data for a specific group of dancers.
2. To determine if an individual possesses attributes necessary for participation in that form of dance.
3. To uncover pathology.
4. To quantify risk (Since this paper, this has been proven to be impossible by Bahr, 2016).
5. To develop characteristics for a given level of performance; and
6. To establish individual baseline data in order to set educational and training or rehabilitative goals

Liederbach did not state when this screening is proposed to be carried out. 'To determine if an individual possesses attributes necessary for participation in that form of dance' should surely be established before acceptance for full-time training, not after the event. To uncover pathology and quantify risk are intrinsic to an informative screen. Liederbach and Richardson (2007) listed body alignment, morphology, muscular flexibility, joint range, joint laxity, muscular strength and balance amongst characteristics to be screened. Liederbach (2010) emphasised that fundamental to this process is the assessment of the dancer's functional ability.

Familiarity with the 16-year-old student about to embark on an intensive training in preparation for entering the profession requires a knowledge of the preferred physique in the audition situation, a knowledge of the rigours confronting this age group, an awareness of the still growing and maturing physique and an understanding of the mind-set of this population.

As previously discussed, the Delphi exercise comprising the first part of this study, revealed two groups in the profession who clearly state their differing needs. The artistic group, comprised of directors, teachers and choreographers - those who select dancers – are concerned with physical proportions and aesthetics in keeping with the art form. The healthcare teams of schools and companies are concerned with selection of the physiques who will thrive in full-time training, strengthen easily, progress technically and with minimal risk of injury.

Injury risk is high in vocational and professional ballet (Luke et al., 2002; Allen et al., 2012; Ekegren et al., 2013; Biernacki et al., 2018) as observed in the Chapter 3 The Risk of Musculoskeletal Injury in Classical Ballet. Considering this, it is important to select those more robust physiques into the profession, as far as possible not choose those vulnerable to injury and therefore lose training time, with possible ultimate failure. As the physique of a sixteen-year-old is growing and maturing the aim of a vocational training is to develop the artist/athlete over an intensive period at a formative time, to prepare for the profession. A high-risk physique may still be taken on because the dancer is artistically strong, with the intension of extra coaching to develop and protect the dancer from injury. The main consideration is that the vulnerable physique is recognised, and decisions are made in full knowledge of the risk. It is conceded however, that vocational training is relentless, and the competition is high, for a professional career.

The use of a physical screen is used in some classical ballet auditions for full-time dance training. Surprisingly some schools select on performance at audition only, with no individual physical assessment. There is no data available on injury or attrition in ballet schools historically, except for the paper by Hamilton et al. (1997). Negative reportage in commercial organisations is not made public. No screen for the specific needs of ballet has previously been formalised or validated. Kenny et al. (2018) present a selection of screening components which they assert is the first to be examined for reliability. The authors classify the selection as pre-participation screening tests. The comprehensive selection clearly cannot be carried out at audition as they cover elements such as Bone Mineral Density and Total Body Fat %. Therefore, we must assume these tests are carried out after the new cohort of students has started their full-time pre-professional training. The Pre-Participation Screen by Kenny et al. includes passive range of movement measurements for joints

– hip and ankle which are proven not to change significantly in the 16 – 17 years age group (Khan et al., 2000) but those are the measures that it is advisable to know prior to acceptance. If performed after acceptance it is assumed that this information can inform on preventive measures to be taken to avoid injury i.e., adaptable and individual teaching methods which is rarely the case in full-time dance schools. The screen takes 60 minutes per dancer. An audition screen, conversely, informs so that the most educated selection process can be facilitated in the first place. Pre-professional implies that it is expected that these students will have the attributes and potential to become professional at the end of their training, a serious responsibility for any vocational school.

Based on the consensus from the Delphi, the needs at the time of audition and the requirement to provide the most information in a short time, a brief but thorough screen will be devised to support artistic decisions in the second part of this research. It is the artistic panel who make the final selection in the light of information from the healthcare team. Any physical screen that questioned artistic decisions would lead to negotiation and the dancer being admitted 'on trial'.

Once consensus was reached in the Delphi Survey and the results fully analysed, it became clear that many co-existing attributes are required in the physique most suited to classical ballet technique and performance. In order to cover the attributes required, the development of a composite screen involving tests to inform on those requirements, supported by research and expert consultation, are the purpose of the second part of the study. The aim therefore is to develop a valid and reliable screening tool suited to the audition situation and to conduct initial psychometric testing.

7.2 Research Objectives

1. To develop a screening tool suitable for entry into vocational ballet.

2. To determine the inter-rater and intra-rater reliability of the tool.

The objectives, of necessity, were to create a screen that can be covered in a short space of time and that can be carried out with minimal interference with the dancer's ability to perform optimally, especially if it is to be performed before the applicant performs before the panel. In so far as it is possible, recommendations from the Delphi were to be taken into account, providing these can be incorporated into a brief but thorough assessment. Anything longer carries the risk of being unwieldy and unused.

The screen must inform maximally on passive range of movement at specific joints where it is important to know the potential range. It is important to know the passive range at isolated joints because hypomobility will mean range demanded by ballet technique will cause strain to be absorbed elsewhere in the chain with possible injury risk. If the measured passive range of a joint is significantly more than the active range, there is control deficit in outer range leaving the joint vulnerable in demanding technique. The aim of training is to instil strength and increase control of a progressively greater active range of movement, and in doing so enhance performance, reduce injury risk, protect, and promote resilience. Therefore, passive range of the major joints used in ballet is important to know. Where on the flexibility scale the physique lies is valuable information, accompanied by evidence of neuromuscular control.

7.3 The Nominal Group Technique

Following the results of the Delphi Survey and consensus, a range of screening tests were devised by the principal researcher to cover the most highly selected physical characteristics in professional classical ballet. Where possible, tests are based on established protocols of already published research. This is reported in Table 6.2. Years of experience working with the full age range and having screened dancers for each level of training up to professional the lead researcher was able to create a baseline selection of tests judged to supply the most important information at the pre-professional stage. However, this was a purely subjective design, and it was necessary to consult with colleagues, experts in the field, to seek their views on the subject of screening for the profession and ask for their advice on each of the selected tests. Without consultation of other professionals working in similar contexts the risk of proceeding with bias is great, especially as there is a lack of consensus on screening procedures in dance. This often refers to annual screening or screening pre-professional dancers in vocational schools. This is the first screen specifically to be used at audition. There are no reliability studies carried out on audition screens in particular, but Kenny et al. performed reliability testing on a pre-participation screen of which a selection of components which will be considered. Once a screening tool has been clarified, the next step would be to proceed with reliability studies.

In this chapter the proposed screen was presented to an expert group of physiotherapists and the Nominal Group Technique (NGT) was employed to consult and obtain consensus. The NGT was developed by Potter and colleagues in 2004 and further expanded by McMillan et al. (2016). The NGT is a more formal way of reaching consensus. Prior to this, Ethical Approval was sought from the Ethics Committee of University College, London (7693/002).

The Nominal Group Technique (NGT) is a documented way of carrying out face-to-face expert group consultation. It was first described in the 1960's as a procedure to facilitate effective group decision-making (Delbecq and van de Ven, 1971). Potter, Gordon and Hamer (2004) state that the purpose of the NGT is to generate information in response to an issue that can be prioritized through group discussion. It is commonly referred to as a consensus method and aims to achieve a general agreement or convergence of opinion around a particular topic (McMillan, King and Tully, 2016). Unlike a focus group, a key strength of this method is the balanced participation from all group members with its structured format (McMillan, King and Tully, 2016). Voices are heard and opinions considered by other members. In this context the participants were requested to review ten clearly defined methods of physical screening are requested to comment, suggest adaptions, approve or disagree.

7.4 Methods

7.4.1 Recruitment

Purposive sampling was used to recruit five experienced physiotherapists representing four vocational schools in London. Only those working in the field can be considered 'experts' with a track record of specialism. Numbers working in this specialist profession are limited and so these are colleagues, although working separately. McMillan et al. report that between two and seven have been successfully used in this technique.

Table 7.1 Inclusion criteria for expert group members

Inclusion criteria	Exclusion
Chartered Physiotherapist	Physiotherapists not currently registered in the UK
MSc in Sports Physiotherapy	Not MSc qualified
Currently working in a vocational school specialising in classical ballet	No experience of vocational training
At least 5 years of experience working with elite level ballet students	Under 5 years of experience in ballet
Proven experience in screening for entry into vocational training	No screening experience
Experience working with international ballet students	No international experience
Experience in dance research	No experience in dance research

Five physiotherapists were selected. Three were Head of Physiotherapy at three different schools with extensive experience in screening. The fourth had over twenty years of experience of specialised physiotherapy and screening in vocational ballet and the fifth was an ex-dancer and specialised physiotherapist. All had international experience and extensive experience in research.

In the NGT, the facilitator should also be an expert on the topic of discussion and familiar with the group meeting process so that quality leadership can be provided

(Potter et al., 2004). The lead researcher in this case also fulfils the criteria for the expert group facilitator.

Three physiotherapists were able to meet with the lead researcher to generate a discussion, explore ideas about the purpose of the audition screen and decide on content following expert group protocol. The other two were consulted separately due to work commitments. The protocol used was adapted from Hennessy et al. (2018) to gather each person's thoughts and encourage group consideration of any request for test adaption. With three physiotherapists and the facilitator (Lead Researcher) a two-hour discussion resulted in several valuable suggestions and adaptions to discuss further with the others in the group. After the two individual consultations additional suggestions were taken on board, synthesised and fed back to the group.

7.4.2 Following the NGT protocol

Each member of the group had been sent a copy of the proposed tests with illustrations, description and suggested scoring to consider one week before the group meeting.

The group understood the overall aims of the research, the expert consultation process and agreed that a screening tool was needed to identify injury risk and any impediment to training, for entry into elite level ballet.

The five stages of the NGT protocol (Potter et al., 2004) were followed in the group meeting.

Stage 1. The participants were welcomed, and the exact protocol of the meeting was explained.

Stage 2. The test was presented with participants referring to the illustration and explanation given to them prior to the meeting. Participants silently reflected and made notes of their individual ideas/criticism of the test and its set-up. Stages 2 to 5 were repeated for each test.

Stage 3. Each of the participants was given time to comment on the test with the facilitator taking detailed notes of each person's comments.

Stage 4. During this clarification stage participants discussed the adaptions suggested by their comments so that everyone understood reasons and meaning, including, excluding or altering ideas.

Stage 5. The physiotherapists were given a form on which they scored using a 6-point Likert scale. These were fed back to the Lead Researcher who had detailed notes of the discussion and could therefore see the reason for each score. A 6-point Likert scale was used to encourage decisiveness. How positive or negative the score was indicated its utility and face validity.

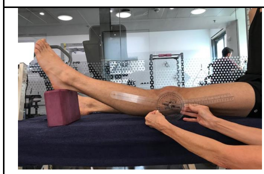
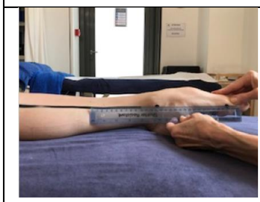
The Lead Researcher was able to conclude the meeting with notes relating to all discussions and individual opinions. Hard copies of the Likert scoring were de-identified and stored anonymously. Paper documents were destroyed once uploaded to a password protected UCL device.

Comments and recommendations were then synthesised and incorporated, building towards the final screen. In some tests each expert preferred a different method and so the Lead Researcher made a pragmatic decision with time management, the composite screen, and its expediency in mind. If an extra test was recommended it was the Lead Researcher's prerogative to include it or not. Consensus is preferred but the NGT can be exploratory in nature, laying the foundation for further thought and testing (McMillan, King and Tully, 2016). The two physiotherapists who were unable to join the meeting were consulted separately and their opinions were assimilated.

7.5 Results 1. Initial Expert Consultation

In the following table is a list of the tests first presented to the expert group for their consideration. Each test is illustrated and described with preliminary scoring. The participants' comments are reported and where possible tests were based on past research. The Plank Test for capacity, was regularly used by one of the expert group and so a modified version for the audition screen, was included for consideration by the rest of the group.

Table 7.2 Initial screen tests generated for review by the expert group

Method	Test Range of Movement	Comments	Reference
	Test 1. Hip External Rotation < 45° = 1 45° - 60° = 2 > 60° = 3	Precise positioning of tested limb Precise positioning of contralateral limb Approved	Khan et al. (2000) Washington et al. (2016)
	Test 2. Passive Knee Extension <0° = 1 0 - 10° = 2 >10° =3	Goniometric accuracy demanded Approved	Boyle, Witt and Riegger-Krugh, (2003)
	Test 3. Foot and Ankle Plantarflexion 1st MTPJ above medial border of tibia=1 1st MTPJ in line=2 1,2 toes touch surface=3	Suggestions: -Novello (1995) Pecil Test suggested -Goniometric: fibula/5th metatarsal is the accepted method -Measure medially as medial aspect is prioritised in ballet	Novel
	Test 4. 1st metatarsophalangeal joint extension < 75° =1 76 - 100° = 2 >100 = 3	-Allow dancer to extend 1st MTPJ -Measure in weight bearing for better accuracy	Benhamú-Benhamú et al. (2015)

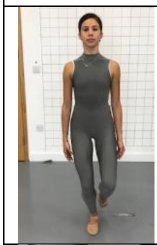
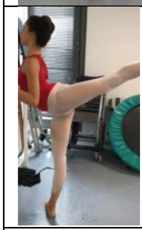
	Test 5. Spinal extension ≥ 65° = 1 66 - 90° = 2 >90° = 3	Further evidence required	Novel No available test
	Test Functional Movement Control		
	Test 6. Functional Turnout Control Scoring criteria to be decided	Mixed reception	Novel
	Test 7. Single Leg Turnout Control Scoring criteria to be decided	-Foot should not be in contact behind. -name it 'Standing Hip Stability'	Novel
	Test 8. Single Knee Bend Scoring criteria to be decided	Assess in turnout	Almangouch, Herrington and Jones, (2014).
	Test 9. Arabesque Test Scoring criteria to be decided	Not approved	Novel
	Test Strength		
	Test 10. Plank Test Scoring criteria to be decided	Increase challenge Decrease holding time	Tong et al. (2014)
Beighton Score		Advised by the group	

Table 7.3 Likert Scoring of the presented screen tests post NGT enquiry 1 = approval 6 = disapproval

	Range of movement	P1 j	P2 k	P3 a	P4 r	P5 a		Functional movement control	P1	P2	P3	P4	P5
Test 1	**Hip external rotation** **Measured in supine set-up** **Washington et al (2016)**	2	1	1	1	1	**Test 6**	**Functional turnout control** **Washington et al (2016)**	4	2	2	3	4
Test 2	**Knee hyperextension** **Goniometric measurement**	2	2	1	2	2	**Test 7**	**Single leg turnout control**	3	5	2	3	3
Test 3	**Plantarflexion of the ankle** **Measured in a specific set-up**	2	3	1	3	4	**Test 8**	**Single leg knee bend parallel**	3	3	2	2	2
Test 4	**1st MTPJ extension** **Goniometric measurement**	3	2	2	5	3	**Test 9**	**Arabesque Test**	6	6	6	6	6
Test 5	**Lumbar spine extension test** **Measured in specific set-up**	3	4	3	4	4	**Test 10**	**Elbow plank-timed**	4	3	2	1	3

The group of five agreed unanimously that passive range of external hip rotation was important in the vocational ballet dancer in order to cope with the specific technical demands at their schools. It was agreed that this testing method should be used. On the advice of Participant 3 it was planned to include the internal rotation measurement. As mentioned in Bennell et al. (1999) vocational dancers displaying more external rotation than internal rotation may suggest an altered axis of hip rotation. This would appear to be advantageous to the ballet dancer and the converse, unfavourable.

The second test using the mobile phone to measure degrees, was the spinal extension, in cobra push up.

There is a paucity in reporting spinal extension measurement in the literature, but a simple prone extension test is suggested here. Because of a dancer's increased range, measuring spinal extension does present a challenge and the group agreed. Above all, the screen must flow smoothly with no need for costly equipment. The group was open to suggestion having had no experience of accurate measuring extension in dancers. Overall flexibility was important in the Delphi Survey results (McCormack et al., 2018) and in discussion the group agreed that both over flexibility and under flexibility can result in a control issue, but the method of measurement was the obstacle and required refining.

Unanimously the group rejected the Arabesque Test and there appeared to be an unwillingness in the group to engage with dance technique whereas the purpose of the test is to assess the range, control and stability of the spine and pelvis and the freedom of the lifted lower limb. Based on the group's use of spinal extension assessment in standing, the Lead Researcher decided to add the Back Bend Test for their consideration in the Stage 5, adapted screen. As this functional movement is similar to the commonly used test, it was decided to appeal. This is a controlled articulation (proximal to distal) of spinal extension to be viewed from the back and the side to assess range and skill.

The Single Knee Bend test was approved which was already used by the participants, but they recommended testing in turn out.

Participant 1 felt the use of Novella's 'pencil test' test (Novella, 1995) lacked face validity, which was an acceptable point. The other members of the group suggested other more time-consuming methods and prompted by Participant 1 who used the straightforward binary 'yes/no' test decided to retain the simple ruler test.

Participant 4 approved of the Plank Test which she used in regular screening (as opposed to audition screen) with advice to redesign to shorten the time taken. The plank test was reconsidered after consultation. The elbows were placed directly under shoulders with forearms and fingers extending forwards (Tong et al, 2013). With shoulders in neutral the scapulae were more easily stabilised. The neck was held in line with the rest of so that the body remained in neutral from head to heels.

7.5.1 Limitations

The expert consultation was not carried out internationally because of time zones and workloads of busy physiotherapists. The experts in this workshop had international experience. London is a centre for vocational training and attracts students from all parts of the world and so this level of internationality was thought to be a compensation.

The 12 tests together take more than 20 minutes to complete but it was thought that including more rather than less at this stage was advisable.

7.6 Discussion

Regarding Test 1, colleagues in Australian Ballet were consulted about the use of the mobile phone to measure angles instead of goniometer. These were the researchers in the study by Washington et al. (2016) and their recommendation was based on accuracy, convenience and less expense. Mobile phones, which everyone owns are being used more and more in place of expensive inclinometers in the clinical situation. It is recognised that the set-up and technique require practise, but this is why the test is recommended rather than testing in other positions that are less precise and have been used in research but have not been universally tested for reliability.

Most recently, Kenny et al. (2018) used two measures - passive external rotation of the hip at 90^{o} flexion (Jenkins et al., 2013) and total passive turnout in supine proposed by Grossman et al. (2008). The argument against using the first is the fact that in flexion the iliofemoral ligament is lax and the relationship of head of femur in acetabulum allows further excursion than in neutral position which is functional. Weight bearing external rotation is also the more challenging for the rest of the lower limb and therefore the passive range in the neutral position, measured with precision is important to establish. “Compensatory mechanisms so commonly used by dancers lacking ideal turnout can predispose to injury and diminish classical ballet technique” (K. J. Crichton, Orthopaedic Consultant to Australian Ballet, 1981 – 2011).

Jenkins even admitted that the flexed position was not a functional position in which to test external rotation of the hip. Kenny used the second 'passive supine turnout test' measurement, presumably because Grossman et al. had found it to be reliable. However, the hip measures chosen were not found to have sufficient intra-rater reliability and therefore were not recommended.

The passive hip external rotation test in supine (selected in this research) is recommended in the review by Angioi et al. (2021) although less reliability studies have been reported to date. The Functional Turn Out test (Test 6) was originally designed to evaluate the difference between the measure of hip external rotation in Test 1 and functional range (estimating the torsion absorbed throughout the lower limb in the dancer's standing position). The manoeuvre was used by Kahn et al. (2000) in their investigation into hip range improvements in 16 – 18-year-old dancers. In piloting our test however, the more important part became the observance of postural faults which were numerous, when the feet are externally rotated. Frequently there are compensations in the body above when the lower limb is externally rotated. Unless carefully schooled these faults can become engrained preventing true stability and coordination of movement. This test therefore progressed to become an examination of postural faults in the turned-out position. Foot angles were recorded for reference, if necessary. In the event of passive range of hip external rotation being low, functional turn out angle being high, and the single leg turn out control with a high number of faults, the injury risk would be significant. Linking and correlating range with control is vital to understand in the young dancer from the injury perspective and the performance enhancement point of view.

The 'cobra' position for measurement of spinal extension was suggested by Sweetman et al, (1974). Nilsson et al. (1993) used Mellin's method (Mellin,1986) finding it difficult to measure the dancer's hypermobile spine extension range in standing. Accurate measurement in standing (fingertip-to-floor) was found to have poor repeatability by Gill et al. (1988). The cobra position was adopted here in order to present the dancer with as little spinal strain as possible during screening.

The reasoning for considering the arabesque test was to observe how the spine is used in dance function, in spite of its deselection by the experts. The aim of including it was to assess movement quality first and secondly to assess ease of range. The arabesque is a much-repeated functional movement in ballet and one that contributes to lower back injuries in dancers if there is less control and increased strain to achieve height of leg. Bennell et al. (1999) mention the strength demands of classical ballet and the vital balance and postural control required by the arabesque and attitude positions. Even after the meeting it was decided to retain this test to encourage engagement with dance function. In the final screen a spinal range measurement (Spinal Extension) is included and two functional control tests (Arabesque Test and Back Bend Test) as the researchers believed this to be an important element for consideration regarding injury prevention.

The Plank Test was reconfigured. The trunk stabilisation was challenged by adding single leg support and the endurance time was shortened to 40 seconds which was considered to be sufficient to test this age group. The initial bridge position was held for 10 seconds, the right foot was lifted, just clearing the floor for 10 seconds, the left for 10 seconds and the plank was held for a further 10 seconds. The test is a quick assessment of strategy, shoulder stabilisation low level strength and each dancer was expected to perform this easily with form well controlled. The shoulder girdle was considered an important part of the trunk and scapular stabilisation was critically marked. Although the tests are specifically lower limb oriented, the shoulder girdle was included as part of the trunk and core stability. The Tong et al. test took the participant to fatigue and failure and is a capacity test, which is not the aim in this screen. The Lead Researcher made a pragmatic decision to redesign the test and its aims based on the age and stage of this cohort – and the fact that this is an audition screen.

Being able to discuss and consider ideas from experienced colleagues allowed a more objective evaluation of the initial battery of tests. The important points were noted by the participants and their advice contributed to the standardisation and repeatability of the tests.

To quote McMillan, King and Tully (2016) “the NGT results may reach consensus or may be exploratory in nature, laying the foundation for further testing”. After consideration the adapted screen was sent to each of the physiotherapists two weeks later for Likert scoring. The Arabesque Test and Back Bend Tests were included with explanation and those two tests were passed more positively than negatively and the participants were interested to know the results of reliability studies.

7.7 Results 2. Final Consultation

Table 7.4 Second Likert Test after amendments

	Passive range of movement	P1 J	P2 K	P3 Al	P4 R	P5 A		Functional movement control	P1	P2	P3	P4	P5
Test 1	**Hip external rotation** **Measured in supine set-up**	1	1	1	1	1	**Test 8**	**Functional turnout control**	3	2	2	3	4
Test 2	**Knee extension**	2	2	2	2	2	**Test 9**	**Single leg turnout control**	3	3	2	3	3
Test 3	**Plantarflexion of the ankle**	2	4	4	3	3	**Test 10**	**Single leg knee bend parallel**	3	3	2	2	2
4	**Dorsiflexion of the ankle**	1	1	1	1	1							
Test 5	**1st MPE extension** **Goniometric measurement**	2	2	3	1	3	**Test 11**	**Backbend Test**	3	3	2	3	4
Test 6	**Lumbar spine extension test**	3	3	3	3	3	**12**	**Arabesque Test**	3	2	3	1	3
Test 7	**Beighton Score**	1	1	1	1	1	**Test 13**	**Elbow plank-timed**	3	2	3	1	3

1st MPE Joint = metatarsophalangeal joint

Three extra tests were added: Dorsiflexion Test in Fig. 6.1, Backbend Test Fig. 6.2 and Single Knee Bend in Turnout in Fig. 6.4 and the Beighton Tests.

The 1st MTPJ Extension test was revised as recommended by Physiotherapist 4 (Fig. 6.4).

Figure 7.1 Dorsiflexion Test Konor et al. (2012) Scoring: ≤ 8 = 1   9-14 = 2   ≥ 15 = 3

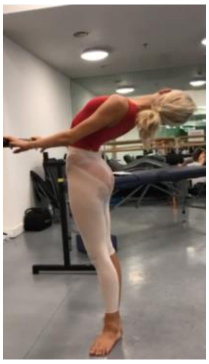


Figure 7.2 Back Bend Test

Figure 7.3 Revised 1st Metatarsophalangeal Joint Extension Test Scoring: < 75° = 1   76 – 99° = 2   ≥ 100° = 3

Figure 7.4 Single Knee Bend in Turn Out

7.8 Results 3. Final Screen

Creating a screen relies on expert advice and evolving ideas and trials until the screen satisfies all the needs of the context. A balance between range and control was the aim here, influenced by the Delphi consensus. After even further piloting post Expert Group Consultation it was decided to measure Spinal Extension in a similar set up but with the port of the iPhone over T6 T7 space to measure whole spinal extension. For both accuracy and speed the end of range extension was gauged by the assessor palpating the point at which the anterior superior iliac spine (ASIS) starts to lift from the plinth. The set up then did not need the seat belt which saved on time.

The Single Leg Knee Bend in turnout was also included after the Expert Group recommendation. The turned out version was easy to include and it was decided that that the scoring would be identical. The Dorsiflexion Test (knee to wall measurement) was also added although the group did not suggest it in our meeting in spite of their own utilization of the test. This was already validated by Konor et al. (2012) who successfully tested reliability and it is routinely used in the clinical situation. In the past, the artistic audition panel has been concerned by the restricted dorsiflexion exhibited in the *plié* position. While not a hindrance to good technique, an awareness of any reduced range here supports the full screen, informing further on foot and ankle function. Any unilateral deficit can be detected, indicating past injury and incomplete recovery.

After careful consideration the Arabesque Test was again taken to the Expert Group in the final enquiry. The reason for this was that a research paper had been published in the interim by Bronner et al. (2020) – a reliability study examining intra- and inter-rater reliability of a ballet-based Dance Technique Screening Instrument used by physical therapists (PTs) and student PTs (SPTs) with prior dance medicine or dance experience. Understanding that technical error is an injury risk in dance (Bronner and Bauer, 2017), it was believed to be an important causation factor in injury. If technique is not explored, important causes of injury can be missed and failure to treat effectively follows. The group passed the test and those persuaded expressed interest in the outcome. Consensus is preferred, but the NGT can be exploratory in nature, laying the foundation for further thought and testing (McMillan, King and Tully, 2016).

7.9 Conclusion

The NGT resulted in a consensus agreement of the screening tool comprised of a range of movement and functional movement control screen which requires psychometric testing. The Delphi study and NGT provide initial face and content validity for the screening tool. The next steps of this thesis were to undertake reliability testing.

Chapter 8. Range of Movement Screen Methods

8.1 Introduction

In this chapter the methodology for the range of movement intra- and inter-reliability screening tests and the creation of functional movement control screen videos are presented and justified. The range of movement (ROM) screen reveals the physiques selected and the functional movement control (FMC) screen reveals stability, strength and training to date. The aim of the study is to use the screen tests to reveal these with reliability. The tests are designed to be used in full or in part at the final audition for the first-year intake.

8.2 Methods

8.2.1 Study Design

A prospective observational study design using repeated measures (Portney and Watkins, 2009) was employed to explore six ROM tests and to assess seven FMC tests. The six ROM tests were examined in two rounds on the same day by three physiotherapist raters. The FMC tests were videoed on the same day for later assessment using video recorded observation. The three physiotherapy raters scored the functional movement tests later on two occasions using a predetermined scoring system. These data were used to calculate inter- and intra-rater reliability. Further details of the protocol are explained below.

8.2.2 Ethical Considerations

Ethical Approval for the study was granted by the Ethics Committee of University College London (7693/003). This required a thorough assessment of risk relating tasks being performed by participants, collection and management of data and those pertaining to safeguarding. As the participants were under 18 years of age, extra safety measures were put in place. Permission was granted by the researcher's workplace for the study to be conducted in the Healthcare Suite of the Royal Opera

House. Written, informed consent was collected from the students themselves and from the physiotherapists before commencing the study.

Data was de-identified at the earliest possible point to ensure data was stored anonymously in password protected UCL electronic devices. Double entry of data reduced the risk of errors arising.

Safeguarding this age group meant the student dancers were accompanied at all times by the Lead Researcher (MM) when in the Royal Opera House.

8.2.3 Recruitment

Eighteen dancer participants, newly accepted into full-time classical ballet training were recruited from vocational ballet schools offering full time pre-professional dance education in London. This allowed for a range of ability. First year students in the autumn term are newly selected and have not yet benefitted from full-time training. A minimum of five and maximum of seven dancers were sought from each of four schools. The sample size was based on previous studies (Gabbe et al., 2004; Konor et al., 2012; Mischiati et al., 2015) and for pragmatic reasons relating to testing availability at the Royal Opera House.

The Artistic Directors of each ballet school were approached by the Lead Researcher who explained the research in an email (Appendix C) and invited student participants from the first year of training to attend a screening day at the Royal Opera House. A poster requesting volunteers was provided to post on the notice board at the school's discretion and student volunteers reported to the Head of Physiotherapy or their ballet teachers.

Under the auspices of their School Artistic Directors the students were released from their respective vocational school commitments for an agreed date to contribute to our research at the Royal Opera House.

Three schools allowed access to students and agreed to take part in the research. Five students from the first school volunteered, seven from the second and six from the third. The fourth school declined. The teachers and school physiotherapists were invited to attend the screening day if they wished, although safeguarding was assured.

Three experienced physiotherapists were recruited to perform the intra- and inter-rater testing and consented. They were purposefully sampled based on their experience and expertise in line with the inclusion/ exclusion criteria (Table 8.1).

8.2.4 Dancer Participants

Healthy young dancers of 16 years and over and under 18, all in the first year vocational setting were invited to take part. Eighteen dancers who met the inclusion criteria (Table 8.1) took part. Eleven female and seven male students made up the participant group, sufficiently representative of their peer group.

Information about the research (Appendix C) was provided and consent forms (Appendix C) could be signed by the students themselves because of their age.

Table 8.1 Inclusion and exclusion criteria for dance student participants

Inclusion Criteria	Exclusion Criteria
Attending full time vocational ballet training	Less than 20 hours training per week
In first year having started in the current term	Has already completed a year of full-time training
Over 16 years but under 18 years	Under 16 years and over 18 years
Able to follow instructions in English – both verbal and written	No English language
No time-loss injury in the last 6 months	In injury rehab or has been in last 6 months

8.2.5 Physiotherapist Participants

Three experienced physiotherapists carried out the screening. Each worked in different settings and did not know each other, but all were working with dancers and were well known to the lead researcher. The first had extensive experience in screening ballet students of all ages and experienced in ballet technique. The second was a sports physiotherapist with five years of experience screening professional dancers. The third was an ex-dancer, now physiotherapist with extensive experience in teaching Pilates and specialised in dance.

Table 8.2 Inclusion and exclusion criteria for physiotherapist participants

Inclusion criteria	Exclusion
Chartered Physiotherapist	Physiotherapists not currently registered in the UK
MSc in Sports Physiotherapy or currently studying	Not MSc qualified or studying
At least 5 years of experience working with dancers	Under 5 years of experience in ballet
Proven experience in screening for dance	No screening experience
Experience in dance research	No experience in dance research

8.2.6 Screening Day Procedure

The three screening days took place in November and December 2019 in a studio in the Physiotherapy Department of the Royal Opera House.

The dancer cohort from the first school arrived at the Royal Opera House at the beginning of the screening day in time to join morning class with the resident ballet company. After one hour of warm up and *barre* with the company, they were received in the Physiotherapy Department where the screening was to take place. The same format was used on each of the three screening days which took place in November and December 2019.

A standardised approach was taken, and the range of movement screen was verbally explained to the students, even though a portion of the tests were familiar to them. After questions were answered the students signed their consent forms.

The students were introduced to the physiotherapists and the timetable for the day was outlined (Appendix C). Each dancer was given a number by which they were identified. All tests were carried out in normal dance attire – footless tights and school regulation leotard. No height and weight measurements were taken. These dancers had already been recently accepted to vocational school and so this was deemed unnecessary as well as intrusive in an unfamiliar, and now professional dance setting.

Three treatment plinths were arranged in a dance studio and each plinth supplied with identical, necessary equipment – goniometers (12, 8 and 6 inch), seatbelt, towels, ruler, iPhone (iPhone 7 plus) and holder and clipboards. A ruler was attached to the floor at 90 degrees to a wall for the knee to wall dorsiflexion measurement. The lead researcher conducted the day, and each dancer was guided to the relevant physiotherapist in a rotational system. Between screens the dancers remained in the studio looking on. As each group was training together at school, there was a relaxed attitude to this.

The rotational system was arranged so that each dancer was examined by each physiotherapist in the morning first round and in the afternoon second round.

The physiotherapists worked alongside each other but working at speed as in a screening situation at audition, without conferring. The tests could be carried out in the same order for flow through the progression of the screen and maintenance of concentration, but this was left to the physiotherapist to decide. Continuous data measurements for right and left sides and scoring where appropriate were recorded on the ROM scoring sheet (Table 8.11). In requesting the dancers adopt positions to allow measurement a scripted protocol was suggested (Appendix).

After both dancers and physiotherapists had a break in the middle of the day, they returned, and the screening procedure was repeated. The ROM screen took approximately 20 minutes to complete in the first round but less than 15 minutes by the second round with the physiotherapists working at the same rate.

RECRUITMENT

Email sent to Artistic Directors of 4 vocational ballet schools to explain study and invite participation.

On consent from AD, email sent to Head of Physiotherapy (H of P) requesting advertisement to be placed on noticeboard asking for volunteers.

Head of Physiotherapy responded to volunteers and list made. Information sheets (Appendix) sent to H of P for distribution.

3 experienced physiotherapist colleagues invited to carry out screening. Consent was obtained and information sheet supplied (Appendix)

2 video experts approached to film the FMC screen and meeting set up to explain requirements.

DATA

Contact details for each AD and Head PT and 3 expert PTs stored in password protected UCL computer.

One school declined. Contact details deleted.

Consent forms signed by student dancers (age appropriate).

PARTICIPATION

On consent, meetings were set up with each physiotherapist (working at different sites) to explain ROM tests, particular method, answer questions and discuss training required. Scoring sheets (Appendix) explained.

Consent forms signed by physiotherapist raters.

Date for first screening day is agreed, timetable is organised and ROH studio is booked. All equipment and 3 couches are organised. Equity representative approached to gain permission for students to join company class for warmup.

Screening Day 1. Consent forms signed by dancers and PTs. Dancers warm up (barre with resident company) and raters practise technique with the iPhone TiltMeter. Each dancer is screened by each PT. Scoring is recorded on prepared score sheet. After a break this is repeated in Round 2. After this the video experts film each dancer (x 2 iPhones front/side) completing each FMC test. The videos are airdropped to one expert's PW protected laptop.

Consent forms and Round 1 and 2 scoring sheets uploaded on to PW protected computer. Hard copies shredded by the end of working day. All data is uploaded to encrypted database using double entry method. All video material will be deleted from iPhones as soon as video expert has

Repeated procedure for Screening Day 2 and 3. After Day 3 the videos are formatted, anonymised and transferred to PW protected USBs and copies retained on PW protected UCL computer.

When videos are airdropped to expert's PW protected laptop they are then deleted from iPhones. Once formatted and anonymised they are transferred to 3 PW protected USBs and to secure UCL computer for safe keeping.

ANALYSIS

All ROM results are de-identified, scored, coded and entered into SPSS for intra- and inter-rater analysis using ICC and Cronbach's Alpha.

Reliability results for ROM tests are presented and displayed in Chapter 8.

Figure 8.1 Flow Diagram explaining the methods for data collection.

Range of Movement Screen Tests

Where possible, each test is supported by previous studies including reliability analysis.

Tests 1,2,5 and 6 are measured in degrees. Test 4 is measured in centimeters. A scoring

system is applied to these continuous measurements and the reasoning for each is explained. The scoring system is displayed on the right column of the table.

8.2.7 Test 1. Hip External Rotation

Table 8.3 Passive hip external rotation measurement with categories and scoring.

Screen	Description	Scoring
Range of movement tests	Ask dancer to sit at the end of the couch and direct into the test position explaining the purpose of the measurement. Secure the seatbelt over ASIS padded with towel, explaining the stabilising effect. Check for neutral lumbar spine. Towel under test knee. Mobile phone holder attached mid-tibia at 0°. Non-test hip into slight abduction. Request the dancer to relax and allow passive movement. Move test hip to end range with overpressure but no pelvic movement or hip abduction.	< 45° = 1 45-60° = 2 >60 = 3
1. Hip external rotation		
Hip internal rotation		

Figure 8.2 Passive Hip External Rotation

A similar protocol was used by Kahn et al. (2000) using a modified goniometer, but only active external rotation was measured, and test-retest reliability calculated. The same position for measuring passive range of external rotation was repeated by Washington et al. (2016) but no reliability study was included.

The scoring here was based on past literature. Hamilton et al. (1992) found the average hip external rotation in a cohort of 28 professional ballet dancers to be 52°. These dancers were classified as 'flexible but not hypermobile'. In Washington's research the average in 45 professional dancers was 50.2°. Bauman (1994) measured an average of 46° in 14 elite ballet dancers (in the prone assessment position) remarking that one of the dancers had 33° of external rotation and noted difficulty with (dynamic) turn out. Under 45° therefore would be considered restricted and is allocated 1 mark, 45-60 would be acceptable at 2 marks and over 60 degrees would be classed as hypermobile and allocated 3 marks.

8.2.8 Test 2. Knee Extension

Table 8.4 Knee hyperextension measurement with categories and scoring

2. Knee extension	Dancer sits leaning back in long sitting, heel resting on block. Knee at EOR. Measured laterally. Proximal arm is directed to the greater trochanter with fulcrum mid joint. Distal goniometer arm is directed to the lateral malleolus.	< 0° = 1 0- 9° = 2 ≥ 10° = 3

Figure 8.3 Goniometric measurement of passive knee extension

Boyle et al. (2003) used this protocol. Reliability of composite scores of the Beighton and Horan Joint Mobility Index was calculated but not the individual tests. More than 10° of hyperextension is regarded as hypermobile and is allocated 3 marks in the scoring system. 0-10° is allocated 2 marks and less than 0° is regarded as restricted and is allocated 1 mark.

8.2.9 Test 3. Plantarflexion of Foot and Ankle

Table 8.5 Foot and ankle passive plantarflexion with categories and scoring

3. Plantarflexion foot/ankle MEDIAL	Lower limb rests on the couch, heel on the firm board with knee in neutral. Dancer is asked to 'point your foot' with back of knee in contact with the table, and then relaxes. The metatarsophalangeal (MTP) joints are flexed but the interphalangeal (IP) joints remain extended. The ruler upper edge is placed in line with the medial border of the tibia and the medial malleolus and towards the midpoint on the medial aspect of the first metatarsophalangeal joint. Pressure down over the metatarsophalangeal (MTPJ) joints takes the forefoot passively into end of range. Toe pads may touch the table with IP joints extended, the first MTP joint may fall in line with the ruler edge or may lie above.	Above = 1 In line/below = 2 Touching = 3

Figure 8.4 The Ruler Test for Plantarflexion of Foot and Ankle

The foot and ankle were identified as one of the main considerations for selection in the Delphi Survey. Ideally, over 100 degrees of plantarflexion should occur at the foot-ankle complex in a professional ballet dancer (Kennedy et al., 2007) and this novel test shows that at least 90 degrees allows a line of weight bearing through the *relevé*.

8.2.10 Test 4. Ankle Dorsiflexion

Table 8.6 Ankle dorsiflexion with categories and scoring

4. Ankle dorsiflexion Knee-Wall in cm	Facing squarely to the wall place the foot over the cm measure. The flexed knee touches the wall, the heel remains in contact with the floor, the front of the ankle relaxes and the measurement of toe to wall is recorded.	≤ 8cm = 1 9 – 14cm =2 ≥15cm = 3

Figure 8.5 Knee to Wall Dorsiflexion

Using this method, in 1998 Bennell et al. measured 13 participants with excellent inter-rater results (ICC = 0.99). Konor et al. (2012) found excellent intra-rater reliability (ICC = 0.96-0.99) in this test with a low SEM (0.4-0.6cm) compared to using a goniometer. The mean measurement in this study was 9.6 ± 2.9cm. This guided the scoring system for this test. 9-14 cm was allocated 2 marks as an average measure. Less or equal to 8cm was regarded as restricted and allocated 1 mark. More or equal to 15cm is regarded as hypermobile and allocated 3 marks.

8.2.11 Test 5. Metatarsophalangeal Joint Extension

Table 8.7 Measuring metatarsophalangeal joint with categories and scoring

5. 1^{st} Metatarsophalangeal Joint Extension (MPE Joint) Valgus Y/N	The dancer stands with test foot placed with medial border in line with edge of the stool. The foot and ankle are plantarflexed to ¾ pointe and dancer asked to push over as far as possible but not into pain. The goniometer fulcrum is placed mid 1^{st} MTPJ with proximal arm along 1^{st} metatarsal shaft and distal along the proximal phalanx.	< 75° = 1 75 – 99° = 2 ≥ 100° = 3

Figure 8.6 First Metatarsal Joint Extension

No research has measured the 1^{st} metatarsophalangeal joint in this position, but this is a functional position for a dancer exerting a significant amount of force through the joint. In research by Benhamú-Benhamú et al. (2015) 1^{st} metatarsophalangeal joint extension of ≥ 95⁰ in adults (non-dancers) was one of 4 clinical signs of hypermobility. Scoring is therefore guided by this research. Hamilton (1988) stated that it was essential for a ballet dancer to have 90-100⁰ of dorsiflexion to achieve a full *relevé*. Less than 75⁰ is classed as restricted, 75-99⁰ is classed as mid-range for a young dancer and more or equal to 100⁰ is classed as hypermobile. There may also be a training effect here but this is as yet unknown. This is the first reliability study to be carried out on the measurement of this joint.

8.2.12 Test 6. Spinal Extension

Table 8.8 Measuring spinal extension in 'cobra' with categories and scoring.

6. Spinal extension – Cobra Push-up	Dancer lies prone, face down. Hands under shoulders. Elbows at side. The port of the iPhone is placed longitudinally over the T6 T7 space. The assessor holds the iPhone® (by the sides) stable and lightly over the location longitudinally and the initial angle (A1) is recorded if not at 0. The other index finger is located under the dancer's anterior superior iliac spine (ASIS) to gauge when this is about to lift from the couch. Allow the dancer to practise the move. The dancer pushes up using the arms and is asked to extend from the top of the spine. EOR is when the ASIS is	≤65° = 1 66 - 90° = 2 >90° = 3

Figure 8.7 Spinal Extension

This is a novel test carried out for the first time in classical ballet dancers. Neither has extension range been determined in dancers before. Nilsson et al. (1993) measured total sagittal mobility in 23 ten-year-old ballet students. This present study is the first to concentrate on spinal extension, the mobility of which is so functionally important to the classical ballet dancer. The three groups of dancers from different schools allowed for a range of physiques and abilities and therefore the scoring system here is approximated from the measurements observed and clinical experience.

8.2.13 The Beighton Scale

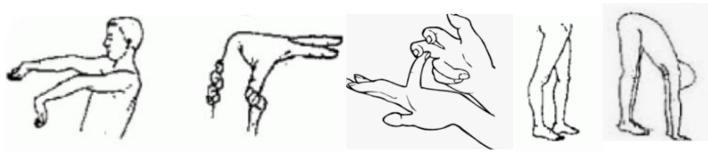


Figure 8.8 The 9-point Beighton Score

Table 8.9 Beighton Scale scored further.

6. Beighton score	Measure with goniometer using the recognised method. Hyperextend the elbow > 10^{o} R and L = 2 Apposition of the thumb to touch the forearm Extension of the 5^{th} metacarpophalangeal joint > 90^{o} R and L = 2 Hyperextend the knee > 10^{o} R and L = 2 Place the hands flat on the floor in front of the feet without flexing the knees =1	1-3 = 1 4-6 = 2 ≥7 = 3

The Beighton Scale (BS) is the currently most frequently used assessment method for classifying General Joint Hypermobility. Although shortcomings have been found in studies on validity of BS, provided there is uniformity of testing, the BS is recommended for clinical use (Juul Kristensen et al., 2017)

Boyle et al. (2003) reported good to excellent intra- and inter-rater reliability in screening for generalized joint laxity in females of 15-45 years of age (0.86 Spearman rho for intra-rater reliability and 0.87 for inter-rater reliability). The authors also allocated a scoring system to their results (0-2=1, 3-4=2, 5-9=3) and the calculated intra- and inter-rater reliability was .81 and .75 respectively. With recent changes in terminology and classification of hypermobility (Malfait et al., 2017) and investigation into laxity in dancers (Chan et al., 2018) the threshold for categorising hypermobility in dancers has risen from 4 to a recommended ≥ 6. As a result, a Beighton Score of 7-9 is hypermobile, 4-6 the middle, more common measurement and 1-3 the more restricted range, has been decided in the present study. Recently, Van Rijn et al. (2021) used the same categories.

When the scores for the Alpha Coefficient are totalled, these can be divided into 3 categories representing those physiques that are regarded as restricted, moderate or hypermobile. Those physiques with isolated hypermobile joints or restricted joints will be taken into consideration.

Table 8.10 Range of Movement total scores – scored further

Possible Scores	Suggested categories for total scores of Alpha Coefficient	
12 - 36	12 – 20 21 – 28 29 - 36	Restricted Moderate Hypermobile

Table 8.11 ROM Screen example scoring sheet

<table>
<tr><td colspan="4">Dancer: Date:

Physiotherapist:</td></tr>
<tr><td>Passive range of movement</td><td>R</td><td>L</td><td>Score</td></tr>
<tr><td>1.Hip External Rotation

Hip IR</td><td></td><td></td><td></td></tr>
<tr><td>2. Knee extension

LATERAL VIEW</td><td></td><td></td><td></td></tr>
<tr><td>3. Plantarflexion foot/ankle

MEDIAL</td><td>Above

= in line

Below

Touching</td><td></td><td></td></tr>
<tr><td>4. Dorsiflexion Knee to wall cm</td><td></td><td></td><td></td></tr>
<tr><td>4. 1st MTPJ extension

Valgus Y/N</td><td></td><td></td><td></td></tr>
<tr><td>5. Spinal extension T6 T7</td><td colspan="2">A1 =

A2 =

Ext ROM =</td><td></td></tr>
<tr><td>Beighton score</td><td>R</td><td colspan="2">L</td></tr>
<tr><td>Thumb</td><td></td><td colspan="2"></td></tr>
<tr><td>5th finger</td><td></td><td colspan="2"></td></tr>
<tr><td>Elbows</td><td></td><td colspan="2"></td></tr>
</table>

8.3 Protocol and Standardisation

Explanation and direction of the dancers and physiotherapists was standardised so that each screening day was conducted in exactly the same way and timing of each day was consistent.

8.3.1 Physiotherapist Training

Prior to testing the lead researcher met with the physiotherapists to ensure standardisation of the ROM protocol. Practise using the iPhone app (TiltMeter®) to measure hip rotation and spinal extension was required. The iPhone was placed in a holder (Gym Phone Armband) and attached to the mid-tibia by Velcro strap in order to measure hip rotation. To measure spinal extension the mobile phone was removed from the holder. The physiotherapists were not able to practise together and discuss methods. Instead individual discussion and training took place with MM. However, on the day before the screening commenced while the dancers were warming up, manipulation of the iPhone with and without the holder was practised together. Rater 2 was already experienced in using an inclinometer but Raters 1 and 3 were less practised. However, explanation and rehearsal was standardised by the lead researcher (MM). Consent forms were signed prior to screening (Appendix B).

8.3.2 Audition Screen Trial

Following the careful assembly of the appropriate dance-specific screening tests, the intention of examining reliability of screening tests was the concluding objective so that they might be widely employed. Although the newly developed screens are for use at audition prior to acceptance, the trials for the screens were carried out on students newly accepted into vocational programmes. Research trials cannot be carried out at final auditions for three different schools due to standardisation, timing and coordination with three different institutions, each with its own protocols ranging from strict screening (no reliability testing) to no physical screen at all. This study therefore was able to gauge a range of different abilities and target the appropriate age group and stage of training.

8.4 Data Storage

The hard copies of data sheets were collected by MM after each screening session. The documents were anonymised and stored securely once they were emailed to a password protected UCL computer. The data were accessible to the lead researcher and supervisors only. All consent forms were handled the same way.

8.5 Data Analysis

Intraclass coefficient (ICC) and the Bland Altman methods of agreement (Bland and Altman, 1986) were used to examine the intra- and inter-rater reliability of the continuous data scores.

ICC estimates and their 95% confident intervals were calculated using SPSS statistical package version 25 (SPSS Inc, Chicago, IL) based on a single measurement, absolute-agreement, 2-way mixed-effects model.

The initial continuous measurements in degrees for Tests 1, 2, 5, 6 and test 4 in cms, were entered into SPSS, treated as a numeric variable, analysed using intraclass correlation coefficient (ICC) with a confidence interval of 95% (CI 95%). The ICC Model 3,1 was used with absolute agreement, using a two-way mixed model (Koo & Li, 2016). The strength of agreement was interpreted using the classification by Indrayan (2013) (Table 8.12). The ICC Model 3, was chosen, as the study raters were the only raters of interest (Shrout and Fleiss, 1979) and one measurement was used (ICC 3,1) rather than an average (ICC 3,3). In this research the ICC was expected to be lower because of several conditions listed in Koo and Li (2016):

- Small number of participants (n=30 is recommended. Discussed in 7.7)
- Small number of raters (3 is the minimum recommended)
- In research terms the participants lacked variety
- Absolute Agreement was used (rather than 'consistency')
- Single measurement was used rather than a mean of several

To assess measurement precision (Kenny et al., 2018) the standard error of measurement (SEM) was calculated (standard deviation x √[1 – ICC]) in order to indicate the amount of variance in a test administered to a group that is caused by measurement error. Minimal detectable change (MDC) was also calculated

(SEM x 1.96 x √2). This represents the minimum change in a measure that must be detected for 95% confidence that a true change has occurred.

Table 8.12 Grading for strength of agreement for ICC values (Indrayan, 2013)

ICC values	Strength of Agreement
<0.25	Poor
0.25 – 0.50	Fair
0.51 – 0.75	Moderate
0.76 – 0.90	Good
>0.90	Excellent

Potential systematic bias and the relationship between the difference and the magnitude of measures by 2 raters were examined by Bland-Altman methods of agreement and 95% limits of agreement. Also considered were the difference and the magnitude of measures in Round 1 and round 2 using Bland-Altman to evaluate intra-rater reliability.

The Bland Altman plot evaluates the agreement amongst the two raters and their measurements. The Y axis shows the differences between the two paired measurements and the X axis represents the average of these measures. The difference of the two paired measurements is plotted against the mean of the two measurements. In the Chapter 9 results, the red middle line indicates the mean. The plot allows identification of any systematic difference (proportional bias) between the raters by using regression analysis. The limits of agreement (green lines above and below) estimate the interval within which a proportion of the differences between the measurements lie. The agreement interval is where 95% of the differences of one rater's measurements fall, compared to another rater. Standard error of measurement and minimum detectable change were calculated to further examine reliability.

Box Plots were also employed to show distributions of numeric data values and visualise, at a glance, the dispersion of the data. Unlike the meticulous Bland Altman plot, their simplicity limits detailed observation of the shape of distributions but they are useful when comparing groups and provide a clear representation of the general trend of the data.

The continuous data were divided into three categories: 1 = restricted range, 2 = moderate and 3 = hypermobile and were entered into the SPSS file. These categorical data were analysed using Cronbach's Alpha (α) and intra- and inter-rater-reliability was calculated. The resulting Alpha coefficient of reliability ranges from 0 to 1 in providing this overall assessment of a measure's reliability. If all the scale items show no covariance then the Alpha coefficient is 0. If the items have high covariance the Alpha coefficient will approach 1. Values greater than 0.60 were considered acceptable, greater than 0.70 were considered good and acceptable, greater than 0.80 were good and above 0.90, excellent. Below 0.6 is usually regarded as unacceptable (Table 8.13).

Table 8.13 Grading for strength of agreement for Cronbach's Alpha (Tavakol and Dennick, 2011; Konting et al. 2009)

Cronbach's Alpha	Strength of Agreement
.61 - .70	Acceptable
.71 - .80	Good and acceptable
.81 - .90	Good
.91 – 1.00	Excellent

All the results of the Range of Movement analysis are reported and illustrated in the following Chapter 9.

The functional movement control tests were filmed at the end of the day, after the ROM tests were completed in two rounds. The methodology related to the FMC Screen is presented in Chapter 9 and followed by the results.

8.6 Power Calculation for Sample Size

The 18 young dancer participants were recruited from three full time classical ballet vocational schools. The screening was standardised in the healthcare department of the Royal Opera House and so students had to be released from their schedules at school. Both standard of training, age, safeguarding and particular school were elements that restricted recruitment. Pre-professional classes are small and so our choice was limited.

Donner & Eliasziw (1992) explain the sample size estimation needed to satisfy the requirements for this study to be 33. This was not possible, but the study proceeded with a smaller cohort. There were three groups of student dancers with varied physiques and abilities making for enough variation in screening results.

The following power calculation justifies the recommended sample size.

Based on Donner & Eliasziw (1992) sample size estimation approach, the sample size needed to conduct a two-sided test with significance level α and power $1 - \beta(1, \lambda, \alpha)$ is:

$$N = \lambda(1,1-\beta,\alpha)\left\{\frac{[\pi(1-\pi)(\kappa_1-\kappa_0)]^2}{\pi^2+\pi(1-\pi)\kappa_0} + \frac{2[\pi(1-\pi)(\kappa_1-\kappa_0)]^2}{\pi(1-\pi)(1-\kappa_0)} + \frac{[\pi(1-\pi)(\kappa_1-\kappa_0)]^2}{(1-\pi)^2+\pi(1-\pi)\kappa_0}\right\}^{-1}$$

Where $\lambda(1,\alpha,1-\beta) = \left(Z_{1-\alpha/2} + Z_{1-\beta}\right)^2$

With $\alpha = 0.05$ and $1-\beta = 0.8$, we have:

$$\begin{aligned}\lambda(1,1-\beta,\alpha) &= (Z_{0.975} + Z_{0.8})^2 \\ &= (1.96 + 0.842)^2 \\ &= 7.851\end{aligned}$$

The proportion each category is assumed at proportionate, therefore we have $\pi = 0.5$.

To test the hypotheses:

$$H_0: \kappa = 0.61$$

$$H_1: \kappa \neq 0.61$$

Where $\kappa_0 = 0.61$ corresponds to the value of kappa characterised by Landis and Koch (1977) as representing substantial agreement. To ensure with 80 per cent probability a significant result at $\alpha = 0.05$ and $\pi = 0.5$ when $\kappa_1 = 1$, we can compute the required number of subjects from the equation above as $N = 33$.

The sample size of dancer participants was smaller than recommended. Based on Donner & Eliasziw (1992) sample size estimation approach, the study required 33 participants, whereas it was possible to recruit 18 to undergo the 14 tests assessed by 3 physiotherapist raters (Landis and Koch, 1977).

It is notoriously difficult to recruit the numbers of participants of the same stage and level of technique to satisfy statistical recommendation. One of the schools approached declined to allow their students off site as the end of term was approaching and the full class was required. Schools where dance takes precedence often do not see the importance of research based on science. Also in professional dance, research is not seen as necessary. It was disappointing and a set-back, but it was decided that the study should go ahead with reduced numbers to explore the outcome.

Chapter 9. Range of Movement Screen Intra- and Inter-rater Reliability Results and Discussion

This chapter presents the results and discussion of the range of movement aspect of the screening tool. In many situations there will be one clinician conducting screening tests. Reliable test-retest results in this situation mean the clinician is consistent in assessment. Good intra-rater reliability does not ensure good inter-rater reliability (Shultz et al., 2006). When there are multiple testers involved inter-tester reliability is important where decisions are concerned, or management plans are being made. Each clinician must agree on a standardised method and approach.

9.1 Range of Movement Screen - Passive Tests

1. Hip External Rotation
2. Knee Extension
3. Foot and Ankle Plantarflexion
4. Ankle Dorsiflexion
5. 1st Metatarsophalangeal Joint Extension
6. Spinal Extension
7. Beighton Score

9.2 Reliability Results

9.2.1 Participant Demographics

Eleven female dancers and seven male dancers took part in the screening. The mean age was 16.6 years (Range: 16.2 – 17.10). They were newly accepted into the first year of full-time study. This age group and stage of training have yet to benefit from intensive study and therefore screening at this phase was thought to reveal the physique and attributes selected for future entry into the profession.

The physiotherapist participants adhered to the inclusion criteria stipulated in Chapter 8, Table 8.2.

9.2.2 Presentation of Results

Each test is presented with intra-rater results first, analysed for Intraclass Correlation Coefficient (ICC), 95% Confidence Interval and Strength of Agreement. This shows analysis of raw data – continuous degrees and Test 4 is measured in centimeters. The Alpha Coefficient is then presented using data divided into categories - ordinal data, with Strength of Agreement. Right and left sides are measured. Strength of Agreement of the ICC is guided by Indrayan's concept explained in Table 9.1. Grading for Strength of Agreement of the Alpha Coefficient is guided by Tavakol and Dennick in Table 9.2.

The inter-rater reliability of each test is presented following intra-rater results using Box Plots and Bland-Altman graphs to illustrate.

To summarise, all data is presented in bar graphs and followed by the discussion section.

In Table 8.1. a benchmark guide to intraclass correlation coefficient is guided by Indrayan's concept of agreement.

Table 9.1 Grading for strength of agreement for ICC values (Indrayan, 2013)

ICC values	Strength of Agreement
<0.25	Poor
0.25 – 0.50	Fair
0.51 – 0.75	Moderate
0.76 – 0.90	Good
>0.90	Excellent

The Alpha Coefficient is a commonly employed index of test reliability. Strength of agreement of internal consistency measured by the Alpha Coefficient is reported by Tavakol and Dennick (2011) in the following table.

Table 9.2 Grading for strength of agreement for Cronbach's Alpha (Tavakol and Dennick, 2011; Konting et al. 2009)

Cronbach's Alpha	Strength of Agreement
.61 - .70	Acceptable
.71 - .80	Good and acceptable

.81 - .90	Good
.91 – 1.00	Excellent

9.2.3 Intra-rater Reliability of Range of Movement Tests

9.2.3.1 Hip External Rotation Intra-rater Reliability

Intra-rater reliability was moderate to excellent (ICC = .689 - .904). Cronbach's Alpha was also significantly better (.741 - .868) demonstrating that the physiotherapists were relatively consistent in their individual approaches

Table 9.3 Hip External Rotation (HE) Right Intra-rater reliability Raters 1,2 and 3.

Right Hip External Rotation	ICC(3,1) Measured in degrees	95% Confidence interval for ICC	Strength of Agreement	Categorical Score: Cronbach's Alpha Coefficient	Strength of Agreement
Rater 1	.724	.404 -.887	Moderate	.841	Good
Rater 2	.792	.524 - .917	Good	.769	Good and acceptable
Rater 3	.689	.351 - .870	Moderate	.816	Good

The box plot is a useful graphical display showing the dispersion of the data and is built around the median or middle of the data and upper and lower quartiles. The interquartile range plots the difference between the two measures of each rater and is composed of the bulk of the data. The results for each of the raters can be viewed for comparison in one plot.

In the following Box Plot the measures for R1 are spread in an interquartile range (IQR) of 9.75^{o}, R2 was 7.75^{o} and R3 was 4.75^{o} but relatively skewed data accounting for the lower ICC.

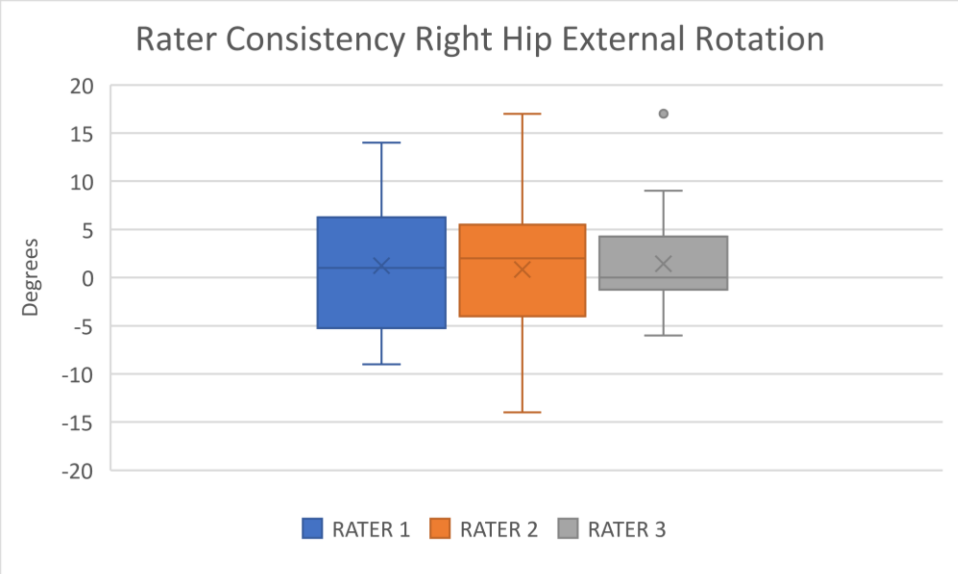


Figure 9.1 . Intra-rater right hip external rotation Raters 1,2 and 3.

The Bland Altman plot shows accurately the rater's consistency (Figure 9.2). shows the difference between the repeated measures plotted against the mean of both measures for Rater 3. The cluster of measures around the mean can be appreciated and the outlier corresponds to that seen in Figure 9.1. The outlier can be regarded as an unusual measure lying far from the majority of the measures.

The Bland Altman Plots for all raters can be examined in Appendix C.

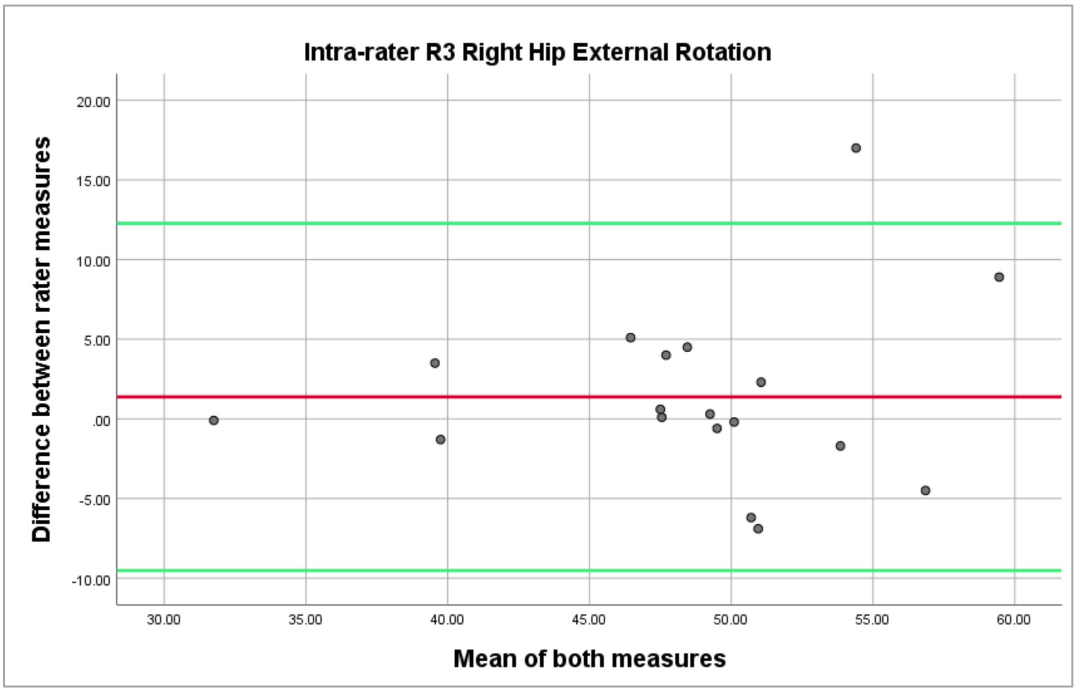


Figure 9.2 Bland-Altman plot intra-rater right hip external rotation Rater 3. Standard Error of Measurement was 4.15, Minimal Detectable Change was 11.5, the Mean (red line) was 1.378 and Limits of Agreement (green lines) -9.52,12.276.

Table 9.4 Hip External Rotation (HE) Left Intra-rater reliability Raters 1,2 and 3.

Left Hip External Rotation	ICC(3,1) Measured in degrees	95% Confidence interval for ICC	Strength of Agreement	Categorical Score: Cronbach's Alpha Coefficient	Strength of Agreement
Rater 1	.712	.370 - .883	Moderate	.868	Good
Rater 2	.904	.761 - .963	Excellent	.767	Good and acceptable
Rater 3	.754	.447 - .901	Moderate	.741	Good and acceptable

The intra-rater measures for left hip external rotation demonstrate moderate intra-rater reliability for Rater 1 and Rater 3, with Rater 2 reaching excellent, with an ICC of .904. This is shown by the following Box Plot (Figure 9.3) where the median for R2 is near zero with the interquartile equally spread. The Box Plots for R1 and R3 show relatively skewed data and therefore lower ICC but raters' measures averaged 7^{o} spread.

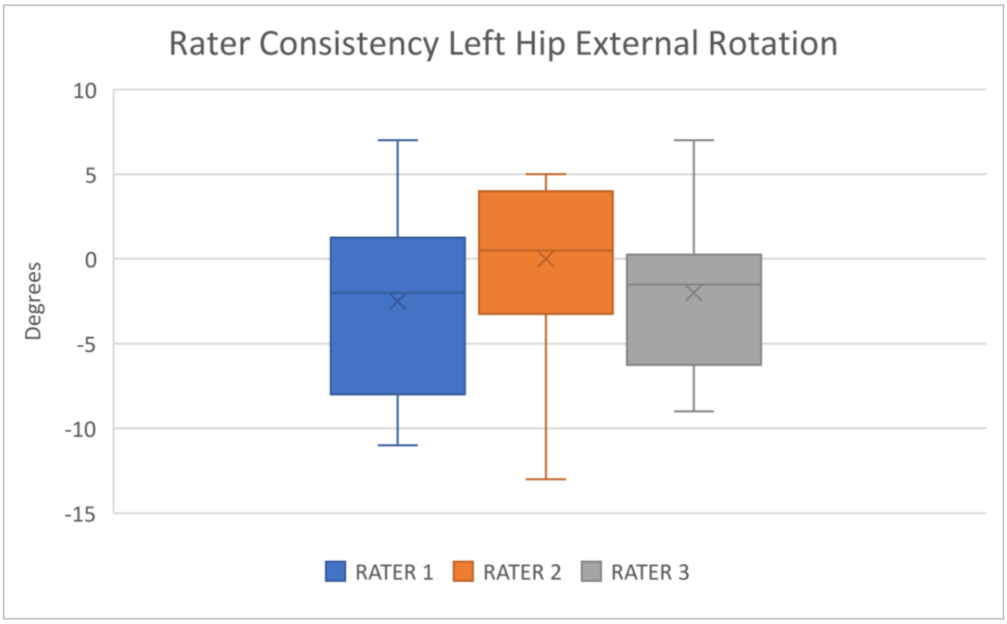


Figure 9.3 Intra-rater left hip external rotation Raters 1,2 and 3.

The Bland-Altman plot for Rater 2 reflects the cluster of the measures around the mean of 0 showing generally good consistency, but the limits of agreement are wide due to the influence of the outlying -13. In these tests only one measure was recorded, as in a 'live' screen. (If the average of three measures had been taken, these anomalies may have been avoided.)

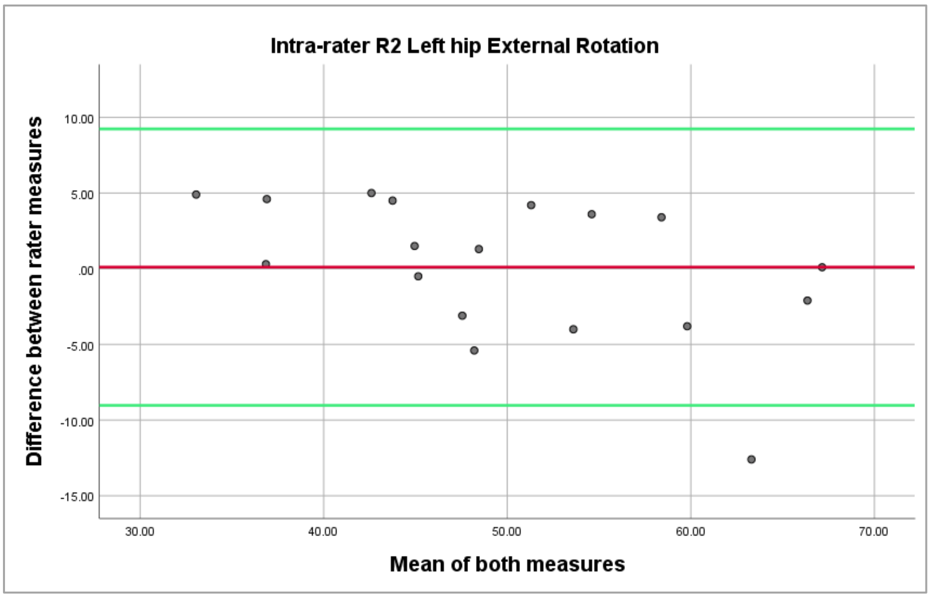


Figure 9.4 Bland-Altman plot intra-rater left hip external rotation Rater 2. Standard Error of Measurement was 2.82, Minimal Detectable Change was 7.8, the Mean (red line) was .1055 and Limits of Agreement (green lines) -9.026,9.237.

The single low measure corresponds to the elongated lower fence in Figure 9.3. but the majority of the measures are clustered around the mean in a 10⁰ spread.

9.2.3.2 *Intra-rater Reliability of Knee Extension*

Intra-rater reliability is shown in the following table. Repeated measures were good to excellent for each rater (ICC = .782 - .934). Alpha coefficients (.618 – 1.000) show again individual consistency for each rater was acceptable to excellent.

Table 9.5 Knee Extension Right Intra-rater reliability Raters 1, 2 and 3.

Right Knee Extension	ICC(3,1) measured in degrees	95% Confidence interval for ICC	Strength of Agreement	Categorical Score: Cronbach's Alpha Coefficient	Strength of Agreement
1	.788	.510 - .916	Good	.710	Good and acceptable
2	.782	.506 - .913	Good	.940	Excellent
3	.934	.831 - .975	Excellent	.857	Good

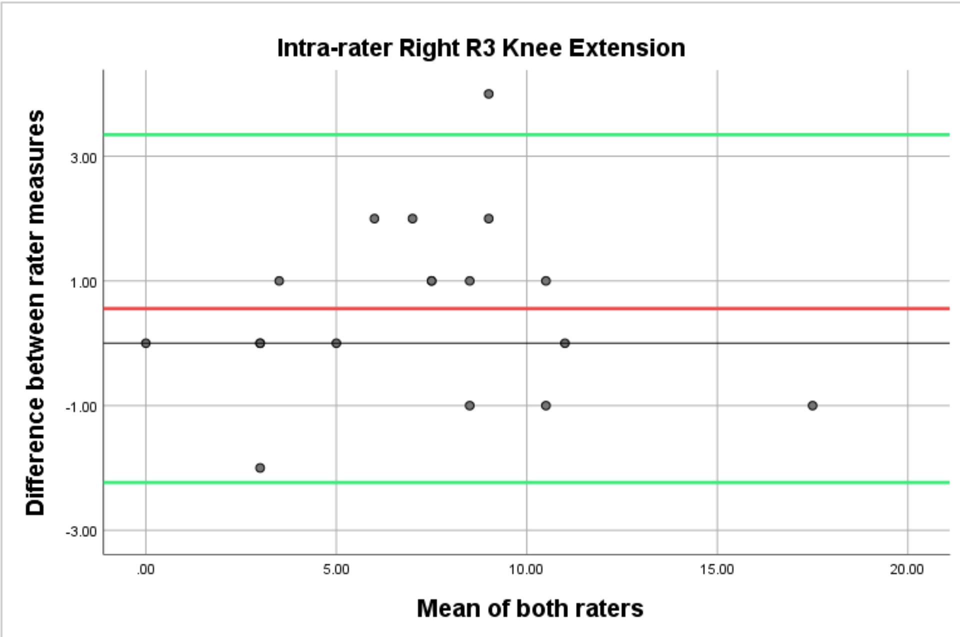


Figure 9.5 Bland-Altman plot intra-rater right knee extention Rater 3. Standard Error of Measurement was 1.06, Minimal Detectable Change was 2.9, the Mean (red line) was .5556 and Limits of Agreement (green lines) -2.234,3.345.

The bulk of the data is clustered around the mean showing generally good consistency.

In the Box Plot of Intra-rater Right Knee Extension, R3 has an interquartile range of 1^{o}, R2 has 4^{o} and R1 has 3.75^{o}. The plot for Rater 3 here shows where the main bulk of the measurements lie and the consistency with tight fences. The outlier is treated as an unusual measure – an error.

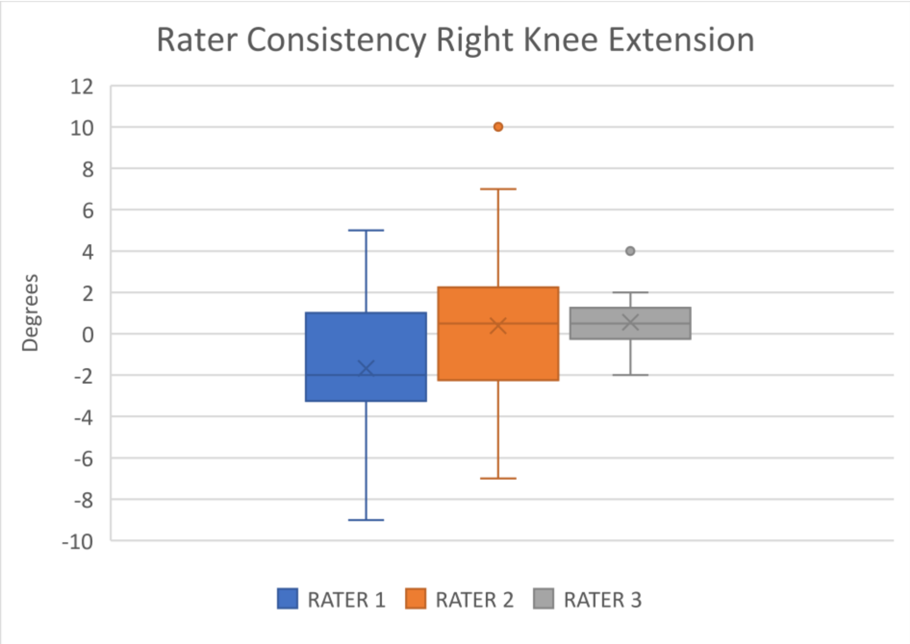


Figure 9.6 Box Plot of Intra-rater Right Knee Extension R1, 2 and 3.

Table 9.6 Knee Extension Left Intra-rater reliability Raters 1, 2 and 3.

Left Knee Extension	ICC measured in degrees	95% Confidence interval for ICC	Strength of Agreement	Categorical Score: Cronbach's Alpha	Strength of Agreement
Rater 1	.914	.789 - .967	Excellent	.816	Good
Rater 2	.812	.562 - .926	Good	.940	Excellent
Rater 3	.901	.759 - .961	Excellent	.924	Excellent

The Box Plot shows that R1 and R3 have excellent intra-rater reliability with interquartile ranges of 3⁰ and 2.75⁰. R2 has good reliability but 5.5⁰ of data range reflecting the lower ICC.

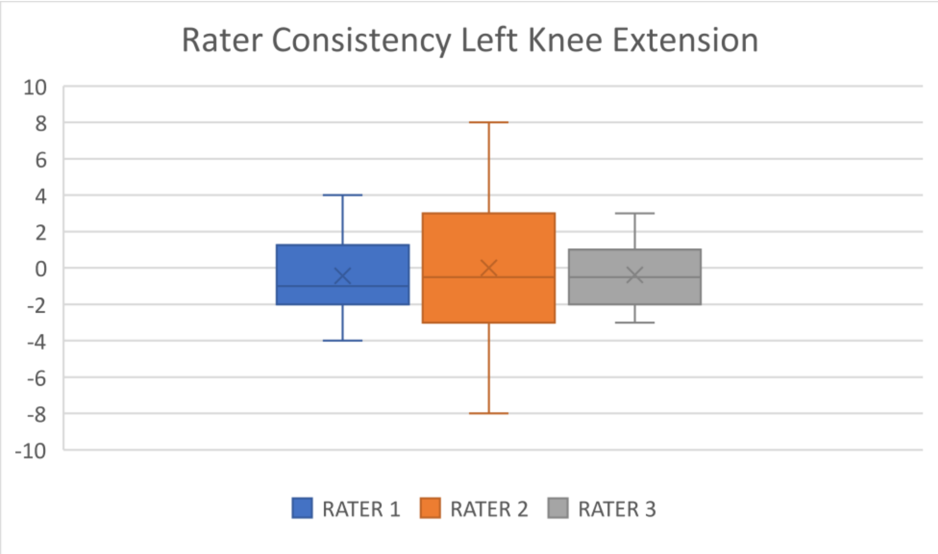


Figure 9.7 Box Plot intra-rater left knee extension Raters 1, 2 and 3

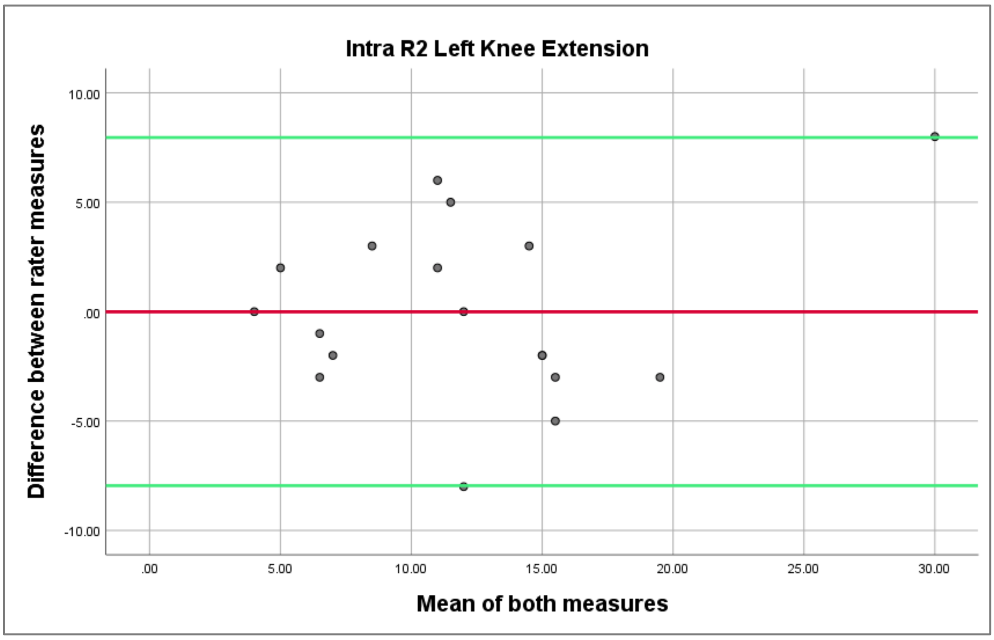


Figure 9.8 Bland-Altman plot intra-rater left knee extention Rater 2. Standard Error of Measurement was 2.97, Minimal Detectable Change was 8.2, the Mean (red line) was .000 and Limits of Agreement (green lines) -7.954464,7.954464.

9.2.3.3 Intra-rater Reliability of Foot and Ankle Plantarflexion

Table 9.7 Plantarflexion Right Intra-rater reliability Raters 1, 2 and 3.

Right Plantar-flexion	Categorical Score: Cronbach's Alpha	Strength of Agreement
Rater 1	.797	Good and acceptable
Rater 2	.710	Good and acceptable
Rater 3	.890	Good

Table 9.8 Plantarflexion Left Intra-rater reliability Raters 1, 2 and 3.

Left Plantar-flexion	Categorical Score: Cronbach's Alpha	Strength of Agreement
Rater 1	.908	Excellent
Rater 2	.868	Good
Rater 3	.879	Good

9.2.3.4 Intra-rater Reliability of Ankle Dorsiflexion

Table 9.9 Dorsiflexion Right Intra-rater reliability Raters 1, 2 and 3. Measured in centimeters.

Right Dorsiflexion	ICC (3,1) Measure in cm	95% Confidence interval for ICC	Strength of Agreement	Categorical Score Cronbach's Alpha	Strength of Agreement
Rater 1	.952	.578 - .988	Excellent	.888	Good
Rater 2	.873	.692 - .951	Good	.929	Excellent
Rater 3	.973	.929 - .990	Excellent	.937	Excellent

All raters had a high intra-rater reliability and the following Box Plot demonstrates this consistency.

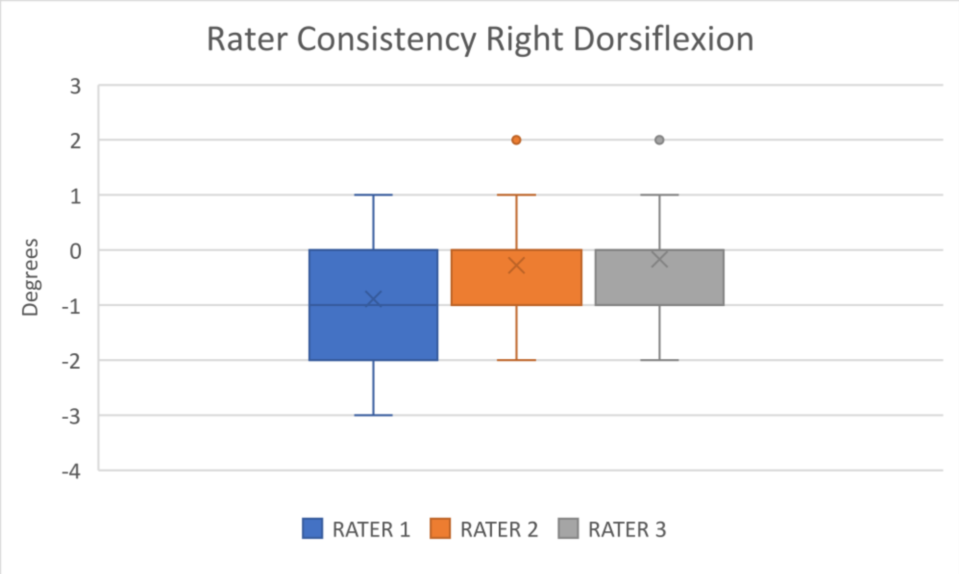


Figure 9.9 Box Plot intra-rater right dorsiflexion Raters 1, 2 and 3.

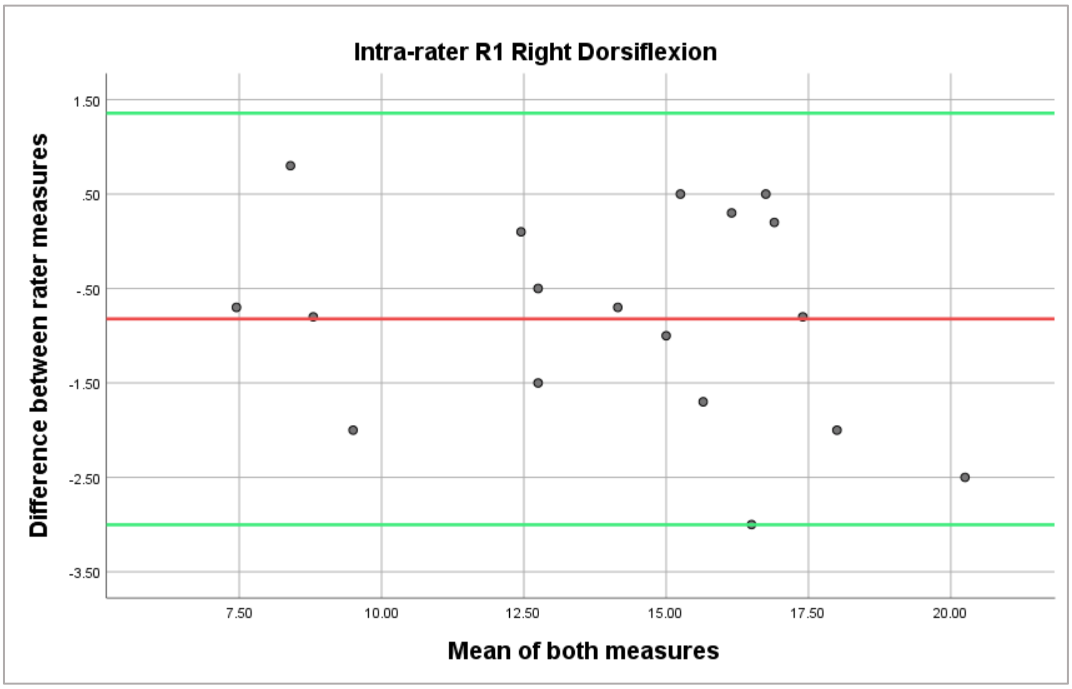


Figure 9.10 Bland-Altman plot intra-rater right dorsiflexion Rater 1. Standard Error of Measurement was .91, Minimal Detectable Change was 2.5, the Mean (red line) was -.8222 and Limits of Agreement (green lines) 1.357, -3.0012.

Table 9.10 Dorsiflexion Left Intra-rater reliability Raters 1, 2 and 3.

Left dorsiflexion	ICC (3,1) measured in cm	95% Confidence interval for ICC	Strength of Agreement	Categorical Score: Cronbach's Alpha	Strength of Agreement
Rater 1	.936	.611 - .982	Excellent	.916	Excellent
Rater 2	.934	.833 - .975	Excellent	.962	Excellent
Rater 3	.976	.937 - .991	Excellent	.936	Excellent

9.2.3.5 Intra-rater Reliability of First Metatarsophalangeal Joint Extension

Table 9.11 Right Metatarsophalangeal joint (Right MPE) Intra-rater reliability Raters 1, 2 and 3.

Right MPE	ICC(3,1) measured in degrees	95% Confidence interval for ICC	Strength of Agreement	Categorical Score: Cronbach's Alpha	Strength of Agreement
Rater 1	.785	.521 - .913	Good	1.000	Excellent
Rater 2	.615	.219 - .837	Moderate	.797	Good and acceptable
Rater 3	.848	.641 - .940	Good	.618	Acceptable

Key: MPE = metatarsophalangeal joint extension

Figure 9.11. shows an interquartile spread of 6.75° for R1 but wide upper and lower fences, 6.5° for R2 and 8.75° for R3 with relatively tight upper and lower fences indicating better consistency.

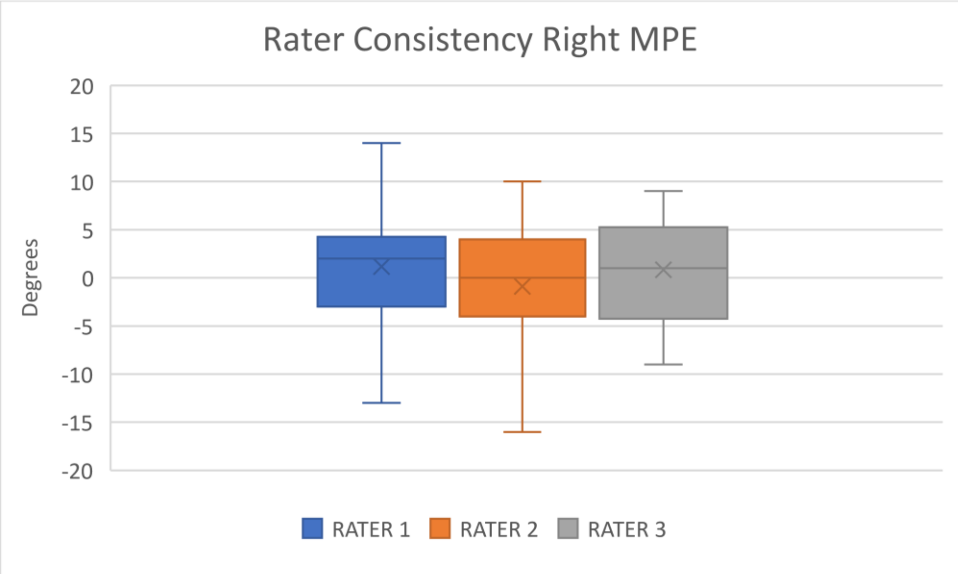


Figure 9.11 Box Plot intra-rater right metatarsophalangeal joint (MPE) Raters 1, 2 and 3.

Table 9.12 Left Metatarsophalangeal joint extension (Left MPE) Intra-rater reliability Raters 1, 2 and 3.

Left Metatarso-phalangeal extension	ICC measured in degrees.	95% Confidence interval for ICC	Strength of Agreement	Categorical Score: Cronbach's Alpha	Strength of Agreement
Rater 1	.748	.444 - .893	Moderate	.796	Good and acceptable
Rater 2	.674	.323 - .863	Moderate	.667	Acceptable
Rater 3	.858	.661 - .944	Good	.816	Good

Key: MPE = metatarsophalangeal joint extension

The following Box Plot shows the tighter upper and lower fences for Rater 3 compared to both Raters 1 and 2. The outlier is noted. R3 has an interquartile spread of 5^{o}, R1 has 8.25^{o} and R2 has 7.5^{o}.

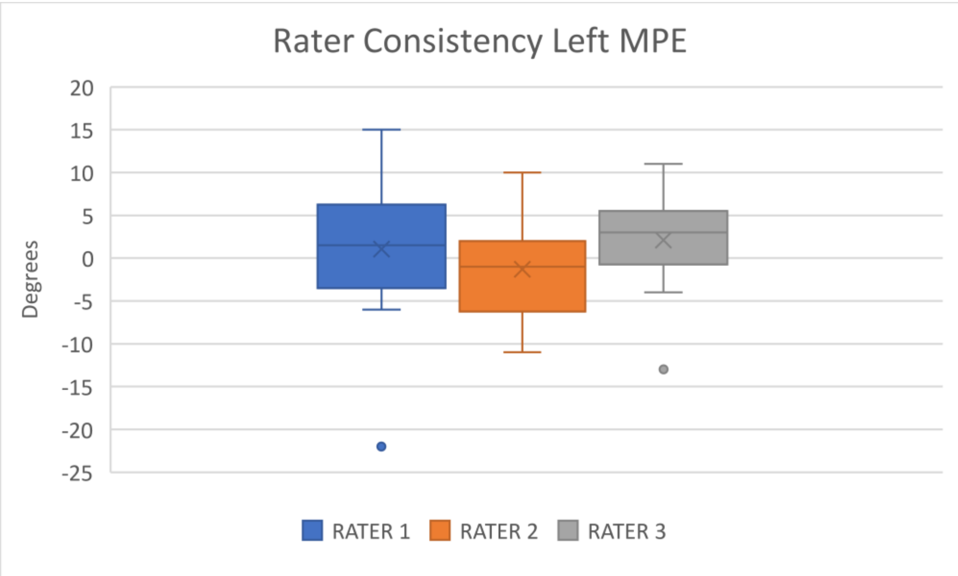


Figure 9.12 Box Plot intra-rater left metatarsophalangeal joint extension Raters 1, 2 and 3.

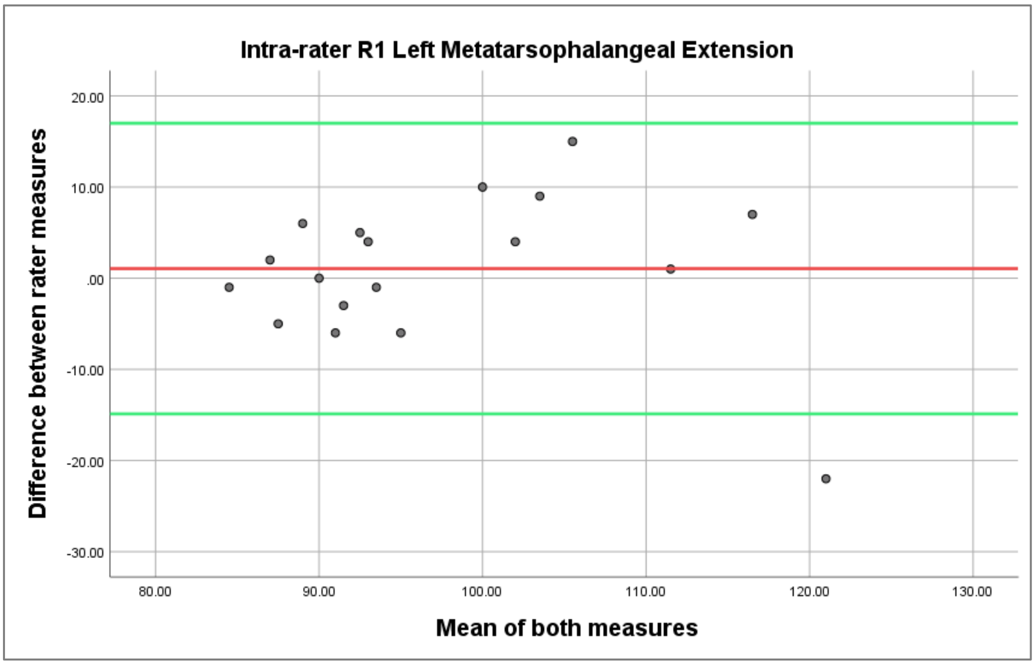


Figure 9.13 Bland-Altman plot intra-rater left metatarsophalangeal joint extention Rater 1. Standard Error of Measurement was 5.5, Minimal Detectable Change was 15.2, the Mean (red line) was 1.0556 and Limits of Agreement (green lines) -14.889,16.999.

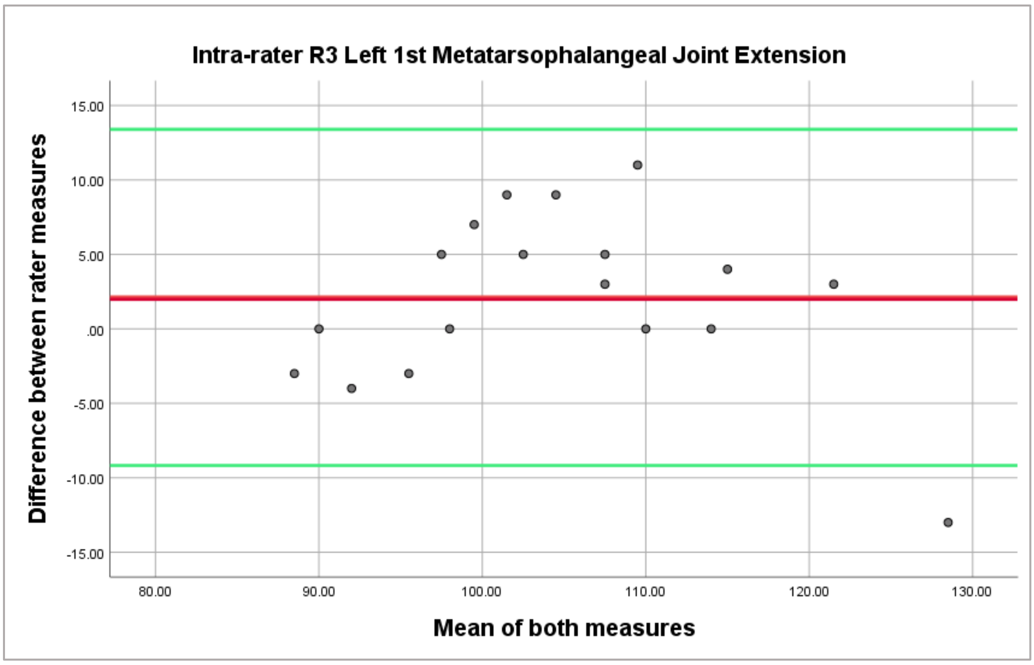


Figure 9.14 Bland-Altman plot intra-rater left metatarsophalangeal joint extention Rater 3. Standard Error of Measurement was 4.07, Minimal Detectable Change was 11.26, the Mean (red line) was 1.980 and Limits of Agreement (green lines) -9.176,13.398.

9.2.3.6 Intra-rater Reliability of Spinal Extension

For intra-rater reliability, only R3 measured with acceptable consistency.

Table 9.13 Spinal Extension Intra-rater reliability Raters 1, 2 and 3.

Spinal Extension	ICC(3,1) Measured in degrees	95% Confidence interval for ICC	Strength of Agreement	Categorical Score: Cronbach's Alpha	Strength of Agreement
Rater 1	.208	-.255 - .602	Poor	.187	Poor
Rater 2	.879	.706 - .953	Good	.934	Excellent
Rater 3	.461	.043 - .752	Fair	.787	Good and acceptable

The intra-rater consistency is represented in the following Box Plot. Rater 1 failed with the first round, mishandling the TiltMeter® and this was reflected by the wide margins of error although the majority of measures were reasonably close. R2 was more adept, reaching a better reliability with tighter margins of error and interquartile range of 7.75^{o}. Rater 3 had a wide margin of error (31^{o}) and an interquartile range of 19.25^{o}.

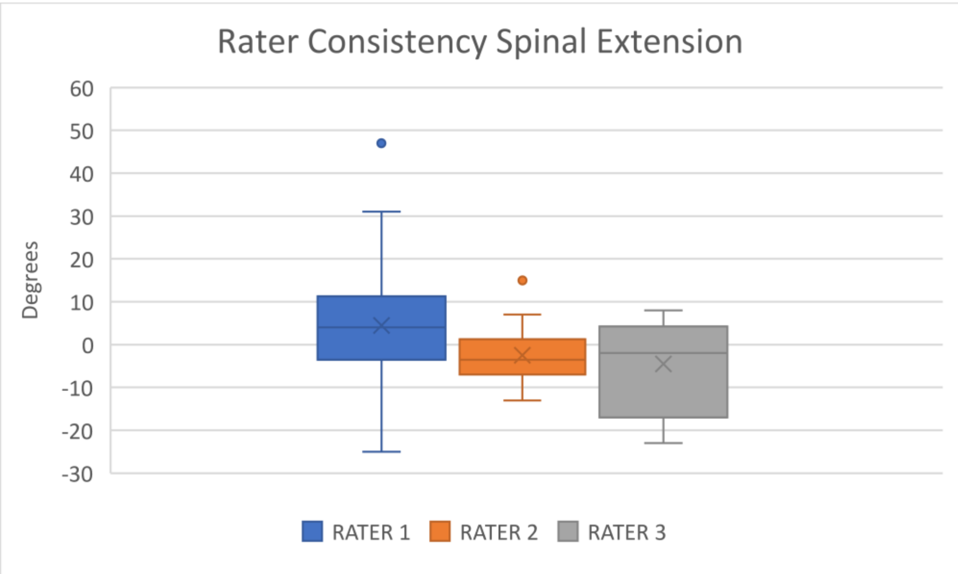


Figure 9.15 Box Plot intra-rater spinal extension Raters 1, 2 and 3.

In the following Bland Altman plot the Limits of Agreement are 25^{0} apart and the MDC is 13.2^{0} which is too wide for precision.

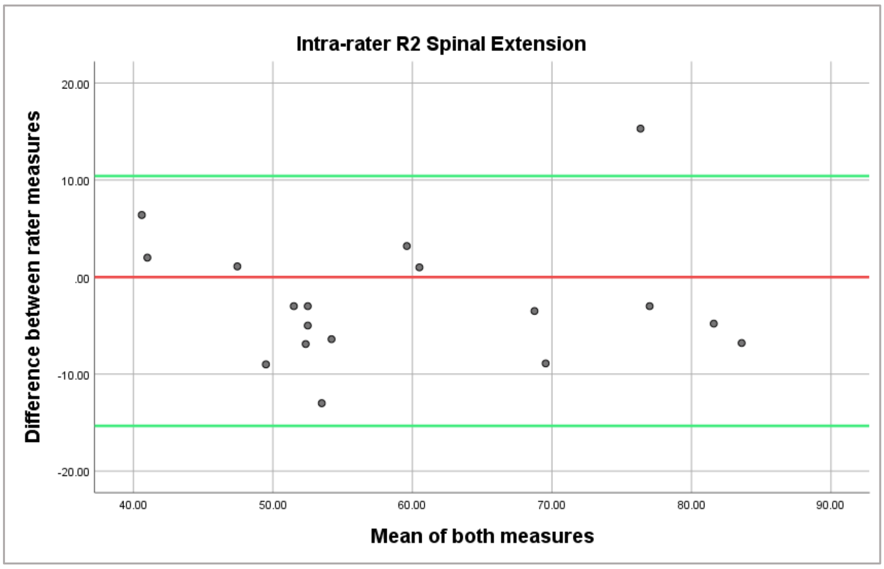


Figure 9.16 Bland-Altman plot intra-rater Spinal Extension Rater 2. Standard Error of Measurement was 4.77, Minimal Detectable Change was 13.2, the Mean (red line) was -2.461 and Limits of Agreement (green lines) -15.338,10.416.

9.2.3.7 Intra-rater Reliability of the Beighton Score

Intra-rater reliability of the Beighton Score was high.

Table 9.14 Beighton Score Intra-rater Reliability

Rater	Test	Cronbach's Alpha Coefficient	Strength of Agreement
1	Beighton	.893	Good
2	Beighton	.899	Good
3	Beighton	.844	Good

9.2.3.8 Intra-rater Reliability of the Total ROM Score

When all the scores for the Alpha Coefficients are totalled the clinician

Table 9.15 Intra-rater Reliability Total Alpha Coefficient Scores for Range of Movement Screen

Rater	Test	Cronbach's Alpha	Strength of Agreement
1	Total Scores	.947	Excellent
2		.960	Excellent
3		.963	Excellent

9.2.3.9 Overview of Intra-rater reliability results

The following bar charts present the overview of intra-rater reliability of each of the 7 tests using ICC (Figure 9.17) and the Alpha Coefficient (Figure 9.18). Table 9.16 displays the rates of reliability of each test (except plantarflexion which is scored) using ICC. The green line indicates the level of moderate reliability and the yellow line indicates good reliability. In this study moderate ICC (≥ .51) is regarded as acceptable for reliability (Indrayan, 2013).

Four out of five tests reached moderate reliability on both sides for all three raters.

Rater 1 had good reliability in all tests except Spinal Extension.

Rater 2 had good reliability except in Metatarsophalangeal Joint Extension.

Rater 3 had good reliability in all but Hip External Rotation which was moderate and Spinal Extension which was poor.

Three tests out of five reached moderate level of reliability on both sides, in both rounds. Hip external rotation reached a moderate level only on the right in both rounds. Spinal Extension reached a moderate level in only the second round. Seven out of ten measures (6 tests) achieved an increased ICC in the second round.

The ICC of the intra-rater reliability is shown in the following bar chart Fig.9.17. Raters 1 and 2 had poor reliability for Spinal Extension but otherwise consistency was good.

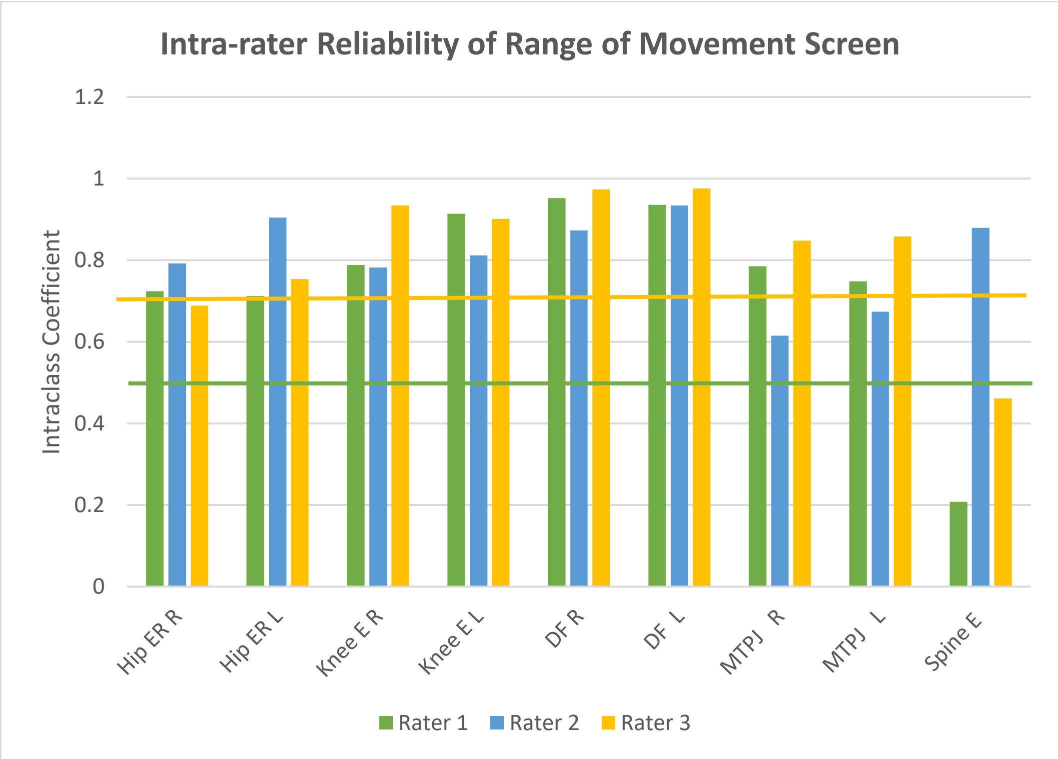


Figure 9.17 Intra-rater reliability of ROM Screen using ICC. Green line = ≥ 0.51 acceptable. Yellow line = ≥ 0.76 good (Indrayan, 2013).

Key:

Hip ER R = Hip External rotation on right

L Knee E = Left Knee Extension

DF R = Dorsiflexion Right ankle

MTPJ L = Metatarsophalangeal joint Left

L Spine E = Left Spinal Extension

The following chart shows intra-rater reliability using the Alpha Coefficient. Rater 1 failed to reach an 'acceptable' (≥ .61) level of reliability in only the Spinal Extension. Otherwise, all tests achieved acceptable intra-rater reliability.

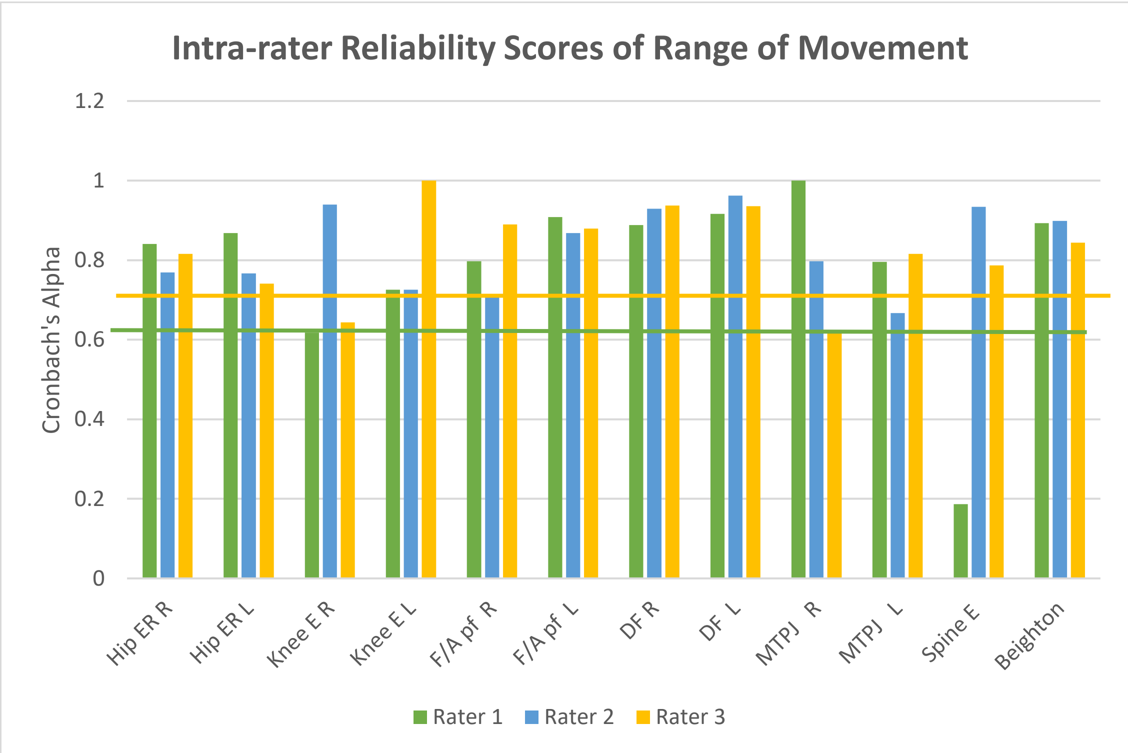


Figure 9.18 Intra-rater Reliability of ROM Screen using Alpha Coefficients. Green line = ≥ 0.61 acceptable Yellow line = ≥ 0.71 good and acceptable (Tavakol and Dennick, 2011).

Key:

Hip ER R = Hip External rotation on right

L Knee E = Left Knee Extension

DF R = Dorsiflexion Right ankle

MTPJ L = Metatarsophalangeal joint Left

L Spine E = Left Spinal Extension

Beighton = Beighton Score

Table 9.16 Intra-rater reliability of screening components

Test	Side	$ICC_{3,1}$ (95% CI)	SEM	MDC	Mean Difference (95%)LOA
Rater 1 HER	R	.724	5.33	14.73	1.094(-11.627,13.816)
Hip External Rotation	L	.712	4.05	11.21	-2.51(-12.647,7.625)
Rater 2 HER	R	.792	4.73	13.1	.6722(-14.819,16.164)
	L	.904	2.82	7.8	.1055(-9.026,9.237)
Rater 3 HER	R	.689	4.15	11.5	1.378(-9.52,12.276)
	L	.754	3.66	10.13	-2.072(-10.973,6.829)
Rater 1 KE	R	.788	2.61	7.21	-1.667(-8.969,5.636)
Knee Extension	L	.914	1.66	4.59	-1.667(-8/969,5.636)
Rater 2 KE	R	.782	3.1	8.61	.3388(-8.816,8.034)
	L	.812	2.97	8.2	.0000(-7.954,7.954)
Rater 3 KE	R	.934	1.06	2.9	.5556(-2.234,3.345)
	L	.901	1.41	3.9	-.3889(-4.018,3.24)
Rater 1	R	.934	.91	2.5	-.8222(1.357,-3.0012)
Ankle Dorsiflexion	L	.938	.92	2.5	-.9222(-3.022,1.1776)
Rater 2	R	.965	.622	2.09	-.250(-2.099,1.599)
	L	.934	.85	2.35	-.0833(-2.692,2.526)
Rater 3	R	.973	.58	1.61	-.0333(-1.649,1.58)
	L	.976	.54	1.49	.0278(-1.5298,1.585)
Rater 1 MPE	R	.885	3.93	10.88	1.167(-10.148,12.481)
Metatarsophalangeal joint extension	L	.748	5.5	15.2	1.055(-14.89,16.999)
Rater 2 MPE	R	.615	4.08	11.27	-.889(-14.299,12.385)
	L	.674	3.5	9.69	1.0556(-14.889,16.999)
Rater 3 MPE	R	.848	4.23	11.68	.833(-10.434,11.987)
	L	.858	4.07	11.26	1.98(-9.176,13.398)
Rater 1 Spinal Extension		.208	11.83	37.7	4.583(-27.58,36.75)
Rater 2 SE		.879	4.77	13.2	-2.461(-15.34,10.416)
Rater 3 SE		.461	6.85	18.93	-4.517(-24.39,15.357)

SEM: Standard Error of Measurement MDC: Minimal Detectable Change
LOA: Limits of Agreement

9.2.3.10 Summary of Intra-rater Reliability Results

- The intra-rater reliability for all tests was high and acceptable using both ICC and Alpha Coefficients. Only the procedural mistake in Round 1 of Test 6 could not be accepted.
- For Test 1. Hip External Rotation the intraclass coefficients ranged from .689 to .904 and Alpha Coefficients of .741 to .868.
- For Test 2. Knee Extension the ICC ranged from .812 - .934 (acceptable to excellent) and Alpha Coefficients .618 – 1.000 (acceptable to very good).
- Test 3. Plantarflexion achieved Alpha Coefficients (CA) of .710 - .908 for intra-rater reliability - mostly very good.
- Test 4. Dorsiflexion had excellent intra-rater agreement (ICC = .943 - .970, CA = .958 -.971).
- Test 5. Metatarsophalangeal Joint Extension had moderate to good ICCs (.614 - .768) and acceptable to very good Alpha Coefficients (.728 - .859).
- In spite of some poor results for Test 6. intra-rater agreement for Rater 2 was .879 ICC and .934 Alpha Coefficient. Rater 3 had ICC of .461 and Alpha Coefficient of .787. Rater 1 had poor results due to a procedural mistake.
- The intra-rater reliability for the Beighton scoring was consistently very good (.844 - .893).
- Intra-rater Total Scores were consistent (R1 = .947, R2 = .960 and R3 = .963).

9.2.4 Inter-rater Reliability of Range of Movement Tests

9.2.4.1 Hip External Rotation Inter-rater Reliability

Following the intra-tester reliability, the inter-rater results are presented. Again, each hip was considered independently. The following tables show the inter-rater reliability of the passive hip external rotation measurement in degrees, using the Intraclass Correlation Coefficient. Rounds 1 and 2 are displayed. Cronbach's Alpha (CA) is also reported, and the improved reliability is noted: the ICC ranged from .419 to .622 (fair to moderate) but Cronbach's Alpha ranged from .687 to .856 (acceptable to very good). The advantages of using the Alpha Coefficient are discussed in the Section *8.5.4.10* of this chapter.

Table 9.17 Passive Hip External Rotation (HE) Inter-rater reliability Raters 1, 2, and 3 in Round 1.

Round 1. Hip External Rotation	ICC(3,1) ROM measured in degrees	Strength of Agreement	95% Confidence interval for ICC	Categorical Score: Cronbach's Alpha	Strength of Agreement
HE Right	.622	Moderate	.322 - .827	.856	Good
HE Left	.437	Fair	.139 - .709	.687	Acceptable

Key: HE=hip external rotation

Table 9.18 Hip External Rotation (HE) Inter-rater reliability Raters 1, 2 and 3 in Round 2.

Round 2. Hip External Rotation	ICC(3,1) ROM measured in degrees	Strength of Agreement	95% Confidence interval for ICC	Categorical Score: Cronbach's Alpha	Strength of Agreement
HE Right	.515	Moderate	.235 - .756	.616	Acceptable
HE Left	.419	Fair	.131 - .694	.759	Good and Acceptable

Key: HE=hip external rotation

The Box Plot in Figure 9.19. shows the interquartile ranges of Right Hip External Rotation demonstrating the spread of data (consistency) comparing R1/2, R2/3 and the smaller interquartile range for R1/3. 50% of the data lie within the smaller interquartile range and therefore there is better agreement between R1/3. The smaller the interquartile range, the more consistent is the data. The data for R1/2 is more spread and therefore less consistent. However, R2/3 are measuring lower with a wider spread of data (upper and lower fences) indicating less reliability. The inconsistency of the mean in each plot supports the low ICC of .515.

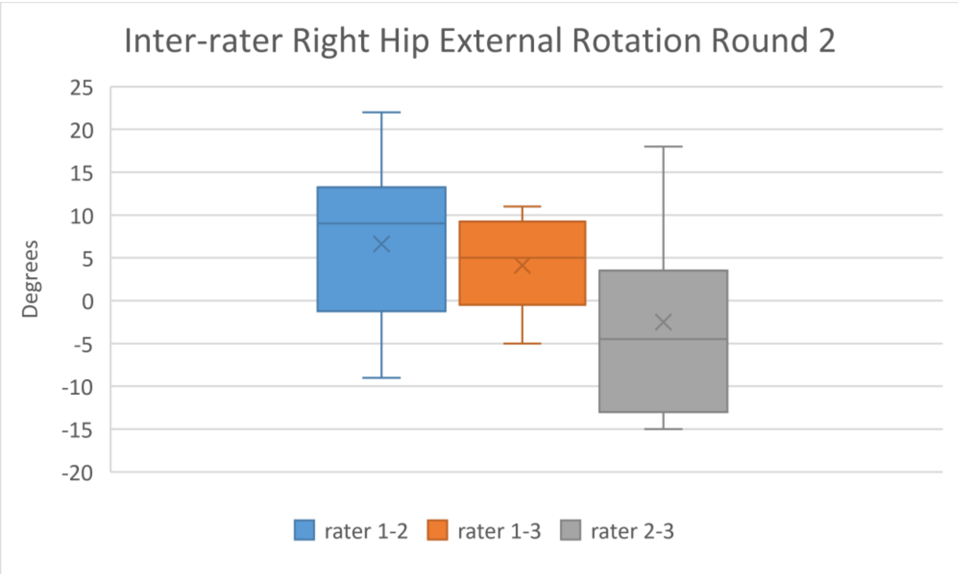


Figure 9.19 Inter-rater right hip external rotation Raters 1/2, 1/3 and 2/3 Round 2.

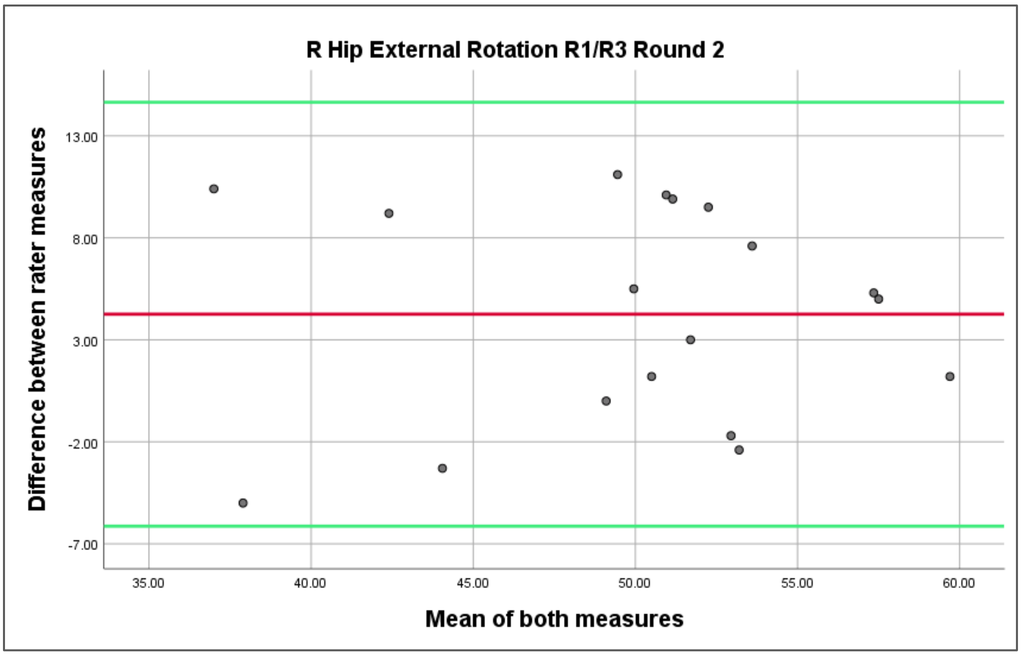


Figure 9.20 Bland Altman Plot for inter-rater reliability of raters R1/R3. Standard Error of Measurement was , Minimal Detectable Change was 7.8, the Mean (red line) was 4.2556 and Limits of Agreement (green lines) -6.1356,14.64679.

Left hip rotation in Round 2 had a lower ICC of inter-rater agreement between 3 raters at .419 and a ‘fair' strength of agreement. However, the following Box Plot demonstrates that raters 1 and 3 (R1/3) were again in moderate agreement with the median near zero and the spread of data, acceptable. Raters 2 and 3 (R2/3) were less consistent with a widely spread interquartile range of 13.75^{o}. R1/2 shows an outlier of -20^{o}, numerically distant from the rest of the data. (It is separately plotted and therefore not included in the ‘expected’ range.)

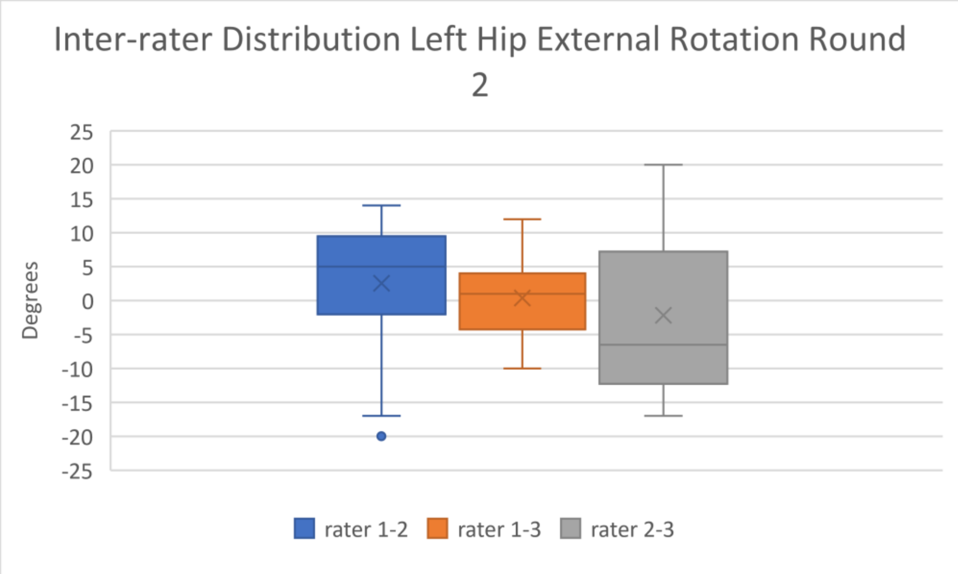


Figure 9.21 Inter-rater left hip external rotation Raters 1/2, 1/3 and 2/3 Round 2.

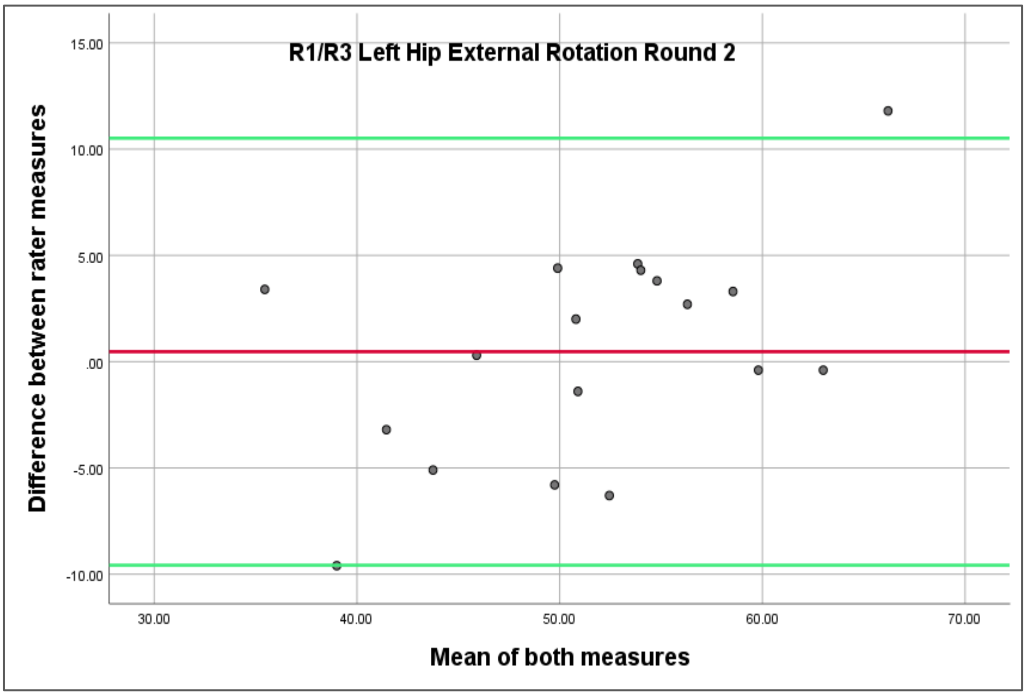


Figure 9.22 Bland Altman Plot Left Hip External Rotation Round 2.

The bulk of measurements lie within a 10^{o} spread around the mean with the two outliers.

9.2.4.2 Inter-rater Reliability of Knee Extension

Inter-rater reliability in this test was moderate for ICC (.554 - .676) and very good for Cronbach's Alpha (.712 - .750).

Table 9.19 Knee Extension Inter-rater reliability Raters 1, 2 and 3 Round 1.

Knee Extension Round 1.	ICC (3,1)	95% Confidence interval for ICC	Strength of Agreement	Score: Cronbach's Alpha	Strength of Agreement
Right Knee Extension	.554	.210 - .795	Moderate	.712	Good and acceptable
Left Knee Extension	.676	.198 - .881	Moderate	.750	Good and acceptable

Table 9.20 Knee Extension Inter-rater reliability Raters 1, 2 and 3 Round 2.

Knee Extension Round 2.	ICC (3,1)	95% Confidence interval for ICC	Strength of Agreement	Score: Cronbach's Alpha	Strength of Agreement
Right Knee Extension	.621	.174 - .850	Moderate	.717	Good and acceptable
Left Knee Extension	.617	.168 - .848	Moderate	.750	Good and acceptable

Although the inter-rater ICC for Right Knee Extension Round 1 was .554 the Box Plot shows the interquartile range for R1/R3 is 2^o and good agreement. The outliers are regarded as distant from the rest of the data but are a concern in reliability. R2/R3 had a spread of 4.5^o with slightly less reliability and R1/R2 (6^o) less still. Scrutinizing the data this way demonstrates better, the reliability between each couple. The ICC for the 3 couples is affected by the lack of agreement between R1/R2 and the outliers evident in R1/R3 and R2/3. Examining the Bland Altman (Fig. 8.16.) those for R1/R2 and R2/R3 (Appendix C) the data can be closely scrutinized.

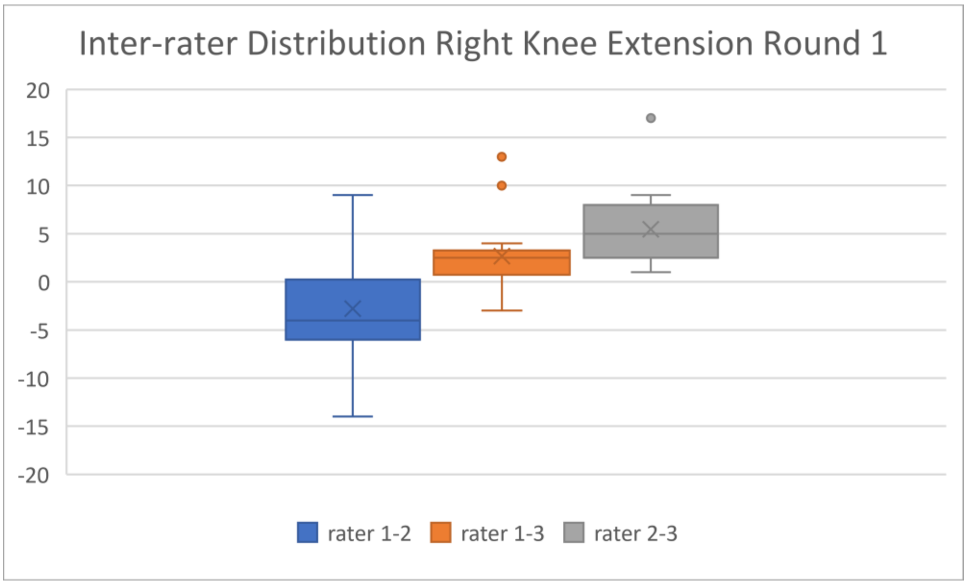


Figure 9.23 Inter-rater right knee extension Raters 1/2, 1/3 and 2/3 Round 1.

The Bland-Altman chart shows the same data for R1/R3 and the cluster of data around the mean. The Bland Altman demonstrates the negative skew in the data seen in the Box Plot. The outlier is noted as are the 'stretched' limits of agreement.

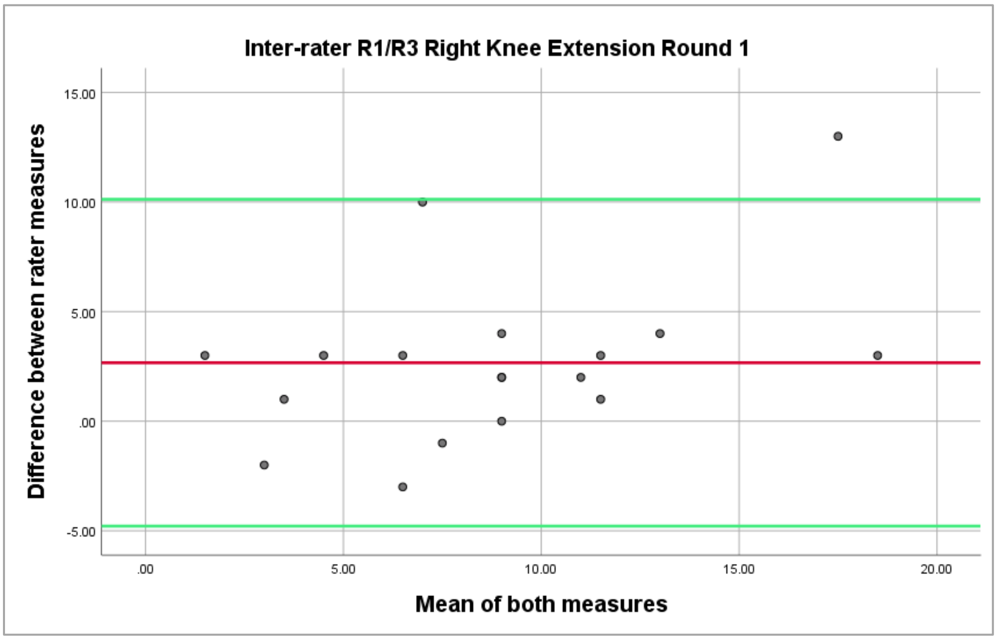


Figure 9.24 Bland-Altman plot inter-rater 1/3 right knee extension Round 1.

In Figure 9.25 the Box Plot shows the interquartile ranges of R1/R2, R1/R3 and R2/R3. Although the ICC was moderate, the interquartile ranges were 5.5^{o}, 2.75^{o} and 2.75^{o}.

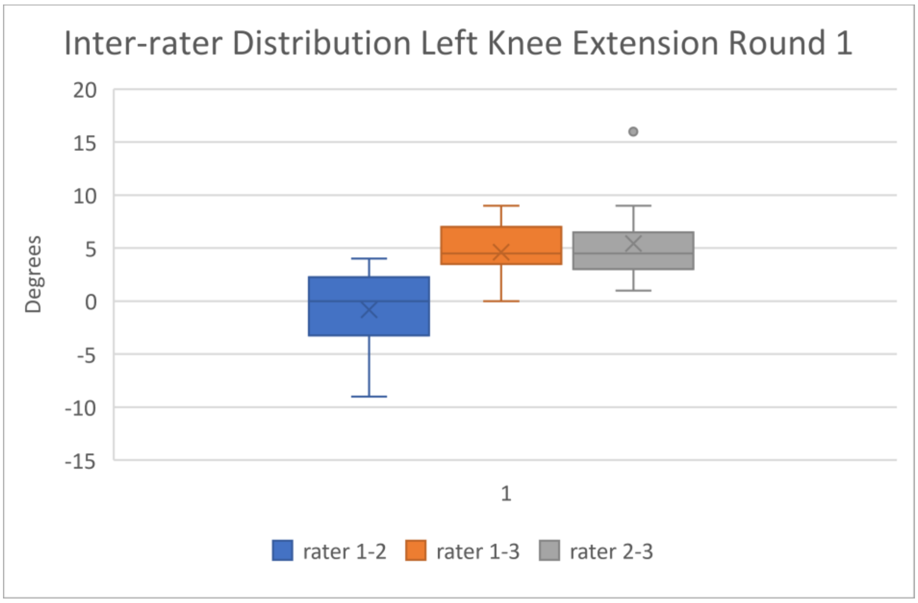


Figure 9.25 Box Plot left knee extension inter-raters 1/2, 1/3 and 2/3 Round 1.

The Bland-Altman Plot shows the consistency of measures of R1/R2 around the mean. The lower fence of -9^{o} seen in the Box Plot and the outlier seen in the Bland Altman plot have influenced the limits of agreement which are too wide, in this case, for reliability.

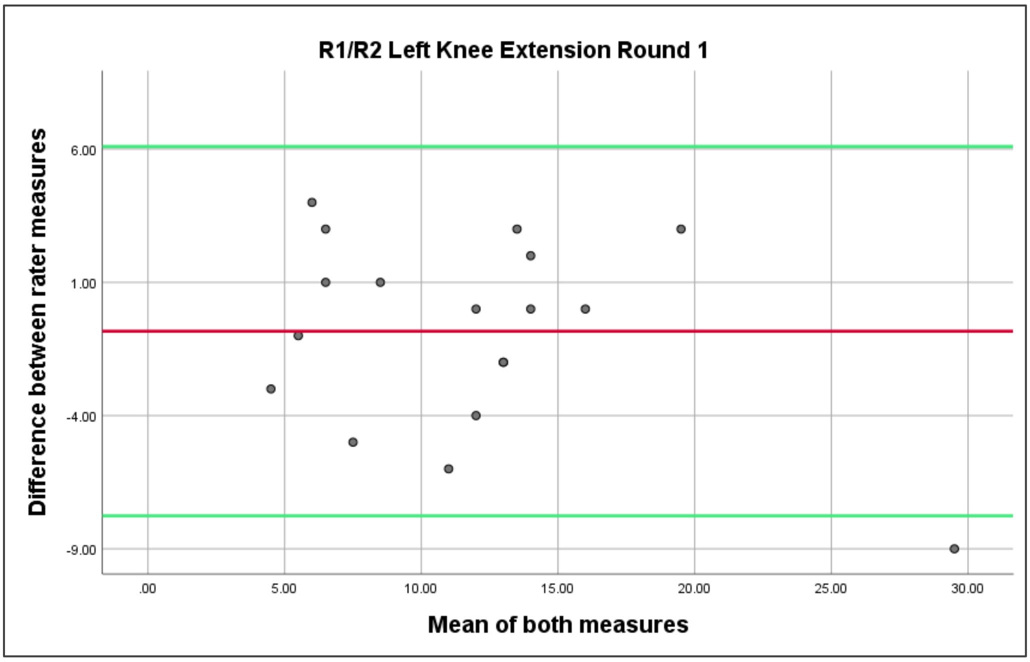


Figure 9.26 Bland-Altman plot left knee extension inter-raters 1/2 Round 1.

9.2.4.3 Inter-rater Reliability of Foot and Ankle Plantarflexion

Only Cronbach's Alpha Coefficient is used here as the physiotherapists scored the range immediately in categories, from 1 to 3. The plantarflexion test results ranged from acceptable to good for inter-rater reliability (.673 to .759).

Table 9.21 Plantarflexion Inter-rater reliability Raters 1, 2 and 3.

Inter-rater reliability	Categorical Score: Cronbach's Alpha	Strength of Agreement
Round 1.		
Plantarflexion Right	.759	Good acceptable
Plantarflexion Left	.766	Acceptable
Round 2.		
Plantarflexion Right	.762	Good acceptable
Plantarflexion Left	.673	Acceptable

9.2.4.4 Inter-rater Reliability Ankle Dorsiflexion

The majority of the measurements lie within the narrow limits of agreement, showing accuracy and excellent agreement. Regression analysis shows no proportional bias.

The knee to wall measurement has already been tested successfully for reliability (Konor et al., 2012; Bennell et al., 1998). This is reflected in our results which were all excellent for inter- and intra-rater reliability using the Intraclass Coefficient and very good using Cronbach's Alpha.

Table 9.22 Dorsiflexion Inter-rater reliability Raters 1, 2 and 3.

Inter-rater reliability	ICC (3,1)	95% Confidence interval for ICC	Strength of Agreement	Categorical Score: Cronbach's Alpha	Strength of Agreement
Round 1					
Dorsiflexion Right	.943	.881 - .977	Excellent	.960	Excellent
Dorsiflexion Left	.956	891 - .983	Excellent	.961	Excellent
Round 2					
Dorsiflexion Right	.956	.891 - .983	Excellent	.971	Excellent
Dorsiflexion Left	.970	.930 - .988	Excellent	.958	Excellent

The Box Plot in Figure 9.27. demonstrates the consistency of agreement between raters 1 and 3 and 2 and 3. Clearly raters 1 and 2 varied 2cm.

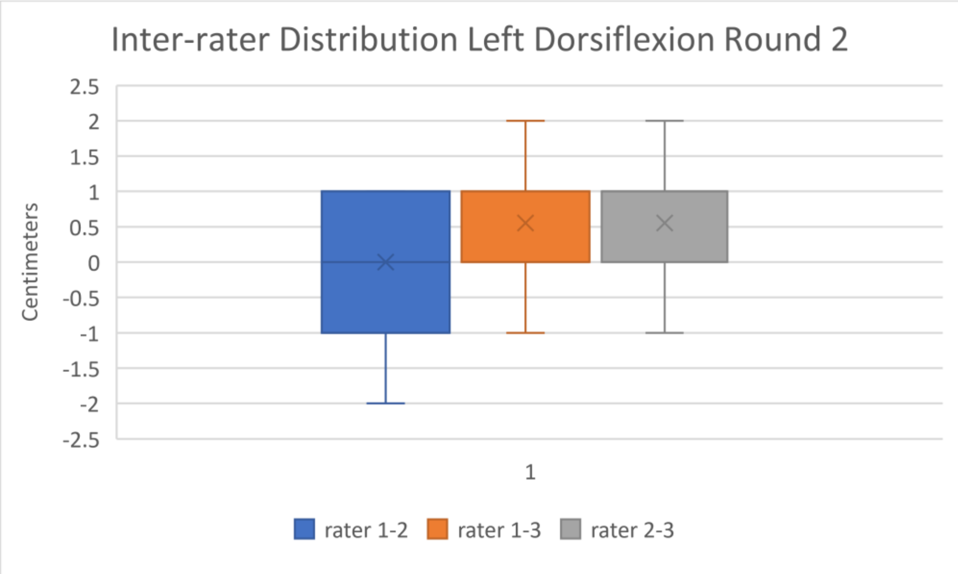


Figure 9.27 Box Plot inter-rater left dorsiflexion Raters 1/2, 1/3 and 2/3.

9.2.4.5 Inter-rater Reliability First metatarsophalangeal joint extension

Reliability Test 5 was acceptable.

Inter-rater reliability of this test was classed as good to better in Cronbach's Alpha (.728 - .859) and moderate to good for ICC (.614 to .768).

Table 9.23 First metatarsophalangeal joint extension Inter-rater reliability Raters 1, 2 and 3

Inter-rater reliability	ICC(3,1) measured in degrees	95% Confidence interval for ICC	Strength of Agreement	Categorical Score: Cronbach's Alpha	Strength of Agreement
Round 1					
MPE Right	.742	.530 - .884	Moderate	.859	Good
MPE Left	.614	.351 - .816	Moderate	.728	Good and acceptable
Round 2					
MPE Right	.768	.570 - .897	Good	.803	Good and acceptable
MPE Left	.755	.550 - .890	Good	.728	Good and acceptable

Key: MPE = metatarsophalangeal joint extension

In Figure 9.28. the Box Plot shows the spread of interquartile ranges for R1/R2 is 9.75°, R1/R3 is 6° and R2/R3 is 10.75°.

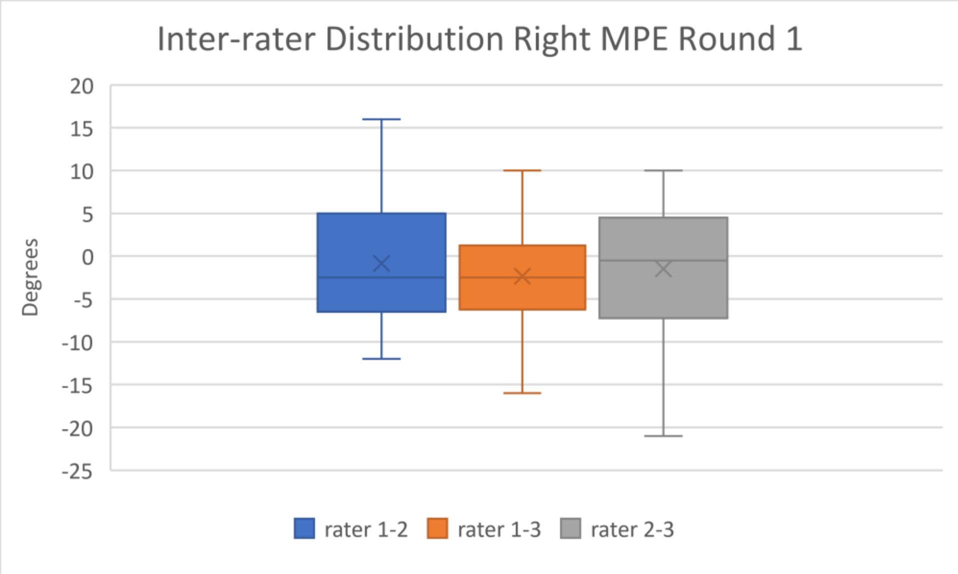


Figure 9.28 Box Plot inter-rater right metatarsophalangeal joint extension Raters 1/2, 1/3 and 2/3 Round 1.

The Box Plot in Figure 9.28. reflects the moderate ICC of right metatarsophalangeal joint extension. The R1/R2 interquartile range reached 7.75°, R1/R3 reached 7.50° and R2/R3 reached 9.25°.

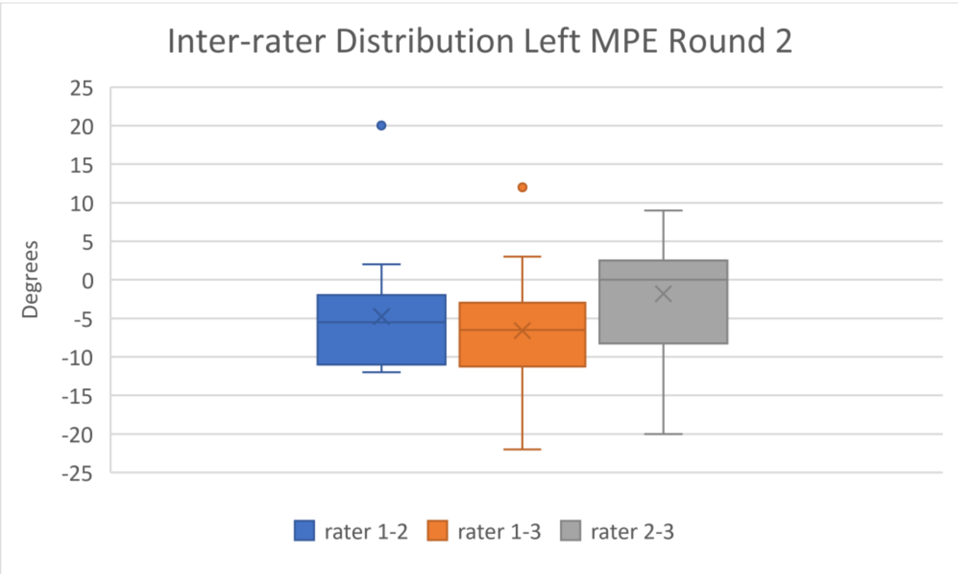


Figure 9.29 Box Plot inter-rater left metatarsophalangeal joint extension Raters 1/2, 1/3 and 2/3 Round 2.

9.2.4.6 *Inter-rater Reliability Spinal extension*

The Round 1 inter-rater reliability results were flawed. Rater 1 had misunderstood instructions regarding the handling of the mobile phone and steady contact with the spine was lost, interfering with the results. Training had included this (Chapter 7, Section 7.6) but could have been forgotten as the physiotherapists were working at speed. In Round 2 the results were much improved with an Alpha Coefficient of .784 and a moderate ICC of .584.

Table 9.24 Inter-rater Reliability of Spinal Extension of Raters 1,2 and 3

Inter-rater reliability	ICC(3,1) measures in degrees	95% Confidence interval for ICC	Strength of Agreement	Categorical Score: Cronbach's Alpha	Strength of Agreement
Round 1					
Spinal Extension	.183		Poor	.447	Poor
Round 2					
Spinal Extension	.584	.308 - .800	Moderate	.748	Good and acceptable

Measurement in Round 1 for Rater 1 was affected and those results were therefore not viable. As the first round was flawed in this test, the Box Plot for the second inter-rater round is illustrated here. R1/2 had wide maximum and minimum values. However, R1/3 and R2/3 reached better agreement although the interquartile range was broad for good agreement.

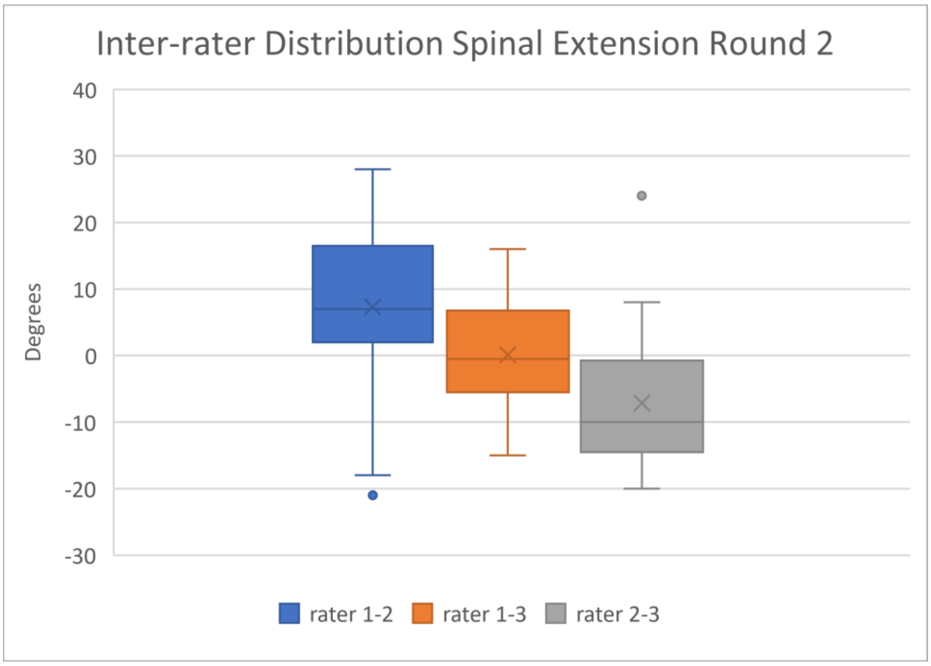


Figure 9.30 Box Plot inter-rater spinal extension Round 2.

9.2.4.7 Inter-rater Reliability Beighton Score

When the Beighton score was divided into three categories Alpha Coefficients were very good - for both inter and intra-rater reliability. The scoring system for this was Beighton 1-3 = 1 (restricted), 4-6 = 2 (moderate), 7-9 = 3 (hypermobile).

Table 9.25 Beighton Score Inter-rater reliability

Inter-rater reliability Beighton Score	Categorical score: Cronbach's Alpha	Strength of Agreement
Round 1.	.884	Good
Round 2.	.950	Excellent

9.2.4.8 Inter-rater Reliability Total Scores for the Range of Movement Screen

Table 9.26 Inter-rater Reliability Total using Alpha Coefficient Scores for Range of Movement Screen

Inter-rater Total ROM	Test	Categorical score: Cronbach's Alpha	Strength of Agreement
Round 1	Total Scores	.962	Excellent
Round 2	Total Scores	.956	Excellent

9.2.4.9 Overview of Inter-rater Reliability Results

The following bar charts present the overview of inter-rater reliability of 5 of tests using ICC and 6 using the Alpha Coefficient. Figure 9.31 displays the rates of reliability of each test (except plantarflexion which is scored) using ICC. The green line indicates the level of moderate reliability and the yellow line indicates good reliability. In this study moderate ICC (≥ .51) is regarded as acceptable for reliability. Three tests out of five reached moderate level of reliability on both sides, in both rounds. Hip external rotation reached a moderate level only on the right in both rounds. Spinal Extension reached a moderate level in only the second round. Seven out of ten measures achieved an increased ICC in the second round. This may indicate that that precision improved on the second side.

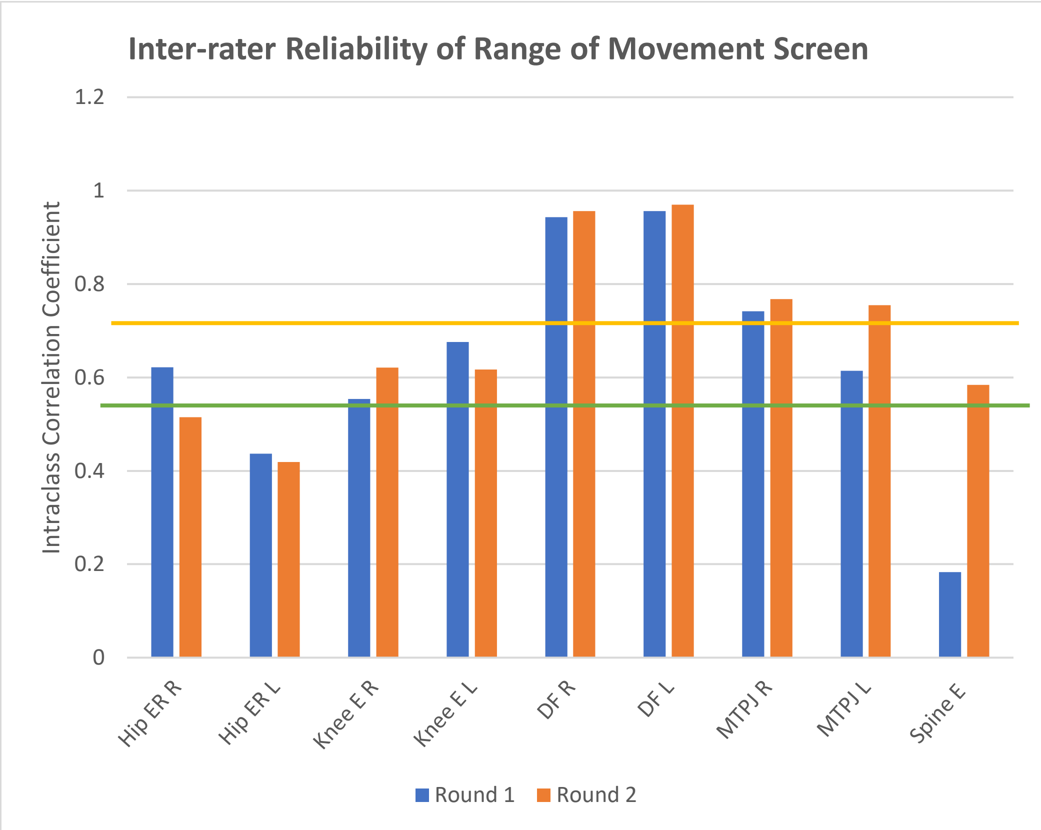


Figure 9.31 Inter-rater agreement of Raters 1, 2 and 3 using ICC. Green line = ≥ 0.51 acceptable. Yellow line = ≥ 0.76 good.

Key: Hip ER R (L) = Hip External rotation on right (left) Knee E R (L) = Knee Extension right (left)

DF R (L) = Dorsiflexion right ankle (left) MTPJ R (L) = Metatarsophalangeal joint right (left)

Spine E = Spinal Extension BS = Beighton Score

Figure 9.32. shows the inter-rater reliability of each test analysed using the Alpha Coefficient. The green line indicates the level at which reliability is acceptable (≥ .61) in this study and the yellow line indicates very good reliability. Six out of seven tests reached acceptable in both rounds and Spinal Extension exceeded acceptable in only the second round.

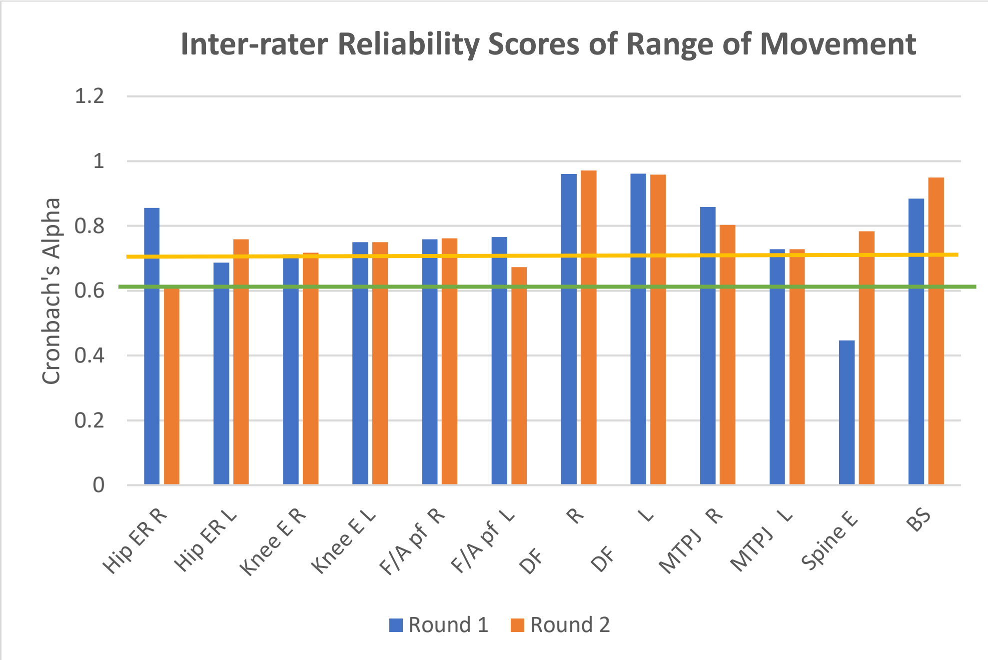


Figure 9.32 Inter-rater agreement using Cronbach's Alpha using scores. Green line = ≥ 0.61 acceptable   Yellow line = ≥ 0.71 good and acceptable

Key: Hip ER R (L) = Hip External rotation on right (left)   Knee E R (L) = Knee Extension right (left)

DF R (L) = Dorsiflexion right ankle (left)   F/A pf R (L) = Foot/Ankle plantarflexion right (left)

MTPJ R (L) = Metatarsophalangeal joint right (left)   Spine E = Spinal Extension   BS = Beighton Score

9.2.4.10 Summary of Results for Inter-rater Reliability

- The intraclass correlation coefficients for three tests (Knee Extension, Dorsiflexion, First Metatarsophalangeal Joint Extension) were acceptable. The Alpha Coefficients for six out of seven tests were acceptable.
- The Intraclass Correlation Coefficient for two tests did not reach acceptability: the inter-rater reliability in ICC for Test 1. Hip External Rotation on the left side and Test 6. Spinal extension in the first round (due to a procedural error).
- When the continuous measures were divided into scores (categories) and Cronbach's Alpha calculated, the Alpha coefficients for Hip External Rotation ranged from .616 to .856 and Spinal Extension Round 2 was .748 (acceptable).
- Test 2. Knee Extension has acceptable inter-rater reliability for ICC and the Alpha Coefficient. Further scrutiny of the results is considered in the discussion section.
- Test 3. for plantarflexion achieved Alpha coefficients of .673 to .766 (acceptable) for inter-rater reliability as plantarflexion was measured in scores only.
- Test 4. for Ankle Dorsiflexion had high reliability (ICC= .943 -.970 and Alpha Coefficient = .958 -.971).
- Test 5. for First Metatarsophalangeal Joint Extension achieved moderate to good reliability for ICC (.614 - .768). The Alpha Coefficient was acceptable to good (.728 - .859).
- The Spinal Extension in Test 6. was less reliably measured with ICCs .183 - .584. and Alpha Coefficients of .447 - .784 with improved reliability. Due to a handling fault, results were flawed.
- Agreement was very good in the Beighton Scoring using Cronbach's Alpha (.884 - .950).
- Total Scores in both rounds had a high inter-rater reliability using the Alpha Coefficient (.962 - .956).

9.3 Discussion

This the first range of movement screen to be presented for pre-entry into classical ballet intensive training. This is also the first proposed screen to highlight hypermobile, average and restricted ranges in the most logical and functional positions. This is critically discussed in the following section.

9.3.1 Test 1. Hip External Rotation

Certainly, the number of different methods to measure hip external rotation and 'turnout' suggest that there is no consensus, and that measurements and reliability are challenging. The set-up used in the present study is similar to that of Karim et al. (2011) who obtained 57% to 70% agreement for inter-rater reliability for hip external rotation (although the precise procedure is not reported). The researchers used a binary measure of either > 45^{o} or < 45^{o}. The test was made simpler by using percentage agreement. Being part of a lengthy screen taking 30 minutes, no doubt time was restricted to execute each test. Grossman et al. (2008) tested 14 participants for inter-rater reliability of passive hip external rotation (prone set-up but no description of procedure) and total passive turnout (hip and lower limb excursion combined) and reported excellent results. However, Kenny et al. (2018) used the same hip and turnout screen on 20 participants and found intra-rater reliability to be lacking and were unable to recommend the test for inclusion in their screen. This measurement in degrees appears to be fraught with inconsistency. A binary categorical measure is regarded as too vague a measure. Karim et al., possibly because the screen was designed for contemporary dancers, regarded hip range of movement as less of a priority than for ballet dancers. The score of three categories, as presented in this study, allows allocation to the 'restricted' (1), 'average' (2) and 'hypermobile' (3) groups which is helpful and practical for the clinician to record and as reported here, has good reliability. Measuring passively brings with it a challenge and researchers are probing for a rapid, convenient and consistent method, possible for a single clinician working alone. The method used in the present study concurs with that recommended in the systematic review of turnout protocols by Angioi et al. (2020), but a gold standard has yet to be established. Tables 8.17. and 8.18. show that only right hip external rotation reached a moderate ICC for inter-rater reliability.

The left side in both rounds reached fair. Using the Alpha Coefficient for inter-rater reliability the left hip achieved .759, which is acceptable.

Examining the data more closely, the Box Plots in Figure 9.21 and Bland Altman Figure 9.22 show that in spite of the low ICC in left hip external rotation Round 2, Raters 1 and 3 have good consistent agreement while Raters 1 and 2 and Raters 2 and 3 have poorer agreement. Viewing the data in Box Plots and Bland Altman Plots allows closer scrutiny of the consistency between raters and the spread of the data.

Intra-rater reliability for hip external rotation reached good consistency on both sides (ICC = .689 - .904) and the example of a Bland-Altman Plot in Figure 9.2 where the difference between rater measures plotted against the mean of the measures shows the consistency of Rater 3. However, the wide Limits of Agreement suggest otherwise (12^{o}, -10^{o}) because of the influence of the outlier. Kenny et al. (2018) regarded the wide Limits of Agreement in their hip measurement (-9.89, 16.54) - not reliable enough to be recommended. In this study the Box Plot is used to visualize the data as consistency is clearly quantified and outliers are noted but do not distort the data.

To gain absolute agreement amongst raters in hip external rotation angle measurements in degrees, would require more time, further equipment and possibly more than one physiotherapist to obtain the precision required. The ultimate purpose of this test is not absolute accuracy of measurement in degrees, but rather accuracy in recognizing the restricted hip as this may involve injury risk and altered training method. Recognition of extreme flexibility is equally important as supplementary control and strength will be required. Each category, restricted, average and hypermobile will require understanding in the context of the whole screen, to know if the pattern is global or selective. There is a persuasive argument for recommending the use of categories here and a scoring system as suggested, based on normative data and clinical experience.

External rotation of the hip can be different on either side. Although the assessors were attempting to standardise their measurement of end of range (until movement in the pelvis is detected) dancers have a preferred standing side and a preferred gesture leg which produce muscular imbalances. Soft tissue tightness may influence the last few degrees of available range due to side-to-side strength differences (Weber et al. 2015).

This raises the discussion about the role of screening and a clearer definition of what is required from screening. The title of the thesis uses the word 'profile' instead of screen, to signify that it is a global profile of the dancer that is sought. A series of angles and detailed measurements are not easily understood but using categories to quantify range is immediately useful. Using categories showed good reliability and once an assessor is practised in scoring the exercise becomes quicker and more convenient. The profile becomes a series of categories that are immediately recognisable. Complimenting the range of movement screen with functional movement tests allows the range to be seen in action, but also fine control of movements basic to ballet can be appreciated. There is no research as yet, to illuminate the dancer's physique and how the various elements of its makeup can successfully function or otherwise. A series of scores and even a total score can be a guidance for the physiotherapist assessor but the action is taken by the artistic panel who select the dancer and consult the screen for reassurance. The role of screening here is that of guidance, considering each element and the overall profile. The screen needs to be put into practise to more clearly define its role and the level of change that is required to stimulate decision making.

The time taken to assess is limited at audition, but a great deal of information is gathered. Clinical reasoning underpins each test contributing to a profile of interdependent information.

9.3.2 Test 2. Knee Extension

In the present study, measurement of knee hyperextension with a goniometer was used and is part of the Beighton Score. This is the Gold Standard (Juul-Kristensen et al., 2007) and demands great precision. These researchers stated that the knee was amongst the joints most needing 'training and discussion'. If measurements are taken by the same tester and follow standardized protocols, the acceptable margin of error is 5^{o}. This is specific to the hand (Bear-Lehman and Abreu, 1989). Inter-rater margins of error are expected to be more than those of intra-rater (Watkins et al. 1991) when measuring the knee. In right and left knee extension (ICC = .554, .676) inter-rater interquartile ranges remain small enough to support reliability (Figure 9.6. and Figure 9.7). It is again argued that for the needs of the clinician, categories and three scores would supply sufficient information (Alpha Coefficient = .712 - .750). Once a clinician is experienced it should be possible to grade this measure allocating a score rapidly. The restricted range is less aesthetically acceptable, and the extremely lax, hyperextended knee needs to be noted as a possible injury risk and teaching challenge and considered in the global impression of the physique.

9.3.3 Test 3. Foot and Ankle Plantarflexion

This test uses a ruler and avoids the use of a goniometer and precision measurement error. As explained in Chapter 6, this test is specifically to measure ankle and foot range for the biomechanics in ballet and is measured medially and not conventionally from fibula to 5^{th} metatarsal shaft. The test still needs careful and precise handling but avoids the difficulty of keeping the movement passive and manipulating the goniometer. Cronbach's Alpha was acceptable for inter-rater reliability (.673 to .766). Intra-tester reliability was mostly very good (.710 – .908). The Alpha Coefficient is acceptable for inter-rater, and intra-rater agreement is mostly very good. The test can therefore be recommended.

9.3.4 Test 4. Dorsiflexion

The test for dorsiflexion using knee to wall and tape measure is a frequently used test in physiotherapy (reliability was established by Konor et al., 2012), especially with dancers where foot and ankle injuries are high. The test produced very good inter-rater reliability for Cronbach's Alpha (.958 – .971) and excellent results for ICC throughout (.943 – .970). It is a recognized test and Konor et al. reported ICCs of .98 - .99, and so the fact that results were high was not surprising. The Box Plots in Figure 9.9 and Bland Altman plot Figure 9.10, support this.

9.3.5 Test 5. Metatarsophalangeal Joint Extension

Measuring the extension of the first metatarsophalangeal joint using a novel method as detailed in Chapter 7 produced acceptable results. Intra-rater reliability was .618 to 1.000 using Cronbach's Alpha and .615 to .858 using ICC and continuous measurement. The ICCs for inter-rater reliability for this measurement were moderate to good (.614 - .768). Cronbach's Alpha produced acceptable to good results (.728 to .859) This particular set-up made it convenient for the tester to measure and for participant to control. The participant can control the angle to end of range without pushing into discomfort and the position is functional, while the clinician can handle the goniometer with precision. Observing inter-rater interquartile ranges, margins of error ranged from 6.5^{o} to 11.25^{o}. Intra-rater margins were less (5^{o} to 8.75^{o}) but more than that recommended by Bear-Lehman and Abreu (1989). Again, the case is made for use of the scoring system and three categories, rather than continuous measurement and the test is recommended for inclusion in the ROM screen.

9.3.6 Test 6. Spinal Extension

In Round 1 the inter-rater reliability for Spinal Extension resulted in poor reliability with ICC of .183 due to a procedural mistake. Round 2 resulted in a better ICC of .584 (moderate) and an acceptable Alpha Coefficient of 0.784 and therefore shows that a great deal more practise is required and familiarity with the TiltMeter®. Mobile phone and inclinometer were shown to have good reliability and validity by Kolber et al. (2013) but our method which has encouraging potential will require further practise and testing on the dancer's hypermobile spine.

No convenient, accurate and rapid way of measuring extremes of spinal extension exists for clinicians and yet the dancer requires facility and ease in this movement and a high degree of flexibility. The inclinometer has 'legs' which stabilise it on an uneven surface (the spine), whereas the iPhone© does not. Rater 2 was more practised in using an inclinometer and this showed in the resulting intra-rater reliability which was very good (ICC=0.879 and Alpha = 0.934). Rater 3 had lower reliability (ICC = 0.461 and Alpha = 0.787) but Rater 1 had poor results due to a mistake in not removing the sleeve from the iPhone which had been used for the hip test. In all, the first round of inter-tester results were poor but in the second round were acceptable with a Cronbach's Alpha of .784 and a moderate ICC of .584. This test cannot be recommended, as yet, for inclusion in the screen until further practise in handling takes place.

9.3.7 Test 7. Beighton Score

Intra-rater consistency for the Beighton Score (.844 - .893) and inter-rater reliability Alpha Coefficients (.884 - .950) were very good. Ranges of plantarflexion, spinal extension and hip external rotation in neutral in dancers do not feature in any other hypermobility screening tests. These joints do not feature in the Lower Limb Assessment Score (Ferrari et al., 2005) although this score has been advocated by Chan et al. (2018) and Phan et al. (2019) for classical ballet dancers. The Beighton Scale alone is inadequate to classify a dancer as 'hypermobile', being composed of mostly upper limb tests. The forward flexion test was invalidated as it is redundant for dancers, by Klemp and Chalton as early as 1984. As there is such a high proportion of dancers in pre-professional training and professional companies who are classed as hypermobile by the cut-point of 4/9 (McCormack et al., 2002) and 5/9 (Chan et al., 2018) a cut-point of 6/9 was advocated by Chan et al. Mayes et al. (2020) found 11 women out of a cohort of 40 professional dancers had a Beighton Score of ≥ 6/9. In the scoring of the Beighton Scale in this ROM screen 8 out of 18 dancers were measured at ≥7, the cut-point for hypermobility used in the current research, attaining 3 points in the scoring system. The three categories were mentioned in early research by Stewart and Burden (2003).

9.3.8 Total Scores

The total scores were made up of individual scores for each test. Calculating a total score for the screen and further division allows a broad understanding of restricted, moderate and hypermobile categories and excellent intra- and inter-rater reliability is demonstrated. Using the Alpha Coefficient inter-rater consistency was .956 - .958

and intra-rater consistency was .947 - .963. The case for using a scoring system is persuasive here, not only for reliability but also for speed, rationale for screening and rapid interpretation. The total score reveals an appreciation of the physique at a glance, post screening. As a conjugated, categorical based screening tool, excellent reliability is demonstrated.

9.4 Conclusion

In each test in the ROM screen intra-rater reliability is consistently high and therefore encouraging. Inter-rater reliability is brought into question in Hip External Rotation when raw data is used but when scored in categories, agreement amongst raters improves. (As reported in 7.6, the ICC model used here will be lower than other models and this should be taken into account.) Scrutinizing raw data with further analysis allows a better understanding of raters' agreement and consistency. Scoring all the tests and using the three categories allows for instant understanding of specific and global joint ranges. At a glance the clinician can see where concerns lie. The Beighton score is included and the total of all the scores can be further divided to rank range. Using categories still requires precise handling and accuracy but allows for a more rapid global assessment of the physique. These results allow an encouraging start to the Range of Movement elements of the Audition Screen.

Chapter 10. Functional Movement Control Screen Methods

10.1 Protocol for creating the Functional Movement Control Screen videos

The FMC screening videos were created at the ROH following the ROM reliability testing session. All dancers were videoed using a standardised format performing the 7 functional movements. An iPhone® and tripod were set up facing the participant for the first functional movement test. A second iPhone® and tripod were set up with a view of the participants left side. The distance from the dancer's pelvis (anterior superior iliac spine: ASIS) to floor was measured and the cameras were adjusted to that height, at a distance of 2 meters away. The floor was marked with tape where the dancer was to stand for each test, where the barre was placed for Test 5 and where each camera was adjusted to for Test 7.

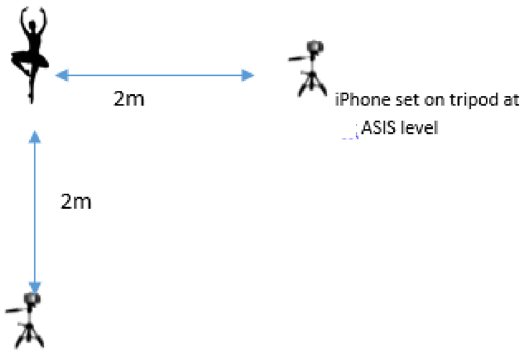


Figure 10.1 Set up for video recording of Functional Movement Control tests.

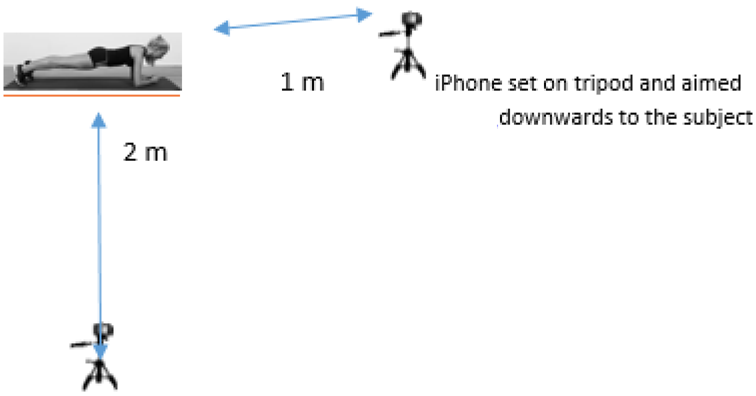


Figure 10.2 Set up for video recording of Plank Test

10.2 Testing Protocol

The students were screened in their number order and were asked to be warm and prepared and have trainers to wear for the Plank Test Otherwise the tests were carried out in bare feet. For each test the dancer was directed to specific marks on the floor and this was consistent.

Before each functional movement test the lead researcher explained what was needed in ballet vocabulary and demonstrated where necessary. For each test there was a simple set verbal command. This was standardised. The dancer could practise if he or she chose.

Each test was recorded by video on the 2 iPhones with front and left side views and synchronised. The lead researcher timed and directed the video experts to synchronise timing.

10.3 Justification for Testing Protocol

Functional movement screening reliability testing using video format is less demanding of time and energy for the dancers who otherwise would have had to return for a second round of testing. The screening day format allowed the dancers to complete their contribution to the research in one day and lose less time from training. Completing the testing in one day and the use of videos avoided losing participants in a second round at a later date. Also, no allowance was needed for participant lack of conformity or a 'learning effect', as the physiotherapists were scoring exactly the same test execution. Shultz et al. (2013) found excellent reliability using video compared to live screening of movement control (ICC = .92) lending more weight to the choice of this protocol.

10.4 Functional Movement Control Screen Tests (filmed)

10.4.1 Functional Turnout Test 1.

Table 10.1 Functional Turnout Test 1. Protocol.

Functional Control	The dancer is requested to stand on the laminated protractor mat as directed in parallel on the mat with 2nd toes in line with the red line and heels placed in heel cups. With weight over the heels the dancer is requested to turn out the legs from the hips and spin the feet as far as possible, to establish their classical ballet 1st position with arms lowered in 'bras bas'. The angle of ER is taken from the middle of 2nd toe. The ASIS to floor measurement is taken and camera lens is matched. In each test the cameras are mounted and placed at a standardised distance from the participant - both front and side views.
1. Functional turnout	
Angle	

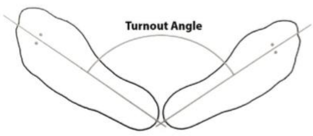


Figure 10.3 First position turnout *First position footprint*

This test examines the classical ballet dancer's posture with the characteristic externally rotated lower limbs demanded by the technique. Equilibrium of stance with body segments in vertical alignment and balance of muscle activation is sought here, providing a foundation for movement. The arms are held in the balletic position.

10.4.2 Single Leg Turnout Control Test 2. Test 2.

Table 10.2 Single Leg Turnout Test 2. Protocol.

2. Single leg TO control	The dancer steps forward on to the protractor mat, placing the right heel in the heel cup in the preferred angle of turnout. The left foot is placed in 5th position behind. From the fifth position the weight is adjusted over the right side – the supporting side and the left foot lifted and placed in the 'coup de pied derrière' not in contact with the supporting calf. The arms are held in the 'bras bas' position – held low in front of the body in the classical position. The position is held for five seconds. Repeat on L.

Figure 10.4 Fifth position with release into coup de pied derrière position

This is a novel test which examines muscular control of the supporting hip and lower limb as the gesture side releases. Stability of the pelvis and trunk are challenged revealing the true angle of turn out the dancer is capable of controlling.

10.4.3 Single Leg Knee Bend Test 3.

Table 10.3 Single Leg Knee Bend Test 3. Protocol.

3. Single leg knee bend	Dancers begin in parallel allowing for tibial torsion. Arms fall to the sides but shoulder and trunk are stabilised in 'ballet posture'. The dancer performs 4 parallel single knee bends. Gesture limb not touching. Knee bend depth not specified. This is scored. Repeat on L.

Figure 10.5 Single Knee Leg Bend in parallel

This is a recognised test for hip, knee and foot alignment in sport. Coronal plane movement of the knee has been a key focus area in research and hip adduction and internal rotation accompanies a valgus knee position. The integrity of the kinetic chain protects the knee in a variety of functional tasks (Hewett et al., 2006; Junge et al., 2012; Almangoush et al., 2014).

10.4.4 Single Leg Knee Bend in Turnout Test 4.

Table 10.4 Single Leg Knee Bend in Turnout Test 4. Protocol.

4. Single leg knee bend in TO	Dancer starts in *1st position* and releases left foot into *coup de pied derrière* , back foot not touching. Arms are held in *bras bas* with shoulders and trunk stabilised in 'ballet posture'. The dancer performs 4 single leg knee bends. This is scored. Repeat on L releasing the right foot.

Figure 10.6 Single Knee Leg Bend in Turnout

In ballet the single knee bend in turnout is called *fondu,* and the same biomechanical principles apply.

10.4.5 Back Bend Test 5

Table 10.5 Back Bend Test 5. Protocol.

5. Backbend test	The dancer stands with feet in 1st position (TO) facing the barre (or equivalent structure), holding lightly - index fingers only. Looking to R (away). The dancer extends the whole spine in a backbend retaining the pelvis position, to end of spinal extension range.

Figure 10.7 Dancer's back bend

This is a frequent move in ballet technique and requires fine control of the anterior chain. Minimal balance is aided by the *barre* and spinal range, stability of the pelvis and lower limb are required.

10.4.6 Arabesque Test 6.

Table 10.6 Arabesque Test 6. Protocol.

6. Arabesque Test	The dancer does a *chassé en avant* into 1st arabesque counts 1-2 (same arm front as standing leg) Lift the leg to 90° or above on count 3 Hold counts 4 – 5 Lower to close count 6

Figure 10.8 Arabesque position

Feipel et al. (2004) explain how the arabesque demands extension, ipsilateral side flexion and contralateral rotation of the lumbar spine. The complex balance of the arabesque position is individual, but the range of extension in the spine controlled by the anterior trunk, height of the gesture leg, reciprocal placement of the arms and absence of tension, produce this position which occurs so frequently in balletic performance.

10.4.7 Plank Test 7.

Table 10.7 Plank Test 7. Protocol.

7. Plank Test	The dancer is directed into the elbow plank position with elbows directly below shoulders, hands flat and with pelvis/trunk/spine in alignment. The plank position is held for 10 seconds. The R leg is lifted and held for 10 seconds, then the L for 10 seconds. The position is then held for 10 seconds. 40 seconds in all. Correct the position verbally if necessary. Trainers are worn for this test.

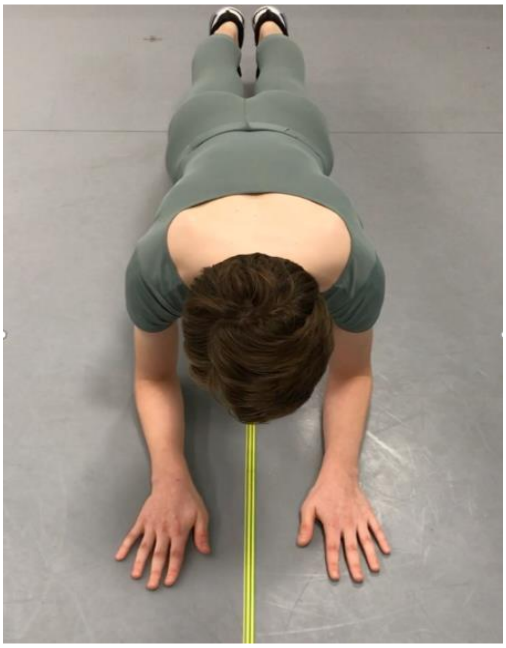


Figure 10.9 Plank position

The plank position challenges global core muscle function (Tong et al., 2014). Trunk stability is further tested with the lifting of each foot from the floor. Throughout this adapted plank test the shoulder girdle and scapular position should remain secure.

10.5 Video Data Management

After each screening day the videos were airdropped to the film expert's password protected laptop. The videos were also stored on a secure UCL computer and then deleted from both iPhones in accordance with UCL Ethics. After the third screening day the filming expert worked to format the 396 videos in PowerPoint. Each participant was anonymised in each video but allowing full view of head, neck and shoulders. The video expert was able to create three PowerPoint files (one for each school group) displaying the front and side views of each dancer on the same slide, performing each videoed test. This process was time-consuming, but the result was a set of easily manipulated videos showing as clearly as possible, without a 360 degree view, the dancers' alignment in each test.

The formatted videos were then transferred to three password protected USBs and a copy sent to a secure UCL computer for safe storage. The videos were accessible to the lead researcher and supervisors and on USB at controlled times to the 3 physiotherapists engaged to rate the FMC tests.

The Scoring sheet for physiotherapists is presented in the following table.

Table 10.8 FMC screen scoring sheet with movement description

Functional Control 1. Functional turnout Angle	The dancer is requested to stand on the laminated protractor mat as directed in parallel on the mat with 2nd toes in line with the red line and heels placed in heel cups. With weight over the heels the dancer is requested to turn out the legs from the hips and spin the feet as far as possible, to establish their classical ballet 1st position with arms lowered in 'bras bas'. The angle of ER is taken from the middle of 2nd toe. The ASIS to floor measurement is taken and camera lens height is matched. <u>In each test the cameras are mounted and placed at a standardised distance from the participant - both front and left side views.</u>	a) Loss of neutral spine – pelvis ant or post tilt (1) b) Weight back/forward (1) c) Flaring of the ribs (thoracic spine extension) (1) d) Patellae directed medial to the 1st toe (1) e) Pronated, abducted feet (1) f) Fails to reach acceptable TO (1) **6** Neutral spinal curves/ alignment of knees and feet (0)	R Foot = Angle	L Foot = angle
2. Single leg TO control	The dancer steps forward on to the protractor mat, placing the right heel in the heel cup in the preferred angle of turnout. The left foot is placed in 5th position behind. From the fifth position the weight is adjusted over the right side – the supporting side and the left foot lifted and placed in the 'coup de pied derrière' not in contact with the supporting calf. The arms are held in the 'bras bas' position – held low in front of the body in the classical position. The position is held for five seconds. Repeat on L.	a) Loss of trunk alignment – shoulders not level/square (1) b) Pelvis drops/hitches on NWB side (1) c) Stands in reduced TO to achieve stability (1) d) Lack of control of pelvis rotation (rotation WB side) (1) e) Lack of foot stability/alignment (1) f) Loss of balance (wobble/body lean/unstable upper body) (1) **6** Good control of pelvis with minimal rotation and good activation of hip stability and external rotation. Minimal foot adjustment (0)	R Angle:	L Angle:
3. Single leg knee bend	Dancers begin in parallel allowing for tibial torsion. Arms fall to the sides but shoulder and trunk are stabilised in 'ballet posture'. The dancer performs 4 parallel single knee bends. Gesture leg not touching. This is scored. Repeat on L.	a) Loss of trunk alignment – shoulders level/square (1) b) Pelvis - loss of horizontal plane (1) c) - Excessive tilt/rotation (1) d) Knee alignment (patella medial to 1st toe) (1) e) Over pronation of foot/ankle (1) f) Wobble from general instability (1) **6** Good placement and control (0)	R	L

4. Single leg knee bend in TO	Dancer steps into TO coup de pied derriere, back foot not touching. Arms fall to the sides but shoulder and trunk are stabilised in 'ballet posture'. The dancer performs 4 single leg knee bends (dancer's normal *fondu*) This is scored. Repeat on L.	a) Loss of trunk alignment – shoulders level/square (1) b) Pelvis - loss of horizontal plane (1) c) - Excessive tilt/rotation (1) d) Knee alignment (patella medial to 1st toe) (1) e) Over pronation of foot/ankle (1) f) Wobble from general instability (1) **6** Good placement and control (0)		
5. Backbend test	The dancer stands with feet in 1st position (TO) facing the barre (or equivalent structure), holding lightly - index fingers only. Looking to R (away). The dancer extends the whole spine in a balletic backbend retaining the pelvis position, to end of spinal extension range.	a) Loss of stance, swaying forwards at the hip (overuse of hip extension) (1) b) Lack of thoracic mobility – hinging in lumbar spine (1) c) Ant/post tilt of pelvis (1) d) Loss of abdominal control (1) e) Lack of range (1) No weight displacement, stable pelvis with overall control (0) **5**		
6. Arabesque Test	The dancer does a chassé en avant into 1st arabesque 1-2 (same arm front as standing leg) Lift the leg to 90° or above on 3 Hold 4 – 5 Lower to close 6	a) Lack of abdominal control - slack lower abdominals (1) b) Hinging at 90° in lumbar spine (1) c) Tension in neck (1) Head held forwards or backwards (spinal misalignment) d) Lack of height in gesture leg (stiff spinal extension) - ≤ 90° (1) e) Trunk lean (leans to the supporting side) (1) Lack of control supporting leg (1) Arabesque position achieved with no tension and leg raises easily above 90° 5	R	L
7. Plank	The dancer is directed into the elbow plank position with elbows directly below shoulders, hands flat and with pelvis/trunk/spine in alignment. The plank position is held for 10 seconds. The R leg is lifted and held for 10 seconds, then the L for 10 seconds. The position is then held for 10 seconds. 40 seconds in all. Correct the position verbally if necessary.	a) Lack of stability in shoulder girdle – winging scapula (1) b) Protraction of shoulders (1) c) Loss of spine and pelvis in line (1) d) Unstable opposite side to leg lift (pelvis/trunk) rotation) (1) e) Unable to sustain 40 seconds (1) f) Visible struggle to sustain position (1) 40 seconds with ease and stability throughout (0) **6**		

10.6 FMC Physiotherapist Training

The lead researcher (MM) met with each of the 3 physiotherapists independently to train them on the FMC video assessment scoring system. Each was able to observe the videos and ask questions prior to commencing the first round of scoring. They were unable to meet as a group to discuss their approach to the exercise as they were working at different sites, for different organisations.

10.7 Inter- and intra-rater reliability testing protocol

The first 50% of round one scoring was carried out in the presence of the lead researcher, MM to ensure understanding. Scoring was recorded on the FMC score sheet Table 12.1. The scoring exercise replicated the clinical situation and so viewing the movement up to 3 times was permitted. The process of observing 22 videos and scoring 12 tests was lengthy and could not be completed in one sitting. The raters were entrusted to retain the USB kept locked and secure along with the completed score sheets when not in use and in between sessions over a three week period. Once the first round was completed the score sheets were collected by the lead researcher. At least a week between rounds was required to allow for wash-out and no conferring between raters. After the second round the score sheets and USBs were collected. The physiotherapists were entrusted to keep the USBs secure in between Rounds 1 and 2.

10.8 Data Analysis – the kappa statistic

The Round 1 and Round 2 scores were coded and entered into IBM SPSS 25.0. Inter-rater reliability calculation of the FMC scoring (categorical data) used Cohen's kappa co-efficient to measure agreement between pairs of physiotherapists: Raters 1 and 2, Raters 2 and 3 and Raters 1 and 3. Intra-rater reliability was also calculated using Cohen's kappa and repeated measures. The kappa statistic is considered a more rigorous analysis of categorical data because it accounts for the actual proportion of observed agreement as well as the proportion of agreement to be expected by chance (Kenny et al., 2018). Mischiati et al. (2015) explained percentage agreement which describes agreement relative to perfect agreement.

Recognised grading of Cohen's kappa is shown in Table 9.9. following previously published guidelines (Landis and Koch, 1977). Although arbitrary, these benchmarks serve well to guide levels of agreement. It was decided that a test should have a kappa value above 0.4 for inter-rater reliability in this study, in alignment with previous studies (Luomajoki et al., 2007: Van Dillen et al., 2003). Furthermore, Luomajoki et al. recommended that the lower bound confidence interval (95%) should be over 0.2 to be able to declare the reliability at least fair.

In this study the benchmark was .40 and upwards.

Table 10.9 Grading of Cohen's Kappa Values (Landis and Koch, 2013). Displays the classification used to interpret scores.

Cohen's Kappa score	Strength of Agreement
0.01 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Good/substantial
0.81 – 1.0	Excellent/Almost perfect

A general indication of agreement was obtained by calculating the percentage agreement (number of exact agreements). The Percentage Agreement was calculated using the following formula:

PA = agreed/ (agreed + disagreed) x 100

The results of the reliability of the scoring of the three physiotherapists is presented in the next chapter.

Chapter 11. Functional Movement Control Screen Results

Intra-rater and inter-rater reliability results of the Functional Movement Control Screen tests are presented here. The scores generated by the physiotherapists were analysed in SPSS and the kappa coefficients between pairs, between three raters are presented here in table form. The strength of agreement is guided by the grading of Cohen's kappa values by Landis and Koch (2013).

The results of each test are displayed here in table form, reporting intra-rater results first with kappa, strength of agreement and interpretation, followed by inter-rater reliability results.

11.1 Functional Turnout Test 1.

Table 11.1 Functional Turnout Test Intra-rater reliability

Functional Turn Out	kappa	% Agreement	Strength of Agreement
Rater 1	0.354	55	Fair
Rater 2	0.727	94	Good
Rater 3	0.840	88	Excellent

Intra-rater reliability was higher and ranged from fair to excellent (.354 to .840).

Table 11.2 Functional Turnout Test Inter-rater reliability

Functional Turn Out	kappa	% Agreement	Strength of Agreement
Round 1 Inter-raters 1/2	-0.036	-	-
Round 2 Inter-raters 1/2	0.049	-	Slight
Round 1 Inter-raters 1/3	0.214	44%	Fair
Round 2 Inter-raters 1/3	0.009	-	-
Round 1 Inter-raters 2/3	0.031	-	Slight
Round 2 Inter-raters 2/3	0.029	-	Slight

The results of this Functional Turn out Test are poor with only Raters 1 and 3 reaching fair agreement (k = .214) in one round.

11.2 Single Leg Turnout Control Test 2.

Table 11.3 Single Leg Turnout Test Intra-rater Reliability

Single Leg Turn Out	kappa Right Side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Rater 1	0.247	44	Fair	0.385	50	Fair
Rater 2	.605		Good	0.607		Good
Rater 3	0.761		Good	0.809		Excellent

Intra-rater reliability was significantly higher than inter-rater reliability with kappa coefficients of .247 - .809.

Table 11.4 Single Leg Turnout Test Inter-rater Reliability

Single Leg Turn Out	Kappa Right side	% Agreement	Strength of Agreement	Kappa Left Side	% Agreement	Strength of Agreement
Round 1 Inter-raters 1/2	0.008	-	-	0.294	38	Fair
Round 2 Inter-raters 1/2	0.004	-	-	0.217	33	Fair
Round 1 Inter-raters 1/3	0.081	33	Slight	0.214	33	Slight
Round 2 Inter-raters 1/3	0.135	33	Slight	0.053	28	Slight
Round 1 Inter-raters 2/3	0.077	28	Slight	0.274	38	Slight
Round 2 Inter-raters 2/3	0.2	33	Slight	0.135	33	Slight

This test achieved only slight inter-rater reliability.

11.3 Single Leg Knee Bend Test 3.

Table 11.5 Single Leg Knee Bend Test Intra-rater Reliability

Single Leg Turn Out	kappa Right Side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Rater 1	0.419		Moderate	0.126		Slight
Rater 2	0.514		Moderate	0.681		Good
Rater 3	1.000		Excellent	0.920		Excellent

Intra-rater reliability was generally high reaching excellent reliability in Rater 3 and moderate in Rater 2.

Table 11.6 Single Leg Knee Bend Test Inter-rater Reliability

Single Knee Bend	kappa Right side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Round 1 Inter R1/2	0.085		Slight	0.147		Slight
Round 2 Inter-raters 1/2	0.502		Moderate	0.438		Moderate
Round 1 Inter-raters 1/3	0.314		Fair	0.390		Fair
Round 2 Inter-raters 1/3	0.257		Fair	0.440		Fair
Round 1 Inter-raters 2/3	0.159		Slight	0.598		Moderate
Round 2 Inter-raters 2/3	0.673		Good	0.387		Fair

The Single Leg Knee Bend inter-rater results ranged from slight to good (.085 - .673).

11.4 Single Leg Knee Bend in Turnout Test 4.

Intra-rater reliability was higher than inter-rater reliability results which were poor.

Table 11.7 Single Leg Knee Bend in Turnout Test Intra-rater reliability

	Single Knee Bend in Turnout Intra-rater Reliability					
Single Leg Turn Out	kappa Right Side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Rater 1	0.419		Moderate	0.086		Slight
Rater 2	0.457		Moderate	0.915		Excellent
Rater 3	0.259		Fair	0.687		Good

Table 11.8 Single Leg Knee Bend in Turnout Test Inter-rater reliability

	Single Knee Bend in Turn Out Inter-rater Reliability					
Single Knee Bend	kappa Right side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Round 1 Inter-raters 1/2	0.305		Fair	0.055		Slight
Round 2 Inter-raters 1/2	0.049		Slight	0.153		Slight
Round 1 Inter-raters 1/3	0.217		Fair	-0.068		
Round 2 Inter-raters 1/3	0.175		Slight	0.042		Slight
Round 1 Inter-raters 2/3	0.325		Fair	0.267		Fair
Round 2 Inter-raters 2/3	0.211		Fair	0.371		Fair

11.5 Backbend Test 5.

Table 11.9 Back Bend Test Intra-rater reliability

Intra-rater reliability			
Back Bend Test	kappa	% Agreement	Strength of Agreement
Rater 1	0.302		Fair
Rater 2	0.820		Excellent
Rater 3	1.000		Excellent

Each of the raters achieved outstanding kappa analysis in intra-rater reliability.

Agreement between the raters when assessing extension of the spine in a common functional but technically demanding movement appeared difficult to achieve with very poor inter-rater results.

Table 11.10 Backbend Test Inter-rater reliability

Inter-rater Reliability			
Back Bend Test	kappa	% Agreement	Strength of Agreement
Round 1 Inter R1/2	0.004	-	
Round 2 Inter R1/2	-0.116	-	
Round 1 Inter R1/3	0.060	-	Slight
Round 2 Inter R1/3	0.023	-	Slight
Round 1 Inter 2/3	0.221	-	Fair
Round 2 Inter 2/3	0.109	-	Slight

11.6 Arabesque Test 6.

In the third technique test each rater achieved substantial to outstanding intra-rater results. The arabesque is a common basic move in classical ballet and physiotherapists need to be able to achieve repeatable results.

Table 11.11 Arabesque Test Inter-rater Reliability

Intra-rater Reliability						
Arabesque Test	kappa Right Side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Rater 1	0.333		Fair	0.283		Fair
Rater 2	0.502		Moderate	0.522		Moderate
Rater 3	0.917		Excellent	0.625		Good

The raters need to be able to assess for injury risk, to agree and recognise a compromised spine and lack of stabilisation and agree on their evaluation. However, they achieved low inter-rater kappa coefficients ranging from mostly fair to substantial.

Table 11.12 Arabesque Test Inter-rater reliability

	Inter-rater Reliability					
Arabesque Test	kappa Right side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Round 1 Inter R1/2	0.124		Slight	-0.161		
Round 2 Inter R1/2	-0.007			-0.125		
Round 1 Inter R1/3	0.236		Fair	0.070		Slight
Round 2 Inter R1/3	0.031		Slight	0.230		Slight
Round 1 Inter 2/3	0.092		Slight	0.192		Slight
Round 2 Inter 2/3	0.116		Slight	0.196		Slight

11.7 Plank Test 7.

Intra-rater reliability was high for Raters 2 and 3 indicating an individual confidence in this test. However, more discussion and piloting for Rater 1 is required to fully agree on tolerance level of fatigue and shoulder girdle assessment.

Table 11.13 Plank Test Intra-rater reliability

Intra-rater reliability			
Plank Test	kappa	% Agreement	Strength of Agreement
Rater 1	0.185		Slight
Rater 2	0.722		Good
Rater 3	1.000		Excellent

Table 11.14 Plank Test Inter-rater reliability

Inter-rater reliability			
Plank Test	kappa	% Agreement	Strength of Agreement
Round 1 Inter R1/2	0.244		Fair
Round 2 Inter R1/2	-.0.125	-	
Round 1 Inter R1/3	0.126	-	Slight
Round 2 Inter R1/3	0.538		Moderate
Round 1 Inter 2/3	-0.067	-	
Round 2 Inter 2/3	0.000	-	

The inter-rater results were not acceptable indicating a need for discussion and agreement of each element within this test.

11.8 Summary of Results

From the first impression of these results, it is apparent that the physiotherapists were not observing movement in the same way, but they are relatively consistent in the way they individually assessed. In 6 out of 7 tests Raters 2 and 3 showed good consistency (.502 – 1.000) between Rounds 1 and 2. Generally Rater 1 was inconsistent. In Test 4 only Rater 2 was consistent. None of the Inter-rater results were acceptable.

11.9 Discussion

Test 1, Functional Turn Out, assesses the dancer's stance in the rotated position. The dancer's turned-out stance in *first position* should follow exactly the same biomechanical principals that apply to recognized balanced posture of shoulder girdle, spine, pelvis, foot and ankle. Levangie and Norkin (2011) state, 'slight deviations from the optimal posture are to be expected because of the many individual variations found in body structure. However, deviations from the ideal posture that are large enough to either create unbalanced forces around joints or to cause other parts of the body to compensate for the deviations need to be identified and remedial action taken.'

The four faults on the scoring sheet for this test are common postural faults seen in dancers as they adopt the turned-out position. There was very little agreement amongst the physiotherapists (k = -0.036 – 0.214). Intra-rater reliability was fair to excellent (k = 0.314 – 0.840). Recognising fundamental problems in a dancer's turned-out stance is basic to identifying not only causes for injury in the young dancer, but also a lack of coordination and technical improvement. This is not only the teacher's domain. There needs to be agreement between physiotherapists as to the identified faulty elements and this directs corrective interventions when caring for a dancer.

Single Leg Turn Out, Back Bend and Arabesque were also low, with agreement negligible. In each case, however, the intra-rater reliability ranged from fair to excellent. The Single Leg Turn Out Test is a basic test that shows the dancer, the teacher and the physiotherapist where true angle of turn out at the feet should be i.e., the foot angle where the hip external rotators can work efficiently to stabilise the externally rotated hip under a steady pelvis. The test can expose weakness in the hip and injury risk where the lower limb is absorbing high rotational torque due to the forced angle of the feet in the initial *5th position*.

The Single Leg Knee Bend which already has a degree of reliability (Almangoush et al., 2014; Junge et al.,2012; Chiemlewski et al., 2007) had marginally more agreement with raters 1 and 2 ranging from slight to moderate (*k* = 0.085 – 0.502), raters 1 and 3 ranging from fair to moderate (*k* = 0.257 – 0.440) and raters 2 and 3 ranging from slight to good (*k* = 0.159 – 0.673). Again intra-rater reliability was significantly better with Rater 3 achieving excellent, Rater 2 moderate to good and Rater 1 slight to moderate.

The same test in turn out was significantly lower in rater agreement, possibly because the placement of the cameras allowed less accurate view of the externally rotated lower limb alignment. The intra-rater kappa coefficients were higher, but erratic, ranging from slight to excellent.

The Plank Test was examined for reliability by Tong et al. (2014) and Boyer et al. (2013) but the current strength/endurance/stability test in this reliability enquiry included assessment of shoulder girdle as well as spine and pelvis. The raters saw faults differently with minimal agreement but subjectively Rater 3 achieved excellent (*k* = 1.000), Rater 2, good (*k* = 0.722) and Rater 3, slight (*k* = 0.185).

11.10 Limitations Exposed by Results

There were 5 -6 movement errors for each FMC test. This level of detail was an attempt to create a more responsive rating system. However, the greater the number of points or faults possible, the closer scrutiny and concentration are required by the raters. It is possible that that rater fatigue was present and this was one of the reasons for poor reliability scores. The more complex and numerous the faults, the more onerous the task and the greater number of scoring options, increases the probability of disagreement (Chmielewski et al., 2007). It was one of the concerns voiced by one of the raters. They were also concerned with their own different levels of tolerance from day to day as the scoring had to be paced due to length of time needed to complete the task. The aim of reliability studies is to establish tests that produce stable results because of strict and consistent criteria. To this end it was realised that the scoring was too lengthy and complex to be practical.

For clarity and simplicity and smooth flow of the video session the positioning of cameras was changed only once, but as a result the rater's view of the Single Knee Bend in Turn Out was thought to be compromised. In the Single Knee Bend Test before, the anterior view of the dancer allowed assessment of pelvis and knee deviation. In the following test with the lower limb externally rotated, the view was compromised, and alignment of knee and forefoot less clearly evaluated. This may have accounted for the lower strengths of agreement. In the clinical situation this would not be an issue as the clinician would locate for the best view of alignment.

Also, in the Single Knee Bend Test the dancer was asked to perform their usual depth of *fondu* (knee bend) but this was not closely monitored and therefore not standardised. Chmielewski et al. used electromagnetic motion-tracking sensors on foot, shank and thigh in order to standardize knee flexion angle during the unilateral squat. One physiotherapist remarked that a slightly shallower knee bend could compensate for lack of stability which may have taken place. In this screen more emphasis and checking knee bend depth could counter such a compensation as technological assistance is not possible in the clinical situation.

None of the raters reported that they had not been coached well enough to score reliably. Each felt that they had a great deal of experience in the field and were surprised to find that they were rarely in agreement throughout the FMC screen. They had felt confident and decisive – evidenced by their intra-rater reliability. Inter-rater reliability is an important aim of this exercise, as this is an initial step towards developing a standardized method of evaluating movement quality during lower extremity and trunk, functional tasks in ballet dancers.

Researchers who have attempted reliability studies have found it necessary to train raters extensively. Kenny et al. (2018) familiarised the raters with their particular test battery by testing protocol over an extensive 3-hour training session 1 week prior to testing. Luomajoki et al. (2007) reported that all four of their therapist raters mentioned that better protocol training could have been carried out before they scored a series of 10 movement control tests for the lumbar spine. (Their inter-tester reliability ranged between 0.24 – 0.71). Van Dillen et al. (1998) in their examination of low back pain found that therapists were less likely to agree on judgements of alignment and movement and advocated thorough familiarization and training on each test. (The therapists studied a supplied manual, took a written exam and had to achieve 90% before testing began.)

In depth training is required in spite of experience, especially if therapists have not worked with one another.

In this study we screened a homogeneous group of pre-professional dancers. The movement and alignment deviations were mostly subtle, to the untrained eye, as classical ballet is based on fine control. Chmielewski et al. stated that severe movement deviations could be easily discriminated, and the challenge is to develop standardized scoring methods to discern minor movement deviations. The physiotherapists were not given instruction for rating severity and questioned how much loss of stability, control or balance was acceptable before allocating the fault. How much tolerance should they have? It was apparent that much clearer demarcation was required.
A solution would be to work with a teacher on scoring technical moves in order to understand common ground. Teachers are not trained in biomechanics and an exchange of ideas would open up a useful dialogue between professions.

11.11 Conclusion

This evaluation can be seen as an initial trial of scoring functional movements in the young classical ballet dancer. It has shown that any of the following could be true:

a. The selected tests are inappropriate for this population.
b. The physiotherapists were not experienced enough in movement control assessment.
c. The physiotherapists had not been trained well enough to have a standardised approach.

d. The scoring system was ambiguous.
e. The tests are all unreliable (inter-rater category).

The selected tests were based on the consensus of a significant Delphi Survey and supported by consultation with an expert group in the field and therefore were believed to be apposite. The physiotherapist raters were purposely selected for their varied experience in the field and therefore assumed to be well qualified to take on this task.

In order to find the way forward it was decided to reconsider the modifiable aspects such as the scoring system and training the physiotherapists further before attempting to repeat the exercise.

Chapter 12 proceeds with the revised protocol used the second time and the same physiotherapists undertook the scoring of exactly the same videos of the Functional Movement Control screen, in order to answer each of these questions.

Chapter 12. Revised Functional Movement Control Screen Exercise Methods

In Chapter 10 the procedure for filming the FMC screen exercises was explained with the testing protocol and justification. In Chapter 10 the results of the intra- and inter-rater reliability studies were presented and discussed. The lack of agreement between the physiotherapists on the scoring of each test, in spite of encouraging intra-rater reliability, meant that the protocol required reconsidering several of its features. The follow-up implementation was based on feedback from the physiotherapists and trialling the tests as a group, to reveal the main weaknesses in the assignment. The process of revising the task and redesigning a repeat exercise is described in this chapter.

12.1 Examining Inter-rater Reliability

The lead researcher MM, met with the physiotherapists to discuss the initial test results. Firstly, the physiotherapists were questioned closely regarding their opinion of the protocols regarding the FMC screen and any particular difficulties they had, especially considering their prior experience.

- While the physiotherapists did not complain of fatigue, they were concerned that their level of tolerance might have been different day to day as the work had to be spread out. They were given three weeks.
- The severity or subtlety of movement deviation was questioned. The words 'acceptable' and 'excessive' can be interpreted differently and while each physiotherapist was consistent in their marking with satisfactory intra-rater reliability, they did not necessarily agree with each other on what was acceptable or excessive and therefore the inter-rater reliability was poor.
- It was suggested by one of the physiotherapists that the camera angles for the Single Leg Knee Bend in Turnout did not allow an accurate view of the turned out lower limb which may have caused ambiguity for that test.

- They were unsure of the shoulder girdle element of the Plank Test 7. And exactly when scapular stability was lost.

They were reassured that a reliability test needed to withstand 'day to day' variability in tolerance. They did not complain however, that they had been poorly prepared for the exercise – they had, after all, been chosen for their expertise. Neither did they question the relevance of any of the tests and their suitability.

It was decided that the scoring should be repeated and that it was important to keep the same number of student participants in the second scoring session by the same physiotherapists in order to retain power in statistics calculation. The physiotherapists were requested to repeat the exercise and each consented. Considering the results, the lead researcher (MM) concluded that the main hurdle was the lack of training compared to that undertaken by other research groups where preparation and standardisation with the physiotherapists in discussion prior to the exercise was given significant time. It had not been possible to meet as a group, pilot, score and compare results as the physiotherapists did not know each other and had not worked together. Shultz et al. (2013) concluded that researchers should focus on the influence of rater training. These researchers also found that their highly repeatable test was less reliable when multiple users were involved.

12.2 Scoring

It was concluded that the expectation to detect numerous, sophisticated and subtle compensations was too ambitious without a great deal more preparation. The initial FMC scoring form had up to 7 possible faults for each test. The raters were consistent with their marking but alignment variations being too numerous and often subtle, resulted in infrequent agreement. Kappa value is influenced by the number of categories - too numerous and the extent of the agreement will generally decrease (Portney and Watkins, 2009). Following this, the scoring of the FMC screen was revisited, and the scoring form made simpler with only the most significant misalignments related to injury risk, listed. A 5-point ordinal scale was used with observation only of the most fundamental faults relating to specific body segments and to which the physiotherapist was repeatedly referred. Perfect execution = 0. Each of 4 faults was allocated a point. The more points accumulated, 1 – 4, the more incorrect the execution.

Table 12.1 Revised FMC scoring sheet

	Functional Movement Control Scoring Physiotherapists				
	Dancer: Date:			R	L
1	Functional turnout test	a	Tension in the neck with poking/retracted chin		
		b	Poor shoulder alignment/stabilisation		
		c	Anterior/posterior tilted pelvis		
		d	Poor lower abdominal activation with/without weight back		
2	Single leg TO control test	a	Pelvis rotates towards WB side		
		b	Loss of pelvic horizontal plane		
		c	Unsteady stance		
		b	Foot has to adjust to preserve balance		
3	Single leg knee bend test	a	Loss of pelvic horizontal plane (hip hitch/drop on lifted side)		
		b	Excessive pelvic tilt or rotation		
		c	Patella points past inside 1st toe (valgus)		
		d	Stance knee/leg wobbles noticeably		
4	Single leg knee bend in TO test	a	Loss of pelvic horizontal plane (hip hitch/drop on lifted side)		
		b	Excessive pelvic tilt or rotation		
		c	Patella points past inside of 1st toe (valgus)		
		d	Stance knee/leg wobbles noticeably		
5	Backbend test	a	Hinging from lower lumbar spine		
		b	Stiff thoracic spine		
		c	Insufficient abdominal activation		
		d	Swaying forwards from pelvis with increased hip extension		
6	Arabesque test	a	Tension in neck with retraction/protraction		
		b	90^{o} line with hinging in lumbar spine		
		c	Poor abdominal control		
		d	Restricted height of leg (due to restricted spinal extension)		
7	Plank Test	a	Loss of line – increased/decreased lordosis		
		b	Visible winging of scapulae		
		c	Rotation of pelvis evident in leg lifts		
		d	Visible struggle to hold for 40 secs		

12.3 Ethics Approval

The Ethics Committee at UCL was informed that the study (7693/003) was delayed. Extra time was requested and granted.

12.4 Supplementary Training of the Physiotherapists

The lead researcher requested each physiotherapist to rate a number of selected tests using the revised score sheet. This was followed by group meetings carried out remotely to examine the results, discuss any ambiguities and recommend further adjustments to the wording of the score sheet. This required two remote sessions of 80 minutes each, to familiarise the physiotherapists with the revisions.
Each test was discussed and each fault and its wording was considered. Each physiotherapist suggested further adjustments to the scoring and therefore felt part of the second exercise. It was also felt that this cohesion encouraged engagement. It was decided that any fault however subtle, if observed, was registered. This is because any lack of control in these simple tests would be magnified in dynamic movement.

Scoring four components within seven tests (11 per dancer with right and left sides) carried out on 18 participants in two rounds was still a challenge for the physiotherapists. There were also 2 views of each dancer to watch, making this still a substantial amount of work requiring considerable concentration, as any screening exercise would be in clinic. However, they felt better equipped, more knowledgeable and discerning after the extra training. The aim was to manage each screen in under 20 minutes.

12.5 Procedure of the repeat FMC Screening Exercise

The procedure was similar to the initial session. The hard copies of the new scoring form and the USBs were delivered to each assessor. Again, there was no conferring between raters. After each scoring round, the hard copies were collected. This USBs were retained and kept securely by the raters in preparation for the second round. Raters 1 and 3 finished both rounds within a month but Rater 2 needed another month due to work commitments. Hard copies were collected and emailed to a UCL computer and then kept securely with the USBs. The results were again entered into SPSS by the lead researcher and analysed as before. This time the total screen score was considered.

The substantial amount of time this screen takes when performed with the 15-minute Range of Movement Screen may be criticised. At audition this amount of time is rarely given to the screening professional unless there are questions posed by the artistic panel regarding some candidates. However, to have a battery of tests from which to select those of key importance, is a valuable tool. There is potential here to even combine tests to accelerate the screen and still acquire an accurate insight into control deficits.

The results of the revised FMC scoring exercise are reported in the next chapter. Following is a flow chart explain the methods for the revised FMC scoring.

FLOW CHART for CHAPTER 12 METHODS – REVISED FMC SCORING

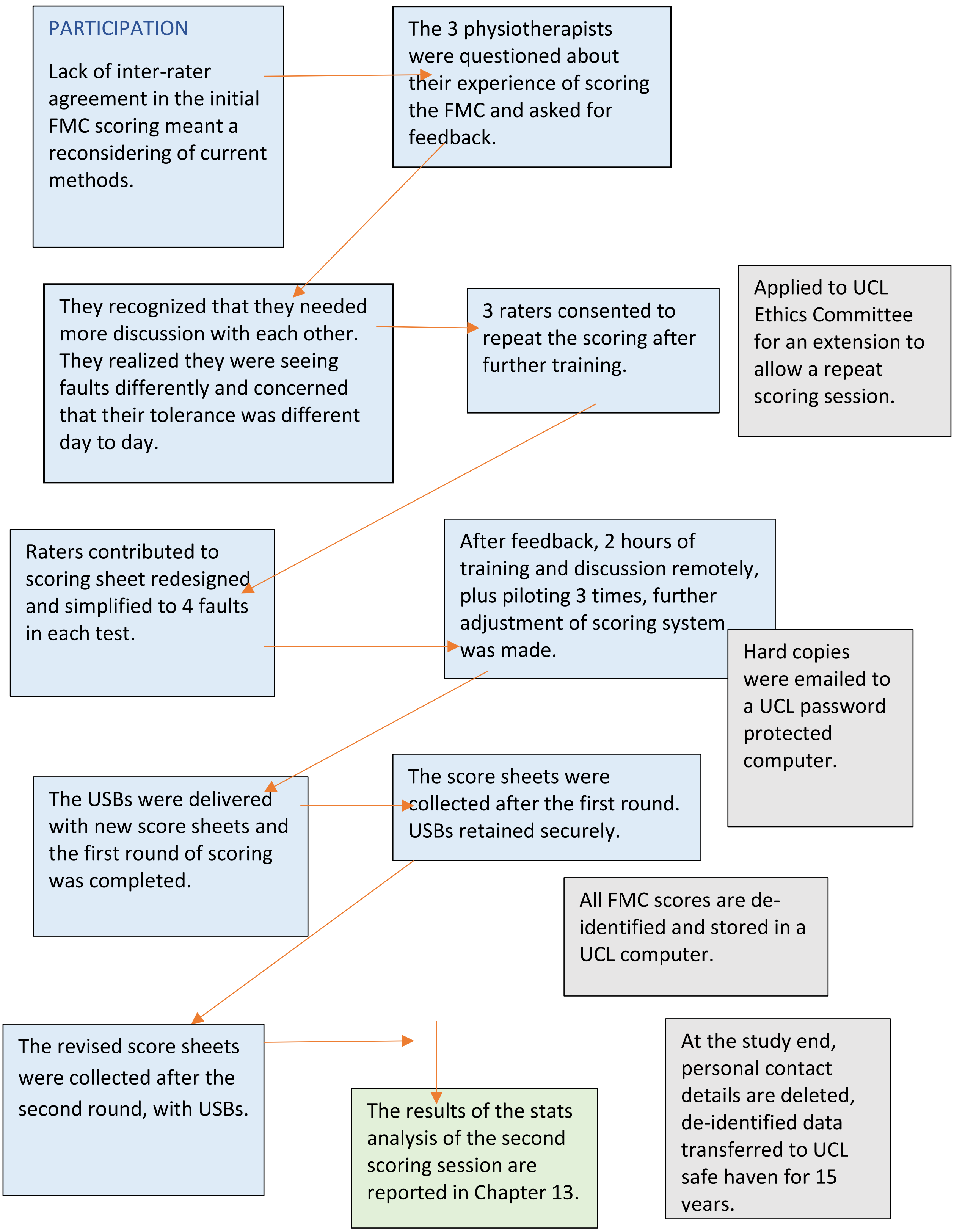


Figure 12.1 Flow Chart for Chapter 12 Methods

Chapter 13. Revised Functional Movement Control Screen Results, Intra- and Inter-rater Reliability, Interpretation and Discussion.

13.1 Introduction

The results of the revised Functional Movement Scoring are presented here. The procedure and analysis were the same, with revised scoring protocol.

It was decided that a test should have a kappa value above 0.4 for inter-rater reliability in this study (reported in Chapter 9.8.), in alignment with previous studies (Luomajoki et al., 2007; Van Dillen et al., 2003). Luomajoki et al. recommended that the lower bound confidence interval (95%) should be over 0.2 to be able to declare the reliability at least fair. In the graphs displayed with each of the test results, this (0.2) is indicated by the red line and the cut-off for kappa (0.4) is indicated by the green line. Reporting percentage agreement as well as the kappa statistic ensures that reliability is fully appreciated. In this study the benchmark was .40 and upwards.

Table 13.1 Scale of kappa value interpretation (Landis and Koch, 1977)

Cohen's Kappa score	Strength of Agreement
>0	No agreement
0.01 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Good/substantial
0.81 – 1.0	Excellent/Almost perfect

Highlight shows acceptable values

13.2 Results

A photograph of each test and its purpose are included here for clarity, followed by results. These are illustrated in table form displaying Cohen's kappa coefficient (κ), the percentage agreement and strength of agreement. Bar graphs showing kappa levels with confidence intervals supporting these.

A photograph of each test and its purpose are included here for clarity, followed by results. These are illustrated in table form displaying Cohen's kappa coefficient (κ), the percentage agreement and strength of agreement. Bar graphs showing kappa levels with confidence intervals support these.

13.2.1 Test 1. Functional Turn Out (FTO)

Figure 13.1 Functional Turn Out

This test examines the classical ballet dancer's posture with the characteristic externally rotated lower limbs demanded by the technique.

The three raters achieved high kappa results with excellent agreement for intra-rater reliability of Functional Turn Out.

Table 13.2 Functional Turn Out Intra-rater reliability and % Agreement

Functional Turn Out	kappa	% Agreement	Strength of Agreement
Rater 1	.849	88.8	Excellent
Rater 2	.843	88.8	Excellent
Rater 3	1.000	100	Excellent

Inter-rater Reliability of Functional Turn Out

Only raters 1 and 3 reached moderate agreement (.410 - .417) with an acceptable kappa score. Reliability of raters 1 and 2, and 3 and 2 was poor. This will be considered in the discussion Section 12.7.

Table 13.3 Functional Turnout: Inter-rater reliability and % agreement

Functional Turn Out	kappa	% Agreement	Strength of Agreement
Round 1 Inter-raters 1/2	.022	22%	Slight
Round 2 Inter-raters 1/2	.079	11%	No agreement
Round 1 Inter-raters 1/3	.410	55.5	Moderate
Round 2 Inter-raters 1/3	.417	55.5	Moderate
Round 1 Inter-raters 2/3	-.098	0%	No agreement
Round 2 Inter-raters 2/3	-.110	0%	No agreement

The contrast of inter- and intra-rater reliability is shown in the following chart. The green line indicates the cut-off for reliability at ≥ .4.

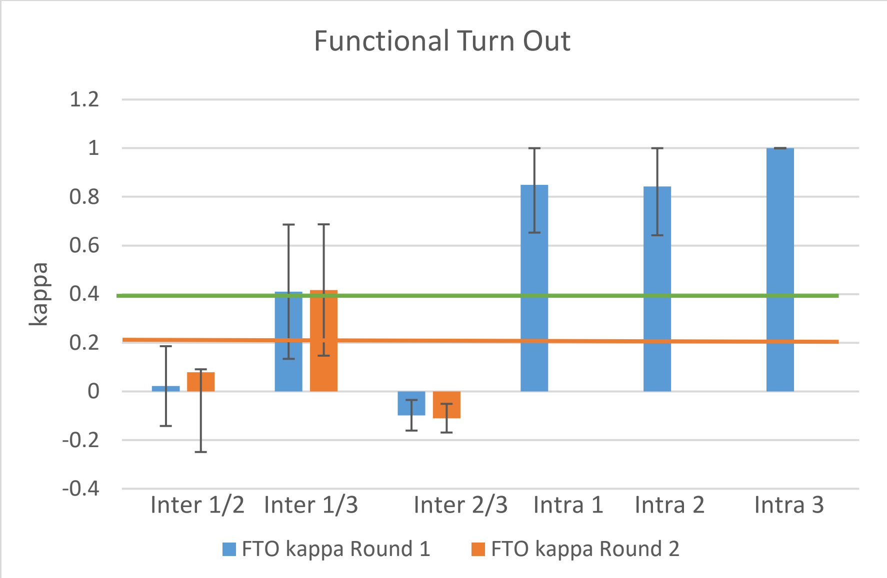


Figure 13.2 Intra- and inter-rater results for the Functional Turn Out test. The lower bound confidence interval (95%) should be over 0.2. The red line indicates this and the cut-off for kappa is indicated by the green line (Luomajoki et al., 2007).

13.2.2 Test 2. Single Leg Turn Out (SLTO) Control

Figure 13.3 Single Leg Turn Out on Right

This test challenges the stability of the supporting side and the ability to maintain external rotation with stable pelvis.

Reliability was substantial to excellent for intra-rater reliability Single Leg Turn Out.

Table 13.4 Intra-rater reliability Single Leg Turnout

Single Leg Turnout	kappa Right Side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Rater 1	.716	83	Substantial	.820	89	Excellent
Rater 2	.711	83	Substantial	.904	94	Excellent
Rater 3	1.000	100	Excellent	1.000	100	Excellent

Inter-rater Reliability Single Leg Turnout

The inter-rater results for this test were moderate to excellent (kappa = .449 – 1.000) making the test one of the most reliable in the FMC screen. Kappa coefficients above .4 but it is noted that in the second rounds of the test the lower confidence intervals reached below .2 for raters 1 and 2 and raters 2 and 3.

Table 13.5 Inter-rater reliability Single Leg Turnout

Single Leg Turnout	Kappa Right side	% Agreement	Strength of agreement	Kappa Left Side	% Agreement	Strength of agreement
Round 1 Inter-rater 1/2	.638	78	Substantial	.567	67	Moderate
Round 2 Inter-rater 1/2	.489	72	Moderate	.449	67	Moderate
Round 1 Inter-rater 1/3	.710	83	Substantial	1.000	100	Excellent
Round 2 Inter-rater 1/3	.604	78	Substantial	.820	89	Excellent
Round 1 Inter-rater 2/3	.813	89	Excellent	.567	67	Moderate
Round 2 Inter-rater 2/3	.686	83	Substantial	.471	67	Moderate

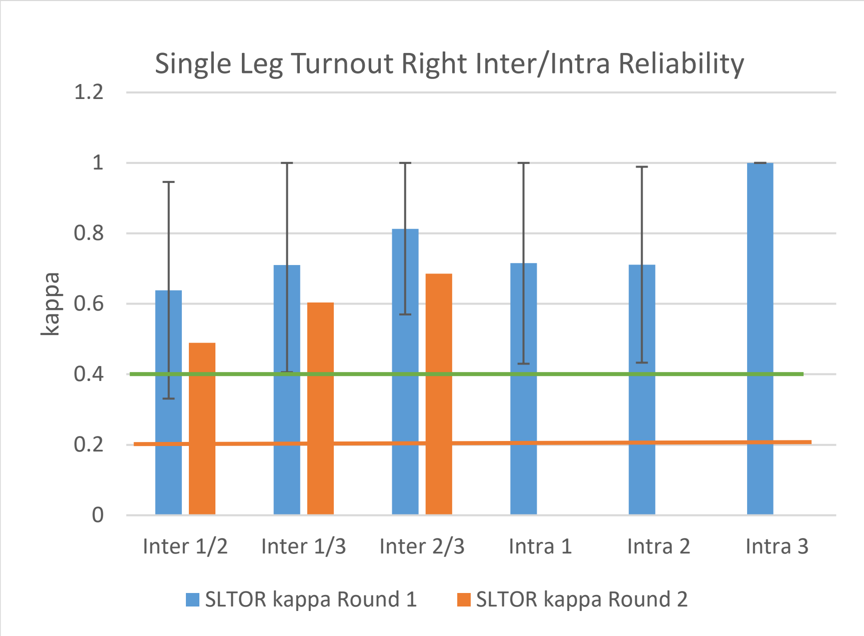


Figure 13.4. Single Leg Turn Out Right side showing inter- and intra-rater reliability with standard error. The lower bound confidence interval (95%) should be over 0.2 (Luomaki et al., 2007). The red line indicates this and the cut-off for kappa is indicated by the green line.

13.2.3 Test 3. Single Leg Knee Bend (SLKB)

Figure 13.5 Single Leg Knee Bend on Right

In ballet technique this functional movement is known as a *fondu* and is performed in hip external rotation. The parallel *fondu* is examined here to assess for joint stability dependent on muscle activation

Intra-rater Reliability Single Knee Bend Test

The intra-rater reliability was substantial to excellent in this test (κ = .679 - .855).

Table 13.6 Single Leg Knee Bend Intra-rater Reliability

Single Leg Turn Out	kappa Right Side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Rater 1	.776	83	Substantial	.693	78	Substantial
Rater 2	.854	89	Excellent	.679	78	Substantial
Rater 3	.710	78	Substantial	.855	94	Excellent

Inter-rater reliability Single Knee Bend

The Inter-rater agreement in this test was moderate to excellent (κ = .379 - .820). The kappa coefficients were all but one, above 0.4. Lower confidence intervals for raters 2 and 3 reached below 0.2 in the second round.

Table 13.7 Single Knee Bend Inter-rater Reliability

Single Knee Bend	kappa Right side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Round 1 Inter-rater 1/2	.426	50.5	Moderate	.457	55.5	Moderate
Round 2 Inter-rater 1/2	.405	50	Moderate	.568	67	Moderate
Round 1 Inter-rater 1/3	.556	67	Moderate	.492	61	Moderate
Round 2 Inter-rater 1/3	.604	78	Substantial	.820	89	Excellent
Round 1 Inter-rater 2/3	.506	61	Moderate	.455	55.5	Moderate
Round 2 Inter-rater 2/3	.490	50	Moderate	.379	50	Fair

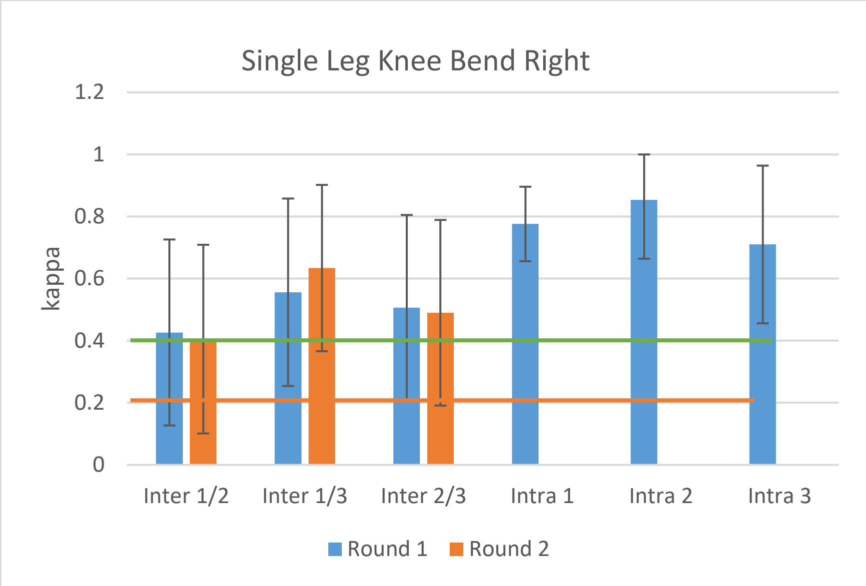


Figure 13.6 Inter- and intra-rater reliability of the Single Leg Knee Bend Test on the right with confidence intervals. The lower bound confidence interval (95%) should be over 0.2. The red line indicates this and the cut-off for kappa is indicated by the green line.

13.2.4 Test 4. Single Leg Knee Bend in Turn Out (SLKBTO)

This test assesses the dancer's *fondu* and the integrity of the kinetic chain with external rotation of the hip.

Figure 13.7 Single Leg Knee Bend in Turn Out

Intra-rater reliability for Single Leg Knee Bend in Turn Out results were mostly excellent

(κ = .702 – 1.000)

Table 13.8 Single Leg Knee Bend in Turn Out Intra-rater reliability

Single Knee Bend in Turn Out Intra-rater Reliability						
Single Leg Turn Out	kappa Right Side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Rater 1	.826	89	Excellent	.702	83	Substantial
Rater 2	.846	88	Excellent	.921	94	Excellent
Rater 3	1.000	100	Excellent	1.000	100	Excellent

Inter-rater Reliability Single Leg Knee Bend in Turn out

Inter-rater results for this test were moderate to excellent (κ = .450 - .827) and although kappa coefficients were all above 0.4, lower bound confidence intervals were below 0.2 for raters 2 and 3 in Round 2.

Table 13.9 Single Leg Knee Bend in Turn Out Inter-rater reliability

Single Knee Bend in Turn Out Inter-rater Reliability						
Single Knee Bend	kappa Right side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Round 1 Inter-rater 1/2	.548	67	Moderate	.502	67	Moderate
Round 2 Inter-rater 1/2	.548	67	Moderate	.596	72	Moderate
Round 1 Inter-rater 1/3	.749	83	Substantial	.449	67	Moderate
Round 2 Inter-rater 1/3	.827	89	Excellent	.724	83	Substantial
Round 1 Inter-rater 2/3	.528	67	Moderate	.505	61	Moderate
Round 2 Inter-rater 2/3	.450	61	Moderate	.442	61	Moderate

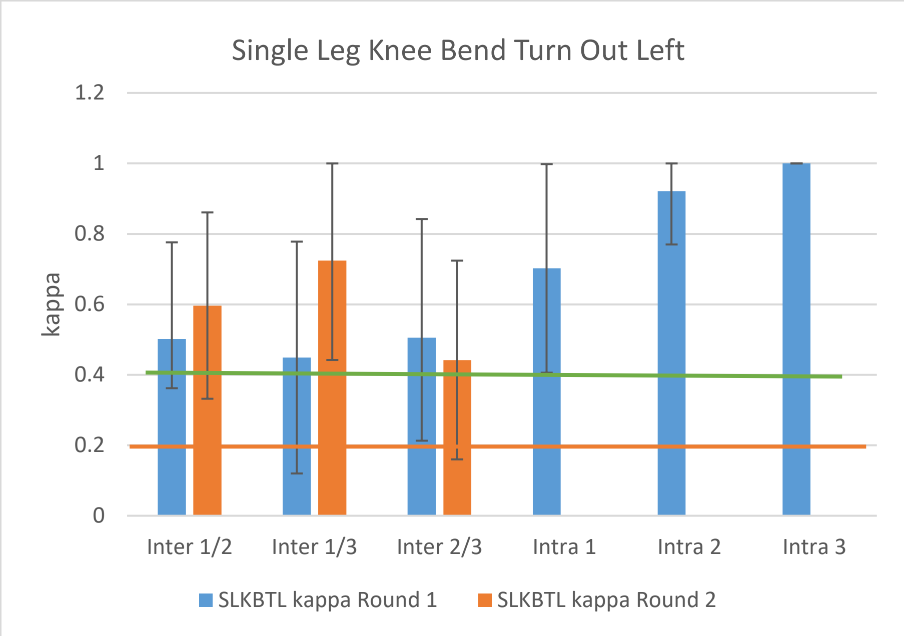


Figure 13.8 Inter-rater and intra-rater reliability of the Single Leg Knee Bend in Turn Out with standard error. The lower bound confidence interval (95%) should be over 0.2. The red line indicates this and the cut-off for kappa is indicated by the green line.

13.2.5 Test 5. Backbend Test

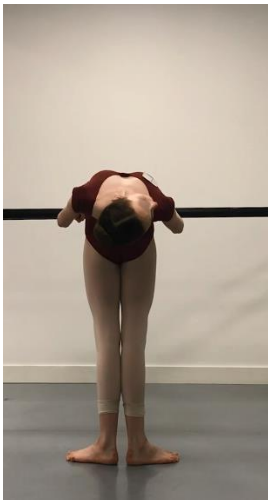


Figure 13.9 Back Bend Test

The balletic back bend requires pelvic stability and use of extension throughout thoracic and lumbar spine. The movement requires spinal flexibility and ease of excursion over lower limb

Table 13.10 Back Bend Test Intra-rater reliability

Intra-rater reliability			
Back Bend Test	kappa	% Agreement	Strength of Agreement
Rater 1	.919	94	Excellent
Rater 2	.846	89	Excellent
Rater 3	.764	83	Substantial

Inter-rater Reliability

Inter-rater reliability was low in this test. Agreement between the raters when assessing extension of the spine, a common functional but technically demanding movement, appeared difficult to achieve. However, each of the raters were confident in their individual observations, achieving outstanding kappa coefficients in intra-rater reliability (.764 - .919).

Table 13.11 Back Bend Test Inter-rater reliability

Inter-rater Reliability Back Bend Test			
Back Bend Test	kappa	% Agreement	Strength of agreement
Round 1 Inter-rater 1/2	.347	50	Fair
Round 2 Inter-rater 1/2	.150	39	Slight
Round 1 Inter-rater 1/3	.311	44	Fair
Round 2 Inter-rater 1/3	.475	61	Moderate
Round 1 Inter-rater 2/3	.129	33	Slight
Round 2 Inter-rater 2/3	.004	-	-

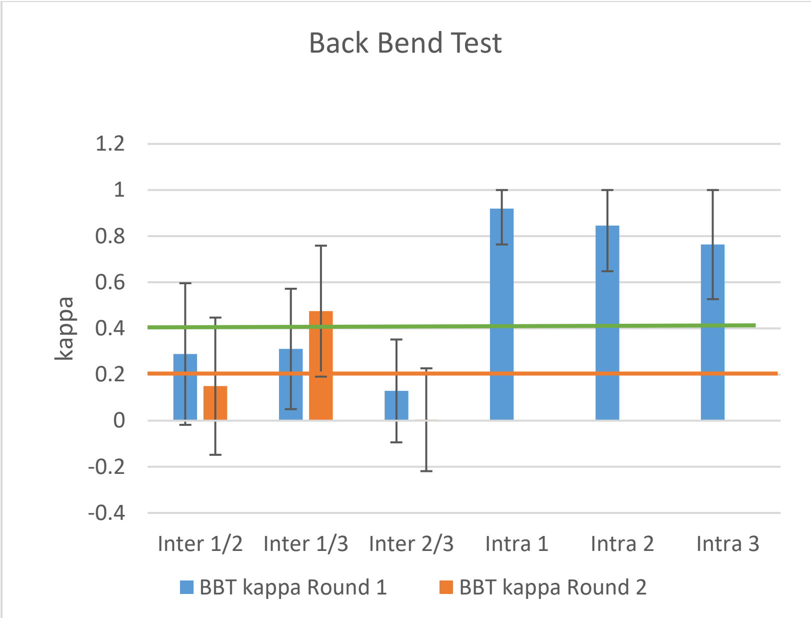


Figure 13.10 Inter-rater and intra-rater reliability of the Back Bend Test with standard error. The lower bound confidence interval (95%) should be over 0.2. The red line indicates this and the cut-off for kappa is indicated by the green line.

13.2.6 Test 6. Arabesque Test

Figure 13.11 Arabesque Test Left

The arabesque move in ballet requires extension of the spine with ipsilateral rotation and side flexion. For spinal integrity, flexibility and ease when extending the hip and lower limb are required, with finely tuned trunk control.

Again, intra-rater reliability was high with each rater achieving substantial to outstanding intra-rater results (k = .713 – 1.000).

Table 13.12 Arabesque Test Intra-rater reliability

Intra-rater Reliability Arabesque Test						
Arabesque Test	kappa Right Side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Rater 1	.822	89	Excellent	.713	72	Substantial
Rater 2	.761	83	Substantial	1.000	100	Excellent
Rater 3	.819	89	Excellent	1.000	100	Excellent

Inter-rater Reliability

The third technique test where the raters assess for injury risk achieved low inter-rater kappa coefficients ranging from mostly fair to substantial (k = .289 - .654). However, inter-rater reliability was moderate to substantial between raters 1 and 3 reaching a kappa coefficient > .6 on the right and > .4 on the left. Lower bound confidence intervals were below 0.2 on the left. Agreement was low between 1 and 2 and 2 and 3.

Table 13.13 Arabesque Test Inter-rater reliability

Inter-rater Reliability Arabesque Test						
Arabesque Test	kappa Right side	% Agreement	Strength of Agreement	kappa Left Side	% Agreement	Strength of Agreement
Round 1 Inter-rater 1/2	.351	55.5	Fair	.336	44	Fair
Round 2 Inter-rater 1/2	.289	50	Fair	.301	44	Fair
Round 1 Inter-rater 1/3	.654	78	Substantial	.460	67	Moderate
Round 2 Inter-rater 1/3	.621	78	Substantial	.511	72	Moderate
Round 1 Inter-rater 2/3	.371	55.5	Fair	.348	55.5	Fair
Round 2 Inter-rater 2/3	.389	50	Fair	.348	55.5	Fair

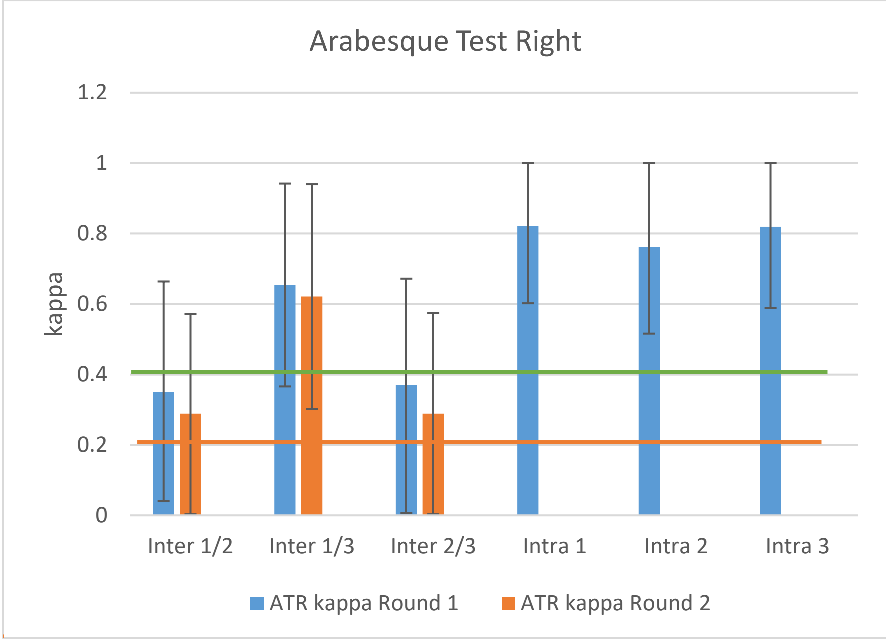


Figure 13.12 Inter- and intra-rater reliability of the Arabesque Test on the right side. The lower bound confidence interval (95%) should be over 0.2. The red line indicates this and the cut-off for kappa is indicated by the green line.

13.2.7 Test 7. Plank Test

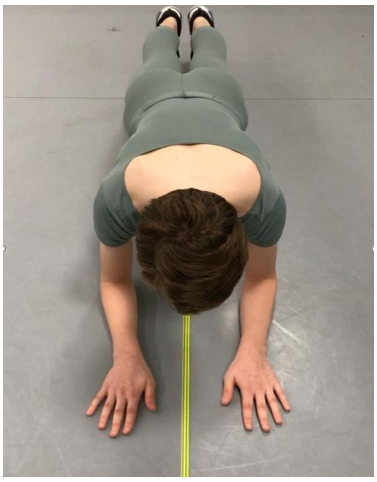


Figure 13.13 Plank Test

The plank assessment is a recognised test for global core integrity and endurance and is used here in an adjusted form.

In the Plank Test the inter-rater agreement was fair to moderate. The intra-rater agreement for each physiotherapist was excellent.

Intra-rater Reliability

Table 13.14 Plank Test Intra-rater reliability

Intra-rater reliability Plank Test			
Plank Test	kappa	% Agreement	Strength of Agreement
Rater 1	.838	89	Excellent
Rater 2	1.000	100	Excellent
Rater 3	1.000	100	Excellent

Inter-rater reliability in the plank test was fair to moderate (k = .347 - .471). The physiotherapists were asked to score shoulder girdle stability, specifically scapular stabilization as part of the core strength in this test but there was a lack of agreement on the fatiguing scapular position. However, intra-rater reliability was outstanding (.838 – 1.000) indicating a consistency in scoring. These incompatible results are discussed in the Discussion section (12.7).

Table 13.15 Plank Test Inter-rater reliability

Inter-rater reliability Plank Test			
Plank Test	kappa	% Agreement	Strength of Agreement
Round 1 Inter-rater 1/2	.347	50	Fair
Round 2 Inter-rater 1/2	.347	50	Fair
Round 1 Inter-rater 1/3	.395	44	Fair
Round 2 Inter-rater 1/3	.471	61	Moderate
Round 1 Inter-rater 2/3	.438	55.5	Moderate
Round 2 Inter-rater 2/3	.438	55.5	Moderate

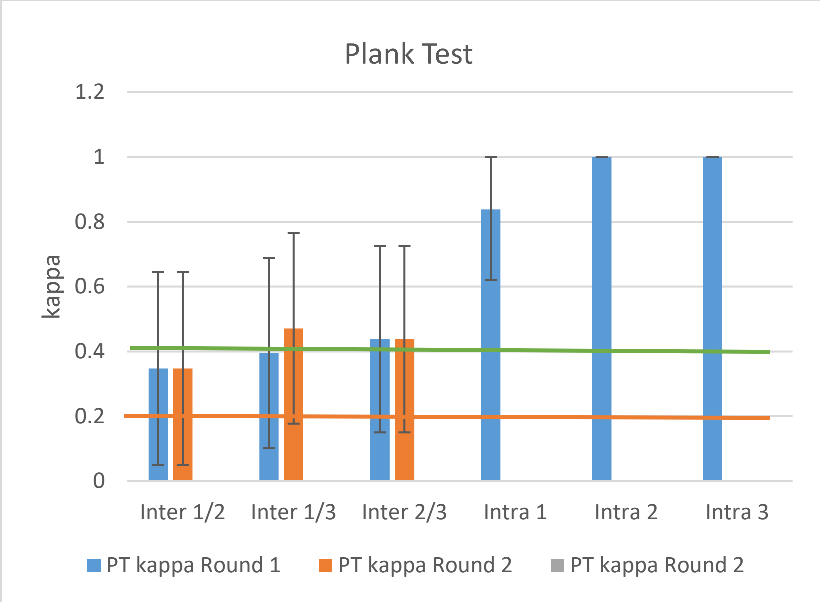


Figure 13.14 Inter- and intra-rater reliability for the Plank Test. The lower bound confidence interval (95%) should be over 0.2. The red line indicates this and the cut-off for kappa is indicated by the green line.

Table 13.16 Total Score for Functional Movement Control Intra-rater Reliability

FMC Screen Total Score Intra-rater Reliability		
	kappa	% Agreement
Rater 1	.679	83%
Rater 2	.893	94%
Rater 3	1.00	100%

Table 13.17 Total Score Inter-rater Reliability

FMC screen Total Score Inter-rater Reliability		
	kappa	% Agreement
Round 1 Inter-rater 1/2	.893	94%
Round 2 Inter-rater 1/2	.893	94%
Round 1 Inter-rater 1/3	.778	88%
Round 2 Inter-rater 1/3	.684	77%
Round 1 Inter-rater 2/3	.684	78%
Round 2 Inter-rater 2/3	.778	88%

13.2.8 Total Scores for Functional Movement Control Proficiency

Maximum score = 44

Minimum score = 0

<u>Suggested categories</u>

0 – 18 = Excellent control

19 – 30 = Moderate control

31 – 44 = Poor control

13.3 Overview of Results

The following Table 13.18. and Table 13.19. show all the tests included in the Functional Movement Control screen, the kappa statistic calculated for Raters 1, 2 and 3 and Raters 1/2, 1/3 and 2/3, 95% Confidence Interval, Standard Error and P-value.

Table 13.18 Results overview of intra-rater reliability for each test in the Functional Movement Control Screen

Rater	Functional Turn Out	Single Leg Turn Out R	Single Leg Turn Out L	Single Knee Bend R	Single Knee Bend L	Single Knee Bend Turn Out R	Single Knee Bend Turn Out L	Back Bend	Arabesque R	Arabesque L	Plank Test
Results of intra-rater reliability											
Rater 1 Kappa	.849(.653-1.0)	.716(.43-1)	.82(.59-1.0)	.776(.656-.896)	.691(.557-.953)	.826(.599-1.0)	.702(.406-.998)	.919(.764-1.0)	.822(.602-1.0)	.713(.427-.999)	.838(.621-1.0)
% Agreement	88.8%	83%	89%	89%	77%	89%	83%	94%	89%	72%	89%
Standard Error	.1	1.46	.116	.120	.134	.116	.151	.079	.113	.146	.111
P-value	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
Rater 2 Kappa	.843(.642-1.0)	.711(.433-.989)	.904(.724-1.0)	..854(.664-1.00)	.679(.411-.947)	.849(.65-1.0)	.921(.77-1.0)	.846(.648-1.0)	.716(.516-1.00)	1	1
% Agreement	88.8%	83%	94%	89%	77%	88%	94%	83%	83%	100%	100%
Standard Error	.103	.142	.090	.097	.137	.1	.077	.125	.125		
P-value		.000	.000	.000	.000	.000	.000	.000	.000		
Rater 3 Kappa	1	1	.710(.456-.964)	.710	.855(.667-1.0)	1	1	.764(.527-1)	.819(.588-1.0)	1	1
% Agreement	100%	100%	77.7%	78%	88%	100%	100%	83%	89%	100%	100%
Standard Error			.130	.130	.096			.121	.118		
P-value			.000	.000	.000			.000	.000		

Table 13.19 Results overview of inter-rater reliability for each test in the Functional Movement Control Screen

Functional Movement Control	Functional Turn Out	Single Leg Turn Out R	Single Leg Turn Out L	Single Knee Bend R	Single Knee Bend L	Single Knee Bend Turn Out R	Single Knee Bend Turn Out L	Back Bend	Arabesque R	Arabesque L	Plank Test

Raters 1/2 Inter-rater reliability											
Round 1 Kappa (CI 95%)	.022(-.142-.186)	.638(.331-.946)	.567(.331-.946)	.426(.127-.726)	.457(.212-.702)	.548(.266-.830)	.502(.362-.776)	.289(-.018-.596)	.35(.04-.664)	.336(.007-.665)	.347(.05-.645)
% Agreement	22%	.78%	72%	55.5%	55.5%	66.6%	66.6%	30%	55.5%	44%	50%
Standard Error	.084	.157	.163	.153	.125	.144	.140	.157	.160	.168	.152
P-value	.795	.000	.000	.000	.000	.000	.000	.014	.016	.023	.005
Round 2											
Kappa (CI 95%)	-.079(-.249-.091)	.486(.135-.837)	.449(.112-.786)	.405(.101-.709)	.568(.264-.829)	.464(.172-.756	.596(.332-.861)	.150(-.003-.447)	.289(.003-.575)	.301(.04-.640)	.347(.05-.645)
% Agreement	-	72%	67%	55.5%	66.6%	61%	72%	39%	50%	44%	50%
Standard Error	.087	.179	.172	.125	.133	.149	.135	.152	.146	.173	.152
P-value	.421	.011	.009	.000	.000	.000	.000	.281	.021	.031	.005
Raters 1/3											
Round 1 Kappa (CI 95%)	.41(.134-.686)	.710(.406-1.0)	1	.556(.254-.858)	.492(.227-.757)	.749(495-1)	.449(.12-.778)	.311(.05-.572)	.654(.366-.942)	.460(.123-.797)	.395(.101-.689)
% Agreement	55.5%	83%	100%	66.6%	61%	83%	67%	44%	78%	67%	44%
Standard Error	.141	.155	0	.154	.130	.130	.168	.133	.147	.172	.159
P-value	.001	.000	0	.000	.000	.000	.000	.015	.000	.007	.002
Round 2											
Kappa (CI 95%)	.417(.134-.686)	.604(.283-.925	.82(.593-1.0)	.634(.366-.902)	.433(.161-.705)	.827(.598-1)	.724(.442-1)	.475(.191-.759)	.621(.302-.94)	.511(.166-.856)	.471(.177-.765)
% Agreement	55.5%	87%	89%	72%	55.5%	88.8%	83%	61	78%	72%	61%
Standard Error	.138	.164	.116	.137	.139	.117	.144	.145	.163	.176	.150
P-value	.001	.001	.000	.000	.000	.000	.000	.000	.001	.003	.000
Raters 2/3											
Round 1 Kappa (CI 95%)	-.098(-.161- -.035)	.813(.57-1.0)	.567(.247-.886)	.506(.207-.805)	.455(.205-.705)	.528(.231-.825)	.505(.213-.842)	.129(-.094-.352)	.371(.007-.672)	.348(.039-.658)	.438(.15-.726)
% Agreement	-	88.8%	67%	50%	55.5%	66.6%	61	33%	55.5%	55.5	55.5%
Standard Error	.032	.124	.163	.153	.128	.152	.149	.114	.154	.158	.147
P-value	.117	.000	.000	.000	.000	.000	.000	.243	.007	.012	.000
Round 2											

	Functional Turn Out	**Single Leg Turn Out R**	**Single Leg Turn Out L**	**Single Knee Bend R**	**Single Knee Bend L**	**Single Knee Bend Turn Out R**	**Single Knee Bend Turn Out L**	**Back Bend**	**Arabesque R**	**Arabesque L**	**Plank Test**
Kappa (CI 95%)	-.110(1.169- -.051	.686(.403-.969)	.471(.158-.784)	.490(.191-.789)	.379(.126-.632)	.450(.14-.759)	.442(.16-.724)	.004(-.219-.227)	.289(.003-.575)	.348((.039-.658)	.438(.15-.726)
% Agreement	-	83%	66.6%	61%	50%	61%	61%	22%	50%	55.5%	55.5%
Standard Error	.030	.146	.160	.153	.129	.31	1.44	.114	.146	.158	.147
P-value	.108	.000	.004	.000	.000	.000	.02	.972	.021	.021	.000

13.4 Summary of results

This is the first set of specialist movement tests (part of composite screen) devised for the ballet dancer.

In general, the intra-rater reliability for each of the tests within the Functional Movement Control screen, was substantial to excellent. The Functional Turn Out ranged from Coen's kappa coefficients of .843 to 1.000 (excellent). The Single Leg Turn Out ranged from .711 to 1.000 (substantial to excellent). The Single Knee Bend ranged from .679 - .855 (substantial to excellent). The Single Knee Bend in Turn Out ranged from .702 – 1.000 and was mostly excellent. The Arabesque Test 6. ranged from .713 – 1.000 which was again, substantial to excellent and the Back Bend Test 5. was similar with .764 - .919. The intra-rater reliability of the Plank Test was excellent (.838 – 1.000). Clearly the physiotherapists were adept at their own individual scoring with good consistency.

The inter-rater agreement in this screen was substantial for some tests and others required close scrutiny and the devising of methods to improve concurrence. The Single Leg Turn Out Test and the two Single Knee Bend Tests were the most reliable in this Functional Movement Control screen. The novel Single Leg Turn Out Test resulted in moderate to excellent kappa coefficients (.449 – 1.000) and is a useful test within any ballet movement screen. The Single Knee Bend had mostly moderate agreement with one kappa coefficient below .4 (.379 - .820). The same movement in Turn Out ranged from .442 to .827 and generally moderate agreement. Where the lower bound confidence interval reaches lower than 0.2, suggests some variance which requires improvement.

However, the inter-rater reliability for the three ballet technique tests resulted in low agreement between raters in spite of exceptionally high test-retest results. The Functional Turn Out was moderate only for Raters 1 and 3 (.410 - .417) with 55.5% agreement. This was surprising as the test assesses standing posture with the externally rotated lower limbs, the only variation from the norm. The Arabesque Test resulted in kappa coefficients ranging from .289 to .654 (fair to substantial). The substantial agreement was again, only between Raters 1 and 3.

The Back Bend Test was poor across all combinations of raters with low agreement between them (unacceptable to a moderate kappa of .475).

Lastly, the Plank Test had low agreement between the physiotherapists (.347 - .471). In spite of high intra-rater agreement, the inter-rater agreement was poor, mostly due to one of the scoring criteria which needed standardising.

13.5 Discussion

Ekegren et al. (2009) stated that observational risk screening is unlikely to achieve the sensitivity of more precise methods (3-D motion analysis) and achieving good reliability from visual information is difficult (Luomajoki et al., 2007; Krosshaug et al., 2007; Eastlac et al., 1991). A set of field test is required in dance and in the absence of an apposite, precise and thorough consideration of the needs in ballet, the Functional Movement Control Tests combined with the Range of Movement information, are proffered in this study.

In these results the decision that a test should have a kappa above 0.4 for inter-rater reliability was based on the exacting nature of the FMC tests and on previous studies such as Van Dillen et al. (1998 and 2003) and Luomajoki et al. who carried out reliability studies on lumbar spine movement control tests.

Luomajoki et al. also set the lower bound confidence interval over 0.2 in order to describe reliability as fair. Where this reaches below 0.2, it should be noted, and further trialling of the low load motor control moves will be required. The interpretation of this outcome depends on how the data is used and the degree of precision required for making rational clinical decisions. In this study the screen may influence an artistic panel's decision to accept a dancer for vocational training. Pragmatic decisions have to be made and guidance from past research is valuable.

The revised Functional Movement Control results were significantly improved after further training with the physiotherapists and discussion amongst them. Simplifying the score sheet allowed them to focus on fewer faults and the most fundamental. The kappa value is influenced by the number of categories - too numerous and the extent of the agreement will generally decrease (Portney and Watkins, 2009). The necessary revision has clarified how important it is to standardise the approach to movement screening and demonstrate to physiotherapists the importance of informed observation and precise systemised movement analysis to identify deficit (and to go on to initiate intervention and prevention strategies).

The most recent systematic review of risk factors for lower-extremity injuries in female dancers (Biernacki et al., 2018) concluded that alignment issues were a common risk factor and there was no standardised screening programme to identify the at-risk ballet dancer. Therefore, the aims of this part of the study were to examine alignment and control of the lower limb in this level of ballet student and determine the utility of these Functional Movement Control tests. Any lack of stability of the pelvis in ballet technique is highlighted in the simple low load motor control moves. The ballet teacher would describe a Trendelenburg sign as 'sinking in the hip'. Stability of the pelvis in transverse, coronal and sagittal planes is the aim in technique.

The Range of Movement screen provides an insight into how each physique fulfils the currently proposed physical requirements for the profession as recommended by the modified Delphi Survey. The functional movement tests examine fundamental control requirements that are the basis for sophisticated technique. Range and control are the foundations of ballet technique and clinicians working in dance require expertise in recognising the importance of both.

The initial FMC screen in Chapters 9 and 10 exposed weaknesses in the management and execution of the screen which served to emphasise the complexity of scoring movement and how much training it takes to reach agreement between raters, regardless of how experienced they are. The revised FMC screen revealed a low agreement in technical movement tests between raters but exceptionally high individual results and this indicated that raters need more time and discussion with each other to enable standardised movement analysis. Raters 1 and 3 consistently had higher agreement which brings into question how Rater 2 was scoring and how each rater evaluated movement. A background in dance may well have been an advantage for Raters 1 and 3. The aim of the study was to observe intra- and inter-rater reliability of those who already undertake screening and assess both novel tests and those already in use.

The inter-rater agreement of the Single Leg Turn Out test was the most reliable. This is a novel test, very clear in its aims and faults are easily observed. Its main value is the ability to show the dancer, teacher and physiotherapist clearly where the fault lies. Combined with the Functional Turn Out Test, the information gained guides the clinician on the intervention required regarding control. When this information is supplemented with the passive hip external rotation measurement in the ROM screen, a more thorough understanding of deficit and potential, results.

Both the Single Leg Knee Bend and the Single Leg Knee Bend in Turn Out resulted in moderate to excellent inter-rater reliability. The physiotherapists were doubtful about the camera views of the externally rotated version after the first session, but this second attempt produced better agreement, possibly because of heightened awareness and scrutiny. (In clinic a full view is possible – 3D - but in these videos only frontal and left sagittal was possible.) It was encouraging though, that Shultz et al. (2013) found excellent reliability for live-versus-video for the Functional Movement Screen.

The Functional Turnout test results were concerning. It was expected that the results of the second, revised session would be improved but they were similarly poor in terms of inter-rater reliability, to those of the first session. This examination of the dancer's posture should be followed up with further enquiry to find out from a larger cohort of physiotherapists and teachers, how misalignments in stance are understood to correlate with injury and impede progress in technique. One of the recommendations included by Biernacki et al. (2018) in their systematic review of injury risk, was attention to posture and it was commented that evidence of prevention strategies was lacking.

The arabesque is a common move in classical ballet and physiotherapists need to be able to agree and recognise a compromised spine and lack of stabilisation due to anterior control deficits in a more complex but frequent move. The scoring directs attention to activation of the lower abdominal muscles, the hinging in the lumbar spine and tension in the cervical spine, all of which inform on spinal control. Incorrect technique is one of the major causes of back pain in dancers (Micheli, 1984; Sohl and Bowling, 1990; Feipel et al., 2004; Gottshlich and Young, 2011). Therefore, again, faults in a common balletic move such as this should be recognized and analysed reliably by any specialised physiotherapist. If this is not possible, a fundamental clue to rehabilitation management/preventative strategy is missing, and indeed, stability and control is the key to performance enhancement.

The back bend movement also requires fine control and strong activation of the anterior chain. Combined with the range of movement test for spinal extension (cobra push up) and the arabesque test, a full appreciation of potential, control and strength is acquired. However, the back bend test will require further observation, practise and discussion.

Many clinical researchers state the importance of biomechanically correct technique (Molnar and Esterson, 1997; Gamboa et al., 2008; Ahonen, 2008; Liederbach et al., 2010; Steinberg et al., 2012 and Sobrino et al., 2017).

Therefore, to label these tests as 'not recommended', is premature for the moment. The intra-rater reliability was excellent and so it is accepted that training methods for the physiotherapist raters are at fault rather than the tests. Interaction and sharing of knowledge between technique teachers and physiotherapists could encourage further understanding and reduce injury risk.

Schools vary in how many healthcare staff are employed. If one clinician is screening, then reliability will be high. In a situation when there are more staff involved the same clinician should be allocated the same tests for better reliability. If tests are conducted by different clinicians, copious preparation is required, and this study would serve as a warning of the pitfalls to inter-rater reliability.

Biernacki et al. (2018) found that alignment was a common injury risk factor in elite ballet dancers and injury prevention required further research focusing on core and peripelvic muscle strength to improve alignment. In this screen the stabilisation of the pelvis is a central consideration in each test. This is because it should be the main focus in training ballet technique and its importance cannot be underestimated.

The Plank Test resulted in fair to moderate results for inter-rater agreement with the shoulder girdle stabilization appearing to cause the most discord of all the score points. Intra-rater reliability in Rater 1 was excellent in the revised second session compared to the first, with the adjusted score sheet and further discussion, making all 3 raters' scores, individually excellent. This test also requires further rater training to clarify recognition and scoring of shoulder girdle stability and endurance. After all, the shoulder girdle is part of the trunk and therefore, is part of core stability.

There were twelve tests to be scored (five had right and left sides) nine views to be scored in each of these six tests, making the screen 18 minutes long based on 2 minutes per view. The testers did not time each screen but reported that 20 minutes was the maximum time spent on any screen. In live screening this would probably take around 12 minutes or less. This is still a substantial amount of time when performed with the 15-minute range of movement Screen. At audition this amount of time is rarely given to the screening professional unless there are questions posed by the artistic panel regarding some candidates. However, to have a battery of tests from which to select those of key importance, is a valuable tool.

The functional technique tests will require further consideration before they are put through additional testing for reliability. To discard any at this point would be admitting that physiotherapists who care for and treat dancers cannot agree when assessing specialised movement. Raters 1 and 3 were the clinicians who had a firm grounding in classical ballet technique. Rater 2 is an experienced clinician with a significant experience in screening in sport. This might account for some of the discrepancies in our screening results. This may highlight the fact that physiotherapists employed in dance require further training in order to understand the specific demands on dancers, technically and biomechanically. Sahrmann, (2014) emphasised that clinicians needed additional skills in the observation of movement to optimize and restore function. To be able to identify correct and flawed biomechanics is understood to be the physiotherapist's expertise in whichever specialty they work.

Van Dillen et al. (1998) in their examination of low back pain found that therapists were less likely to agree on judgements of alignment and movement and advocated thorough familiarization and training on each test. (The therapists studied a supplied manual, took a written exam and had to achieve 90% before testing began.) Luomajoki et al. (2007) reported that all four of their therapist raters mentioned that better protocol training could have been carried out before they scored a series of 10 movement control tests for the lumbar spine. (Their inter-tester reliability ranged between 0.24 – 0.71). Researchers who have attempted reliability studies have found it necessary to train raters extensively. Therapists require far more pilot testing and trials than were carried out in this study, even though they were experienced. Standardisation is the challenge.

Lastly, the broader conceptual question that sits at the heart of all screening tests is do these movement patterns characterise those that are adapted during real-life dance and how do they relate to the execution of these skills in a dynamic performance environment where there are many other aspects such as music, fellow dancers, and the audience?

Dancers of this age and stage are accustomed to one-to-one training and are expected to have both confidence and discipline to negotiate and carry out any movement requested when in an audition situation. In terms of ecological dynamics, the dancer is not in a studio performing the same move as other dancers and instead is in an enclosed space being observed closely by a single clinician. Neither is there any music to accompany movements (brief as they are.) This could be seen as sterile and removed from the dancer's reality, but practicalities must allow the clinician to observe a physique closely and work quickly. The clinician requests simple variations of movements the dancer is familiar with – technically based and easily understandable. Ideally the clinician recognises biomechanical deficits and scores or comments accordingly. Passive range of movement has been measured and functional movements will use available range, ideally displaying appropriate movement strategies and control. This arrangement has been deemed the best strategy to gather information about the physique, how it moves and build a global profile which can be used by the audition panel to support decisions at audition for entry into vocational ballet at 16 years of age. At this age class work and training make up the bulk of the workload, unlike in sport where the game is the main workload. In class and training the dancer employs learned patterns of movement that underpin more complex combinations. For example, a single leg knee bend translates to a 'fondu'. Terminology familiar to the dancer is used. In the FMC tests these basic underpinnings are explored for shortfall. In more complex technical moves, there will be individual variation according to the physique. The FMC scoring system is simple and succinct and the fact that assessors found it challenging points more to the fact that they require more practise.

Analysing in dance is different to analysing a cutting move in football that requires the presence and challenge of other players in a game situation. Dancers can analyse specific movement and then run the combined moves in an *enchaînement* to improve the move in question. This happens constantly in teaching. Once the academics are understood, then the dancer 'dances' it with music.

Chapter 14. Project Summary and Future Strategy

14.1 Overview of Project

What is already known

- The criteria for selection into vocational training and then the classical ballet profession are not clearly understood.
- Musculoskeletal screening at audition is regularly carried out based on suitability for entry into the profession, and to identify injury risk.
- Few tests have been examined in the dancer, for intra- and inter-rater reliability.
- There are high levels of injury in pre-professional and professional classical ballet.
- There is no universally approved set of screening tests established and used at audition.

Procedure for Study

- The criteria for selection into the profession was obtained by using a modified Delphi Survey to find out the opinions of the artistic leaders in the profession and those in healthcare, working with dancers.
- A battery of tests was devised based on the consensus of the modified Delphi Survey.
- The tests were finalised after expert consultation.
- The tests were assessed for intra- and inter-rater reliability.

What is now known based on the results of this study

- A set of 23 interrelated physical attributes are sought after in the professional classical ballet dancer. These are both range of movement and functional movement control requirements.
- 6 range of movement tests and 7 functional movement control tests were recommended after intra-rater reliability studies.
- There were encouraging results for inter-rater reliability of the range of movement tests and 3 of the functional movement tests with multiple raters.

14.2 Introduction

The purpose of this concluding chapter is to return to the aims of the study emphasising their importance, to explain the sequence of procedures, to summarise the findings and recommendations and consider the issues raised during the study.

The first part this research study sought to gain consensus of the attributes most desired in classical ballet and were investigated by way of a modified Delphi Survey. This included the views of those artistic leaders – directors, principal teachers and choreographers regarding the preferred attributes of the professional ballet dancer. Considering also, the athletic needs of the dancer and the high levels of injury in dance, clinicians and those caring for dancers were also consulted.

Being both a visual performing art and an athletic pursuit, the complexity of classical ballet choreography requires a particular physique for selection into the profession. In addition to the biomechanical advantages of a specific body type, being a visual art form, there are important aesthetic prerequisites demanded globally by the profession. Thirdly, injury risk is an important consideration when assessing physical attributes and dance, as the incidence of injury remains high in vocational and professional ballet (Vassallo et al., 2019; Biernacki et al., 2018).

The modified Delphi survey was conducted in three rounds until a consensus was reached, clarifying the specific recommendations of all those involved in selection into the profession. The final consensus was composed of 23 physical attributes (Table 14.1) to inform on suitability for the profession and injury risk to be used at audition in order to support the artistic panel in their decision making.

In the second part of the study the tool was developed in consultation with a group of expert clinicians incorporating both range of movement and functional movement control tests, supporting the range of consensus results. The purpose was to create a screening tool to be used at audition prior to acceptance into vocational training to allow a more thorough understanding of potential.

The third part of the research study was devoted to putting these tests into action and they were used to screen a cohort of pre-professional dancers. Intra- and inter-reliability studies analysing the 14 tests were carried out. The purpose of this was to gauge their suitability for widespread use as part of the audition process.

Kenny et al. (2018) carried out intra-rater reliability studies on their varied screen after critical appraisal of research investigating risk factors for musculoskeletal injury in dancers and the authors admitted that high quality reliability studies are lacking.

In many schools there will be a sole clinician employed who will screen, profile and monitor students. Tests which have successfully undergone intra-rater reliability studies, as those in this screen, will be useful and provide confidence that the tests are accessible and reliable. If in larger establishments more than one clinician participates in the screening it is important to know that inter-rater reliability has been achieved. Uniform decisions have to be made and uniform information shared with the artistic selection panel at audition.

No audition screen has been proposed to date in dance research, although some schools use screening tools that have not been fully tested for reliability or validity. The aims of the second and third parts of this study were to develop a screen and then test it.

14.3 The Delphi Survey

This investigation is the first of its kind to obtain a consensus from those international experts in the profession who select dancers as well as those who care for dancers' health. Matters raised by the Delphi enquiry are discussed further, throwing light on a culture, in many ways similar to sport but also very different, with its unique issues.

The physical attributes were generated by the artistic and healthcare panels. Control, stability, and coordination are all subgroups of motor control. In an effort to bring these groups together in understanding, they are treated separately.

The following table shows the range of attributes reaching consensus in the Delphi Survey in ranked order. The ranks are colour coded and shown in 12 tiers.

Table 14.1 Round 3. Attributes reaching consensus

	Attribute	**Number selected**
1	Coordination	**78/84**
2	Overall strength	**73**
	Spinal strength	**73**
	Overall control	**73**
3	Overall flexibility	**72**
	Stamina	**72**
	Good pointe position	**72**
4	Overall stability	**71**
5	Hip turnout flexibility	**70**
	Balance	**70**
6	Overall Power	**69**
	Ankle & Foot Strength	**69**
	Leg strength	**69**
7	Ankle & Foot Flexibility	**65**
	Upper Body Strength	**65**
	Jump Ability	**65**
8	Overall Good Proportions	**64**
	Good demi plié	**64**
9	Spinal Stability	**63**
10	High Extensions	**59**
	Ability to turn	**59**
11	Shoulder stability	**58**
12	Flexibility of big Toe	**51**

Key: Colours indicate attributes selected by the same number of respondents.

14.4 Range of Movement - Emphasis on Flexibility

The first round of the Delphi revealed the Artistic Panel's propensity for generalised flexibility. The expressions 'overall flexibility', 'hip turnout flexibility', 'foot and ankle flexibility' and 'high extensions' (hamstring and adductor flexibility). 'Hypermobile but not too hypermobile' was also tentatively mentioned in the first round, implying that only the positive implications of increased flexibility were desired and not the negative, linking hypermobility with pain and injury risk as reported (Scheper et al., 2017).

It is important to assess the major joints, mostly lower limb, used to end of range in the ballet dancer being aware that the Beighton Score assesses mainly upper limb. Higher cut-offs for the Beighton Score in dancers have been recommended (≥ 6) and the use of The Lower Limb Assessment Score (LLAS) to expand measures (Chan et al., 2018). The LLAS is a binary assessment still omitting the ballet-specific measure of hip rotation, spinal extension and foot and ankle plantarflexion that are so important to gauge in a dancer. If an augmented range of movement screen is carried out, as in the Range of Movement (ROM) screen proposed in this research, with an added Beighton score, the clinician can proceed if required, with further questioning to identify those with more serious connective tissue disorders such as Ehlers Danlos Syndrome. The range of movement screen in this study satisfies those requirements and those of the panel's consensus and could be regarded as the first step in devising a hypermobility screen specifically for dancers.

Bronner and Bauer (2018) in their enquiry into risk factors for injury in 180 elite pre-professional modern dancers over 4 years, found that those with high Beighton scores (≥ 5) were 1.43 times more likely to be injured and low scores (≤ 2) were 1.22 times more likely than those with mid-range scores. This gives some support to the present study which prioritises the importance of having a clear understanding of the global or selective joint flexibility of each physique in question. Further support is added by Biernacki et al. (2018) stating 'screening ballet dancers for variations in joint range of movement may predict those at high risk of injury'.

The Delphi Survey drew attention to the hyperextended knee which was selected in Round 1 but deselected by Round 3 of the Delphi as one of the criteria for entry into the profession. As already mentioned, 'hypermobility' was not a selected attribute in the final round and ballet teachers find the hyperextended knee difficult to teach. However, half the participants in this study had over 10^{o} of knee hyperextension and ≥ 100^{o} of metatarsophalangeal joint extension. This confirms the emphasis on flexibility as a highly selected attribute with the contour of the hypermobile knee in open chain movements the desired line in classical ballet. The ROM tests also showed that the hyperextended knee was accompanied by the hypermobile foot and ankle in plantarflexion which was one of the most sought-after selection criteria. In sport the hypermobile knee is known to be an injury risk (Ostenburg and Roos, 2000; Soderman et al., 2001) and Ambeogonkar (2016) found that lower limb hypermobility affected balance in collegiate dancers. Developing the required proprioception and neuromuscular control in the hypermobile knee is a challenge and this may be the reason for lack of selection in the Delphi Survey.

By the third round of the Delphi, overall flexibility sat in the third tier of attributes with foot and ankle flexibility (pointe position). Hip turnout was in 5^{th} place, *demi plié* sat in 8^{th} place and flexibility of the big toe (metatarsophalangeal joint extension) in 12^{th} place. All flexibility attributes were assessed by the tests in the Range of Movement section of the audition screen.

14.4.1 Hip External Rotation Test

'Turnout is the fundamental framework of classical ballet technique and the ability to perform it is influenced by soft tissue extensibility, muscle strength, and bony anatomy' (Hamilton et al., 2006). Hip 'turnout' was placed in the 5^{th} tier the list in the Delphi consensus.

Hip external rotation is one of the most frequently included tests in any ballet screen (Armstrong et al., 2019) but there is controversy about which passive measure to use for external rotation of the hip, and this issue was raised while devising this ROM test and examining reliability.

The relationship between femoral version, passive external rotation of the hip joint (in functional neutral), active turnout in standing and supine passive turnout (Grossman et al., 2008) has produced valuable research over the years. Investigations into the best strategies to achieve safe biomechanics in the classical ballet dancer, continue. Reliability studies are needed to recommend screening procedures and arrive at consensus.

The supine test for passive external rotation is used in this study (Washington et al., 2018). The intra-rater reliability reached good consistency (ICC = .698 - .904) but inter-rater reliability reached only fair to moderate. Consistency amongst raters for this measurement appears to be problematic and this is probably why there is no consensus to date as to which measurement method is the most precise, informative and reliable. The solution, which is a practical compromise, is to attribute the measurement into restricted, moderate and hypermobile categories. This may be sufficient for a clinician's needs and allows an instant understanding of a physique. Continuous measures are not required (not understood) by the audition panel. When the measurements were allocated a score and Cronbach's Alpha applied, the results ranged from moderate to good. When this test sits alongside the other six ROM tests also categorized, a pattern emerges allowing prompt recognition of global or specific facility or restriction. Interestingly, one of the participants scored a 3 (hypermobile) in each joint measured (and the Beighton categorical score) except for hip external rotation which was 1. Clearly this physique is hypermobile but hip morphology allows less external rotation in neutral. These facts suggest an injury risk for the lower limb.

Considering the Functional Turnout tests adds to the picture. The Single Leg Turn Out Test 2. reveals true control over the single leg. Information from ROM Test 1., FMC Test 1. and Test 2. provide full, concise information regarding hip external rotation. How the ROM screen tests, and the FMC screen tests complement each other is discussed in Section 13.9.

14.4.2 Spinal Extension Test

The results for this novel test were flawed due to a procedural mistake by one of the clinicians. Raters 2 and 3 achieved intra-rater ICC of .879 and .416 respectively and Alpha Coefficients of .934 and .787. The ICC was .183 - .584 for inter-rater reliability indicating that further practise by professionals with varied experience to obtain better technique and precision using this test. It is too early to discard it without a convincing number of trials accompanied by reliability studies.

14.4.3 Foot and Ankle Tests

The Foot and Ankle Plantarflexion Test had moderate intra-rater Alpha Coefficients of .710 - .908, the Metatarsophalangeal Test had intra-rater reliability .615 - .858 and inter-rater reliability of .614 - .768 using ICC. and the Dorsiflexion Test was universally excellent at ICC of .943 - .970. Considering each of these measurements provides a thorough appreciation of the foot and ankle, consistently cited as a frequently injured, in the ballet dancer.

14.4.4 Intra- and inter-rater Reliability

The intra-rater reliability for all tests was high and acceptable using both ICC and Alpha Coefficients. Even the Spinal Extension Test had encouraging results but standardisation of method and discussion with the Expert Group will be required.

Inter-rater reliability of measures for external rotation of the hip using iphone© and Tiltmeter® and knee extension using goniometer will require further discussion and practise amongst clinicians to achieve higher ICCs and further precision.

Using categorical data and the Alpha Coefficient, inter-rater reliability for 6 out of 7 tests from this tool can be recommended. Once Spinal Extension reaches acceptable inter-rater reliability, Total Scores for the screen can be considered.

14.4.5 Range of Movement Scoring using Categorical Data

The use of a scoring system in the ROM screen allowed a broader and more immediate understanding of a physique. Measuring joint range and reporting precisely as a continuous measurement is challenging in a time-sensitive screening situation. Once familiar with category cut-offs the clinician can allocate a score to each joint and then review for instant feedback. The cut-offs are pragmatically decided based on current data available and experience with dancers (Bronner and Bauer, 2018). The clinician needs to know whether a joint is restricted, moderate or hypermobile and appreciate the global and specific assessment of the physique. Once each joint is scored, these can be totalled and a further dividing into categories can take place, but the example mentioned in 13.4.1. should not be missed. When the alpha coefficient was used in this study after ICC had been calculated inter-rater reliability was improved.

14.5 Functional Movement Control Tests

Tests 2,3 and 4 were the most reliable in this Functional Movement Control screen. The Single Knee Bend tests achieved kappa coefficients of .379 - .827 and the novel Single Leg Turn Out Test resulted in a moderate to excellent kappa (.449 – 1.000) and is a useful test within any ballet movement control screen. The test is recommended for the technique teacher too, who is not privy to the whole screen. The parallel single knee bend has been validated (Ageberg et al., 2010) and the knee extension measurement (Juul-Kristensen et al., 2007). The technique-based tests, Functional Turn Out, Back Bend and Arabesque, will require further trialling only after introduction to the ballet vocabulary and in-depth training. Eventually a Total Score for the FMC screen can be divided into three categories of skill – excellent, moderate and poor, much like the Functional Movement Screen, but more feasible, which has two categories – high and low (Shultz et al., 2013).

14.5.1 Motor Control

Although they are closely interrelated, for the purposes of analysis of the various attributes generated by the Delphi Survey, coordination, control, stability and balance are discussed separately. Coordination was selected before all other attributes in Round 3 of the Delphi Survey. This is assessed by the panel at audition as the dancer performs the class vocabulary. Overall control (motor control) sits in the next tier along with strength and is assessed with tests in the Functional Movement Control assessment.

Ruemper and Watkins (2012) mention hypermobility in contemporary dancers and lack of proprioception and motor control. Roussel et al. (2009) found dancers with impaired motor control were at risk of developing injury and has demonstrated this in dancers with low back pain (Roussel et al., 2013). As classical ballet technique is built on precision of movement and motor acuity, it is important to recognise deficits that that can impact on performance and ultimately lead to injury as suggested by Biernacki et al. (2018). With a lack of fine control, agility and speed needed for fast-moving technique and choreography put a dancer at a disadvantage. Simmonds and Keer discussed quality of movement and motor control when assessing hypermobile individuals in 2007, emphasising their importance as much as measuring range. Mischiati et al. (2015) examined the Foundation Matrix, a set of tests to identify movement impairments. Comerford and Mottram (2012) have devoted much research to testing motor control and Sahrmann (2013) was the first to categorize movement impairment disorders. In this study the three functional movement control tests in FMC screen - Single Leg Turnout test, Single Leg Knee Bend and Single Leg Knee Bend in Turnout - attempt to identify misalignments and lack of control in movements fundamental to ballet technique.

These three tests in the FMC screen are extremely informative. The novel Single Leg Turnout Test shows clearly the 5th position angle of turnout used by the dancer. Control of external rotation in single leg standing is clearly revealed. The release of the back foot and holding of contralateral hip external rotators to maintain pelvis alignment, quickly reveals any control deficits as the pelvis rotates towards the weightbearing side. This test, first introduced in this study, had moderate to excellent inter-rater agreement and excellent intra-rater reliability. The Single Leg Knee Bend tests reveal hip muscle weaknesses if the Trendelenburg sign is noted and motor control deficits which may also reveal valgus knee alignment. This may be magnified in jumping. Both had mostly moderate inter-rater agreement. Jumping tasks were not included because of the audition situation and the inconsistency of warm up.

14.5.2 Strength

Strength, spinal strength and overall control were placed in the 2nd tier under coordination in the consensus. Strength deficits in dancers are thought to contribute to injuries of the lower extremities and the spine: the weaker the dancer, the greater the risk (Koutedakis et al., 1997) It is also reported that strength baselines are lowered in the hypermobile physique (Scheper et al., 2013; Jindal et al., 2016). The physical demands on dancers due to choreography, performance demands and the repetitive nature of dance movement patterns in classes and rehearsals, put dancers at risk of injury (Moita et al., 2017). In an audition screen it is inadvisable and unfair to include any test that may overtax the auditionee, especially if warm up before screening is not guaranteed and jump tests are demanded.

The Plank Test which was modified to assess anterior chain and shoulder stability (11 in the consensus) was the most taxing. This test was thought to provide enough challenge to inform the physiotherapists of deficits or otherwise. This test achieved excellent intra-rater reliability but further training of raters is required to achieve better inter-rater agreement regarding shoulder girdle stability.

14.5.3 Technique-based Tests and the Specialist Approach

Jump ability (7th tier) and ability to turn (9th tier) were not assessed as these were observed by the panel in class when dancers are warm and neuromuscularly prepared.

Instead, the simple moves performed in turnout in the FMC screen informed on skill, stability and control. The two more complex moves, Arabesque and Back Bend informed on range, strength and control and were chosen to highlight injury risk and be considered beside the ROM Spinal Extension Test 6.

'Faulty dance technique involving poor alignment and motor control are frequently cited as possible risk factors for injury' (Bronner and Bauer, 2018).

In their pre-professional screen for injury risk in modern dance students, Bronner and Bauer (2018) included three dance technique tests which were assessed qualitatively using a points system. Physiotherapists assessed the moves. The authors from this vocational school also state, 'In our injury clinics, we found that correction of errors in technique frequently eliminated musculoskeletal problems.' An understanding of correct biomechanics of dance moves is required in the specialist context. Gamboa et al. (2008) also used technique tests and analysed posture (but not in functional turnout). Initial posture and muscular recruitment set the pattern for the dynamic moves which follow. Dancers' posture often assumes compensatory patterns in the balletic position, whereas there should still be alignment and balance of muscular recruitment to ensure the best recruitment in dynamic moves. Posture requires assessment and is included in the FMC screen in simple *1st position*. Liederbach (2010) expertly states that the informed clinician 'should possess a trained eye sensitive to the full palette of demands and nuances of the movement form'. As with any sport there are specific knowledge requirements. Recognition and understanding of movement patterns and biomechanics in dance need to be appreciated.

The Backbend Test and the Arabesque Test assess range, control and trunk muscle recruitment in the FMC screen. These were assessed consistently by the physiotherapists who achieved substantial to excellent intra-rater reliability. However, inter-rater reliability was acceptable between only two of the raters in the Arabesque Test. This would indicate that understanding the biomechanics of ballet technique needs more discussion, observation and training in clinicians to make them truly 'specialist'.

14.6 The Silent Vote

The artistic panel selected 'slimness' in the first and second round but it was deselected by the third round. This was not a priority for the healthcare panel. It is a controversial issue in dance. However, it is not in Russia. It is noted that at The Vaganova Academy in St Petersburg students are weighed before ballet examinations and their weight contributes to their marks. Attributes such as 'slim' and 'low weight' in the Delphi rounds are handled extremely carefully, possibly because the subject has attracted criticism of the profession in the past and low weight and BMI have been linked to injury in dancers (Benson et al., 1989).

14.7 Challenges of the Selected Physique in Ballet

The Delphi survey may also help to explain the persisting high levels of injury in classical ballet. The proportions sought by the artistic panel are those of the ectomorphic somatotype – the common features of which include 'linearity and fragility' (Bale, 1994, cited in Twitchett et al. 2008). The same research by Twitchett and colleagues found that high ectomorphy ratings and low mesomorphy ratings (following the Heath-Carter protocol) were linked to injury in ballet students. Garrick and Requa (1994) state 'few artistic or athletic activities require the anatomic excesses demanded of the ballet dancer'. With the emphasis on flexibility steering selection, the combination of the longer limb, agility and strength deficits (Karpodini et al., 2017), light weight, low body mass index and classical technique arguably more testing than any sport, the healthcare professional is truly challenged. Discussed in Chapter 3 is the predilection for neoclassical and contemporary choreography that take full advantage of the classical dancer's range, emphasising the aesthetics of flexibility and pushing lower extremity postures to increasing extremes in choreography (Wyon, 2010). Bronner and Bauer (2018) cite Kumar (2001), 'working at the extremes of motion required in ballet and modern dance puts muscles at the greatest mechanical disadvantage with increased risk for injury.' The characteristics that put a ballet physique at risk accumulate, and incidence of injury remains high in the profession. Many physiques selected do not have the attributes that allow for robustness, power and endurance but with full awareness and understanding of the selected dancer's physique (through screening), the modifiable shortfalls can be tackled appropriately. A physique with appropriate proportions, moderate ranges of flexibility, stability of the pelvis and hip displayed in the FMC tests and few faults in the technique tests would be an ideal selection.

14.8 The Purpose of the Ballet Audition Screen

Screening is carried out in many dance contexts, but it seems rarely at audition, with no published pre-entry screen available. Pre-professional screens are presented (Kenny et al., 2018; Southwick, 2017; Liederbach, 2010; Bronner et al. 2006; Molnar and Esterson, 1997;) which are used to screen after entry. Undoubtedly, the information from a screen guides the clinician as to the interventions and surplus training required by each individual student and provides baseline measurements. Screening after the artistic panel have made their selection leaves a lost opportunity to answer queries on physique and range, which invariably occur within an audition context. The Royal Ballet School in London has screened physiques at audition for 50 years and the efforts are driven by injury prevention (Howse, 1988). Current practises at the Royal Ballet School have not been tested for reliability. The purpose of this thesis is to do just that, and to support current practises, with some supplementary material to investigate possibilities. The entry requirements to the Vaganova School in St Petersburg are famously stringent but driven by performance enhancement motives (personal contact) and injury is not acknowledged by the school. Both attempt to optimize selection before commitment. Hamilton (1997) reported a 55% drop out rate from a renowned vocational ballet school and that a post acceptance 'orthopaedic' screen had predicted this. The author continues, 'the orthopaedic exam is a useful screening tool to diagnose potential problems in dancers'. However, there was no follow-up evidence of change of strategy. The annual screen during training monitors different parameters. Passive range of movement at the hip, and the spine, for example, is information that should be known before acceptance. The full potential or structural deficit is not always readily observable in an audition class and unless dancers are carefully assessed problems can arise with the intensity of full-time training.

The newly developed ballet specific screening tool was devised to include the range of movement of joints considering both connective tissue and joint morphology. Global and selective joint range accompanied by information from stability and ballet specific motor control tests aim to provide a comprehensive profile of the physique. Added to this, the technique-based tests, Backbend and Arabesque which are commonly used throughout the classical ballet repertoire, provide more complex functional information. These particular tests have not been used in any screening research to date, but in this study, they are thought to enhance the information required and complete the profile of each individual physique.

14.9 Using the New Audition Screen

The selected tests in this audition screen are designed as a whole, covering necessary elements and intended to be evaluated beside each other. The range of movement screen tests measure quantity and the functional movement control screen tests measure quality of movement. It is the combination that were sought after in the consensus of the Delphi Survey. However, they do not necessarily need to be considered a unitary construct. ROM and FMC could be evaluated with conclusions drawn from each subitem according to the needs of the clinician and the school. Clinicians may also suggest that some elements are more important than others and should be valued at more.

The tests are designed to complement and support each other. Test 1 in the ROM, tests passive external rotation of the hip. Active control of this is tested in Test 2. of the FMC, Single Leg Turn Out Test. The two show clearly, range and function but the wider the difference between passive and active angles are, the greater the risk of injury (Wyon et al, 2013). The Spinal Extension Test followed by both the Backbend and Arabesque Tests reveal range, global and specific control and strength of the spine.

The screen does not predict dance performance. It is designed to inform on potential for performance enhancement and potential injury. If results stimulate appropriate interventions, they can be regarded as effective from an athletic and aesthetic standpoint.

14.10 Training for Efficient Screening

As reported in Chapter 9, the Functional Movement Control Screen tests had to be repeated because of lack of inter-rater agreement. However, the second session of scoring (Chapter 12) following further training and clearer guiding assessment criteria (Chapter 11), brought about significant improvements emphasising the need to have each assessor well versed in the aim of each test. A full understanding of each particular risk possible for the test to reveal, required discussion. The Functional Movement Control screen however, still had mixed results. In spite of high intra-rater reliability, inter-rater reliability was varied. Shultz et al. (2006) stated that intra-tester reliability does not always ensure acceptable inter-tester reliability. Kenny et al. (2018) trained assessors in a concentrated three-hour session one week before screening and even then, found intra-rater reliability for two tests for external rotation of the hip not reliable enough to recommend. Kraus et al. (2014) advised that the assessor requires more than a hundred trials to be familiar with the screening tool and that it is the number of trials practised that is more important than physiotherapy experience.

The experienced physiotherapists invited to participate in this research were sent the ROM screen information and prepared as much as possible individually in an attempt to regulate technique and standardise handling. They were not able to confer with each other prior to the first screen or take part in group training as they worked in different clinical settings. In effect, they trialled a battery of screen tests relying on their individual experience and accuracy. In essence this context could be seen as a usefully generalizable scenario revealing both limitations and strengths. If relatively inexperienced student physiotherapists had been recruited, exhaustive training would have been necessary and our results for inter-rater reliability may have been stronger. The physiotherapists in this research relied on their individually developed methods which resulted in favourable intra-rater reliability. Our inter-rater reliability, we learn through our results, required further training and standardisation. Experience does NOT make for agreement. Therefore, the need for meticulous training in screening tests, regardless of the clinician's expertise is emphasized here.

The physiotherapists later realized the importance of training when the FMC screen was repeated. This was emphasised by Luomajoki et al. (2007) in their movement control tests of the lumbar spine. Clearly, in spite of the deficit in training, the clinicians in our study were still able to assess movement deficits consistently but without sufficient inter-rater agreement. They could demarcate those with high, mid and low levels of flexibility in the ROM screen. In a screen that is performed under time constraint, technique has to be swift and accurate. The fact that intra-rater reliability was significantly better showed how confident each rater was in their own particular method. Further standardisation through practise, colleague observation and discussion will improve inter-rater agreement throughout the screens. The reason for screening in this context is to identify injury risk and potential and support an artistic panel. In annual screening the aim is to subsequently devise appropriate prevention strategies. Dissimilar conclusions in a clinical situation about the same dancer may interfere with opinion and result in different treatment plans. In both cases if more than one clinician is involved, inter-rater reliability is vitally important.

Vocational schools employ physiotherapists to treat injury, reduce injury and support artistic staff. Schools have a duty of care. To select students with elements in the physique not suited to the school's ethos of teaching, could be seen as irresponsible. Physiotherapists have duty of care to support student selection to the best of their ability, based on reliability and science, if that is what employers request.

14.11 Strengths

- This is a novel screening tool that is dance-specific and its development through the Delphi Survey, expert consultation and Nominal Group Technique increases its face and content validity.
- Homogeneity of testers: the fact that the physiotherapists in this study were experienced meant that they confidently tackled the ROM screen adhering to the prescribed methods with good intra-rater reliability.
- The dance student participants closely represented those auditionees at a final audition where the screening tool is intended for use.
- Although the student participants had been accepted for vocational training, there was still a range of abilities amongst the separate cohorts.
- The balance of male (40%) and female (60%) dancer participants was good reflecting the gender balance in many vocational schools.
- The use of video insured that in conducting a test-retest study, participants were not overburdened. Shultz et al. (2013) found excellent reliability for live-versus-video for the Functional Movement Screen (FMS).
- The ROM screen protocol closely resembled the audition screening process which helps to make it transferable in real life context.
- Not every clinician has access to an inclinometer. Use of the mobile phone for measuring angles in joint assessment is a great step forwards towards accuracy of assessment without increased cost.

14.12 Limitations

- The Delphi Survey sampling was restricted to English and so China, Japan and Russia, where Classical Ballet has a high profile were not included.
- In the reliability studies it is acknowledged that the number of dancer participants available to recruit affected the power of the study.
- It is debatable whether the repeated measures which took place on the same day was a limitation. Because of the limited number of participants, it was important that there was no attrition within the cohorts. Performing the repeat ROM screen on the same day meant it was not necessary for students to miss more of their training by returning to the Royal Opera House a week later. The clinicians reported that they were working at such a rate that they were not able to remember participant measurements from morning to afternoon.
- The participants were recruited from the beginning of first year, vocational training. This was the nearest to auditionees possible. It could be construed that the participants were too similar in standard and ability to be able to screen a variety of physiques.
- There is an argument for NOT using experienced physiotherapists. They may feel they do not need training and using physiotherapists working in different sites make communication amongst them harder to achieve.
- Demonstrated by the unsuccessful first attempt to score the functional movement, it was patently necessary that the raters required further training and a simplified marking guide. Even after a second more successful screening session, although intra-rater reliability was good, inter-rater agreement needed improving. Exhaustive training of raters is recommended for movement control screening.
- Using video for Movement Control screening is dependent on placement of cameras. In this study the views were frontal and sagittal but in the clinical situation the physiotherapist can view the movement from all angles. Shultz et al. (2013) used video

from three views which makes this a more complex viewing/scoring task than when observing live.

- Using the mobile phone app requires practise. One of the clinicians was not using their own device and therefore handling was not as adept as it could have been with more practise.
- It must be appreciated that the ICC model used in this research may be lower than other studies using a different model (there are 10 possible models).

14.13 Summary

- This novel, ballet-specific screening tool to be used for screening purposes, has been developed with influences from both artistic and clinical groups.
- Good intra-rater reliability has been established for all tests within the screen.
- Inter-rater reliability testing produced promising results in the ROM screen with further testing and practise protocols recommended.
- The inter-rater reliability of the FMC screen highlighted the need for further specialist education for clinicians.
- Although initial face and content validity was partly addressed through the process of development the screening tool will require further validation through longitudinal injury studies.
- In depth training of clinicians is required for any musculoskeletal screen, whether experienced professionals or relatively inexperienced. This cannot be emphasised enough. Range of movement, joint morphology and connective tissue laxity related to function should be fully understood. Method and standardisation require a great deal of practise.
- Movement analysis requires discussion, practise and trialling before a clinician is fully competent, regardless of experience. Assessment criteria needs to be simple and directed at only the essential few points to fully guide the clinician.
- A working knowledge of ballet terms and technical moves is expected and an ability to recognise biomechanical errors is required for the dance specialist.
- A better understanding between artistic and healthcare (in mutual support of the dancer) is required – identified by the Delphi Enquiry.
- The Beighton Score is still being used, even for dancers, but is inadequate. This ROM screen is the first step in devising a Hypermobility Screen for Dancers.
- Measuring hip external rotation requires further exploration and consensus of method.

14.14 Future Publications

1. The Delphi Consensus and the Attributes Selected in Professional Ballet Dancers
2. An Audition Range of Movement Screen for Vocational Ballet Dancers
3. A Functional Movement Control Screen for Assessment of the Vocational Ballet Dancer
4. A Review of Hypermobility in Dance
5. Measuring Hypermobility in Dance – An Initial Proposal

Future Strategy

- Measuring the hypermobile spine in extension poses a problem for the clinician but this measurement is vital to the screen as a whole and will require further exploration. Measurement of spinal extension requires further testing using the mobile phone app TiltMeter®. The set-up is appropriate for the convenience of clinician and dancer but the method of stabilising the implement on the spinal segment will require further thought, practise and systematic comparison with inclinometer (Salamh and Kolber, 2012).
- A video to accompany the ROM screen will be created to lead the clinician through the purpose, method and pitfalls of each test.
- Although challenging, video guidance through the FMC screen will be created to direct the clinician and enable clear recognition of control deficits in the tests presented. The technique-based tests will be included with clear analysis and pointers to direct the clinician's assessment.
- A discussion with international colleagues regarding standardising methods for measuring external rotation of the hip in dancers, is required. A working group will be instigated within the International Association of Dance Medicine & Science to consider this, using a Nominal Group Technique, to reach consensus consulting experts worldwide.
- The screen will be trialled on less experienced clinicians to investigate reliability.
- Identifying injury risk in sports and dance is complex and Bahr (2016) warns that screening does not work. In the present context in ballet, we need information and guidance as to whether a physique profile should be encouraged to rise to the

demands of vocational training. Therefore, once the screens have been tested further for reliability, validity will need to be examined. There are no gold standards for these tests. Hence, getting the test battery or individual tests put into use by different professionals in the field will help validate parts or all of the ROM and FMC screens.

- With prospectively designed screening and injury surveillance, risk factors for injury can be explored.
- Experienced clinicians may consider that deficits in one area may be compensated by surplus in another for example, a mobile hip will compensate for restricted spinal extension and vice versa. Future work using these screens may allow such associations to be made.

14.15 Conclusion

This research sought to develop a ballet-specific screening tool to be used by vocational schools. Only once reliability has been tested can a screen be used with confidence.

It is also hoped that this study will allow clinicians working with young ballet dancers to understand the aesthetics demanded by the profession and the demands on the classical ballet dancer's physique. To be able to detect intrinsic weaknesses, identify muscle imbalance however subtle, appreciate joint morphology and tissues of varying laxity, allows the clinician to care and advise on the vocational path. Planning the management required to reduce injury risk, results from an in-depth understanding of the dancer's physique and the demands of the profession.

Artistic purists may argue that we are losing sight of the elements of this art form - musicality, interpretative brilliance and 'artistic quality'. But these alone, sadly, cannot make the dancer and a particular physique today is required to reach professional heights.

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Appendix A

UCL RESEARCH ETHICS COMMITTEE
ACADEMIC SERVICES

23 November 2015

Dr Jane Simmonds
Institute of Child Health
UCL

Dear Dr Simmonds

Notification of Ethical Approval
Project ID: 7693/001: What qualities make a great classical ballet dancer?

I am pleased to confirm in my capacity as Chair of the UCL Research Ethics Committee (REC) that I have approved your study for the duration of the project i.e. until November 2016.

Approval is subject to the following conditions:

1. You must seek Chair's approval for proposed amendments to the research for which this approval has been given. Ethical approval is specific to this project and must not be treated as applicable to research of a similar nature. Each research project is reviewed separately and if there are significant changes to the research protocol you should seek confirmation of continued ethical approval by completing the 'Amendment Approval Request Form': http://ethics.grad.ucl.ac.uk/responsibilities.php

2. It is your responsibility to report to the Committee any unanticipated problems or adverse events involving risks to participants or others. The Ethics Committee should be notified of all serious adverse events via the Ethics Committee Administrator (ethics@ucl.ac.uk) immediately the incident occurs. Where the adverse incident is unexpected and serious, the Chair or Vice-Chair will decide whether the study should be terminated pending the opinion of an independent expert. The adverse event will be considered at the next Committee meeting and a decision will be made on the need to change the information leaflet and/or study protocol.

   For non-serious adverse events the Chair or Vice-Chair of the Ethics Committee should again be notified via the Ethics Committee Administrator (ethics@ucl.ac.uk) within ten days of an adverse incident occurring and provide a full written report that should include any amendments to the participant information sheet and study protocol. The Chair or Vice-Chair will confirm that the incident is non-serious and report to the Committee at the next meeting. The final view of the Committee will be communicated to you.

On completion of the research you must submit a very brief report of your findings/concluding comments to the Committee, which includes in particular issues relating to the ethical implications of the research.

Yours sincerely

Professor John Foreman
Chair of the UCL Research Ethics Committee

Academic Services, 1-19 Torrington Place (9th Floor),
University College London
Tel: +44 (0)20 3108 8216
Email: ethics@ucl.ac.uk
http://ethics.grad.ucl.ac.uk/

Opinio Survey 1.

standard report

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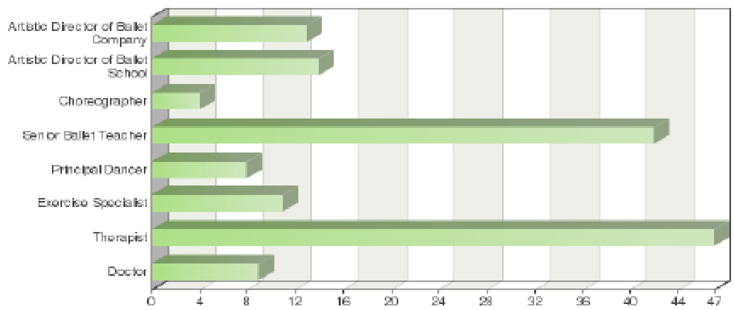
Report info

Report date:	Wednesday, August 4, 2021 5:56:24 PM BST
Start date:	Monday, March 14, 2016 6:00:00 PM GMT
Stop date:	Friday, April 15, 2016 11:00:00 PM BST
Number of completed responses:	148
Number of invitees:	217
Invitees that responded:	70
Invitee response rate:	32.26%

Question 1

What is your professional role? (Please select one answer)

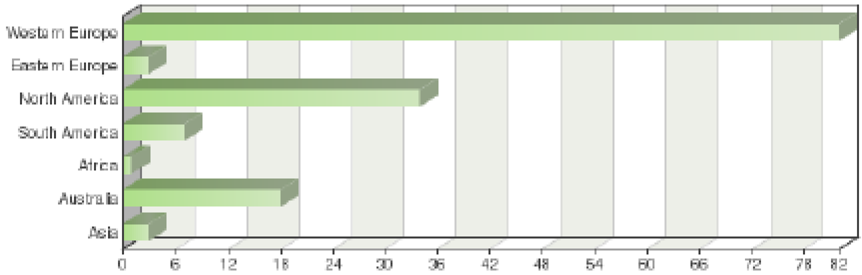


Frequency table

Items	Absolute frequency	Relative frequency	Adjusted relative frequency
Artistic Director of Ballet Company	13	8.78%	8.78%
Artistic Director of Ballet School	14	9.46%	9.46%
Choreographer	4	2.7%	2.7%
Senior Ballet Teacher	42	28.38%	28.38%
Principal Dancer	8	5.41%	5.41%
Exercise Specialist	11	7.43%	7.43%
Therapist	47	31.76%	31.76%
Doctor	9	6.08%	6.08%
Sum:	148	100%	100%
Not answered:	0	0%	-

Question 2

Where are you located? (Please select one)



Frequency table

Items	**Absolute frequency**	**Relative frequency**	**Adjusted relative frequency**
Western Europe	82	55.41%	55.41%
Eastern Europe	3	2.03%	2.03%
North America	34	22.97%	22.97%
South America	7	4.73%	4.73%
Africa	1	0.68%	0.68%
Australia	18	12.16%	12.16%
Asia	3	2.03%	2.03%
Sum:	148	100%	100%
Not answered:	0	0%	-

Question 3

Please list up to 10 physical attributes that you think make a great classical ballet dancer.

The Physical Attributes Most Required in Professional Ballet: A Delphi Study

OPEN ACCESS

Authors
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ABSTRACT

Background It is commonly accepted that dancers are undoubtedly athletes, with ballet perhaps the most demanding dance form. No previous study has sought to define the physical attributes most desired for classical ballet by professional companies and vocational schools. These are likely to include both aesthetic features and attributes that reduce the risk of injury as well as enhance performance.

Method An initial survey question using the modified Delphi technique was sent using Opinio Survey Software to a selected international expert panel. This was drawn both from those involved in selection of elite professional ballet dancers, and the international medical professionals involved in the care of dancers. The first questionnaire was open-ended to scope for all the physical attributes most favoured by the professional experts.

Results There were 148 responses from the panel of international experts. In total 34 physical attributes were suggested. The 2 most recommended physical criteria for selection into the profession were overall flexibility and overall strength. These results are discussed in the context of the published literature on the mechanics, anatomy and physiology of ballet.

Conclusion Flexibility and strength are the 2 features most sought after in elite ballet dancers.

Introduction

Dancers provide a unique blend of athlete and artist [17], for whom ideal physical attributes are just as important as they are in sport. In addition to their performance, musicality, and technique skills, ballet dancers are selected particularly for their physical qualities amongst other attributes [41]. Ballet students are selected into vocational schools based on their potential talent and physical characteristics [41]. However, incidence of injury in professional companies and in vocational schools remains high [1, 11]. Howse (1970) advocated for physical screening in ballet students at auditions for the Royal Ballet School. This was based on the premise of reducing injury risk [18]. An audition involves participating in a class where a dancer performs for a panel of experts, and because many companies select dancers from their own schools, it can be assumed that professional ballet dancers set the trend for selection into vocational schools. This study was confined to the physical attributes most desired in elite ballet dancers. This study forms the first part of a Delphi Survey designed to provide information on the requirements to identify professional dancers with lower risks of injury than at present.

Talent identification in aesthetic sports such as gymnastics has been investigated [40] with the conclusion that an appropriate physique in gymnastics for both aesthetic reasons and biomechanical advantages is well known to be important. Such studies have not previously been applied to ballet. Of all dance genres, classical ballet is relatively uniform with a vocabulary that is internationally recognized.

The Delphi technique is a recognised research method that uses a series or round of questionnaires to gather opinions that are continued until a group consensus is achieved [15, 28]. The technique involves presenting a questionnaire to a panel of preselected, informed individuals or experts to seek their opinion on a particular subject.

In this paper we present and discuss the first round of a Delphi questionnaire in which the physical characteristics most required for classical ballet were obtained, grouped and ranked in order of importance.

Methods

Ethical approval was obtained from the Ethical Committee of University College London and meets the ethical standards for this journal [16].

Study design

Purposive sampling was used to identify an initial panel of international professional company directors, vocational ballet school directors, choreographers, senior teachers, principal dancers, exercise specialists, therapists and doctors. This formed a panel of experts involved in the selection, training and therapeutic treatment of dancers. Purposive sampling is a form of non-probability sampling [9]. Depth and specificity of knowledge and expertise were required and therefore a purposive approach was used to recruit appropriate professionals. Snowball sampling was also used to further increase the size of the panel. This method was helpful to access further, well-informed potential participants not known to the researcher [9]. Colleagues in ballet familiar with the criteria for panel inclusion were requested to distribute the questionnaire.

Data collection

For the first round of the Delphi survey, an anonymous online questionnaire comprising 3 questions was created using Opinio software 7.6.4. Two questions were closed questions, requesting demographic information and profession. The third question was an open-ended question which asked for up to 10 physical attributes expected in today's elite dancer. The request was 'Please list up to 10 physical attributes that you think make a great classical ballet dancer'. Although responses were anonymous it was possible for the researcher to see non-responders in order to send reminders via email.

Data analysis

Data was downloaded from Opinio to MS Excel. Demographic and profession data was analysed using descriptive statistics. The open question responses were reviewed and inappropriate recommendations were excluded such as psychological or artistic attributes. The remaining data was coded, thematically analysed and grouped into categories of similar responses by the primary researcher. Thematic analysis is useful when assessing the varied responses to an open-ended question and patterns of similar responses/topics can be grouped allowing the researcher to capture all the data and organise it under distinct headings [7, 19]. The categories were then reviewed, refined and agreed with 3 members of the research team, HB, JS and AdeM prior to further analysis using descriptive statistics.

Results

Demographics

One hundred and forty-eight participants completed and returned questionnaires. The majority of respondents were physiotherapists and ballet teachers (▶ **Table 1**). Although 6 continents were represented, most of the respondents were from Western Europe and North America (▶ **Table 2**).

Reported physical attributes

Thirty-four attributes were reported. These are listed in thematic groups (▶ **Table 3**). Overall flexibility, overall strength, turnout, body proportions, and foot and ankle flexibility were the most frequently reported.

Discussion

This first round of the Delphi Survey highlights the wide-ranging physical attributes preferred in the ballet dancer today. Thirty-four attributes were recommended. A pragmatic approach was then taken to group these into themes to facilitate a synthesized initial discussion prior to the second round of the Delphi.

Overall flexibility was the most frequently recommended attribute by the expert panel. The demands of ballet technique require dancers to have a greater than normal range of movement at the hip

▶ **Table 1** Professional Background of Participants.

Profession	Number
Artistic Director Company	14
Artistic Director School	14
Senior Ballet Teacher	44
Choreographer	3
Principal Dancer	8
Exercise Specialist	10
Physical Therapist	46
Doctor	9

▶ **Table 2** Geographical Location of Participants.

Location	Number
Western Europe	82
North America	34
Australasia	18
South America	7
Eastern Europe	3
Africa	2
Asia	2

▶ **Table 3** Reported Physical Attributes (ranked by frequency of selection and expressed as a percentage), grouped within each of the broad themes most applicable to ballet.

Theme		Attribute	Frequency	%
Flexibility	1.	Overall flexibility	86	58
	2.	Hip turnout flexibility	75	50
	3.	Foot and ankle flexibility	69	46
	4.	Good pointe position (plantarflexion)	21	14
	5.	High extensions	13	8.7
	6.	Not too hypermobile	12	8
	7.	Good demi plié (dorsiflexion)	8	5
	8.	Hyperextended knee	7	4.6
	9.	Flexible big toe	2	1
Strength	10.	Overall strength	85	57
	11.	Spinal/core strength	25	16.7
	12.	Foot and ankle strength	10	6.7
	13.	Power	12	8
	14.	Ability to jump	10	6.7
	15.	Leg strength	4	2.6
	16.	Upper body strength	1	0.6
Coordination	17.	Coordination	34	22.8
	18.	Balance	13	8.7
	19.	Ability to turn (pirouette)	1	0.6
Stability	20.	Overall stability	3	2
	21.	Spinal stability	2	1
	22.	Shoulder stability	2	1
	23.	Control	36	24
Proportions	24.	Overall good proportions	71	48
	25.	Head/neck	35	23
	26.	Long Legs	33	22
	27.	Long arms	17	11
	28.	Short trunk	14	9
	29.	Height	2	1
Aesthetics	30.	Slimness	45	30
	31.	Leg shape	17	11
	32.	Beauty	14	9
Fitness	33.	Stamina	44	29.5
Miscellane-ous	34.	Eyesight	1	0.6

[6, 14, 26], spine [29], and foot and ankle [34]. The implications of this are reviewed in detail by Day, Koutedakis and Wyon, 2011 [8]. The authors contend that although this is aesthetically attractive, the risks of injury caused by excessive flexibility may have been overlooked, because some 44 % of dancers display hypermobility. However, conventional hypermobility scoring systems are not specifically aimed at dancers and much more research is needed in the area.

Flexibility in dancers is thought to be partly inherited and partly acquired [13]. Inherited characteristics include both the shape of the articulating surfaces of bone and collagen structure [3, 12]. Additional inherited factors influence range of movement in ballet. External rotation of the hip is further influenced by femoral anteversion angle [2, 30], acetabular version and depth, and laxity of the anterior iliofemoral ligament [2]. In addition to these inherited traits, range of movement may also be influenced by prolonged static stretching as part of training [13].

'Hypermobility', normally understood to be a greater than average range of movement at joints compared to the average population [13], was cited as a desirable feature. Inevitably this overlaps with the more frequent selection of 'overall flexibility' as being desirable. The cut point at which flexibility (which more correctly refers to muscle length) becomes 'hypermobility' is somewhat arbitrary even when standard scales not applied to dance are used and many respondents may not have appreciated this. However, because many respondents, in their open comments, specified that desired 'hypermobility' should not be excessive (▶ **Table 3**), it is probable that the medical community sampled was aware of the greater risk of injury associated with 'hypermobility'.

Referring to the selected physical attributes in ▶ **Table 3**, the flexible hip desirable in classical ballet technique is based on 'turn-out', where the lower limb is externally rotated and the available range of movement in the hip joint is increased [24]. Turnout is qualified as the summation of external rotation of the lower extremities [21, 24] including contributions from the hip, femur, knee, lower-leg, and foot-ankle complex. Sufficient external rotation at the hip in ballet dancers facilitates control of the lower limb and is thought to reduce the risk of injury [2].

Foot and ankle flexibility and good 'pointe' position were often cited as necessary. Ballet dancers weight-bear on extreme ranges of plantar flexion (the en pointe position or ¾ pointe) [34, 35] in order to execute ballet-specific movements and achieve ideal aesthetics. The fully plantar-flexed position must allow the body weight to descend through the tips of the toes encased in the box of the pointe shoe or ¾ pointe (through the toes and dorsiflexed metatarsophalangeal joints). There is also an important aesthetic element where the plantarflexed foot and ankle continue the length of line of the lower limb. Articulation of the ankle contributes to most of the range of movement, with the remaining contribution from the midfoot [34]. Sufficient weight-bearing dorsiflexion is required to allow the dancer to execute the 'demi plié', which allows dancers to execute explosive jumps as well as sustained manoeuvres [5, 20]. Range of motion here relies on bone shape, soft tissue laxity and neuromuscular tone.

Strength was also frequently reported. The leaps and jumps in ballet demand high muscle torque as well as the balance and postural control required for highly complex moves such as pirouettes. In the past dancers have been considered not as fit or well conditioned as equivalent athletes [23] particularly with respect to strength. However, there has been a movement over the last 5 years to include strength training in dancers' conditioning [22]. Dowse et al. (2017) advocate for resistance training in dancers, because in their study dynamic balance, lower-body strength and power were improved without affecting artistic or aesthetic components [10].

Core strength and spinal stability, referred to in ▶ **Table 3**, often come under the term core stability, which is the integration of passive (non-contractile), active (contractile), and neural structures to minimize the effects of external forces and maintain stability [31]. However, this is really a default term applied to all motor control training around the trunk. Core strength, motor control stability and endurance involve different concepts [27]. Injuries to the lower back are high in professional and pre-professional dance

[1, 11] and lack of pelvic stability has been implicated [33]. Impaired core proprioception has also been shown to be predictive of knee injury in female athletes [42]. Further examination of all the components of core stability – core power, strength, endurance and sensory-motor control – is advised in order to understand its multifactorial role in reducing injury and enhancing performance in dancers [31].

Stamina is another attribute important in the elite dancer. This was reported by nearly one-third of respondents. Classical ballet is characterized as a high-intensity, intermittent form of exercise [32, 38] demanding muscle power reserves for explosive jumps, muscular endurance to maintain high levels of power output, and cardiorespiratory endurance to execute low-intensity exercise. Without these physiological foundations, the dancer is left susceptible to fatigue, and this in turn has an effect on skill and alignment which may increase the risk of injury [38]. Therefore it is believed that enhancing these foundations also enhances aesthetic competence [32] and artistry, and frees the dancer to perform to music, express emotion, and thus captivate an audience.

Motor control and coordination requires an integration of visual, vestibular, and somatosensory information to facilitate accurate positioning and movement of the body in space [36]. Dance training requires the integrity of sensory inputs to coordinate the musculature of the body and to maintain proper alignment while moving through the positions and shapes intrinsic to it [36, 37].

Physical proportions scored highly in the survey with almost half of the panel highly ranking good proportions. Ballet is demanding in all the above physiological, anatomical, and functional characteristics but remains an art form, and aesthetic attributes are also important. So far, the literature has identified the ideal balletic physique as primarily ectomorphic [25, 39]. The Vaganova School in St. Petersburg measures and compares lower limb length to trunk length at audition for vocational training in order to attain physical conformity (G. Anthony, personal communication, July 17, 2016). Head and neck proportions as well as slimness are preferred in professional ballet. The slim physique in ballet has been much criticised [4], but lightness and an ability to show "line" in balletic positions are the aesthetic required.

Inevitably there are some weaknesses in this preliminary study. The artistic directors (18 % of participants) of companies and schools make the final decisions in recruitment to the profession, but they are supported by their artistic staff of senior ballet teachers (29.7 % of the survey panel), who still have a significant influence. Inevitably there will be more teachers than artistic directors. The physiotherapists, doctors and health professionals who participated were all selected because of proven involvement in dance, usually evidenced by their research in dance. Physiotherapists are used in many institutions to screen candidates in support of panel decisions. Their inclusion adds the perspective of injury prevention to the study, and a more detailed future analysis of how the responses of the participating groups differed is planned.

Neither were sex-specific physical attributes studied, although this also could form the basis of an interesting and important future study.

We believe this investigation is the first of its kind to obtain the preferences from those international experts in the profession who select dancers as well as those who care for dancers' health. It is clear that generalized flexibility takes precedence though specific examples such as hip turnout and foot and ankle flexibility are also sought. However, flexibility can never be separated from strength and control in achieving the range of controlled movement required. Aesthetic requirements were also considered but ranked as less important.

These results will form the basis for further rounds of the Delphi Survey in order to arrive at a consensus. It is hoped this might help guide those who train and those who care for dancers both in performance enhancement and injury risk management.

Acknowledgements

Private Physiotherapy Education Foundation Rudolf Nureyev Foundation Harlequin Floors UK.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Appendix B

<u>Participant Information Sheet for Physiotherapists working in Classical Ballet</u>
UCL Research Ethics Committee Approval ID Number: 7693 - 002

INFORMATION SHEET

The Development of a Screening Tool for Entry into Classical Ballet

---

Department:
UCL: Institute of Sport Exercise and Health

Dear _____________,

We would like to invite you to take part in a research workshop to discuss a selection of screening tests to be carried out at audition for 16-year-old entry into vocational ballet.

The workshop is proposed to take place over no more than two meetings where we hope to discuss
the merits (or otherwise) of a selection of tests familiar to all of us working in ballet.

You are invited specifically because of your expertise in physiotherapy and specialist ballet experience. However, before you decide, it is important to understand the aims of the research and exactly what this part will involve. Please, if you have any questions, contact me.

Thank you very much for reading this.

This is part of a PhD programme of research.
A Delphi Survey has been conducted to establish from the international artistic community the preferred physical attributes sought in the professional classical ballet dancer. This has guided a proposed selection of screening tests to inform on suitability and injury risk for the young dancer entering vocational ballet.
It is proposed to hold a workshop in order to share opinions on these specific tests.
Six physiotherapists in all will be invited to this meeting, and each has spent extensive time working in classical ballet. Your collective experience in the field is invaluable and discussion within the group will help establish a screen that is efficient, well developed and without bias.

Your participation will be much appreciated and hopefully the exercise will be interesting for all of us, with an opportunity to connect and discuss an area in which we are all involved. Your support is of course entirely voluntary, and you may withdraw at any moment.

It is planned to hold no more than two meetings in June 2019 for two hours each, at times that are convenient, but we understand how busy you all are, especially in preparation for the summer performances.

The meetings will follow the Nominal Group Technique (McMillan, King and Tully, 2016) and as each test is considered your opinions will be noted and if necessary, recorded for further reflection, but

only with your prior consent. You will also be requested to approve and vote on the inclusion of certain tests or variations.
There are nine tests covering passive range of movement, functional movement control and strength which will be presented to you for your opinion. Each of you will be asked to comment and we will discuss each test as a group. In conclusion we would appreciate your approval or otherwise and your guidance, to reach agreement.
Each meeting will be reported and kept confidential, and your opinions and guidance will be kept anonymised as will voting papers.

Any travel expenses will be reimbursed, and meetings will be held at the Institute of Sport Exercise and Health, 170 Tottenham Court Road, W1T 7HA.
Notes from the meeting and any recording undertaken will be used for analysis only and retained confidentially and no one outside the project will have access at any time.

There are no immediate benefits to any of the participants, but it is hoped that bringing together professionals in the same area can stimulate interesting discussion, exploration and sharing of knowledge. While we are colleagues, our busy professional lives do not normally allow much interaction. We see this as a valuable opportunity.

The Principal Researcher is available at any time should you be dissatisfied with the procedure and the research is carried out with the support and approval of the Chair of the UCL research Ethics Committee – ethics@ucl.ac.uk

All the information that we collect from you will be kept strictly confidential and you will not be identified in any ensuing reports or publications unless you have specifically given your consent. Your assistance with ideas and guidance is all that is required here. Confidentiality will be respected subject to legal constraints and professional guidelines and the information retained only until the conclusion of the PhD.

When agreement has been reached on the suitability of each screening test, this will facilitate the second part of the research programme. This will be a lengthy project to establish reliability of these tests and the composite screen. The published results of this will be only available on completion of the PhD.

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk
This 'local' privacy notice sets out the information that applies to this particular study. Further information on how UCL uses participant information can be found in our 'general' privacy notice: for participants in health and care research studies, click here

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

Contact for further information

Doctor Jane Simmonds MCSP SFHEA
UCL Great Ormond Street Institute of Child Health
Faculty of Population Sciences

You will be given a copy of the information sheet and a signed consent form to keep.

Many thanks for reading this and considering being part of this project.

Moira McCormack MSc MCSP

Letter of Invitation

Dear Colleague,

I am writing to see if you can help me with an important research project at University College London which I am conducting as part of my PhD.

I would like to invite you to a meeting with five other physiotherapists where I would value your opinion on a selection of screening tests for classical ballet dancers at audition, for entry at 16 years of age. You are all specialists working in vocational ballet and have been invited for your expertise.

The project is composed of two meetings lasting 2 hours each (planned for June 2019) where, following a Nominal Group Technique, we will consider and discuss the merits (or otherwise) of nine tests and hopefully agree on a composite screen.

Your valued opinion will help me to create an efficient screening tool for dancers. This is an initial project which will allow me to progress to reliability studies for each test, knowing that I have your informed approval. The results of our meeting will be analysed and shared with you.

Data will be confidential and anonymous, but an information sheet and consent form will follow this initial invitation.

I very much hope you will be interested and positive enough to take part, although I am sure you are busy.

With thanks,

Moira McCormack MSc MCSP

Appendix C

Mr./Ms. ……………
Director of Dance
……………….. School

20/9/19

Research Project: A reliability study of a scored musculoskeletal screen for entry into classical ballet.

Dear ……………,

I am a physiotherapist working at the Royal Ballet Company and currently completing PhD studies at University College London.

As part of my research, I hope to carry out screening studies on ballet students to see if the tests we use in Physiotherapy are reliable. We use flexibility tests and movement control tests routinely on our dancers, but we have not yet proven their reliability.

I would like to invite first year students from your school to take part.

If you are in agreement, three female students and two males would be invited to the Opera House and join the company morning barre for a thorough warm up at 10.30. They would be taken to the Healthcare Department at 11.30 where we would commence screening with three experience physiotherapists. It is a repetitive process, but we would break for lunch of their choice, provided by us in the canteen.

There are five range of movement tests (flexibility) which are repeated. The five movement control tests are filmed to avoid further repetition. We should be finished by 4.30.

Participation is purely voluntary; confidentiality is respected at all times and UCL Ethics Committee have approved the project. It will be an interesting and enjoyable day out for them, and they will be contributing to dance-specific physiotherapy research.

We are aiming to do this in early November.

If you agree, I shall send you a detailed Information Sheet and a copy of the Students' Consent Form for your consideration. Please contact me with any queries or concerns you might have. I would be so appreciative of your support.

Your physiotherapist would be welcome to accompany the students. Otherwise, I will be with the students at all times.

With best wishes,

Moira

Moira McCormack MSc MCSP

Physiotherapist Royal Ballet Company

Dance Specialist

PhD candidate University College London

Physiotherapy Research

FIRST YEAR STUDENTS (16-17 yrs)

We need your help!

In caring for dancer/athletes we carry out screening tests routinely to identify areas that can be improved, lower the risk of injury and enhance performance.

But we need to know that our screening tests are reliable and can be repeated easily and used by any physio.

Therefore, we need to practise on dance students and know we are obtaining reliable results.

So, we are asking for your time to help us achieve good results in this research.

If you are interested and feel you can give us some time, please help with this research in screening by contacting

Moira McCormack – moira.mccormack@ucl.ac.uk or speak to your physio who will put us in touch.

I will explain in detail and send you an information sheet when you email me.

Thank you for reading and considering this.

<u>Participant Information Sheet for Ballet Students and their Parents</u>

UCL Research Ethics Committee Approval ID Number: _______

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

A reliability study of a scored musculoskeletal screen for entry into classical ballet.

Department:

Division of Surgery and Interventional Science

Institute of Sport Exercise and Health

170 Tottenham Court Road

London W1T 7HA

Name and Contact Details of the Researchers:

Dr Jane Simmonds

Moira McCormack

Name and Contact Details of the Principal Researcher:

Professor Fares Haddad

Dear ………………………….,

You are being invited to take part in a research study at University College London to investigate the reliability of physiotherapy screening tests in classical ballet.
Before you consent to take part, it is important you understand why the research is being done and what participation will involve. Please take time to read the following before giving your permission and ask us if anything is not clear or you wish further information.
Thank you for reading this.
You are encouraged to share this with your parents/guardian.

What is the project's purpose?

In Physiotherapy one of our remits is to reduce risk of injury. Accurate screening is one of the ways we can attempt to do this.
All athletes undergo screening to identify injury risk, but we need to know that any screening test we use is reliable, precise and gives us the information we need to reduce injury. Before we can use screening tests with confidence, we need to know they have

been thoroughly examined for reliability and give us the information we need. This will involve asking you to undergo a 15-minute screen carried out by 3 different dance-specialist physiotherapists over a period of time. Every effort will be made so as not to impose on your time.
This is part of a PhD at University College London.

Why have I been chosen?

You are one of fifteen students who are invited to support this study. You will have started training recently in your first year, and you are between 16 and 18 and are fit and healthy.

Do I have to take part?

Taking part is entirely voluntary and involves no penalty. You may discontinue participation at any time. It is up to you to decide.
If you decide to take part, this information sheet will be supplied, and you will be asked to sign a consent form. Withdrawal at any time is permitted and you will be asked what should happen to the data collected up to that point.

What will happen if I take part?

You will be asked to attend up to six 15-20 minute testing sessions which will be spread out to allow assessment by 3 different physiotherapists and yet not impose unnecessarily on time. This series of brief tests will be carried out in the school physiotherapy department to measure range of movement at major joints, functional control and strength. The physiotherapist testing will record the score for each test, but this data will be confidential and used only within this current research, accessible only by those involved in this study.

You will be asked to sign a consent form.

What are the possible disadvantages and risks of taking part?

There are no foreseeable disadvantages, discomforts or risks involved in this research. The chartered physiotherapists involved are specialists who are experienced, and their conduct adheres to standards laid down by their governing body, the Chartered Society of Physiotherapy.

Each test will be fully explained to you and any questions will be answered. Screening will take place after morning class when the body is warm, tissues are pliable, and control is at its best.

What are the possible benefits of taking part?

Whilst there is no immediate intended benefit to the student it is hoped that this study will contribute to our understanding and efficiency in caring for and supporting vocational students while they are in full-time training, and they will learn more about research and their own physiques.

What if something goes wrong?

Any complaint during the research process should be raised with the Principal Supervisor or if it requires taking further, it is advised to contact the Chair of the UCL Research Ethics Committee - ethics@ucl.ac.uk
The Lead Researcher will be present at all times

Will taking part in this project be kept confidential?

All information and data we collect will be kept strictly confidential and student will not be able to be identified in any ensuing reports or publications.

Limits to confidentiality

- Please note that assurances on confidentiality will be strictly adhered to unless evidence of wrongdoing or potential harm is uncovered. In such cases the University may be obliged to contact relevant statutory bodies/agencies.
- Confidentiality will be respected subject to legal constraints and professional guidelines.

What will happen to the results of the research project?

The results of the research project will be published after the data has been collected and analysed. However, no students or schools will be identified in any report or publication.

What happens now?

If you are interested in taking part in this study, please reply to this e-mail accepting the invitation to the study. There will be an opportunity to ask questions. You will be provided with a consent form to sign.

If you require any further information, please don't hesitate to contact Moira McCormack:

The Principal Researcher is available at any time should you be dissatisfied with the procedure and the research is carried out with the support and approval of the Chair of the UCL research Ethics Committee – ethics@ucl.ac.uk

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data and can be contacted at data-protection@ucl.ac.uk. This 'local' privacy notice sets out the information that applies to this particular study.

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

Contact for further information:

Professor Fares Haddad

You will be given a copy of the information sheet and a signed consent form to keep.

Thank you for reading this information sheet and for considering allowing your son/daughter to take part in this research study.

Moira McCormack MSc MCSP

Please complete this form after you have listened to an explanation about the research.

Title of Study: A reliability study of a scored musculoskeletal screen for entry into classical ballet

Department: Institute of Sport Exercise and Health

Name and Contact Details of the Researcher(s):

Moira McCormack

Doctor Jane Simmonds

Name and Contact Details of the Principal Researcher:

Professor Fares Haddad

Name and Contact Details of the UCL Data Protection Officer: Spencer Crouch

This study has been approved by the UCL Research Ethics Committee: Project ID number: 7693/003

Thank you for considering participating in this research. The person organising the research will explain the project to you before you agree to take part. If you have any questions, you will be able to ask the researcher before you decide whether to give your permission. You will be given a copy of this Consent Form to keep and refer to at any time.

I confirm that I understand that by ticking/initialling each box below I am consenting to this element of the study. I understand that it will be assumed that unticked/initialled boxes means that I DO NOT consent to that part of the study. I understand that by not giving consent for any one element that I may be deemed ineligible for the study.

1.	*I confirm that I have understood the information about the above study. I have had an opportunity to consider the information and what will be expected. I will have the opportunity to ask questions which will be answered *(and give my consent to take part in (please tick the following)* - ***The musculoskeletal screening project***

2.	*I understand that I will be able to withdraw my data at any point
3.	*I consent to participation in the study. I understand that my personal information will be used for the purposes explained to me.
4.	**Use of the information for this project only** *I understand that all personal information will remain confidential and that all efforts will be made to ensure I cannot be identified. I understand that data gathered in this study will be stored anonymously and securely. It will not be possible to identify me in any publications.
5.	*I understand that my information may be subject to review by responsible individuals from the University for monitoring and audit purposes.
6.	*I understand that participation is voluntary and that I am free to withdraw at any time without giving a reason. I understand that if I decide to withdraw, any personal data I have provided up to that point will be deleted unless I agree otherwise.
7.	I understand the potential risks of participating and the support that will be available to me should I become distressed during the course of the research.
8.	I understand the direct/indirect benefits of participating.
9.	I understand that the data will not be made available to any commercial organisations but is solely the responsibility of the researcher(s) undertaking this study.
10.	I understand that I will not benefit financially from this study or from any possible outcome it may result in in the future.
11.	I agree that my anonymised research data may be used by others for future research. [No one will be able to identify you when this data is shared.]
12.	I understand that the information I have submitted may be published as a report.
13.	I consent to participating in this research involving musculoskeletal screening and data collection. Data will be stored anonymously, using password-protected software and will be used for this study only.
14.	I hereby confirm that I understand the inclusion criteria as explained to me by the researcher.
15.	I hereby confirm that I understand the exclusion criteria as explained to me by the researcher.
16.	I am aware of whom I should contact if I wish to lodge a complaint.
17.	I volunteer to participate in this study.
18.	I would be happy for the data provided to be archived at UCL. I understand that other authenticated researchers will have access to [anonymised] data.

___________________________ ________________ ___________________

Name of participant Date Signature

___________________________ ________________ ________

[Name of parent Date Signature]

Moira McCormack

Researcher Date 9/1/2020

Project: A reliability study of a scored musculoskeletal screen for entry into classical ballet.

Dear Colleague,

I am writing to see if you can help me with an important research project at University College London which I am conducting as part of my PhD.

I would like to invite you to take part in a musculoskeletal screening study where the aim is to establish intra- and inter-reliability. You would be one of three physiotherapists involved.

We use screening tests routinely in physiotherapy but as yet we do not have a reliable or valid screen to support our work.

After thorough familiarisation you would be asked to conduct a fifteen-minute screen on fifteen ballet students. The project requires commitment, but I would be present at all screening to answer questions and to time keep.

All data will be confidential and anonymous. If you are interested an information sheet and consent form will follow this initial invitation and I am available to answer questions at any time.

I would very much appreciate your involvement in this study and hope that you will lend your support as I value your experience and expertise.

With thanks,

Moira McCormack MSc MCSP

<u>Participant Information Sheet for Physiotherapists Working in Classical Ballet</u>

UCL Research Ethics Committee Approval ID Number: _______

INFORMATION SHEET

The Development of a Screening Tool for Entry into Classical Ballet

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Department:

UCL: Institute of Sport Exercise and Health

Researcher:

Moira McCormack

Principal Researcher:

Professor Fares Haddad

Dear ____________,

You are being invited to take part in a research project. Before you decide it is important that you understand why the research is being done and what will be involved. Please take time to read the information below carefully. Ask any questions, if anything is not clear, or you would like further information, contact us on the details above. Thank you for reading this.

Introduction

This research project is part of my PhD studies. The aim of this stage of the research is to agree a battery of tests for use in screening for young ballet dancers aged 16 years entering vocational training. Once the tests have been agreed upon, further testing of their reliability and validity will be undertaken as the next stage of my PhD.

Why have you been chosen to take part?

You have been selected because you are an experienced ballet physiotherapist. This research requires expert opinion to help decide on the best tests for screening young dancers.

Do I have to take part?

It is up to you, to decide whether or not to take part. If you decide to participate you will be given this information sheet to keep. You can withdraw at any time without having to give a reason and without any effect. If you decide to withdraw you will be asked what you wish to happen to the data that has been provided to us up to that point.

What will I have to do if I agree to take part?

If you decide to take part be required to attend up 2 workshops, lasting no longer than 2 hours. There will be 6 physiotherapists in the workshop. The workshops will take place at UCL Institute of Sport, Exercise and Health, 170 Tottenham Court Road, London. The workshops will be undertaken at time/s convenient to you in June 2019.

In the workshop, we will discuss a range of possible screening tests which I have collated based on the findings from a large Delphi study on physical attributes of dancers which I conducted and from the published research literature on ballet injury and screening tools.

After discussions with you all, there will be a vote on whether to include the test or not. We will use a method called the Nominal Group Technique to do this. I will take written notes of the workshop and the decisions made. I may need to audio record parts of the discussion so that I can reflect later when writing up the research.

What will happen to the recorded media and how will it be used?

All written notes from the workshop meetings will be anonymised and will be scanned into a password protected computer and used for the analysis. Any hard copy notes will be stored securely in a locked filing cabinet when not in use. The hard copy notes will be disposed of in the confidential waste at UCL within 6 weeks of transcription.

The audio recordings which may be made during the workshop/s will be used only for analysis. They will be transcribed by me. They will not be used for any other purpose without your written permission, and no one outside the project will be allowed access recordings. The recordings will be stored in a secure password protected laptop. After transcription they will be deleted within 6 six weeks of the transcription.

At the end of the study all electronic transcriptions and notes will be stored securely by University College London for 15 years.

What are the possible disadvantages of taking part?

There are no foreseen disadvantages. The workshops will require up to 4 hours in total of your time. If you wish to be named in the acknowledgements of research publications, this option will be offered to you. Standard travel will be reimbursed.

What are the possible benefits of taking part?

Whilst there are no immediate benefits for those people participating in the project, there are potential benefits for young dancers and ballet companies as the proposed screening tool will help to identify potential injury risks which can then be potentially, better managed.

What if something goes wrong?

If you are not happy with the research and feel that something has not been conducted properly or wish to report an adverse effect as a result of taking part in the study you are encouraged to contact

Jane Simmonds (contact details above). If you feel that your complaint has not been handled appropriately you can contact the Chair of the UCL Research Ethics Committee (ethics@ucl.ac.uk)

Personal Information:

The only personal information I will collect from you is your years of experience as a ballet physiotherapist. All other information such as your name and place of work will be fully anonymised.

Will my taking part in the study be confidential?

All the information that we collected during the course of the research will be anonymised and kept strictly confidential.

Limits to confidentiality: Please note that confidentiality will be maintained as far as it is possible, unless during our conversation I hear anything which makes me worried that someone might be in danger of harm, I might have to inform relevant agencies of this. This will be conducted in line with your school's/club's safeguarding policy, or that of UCL.

What happens now?

If you are interested in taking part in this study, please reply to this e-mail accepting the invitation to the study. There will be an opportunity to ask questions. You will be provided with a consent form.

If you require any further information, please don't hesitate to contact Moira McCormack:

The Principal Researcher is available at any time should you be dissatisfied with the procedure and the research is carried out with the support and approval of the Chair of the UCL research Ethics Committee – ethics@ucl.ac.uk

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk. This 'local' privacy notice sets out the information that applies to this particular study.

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

Contact for further information:

Professor Fares Haddad

You will be given a copy of the information sheet and a signed consent form to keep.

Many thanks for reading this and considering being part of this project.

Moira McCormack MSc

CONSENT FORM FOR PHYSIOTHERAPISTS

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study: A reliability study of a scored musculoskeletal screen for entry into classical ballet

Department: Institute of Sport Exercise and Health

Name and Contact Details of the Researcher(s):

Moira McCormack

Doctor Jane Simmonds

Name and Contact Details of the Principal Researcher:

Professor Fares Haddad

Name and Contact Details of the UCL Data Protection Officer: Spencer Crouch

This study has been approved by the UCL Research Ethics Committee: Project ID number: ____________

Thank you for considering participating in this research. The person organising the research must explain the project to you before you agree to take part. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide. You will be given a copy of this Consent Form to keep and refer to at any time.

I confirm that I understand that by ticking/initialling each box below I am consenting to this element of the study. I understand that it will be assumed that unticked/initialled boxes means that I DO NOT consent to that part of the study. I understand that by not giving consent for any one element that I may be deemed ineligible for the study.

19.	*I confirm that I have read and understood the Information Sheet for the above study. I have had an opportunity to consider the information and what will be expected of me. I have also had the opportunity to ask questions which have been answered to my satisfaction. *(and give my consent to take part in (please tick one or more of the following)* - ***The musculoskeletal screening project***
20.	*I understand that I will be able to withdraw at any point
21.	*I consent to participation in the study. I understand that my personal information *(names and address)* will be used for the purposes explained to me. I understand that according to data protection legislation, 'public task' will be the lawful basis for processing.
22.	**Use of the information for this project only** *I understand that all personal information will remain confidential and that all efforts will be made to ensure I cannot be identified. I understand that data gathered in this study will be stored anonymously and securely. It will not be possible to identify me in any publications.
23.	*I understand that my information may be subject to review by responsible individuals from the University for monitoring and audit purposes.
24.	*I understand that participation is voluntary and that I am free to withdraw at any time without giving a reason. I understand that if I decide to withdraw, any personal data I have provided up to that point will be deleted unless I agree otherwise.
25.	I understand the potential risks of participating and the support that will be available to me should I become distressed during the course of the research.
26.	I understand the direct/indirect benefits of participating.
27.	I understand that the data will not be made available to any commercial organisations but is solely the responsibility of the researcher(s) undertaking this study.
28.	I understand that I will not benefit financially from this study or from any possible outcome it may result in in the future.
29.	I agree that my anonymised research data may be used by others for future research. [No one will be able to identify you when this data is shared.]
30.	I understand that the information I have submitted will be published as a report and I wish to receive a copy of it. Yes/No
31.	I consent to participate in this research involving musculoskeletal screening and data collection. Data will be stored anonymously, using password-protected software and will be used for this study only.
32.	I hereby confirm that I understand the inclusion criteria as detailed in the Information Sheet and explained to me by the researcher.
33.	I hereby confirm that:

	I understand the exclusion criteria as detailed in the Information Sheet and explained to me by the researcher.
34.	I am aware of who I should contact if I wish to lodge a complaint.
35.	I voluntarily consent to participation in this study.
36.	I would be happy for the data provided to be archived at UCL. I understand that other authenticated researchers will have access to [anonymised] data.

If you would like your contact details to be retained so that you can be contacted in the future by UCL researchers who would like to invite you to participate in follow up studies to this project, or in future studies of a similar nature, please tick the appropriate box below.

	Yes, I would be happy to be contacted in this way	
	No, I would not like to be contacted	

____________________________ __________________ _____________________

Name of participant Date Signature

Moira McCormack 29/05/19

Researcher Date

ROYAL OPERA HOUSE
COVENT GARDEN
LONDON
WC2E 9DD

TEL : +44 (0)20 7240 1200
FAX : +44 (0)20 7212 9502

www.roh.org.uk

ROYAL
OPERA
HOUSE

Institute of Sport and Exercise Health
University College London
170 Tottenham Court Road
London
W1T 7HA

15th December 2015

To whom it may concern,

Re: Study proposal: Development of a screening tool for elite ballet dancers with particular reference to hypermobility, to inform on optimum training and reduce the risk of injury.

I am writing in support of the above study which is being undertaken by Ms Moira McCormack as part of her PhD Thesis at UCL, through the Institute of Sport and Exercise Health.

This particular research is both novel and unique in the world of classical ballet and will help us better analyse the unique markers for hypermobility and then develop a tool to assess for these characteristics which is a significant clinical challenge in this population group.

In a wider context the research will add to an overall picture of the physiological challenges associated with classical ballet, especially as interest in using ballet as an exercise modality for wider public involvement increases.

I have spent some time discussing the practicalities for implementing this study with Ms McCormack, and I am confident that we will be able to find suitable dancers from the Royal Ballet Company to assist in completion of this piece of research.

Ms McCormack may contact the dancers with our support and carry out the research on the premises of the Royal Opera House.

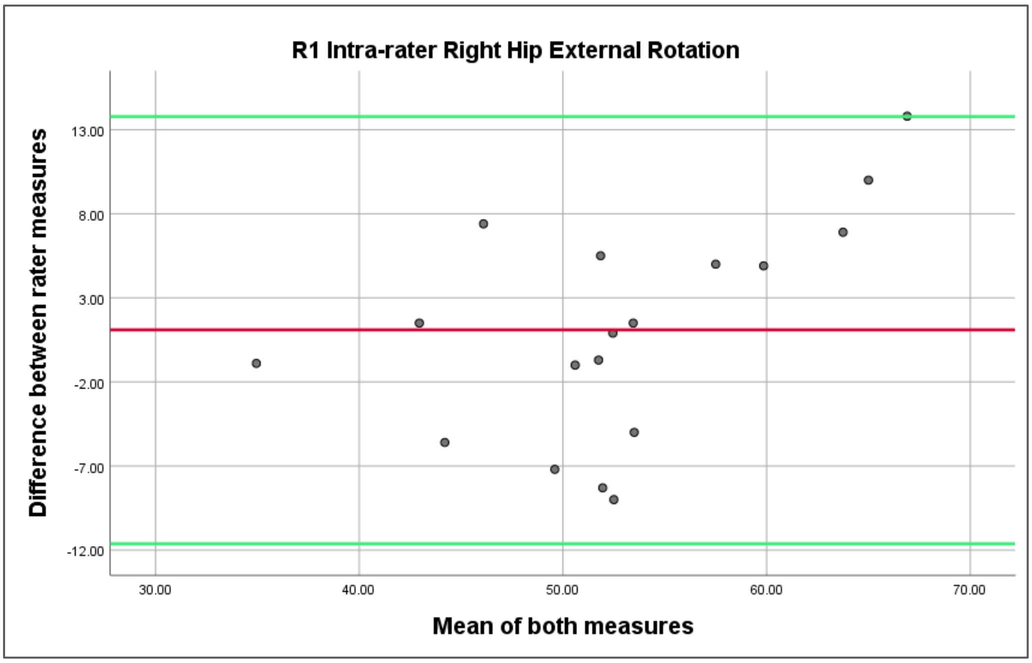
Please feel free to contact me with any additional queries.

Yours faithfully

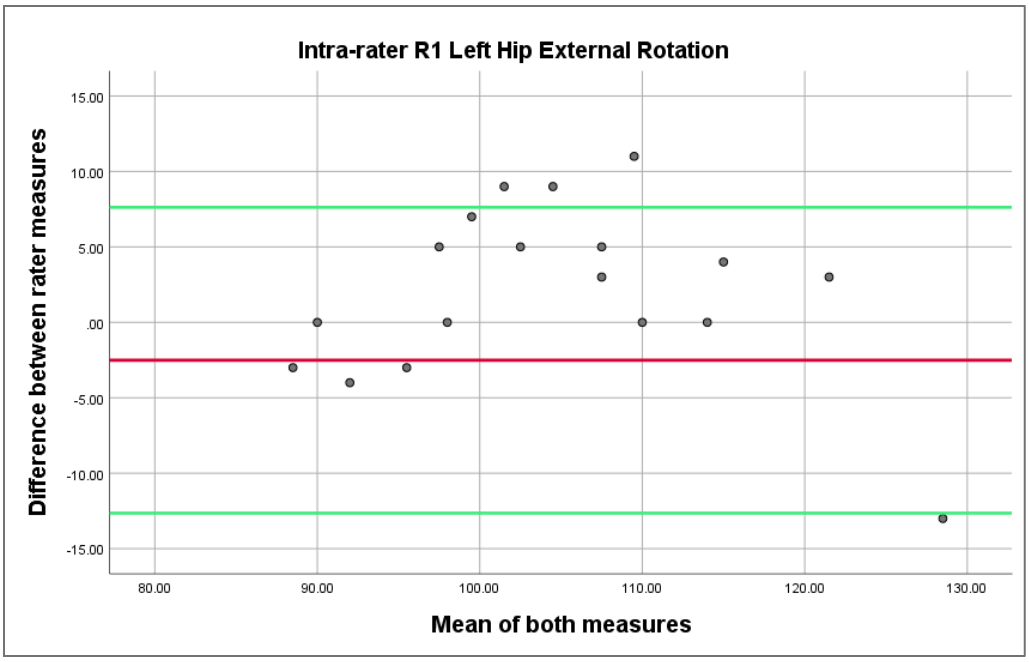
System P

Appendix C Bland Altman Plots - Intra-rater Reliability Range of Movement Tests

Chapter 8

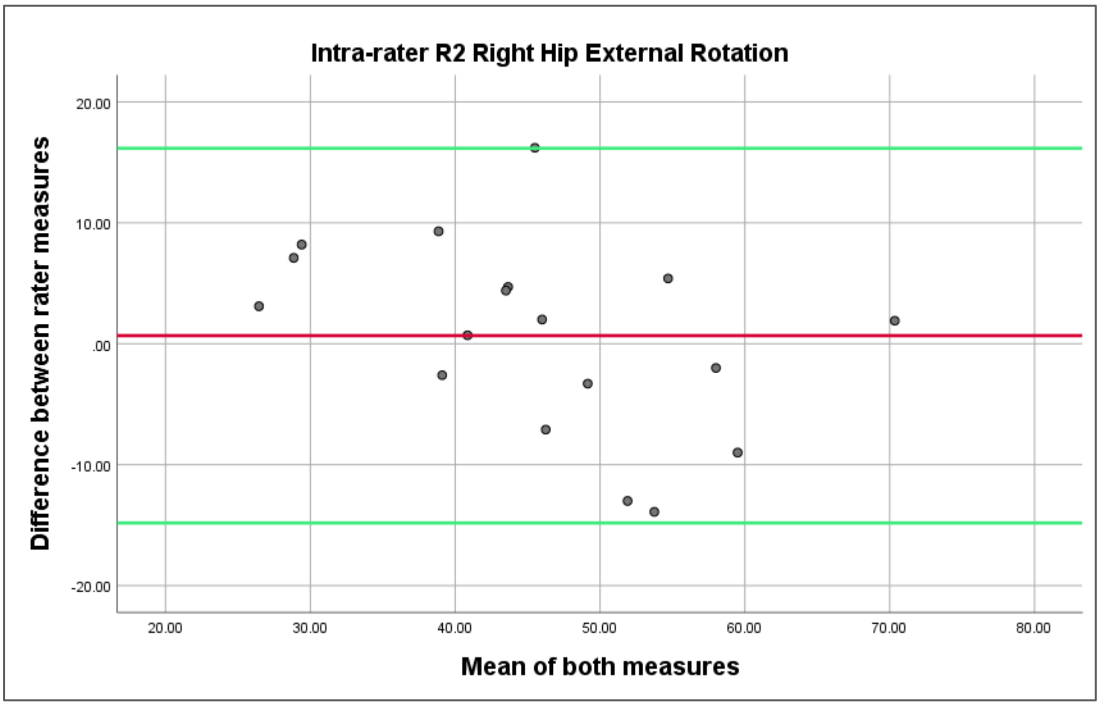


Bland Altman Intra-rater R1 Right Hip External Rotation
SEM = 5.33, MDC = 14.73, Mean Difference = 1.094, LOA = (-11.627,13.816)

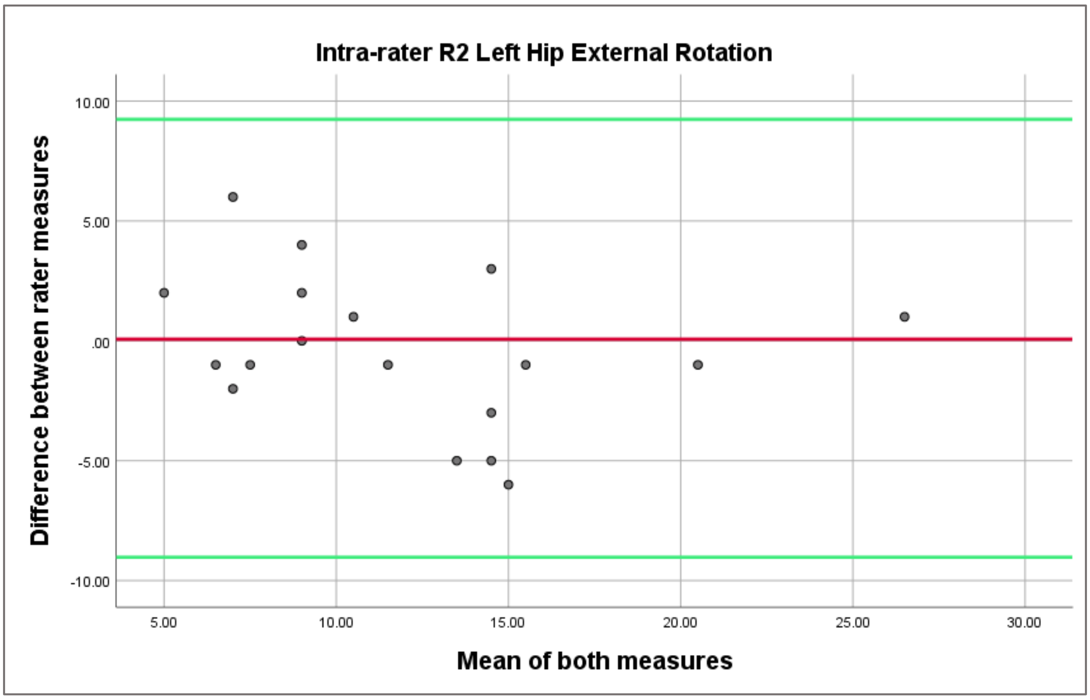


Bland Altman Intra-rater R1 Left Hip External Rotation

SEM = 4.05, MDC = 11.21, Mean Difference = -2.51, LOA = (-12.647,7.625)

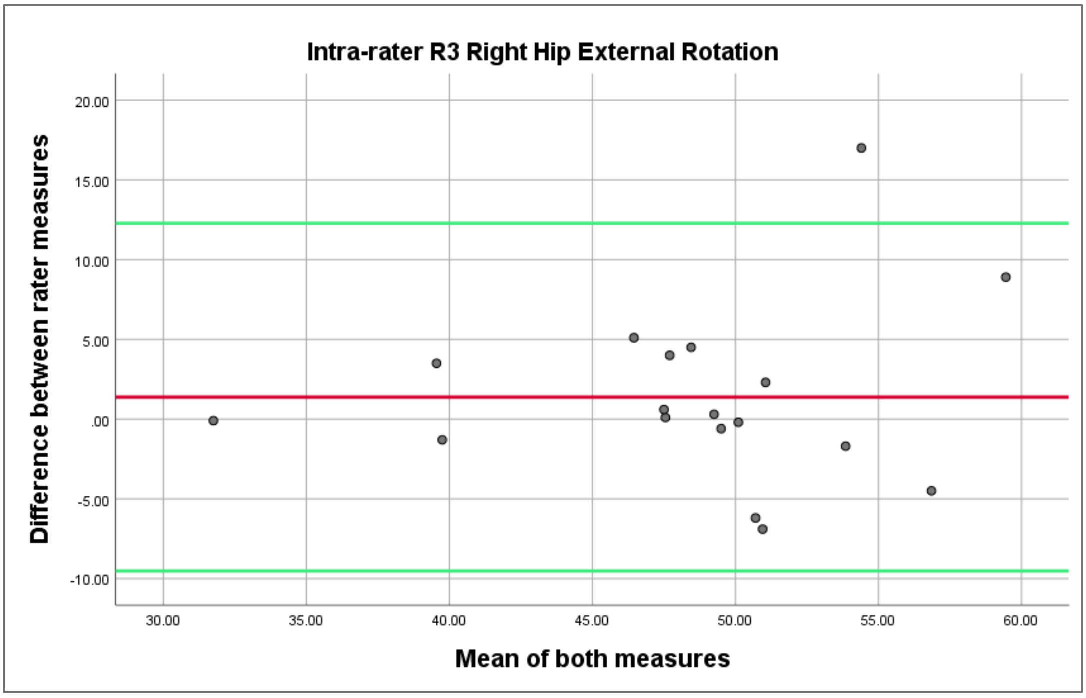


Bland Altman Intra-rater R2 Right Hip External Rotation
SEM = 4.73, MDC = 13.1, Mean Difference = .6722, LOA = (-14.819,16.164)

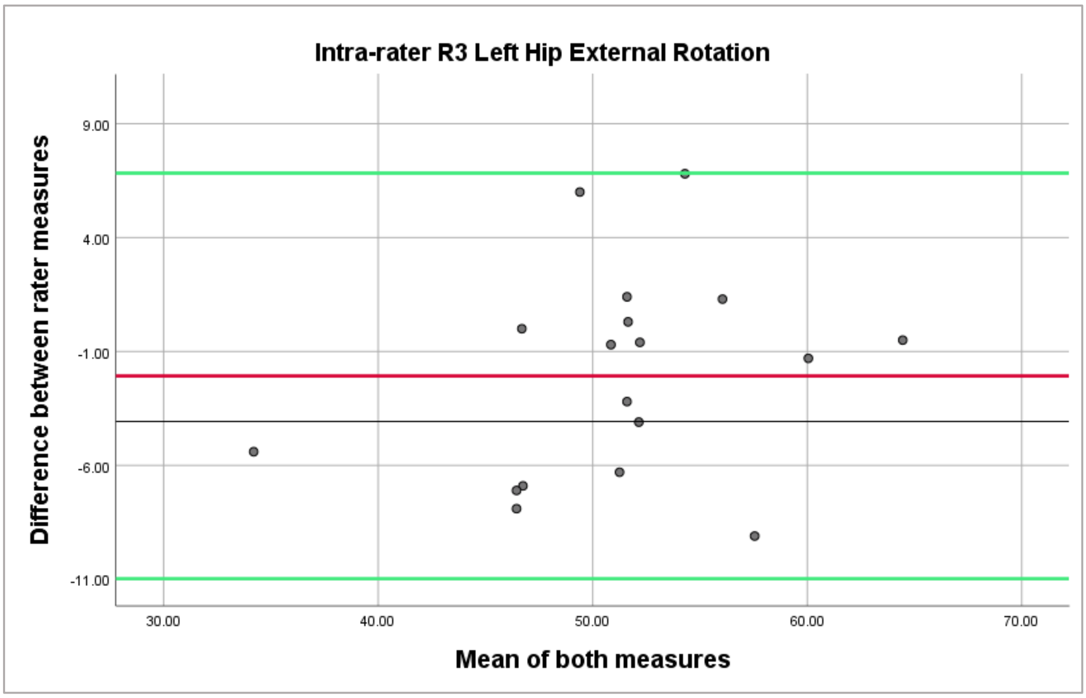


Bland Altman Intra-rater R2 Left Hip External Rotation

SEM = 2.82, MDC = 7.8, Mean Difference = .1055, LOA = (-9.026,9.237)

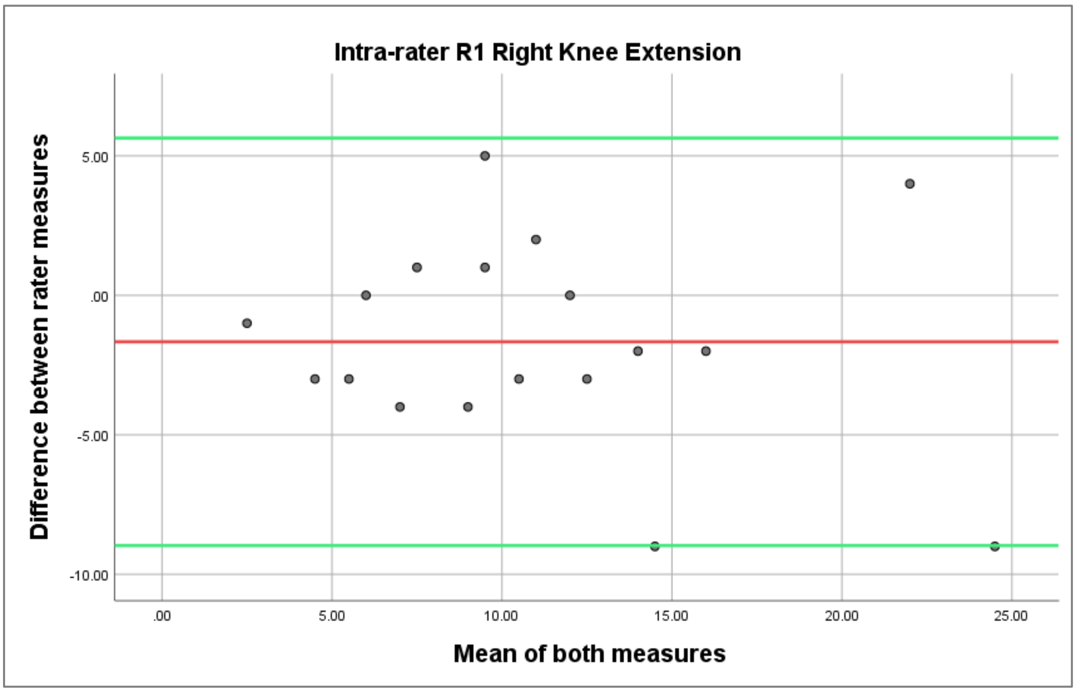


Bland Altman Intra-rater R3 Right Hip External Rotation
SEM = 4.15, MDC = 11.5, Mean Difference = 1.378, LOA = (-9.52,12.276)

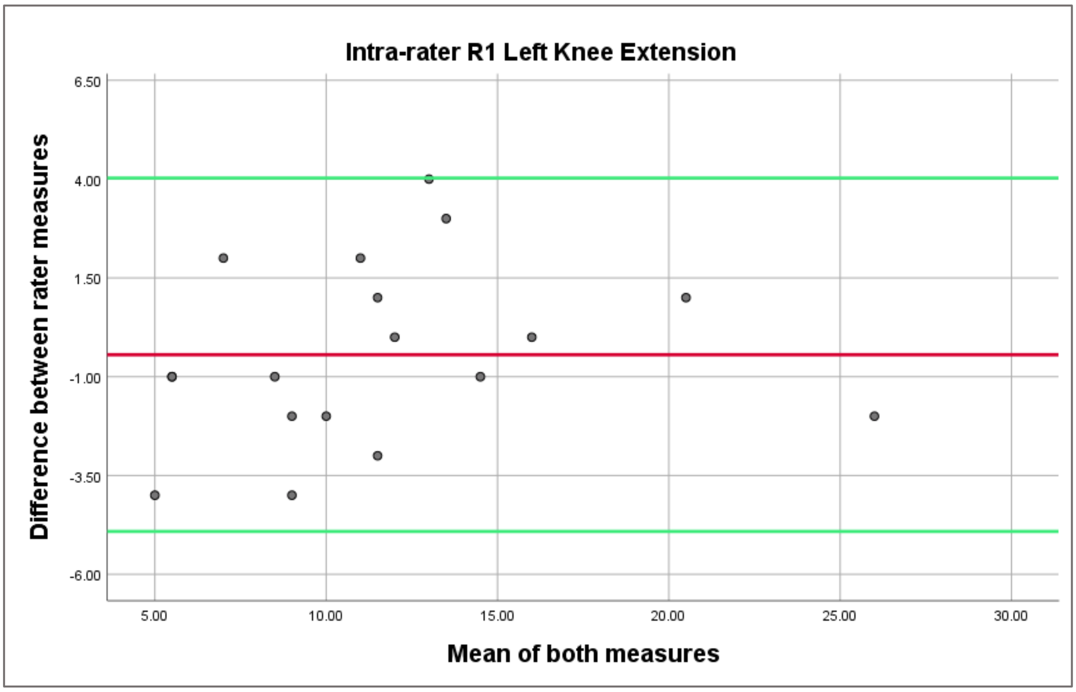


Bland Altman Intra-rater R3 Left Hip External Rotation

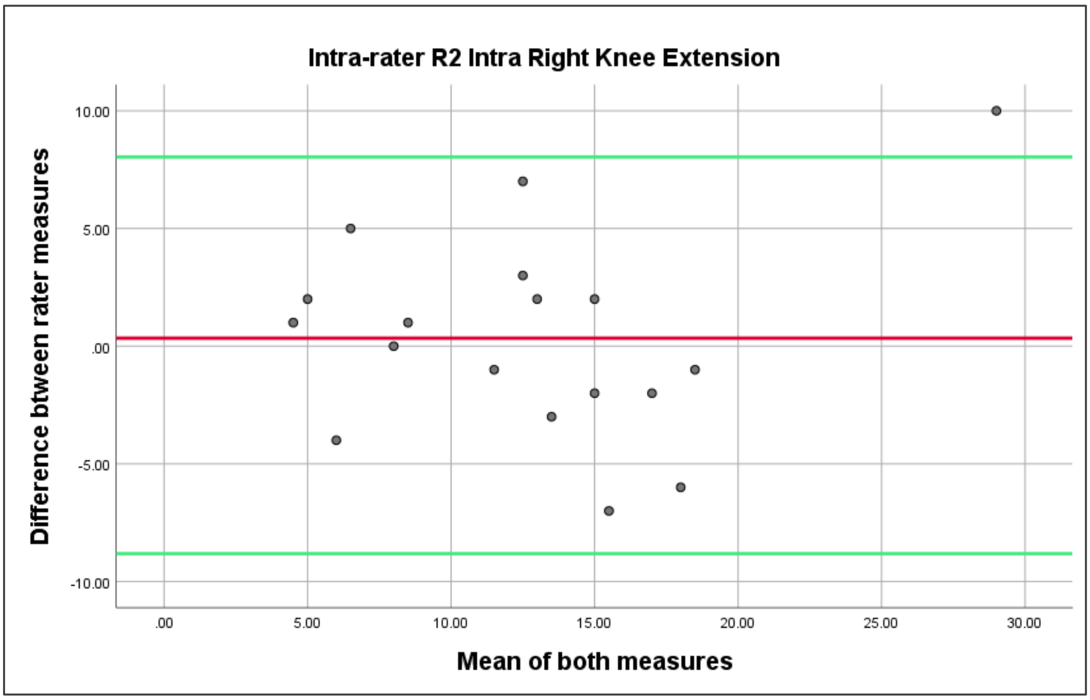
SEM = .3.66, MDC = 10.13, Mean Difference = -2.072, LOA = (-10.973,6.829)



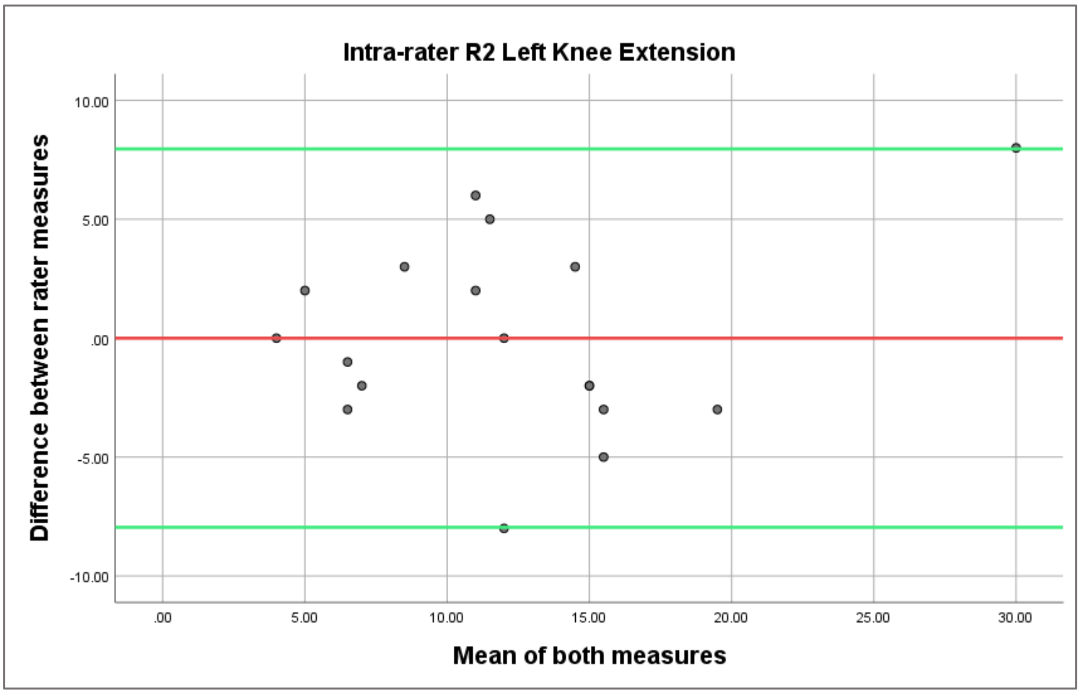
Bland Altman Intra-rater R1 Right Knee Extension
SEM = 2.61, MDC = 7.21, Mean difference = -1.6667 LOA = (-8.969,5.636)



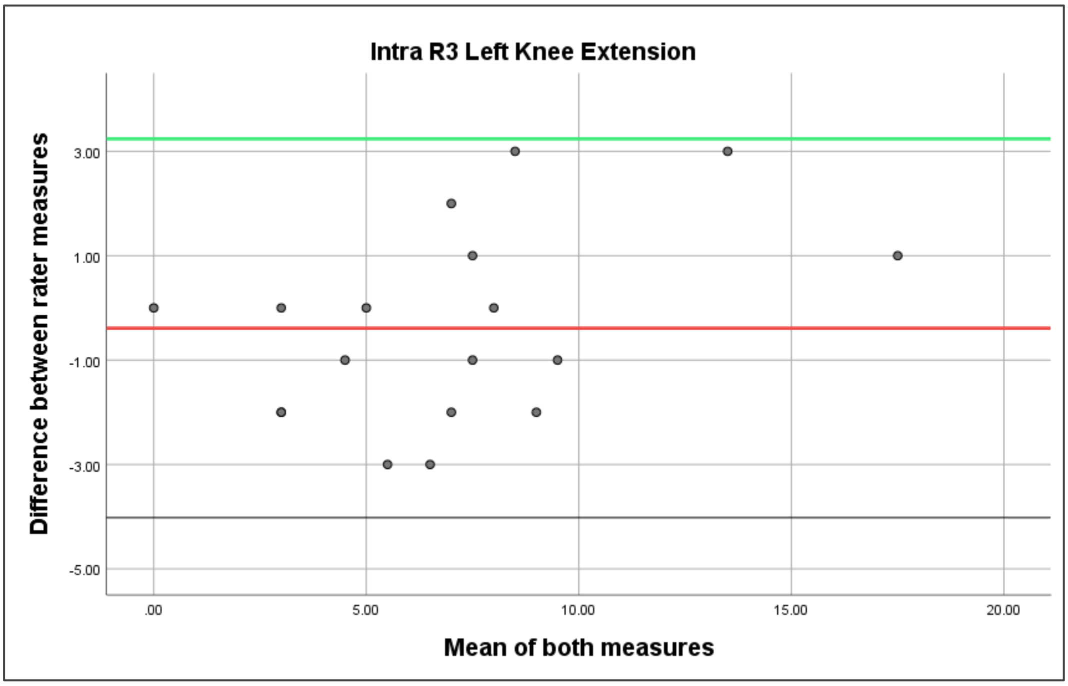
Bland Altman Intra-rater R1 Left Knee Extension
SEM = 1.66, MDC = 4.59, Mean Difference = -.444, LOA = (-4.915,4.026)



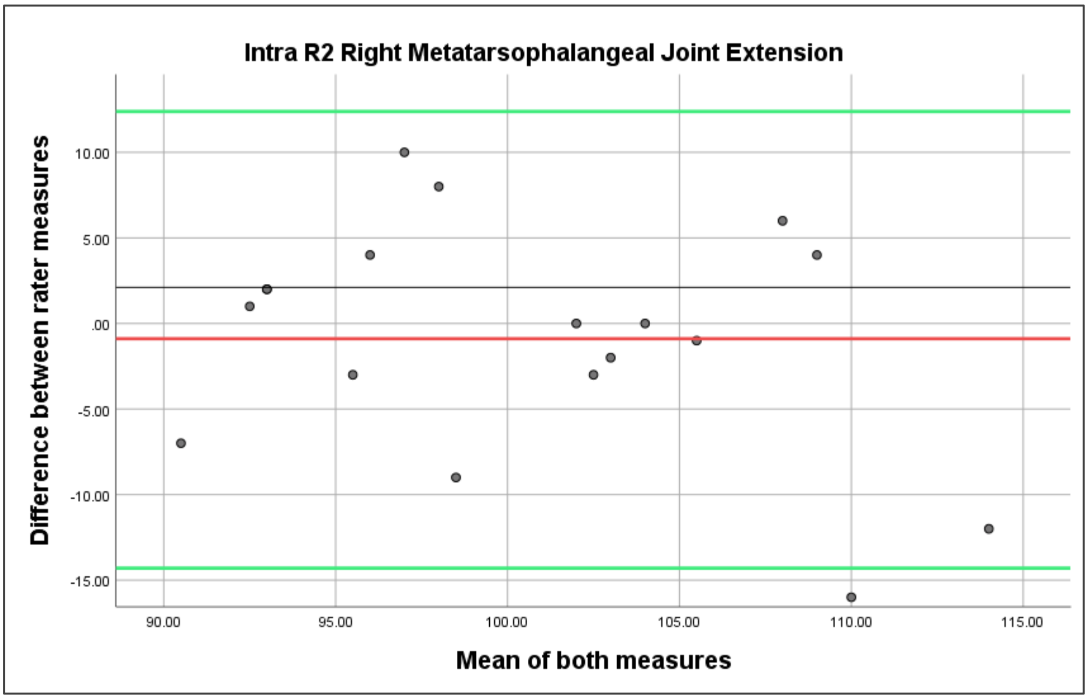
Bland Altman Intra-rater R2 Right Knee Extension
SEM = .58, MDC = 1.61, Mean Difference = -.0333, LOA = (-2.692,2.526)



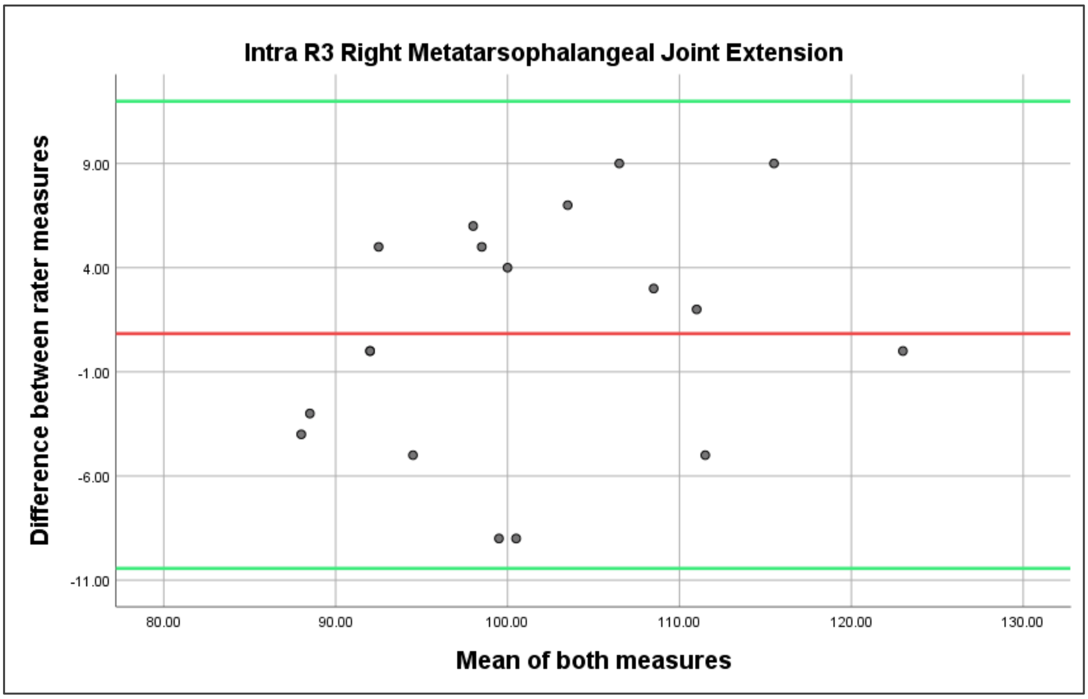
Bland Altman Intra-rater R2 Left Knee Extension
SEM = 2.97, MDC = 8.2, Mean Difference = .000, LOA = (-7.954,7.954)



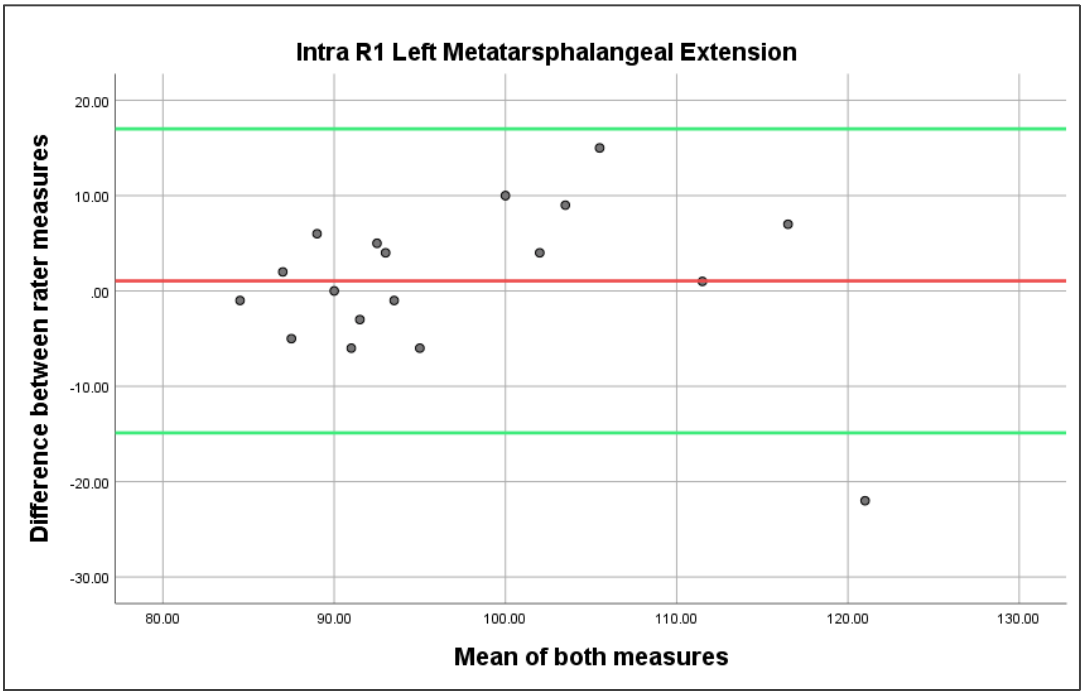
Bland Altman Intra-rater R3 Left Knee Extension
SEM = 1.41, MDC = 3.9, Mean Difference = -.3889, LOA = (-4.018,3.24)



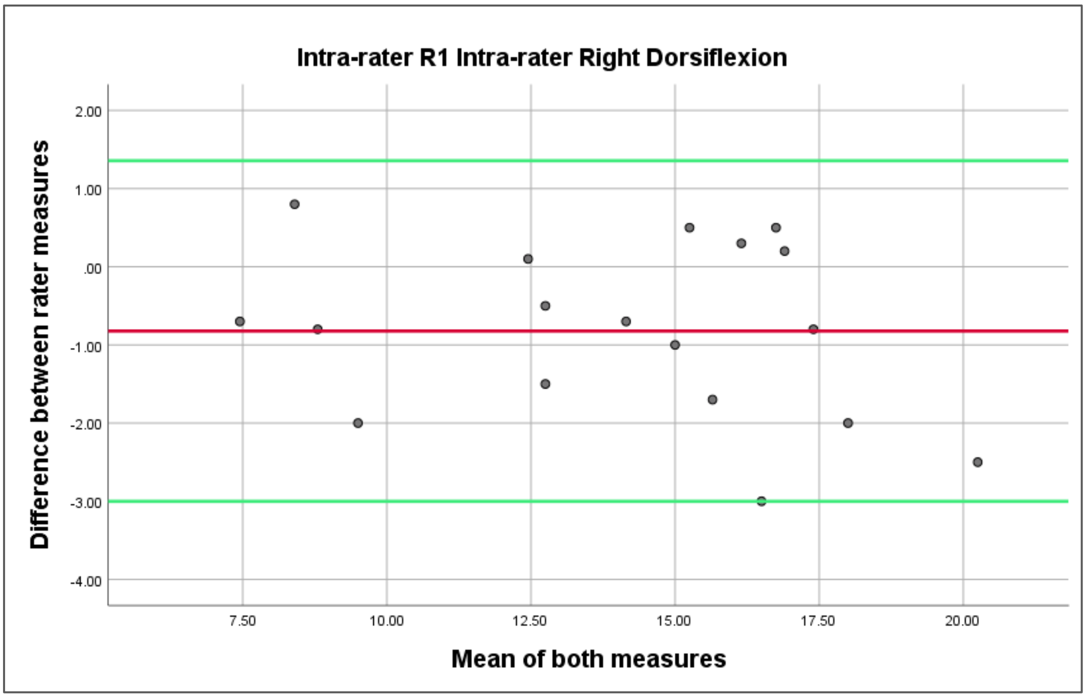
Bland Altman Intra-rater R2 Right Metatarsophalangeal Joint Extension
SEM = 4.08, MDC = 11.27, Mean Difference = -.889, LOA = (-14.14.299,12.385)



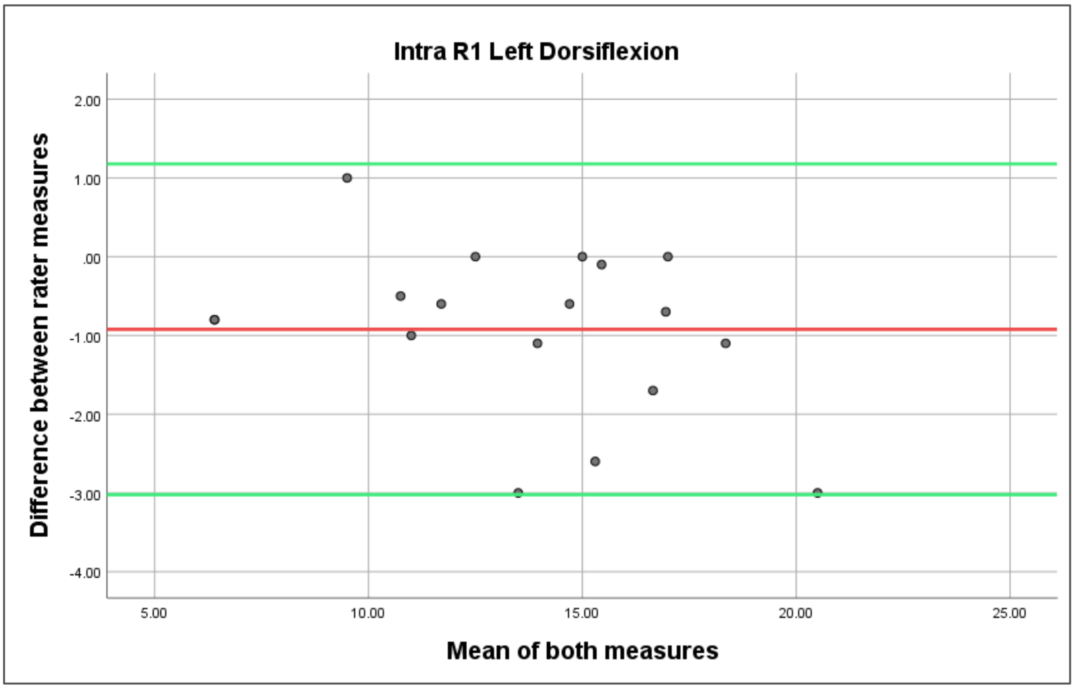
Bland Altman Intra-rater R3 Right Metatarsophalangeal Joint Extension
SEM = 4.23, MDC = 11.68, Mean Difference = .8333, LOA = (-10.434,11.987)



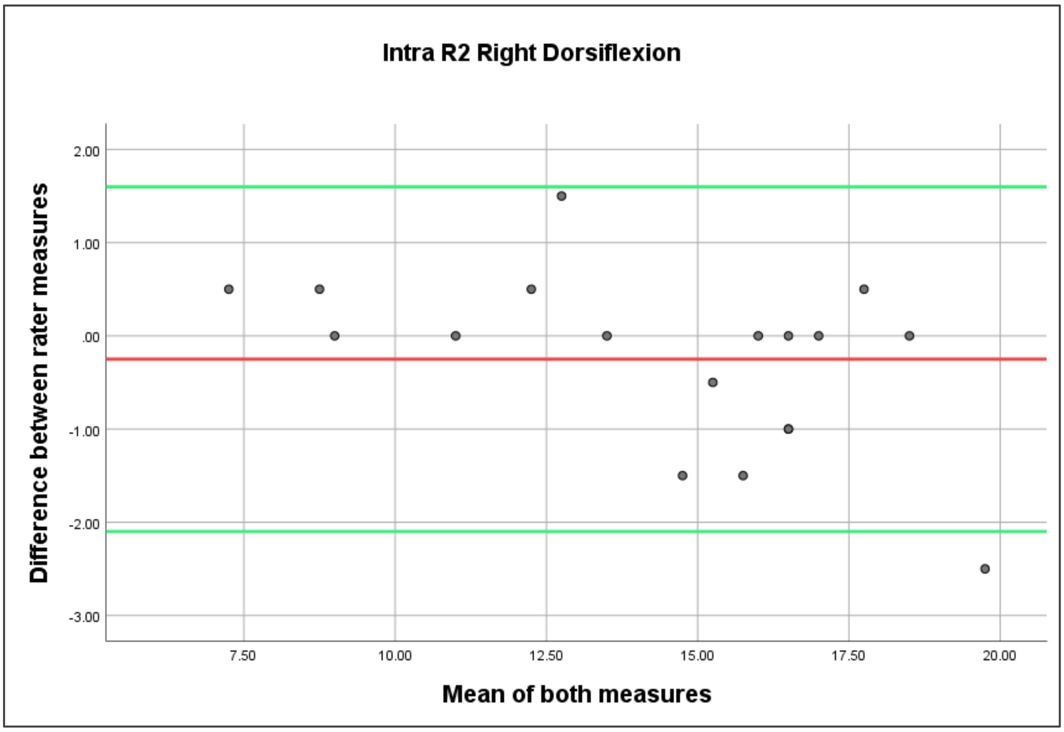
Bland Altman Intra-rater R1 Left Metatarsophalangeal Joint Extension
SEM = 3.93, MDC = 10.88, Mean Difference = 1.0556, LOA = (-14.88, 16.9996)



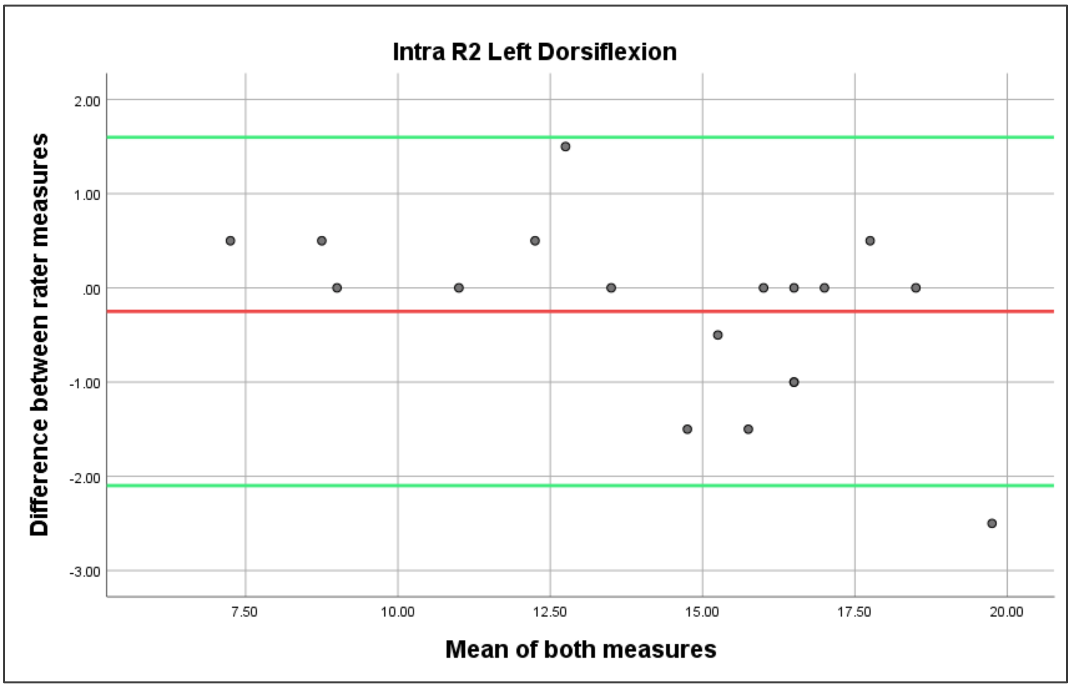
Bland Altman Intra-rater R1 Right Dorsiflexion
SEM = .91, MDC = 2.5, Mean Difference = -.8222, LOA = (1.357,-3.0012)



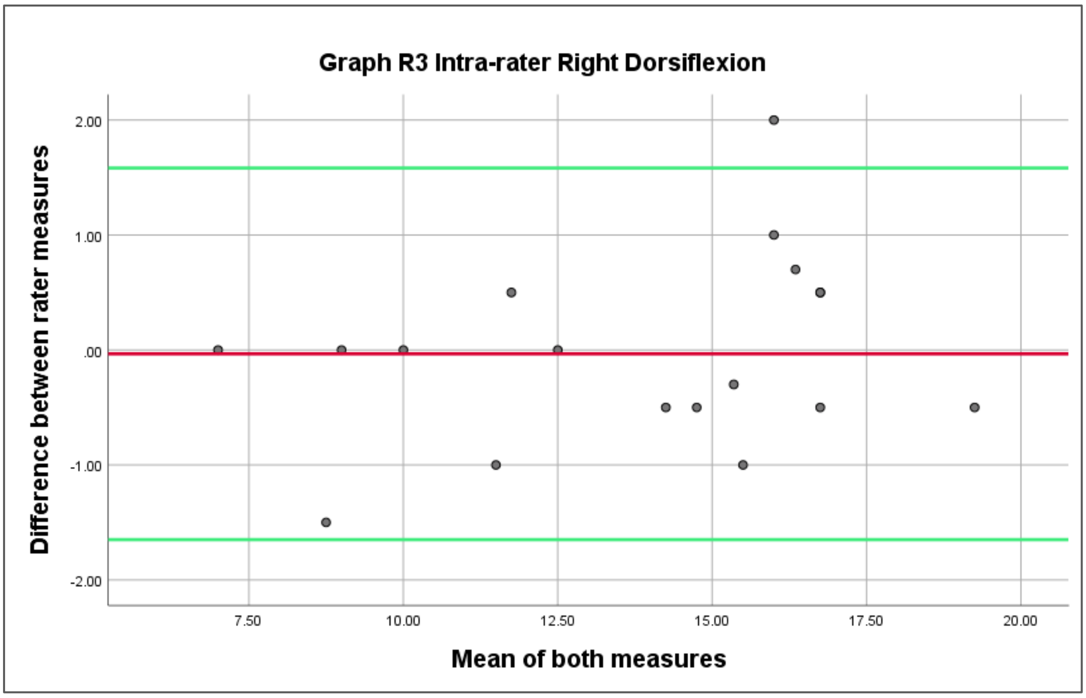
Bland Altman Intra-rater R1 Left Dorsiflexion
SEM = .92, MDC = 2.5, Mean Difference = .0278, LOA = (-3.0219,1.1775)



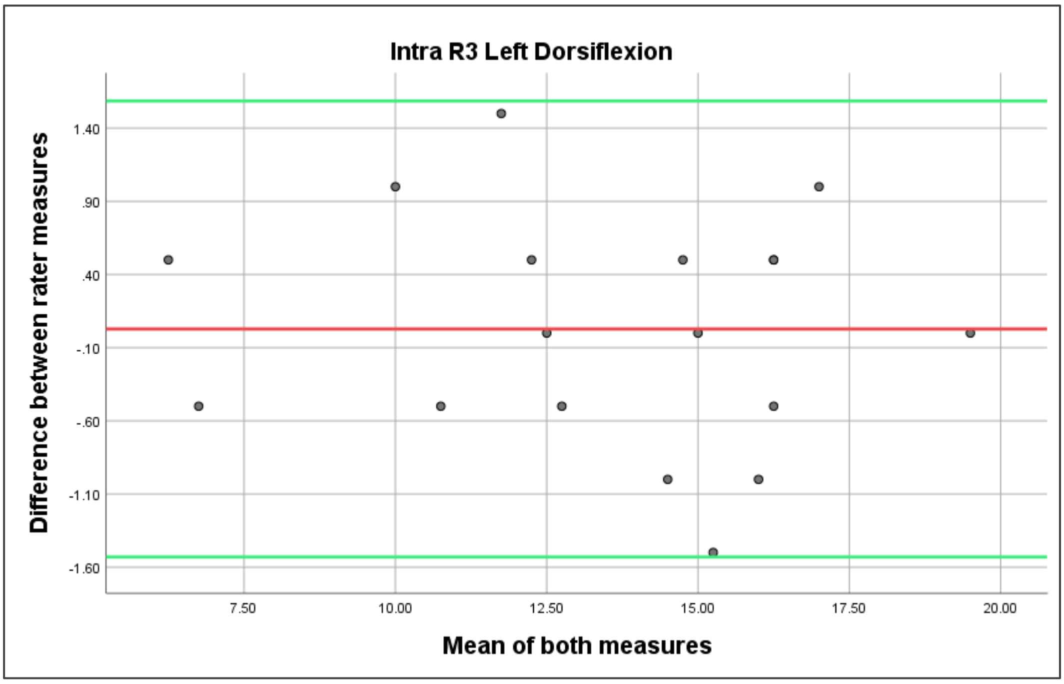
Bland Altman Intra-rater R2 Right Dorsiflexion
SEM = .622, MDC = 2.09, Mean Difference = -.250, LOA = (-2.099,1.599)



Bland Altman Intra-rater R2 Left Dorsiflexion
SEM = .92, MDC = 2.5, Mean Difference = .0278, LOA = (-3.0219,1.1775)

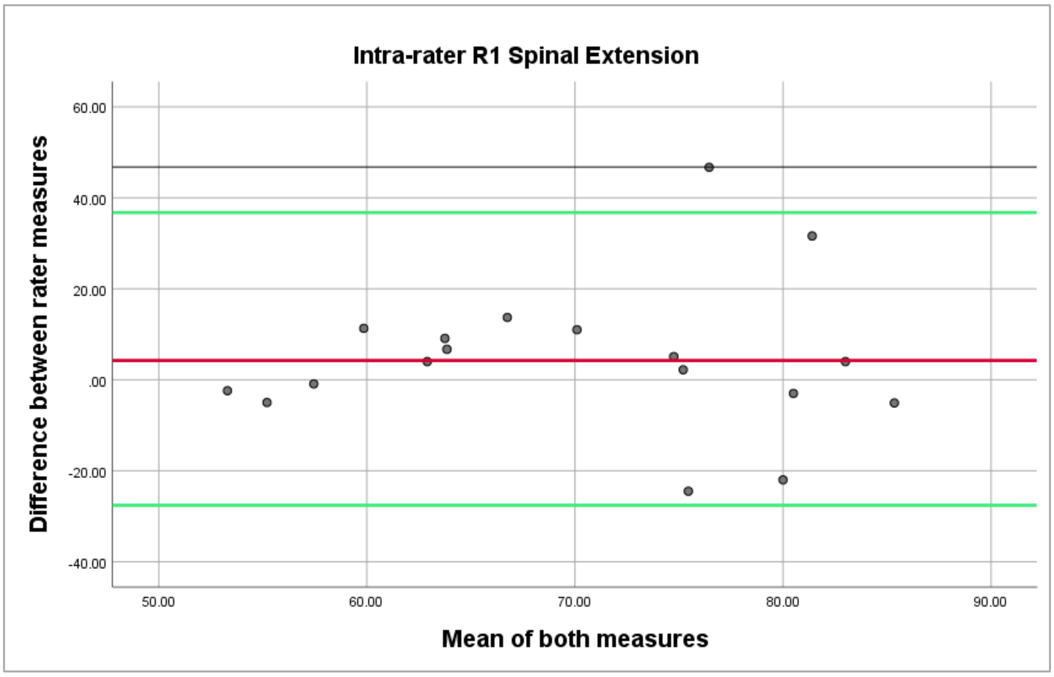


Bland Altman Intra-rater R3 Right Dorsiflexion
SEM = .58, MDC = 1.61, Mean Difference = -.0333, LOA = (-2.692,2.526)

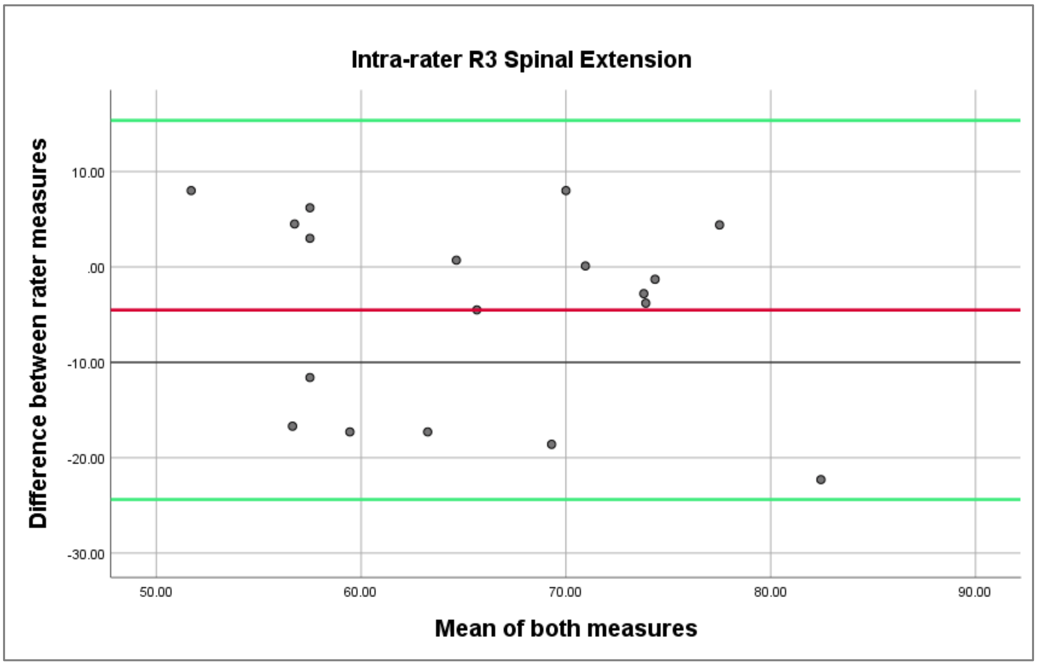


Bland Altman Intra-rater R3 Left Dorsiflexion

SEM = .54 , MDC = 1.49, Mean Difference = .0278, LOA = (-1.52979, 1.585392)



Bland Altman Intra-rater R1 Spinal Extension
SEM = 11.83, MDC = 37.7, LOA = (-27.584,36.751)



Bland Altman Intra-rater R3 Spinal Extension
SEM = .416, MDC = 6.85, Mean Difference = -4.517, LOA = (-24.39,15.357)