

The Use of Physical Screening Tools to Identify Injury Risk Within Pre-Professional Ballet Dancers: An Integrative Review

El uso de herramientas de cribado física para identificar el riesgo de lesiones en los bailarines de ballet pre-profesionales: Una revisión integradora

Abstract

Objective. To conduct an integrative review of all relevant research investigating the physical risk factors for injury within pre-professional ballet dancers to provide insight that may benefit practitioners within these institutions and highlight areas for future research within this specialised population.

Design. Studies were identified from the following electronic databases: MEDLINE via PubMed, SPORTDiscus via EBSCOhost and Web of Science Core Collection via Web of Science. 8,415 titles were identified during the electronic search process. Five studies satisfied the inclusion criteria and were included in the review. The modified Agency for Healthcare Research and Quality (AHRQ) scale for observational studies was used to assess study quality.

Results. The review identified that the following physical characteristics may influence prospective injury risk in pre-professional ballet dancers: age & maturation status; anthropometrics and body composition; strength and power; joint mobility and range of motion; specific dance function; cardiorespiratory fitness.

Limitations. The research identified lacked methodological quality. This, combined with the low number of studies identified, makes the design of screening protocols challenging for practitioners.

Originality. Despite the number of pre-professional balletic institutions worldwide, previous reviews have not used a systematic search strategy or investigated both sexes in this cohort. Due to the unique demands of ballet, an understanding of the interaction between injury and physical characteristics is a critical step in order to reduce injury burden.

Conclusions. This review succeeded in determining risk factors for injury within this population but due to insufficient evidence could not provide robust screening recommendations.

Keywords: Dance, Injuries, Risk Factors, Ballet, Pre-Professional, Review, Adolescent, Screening, Biomechanics, Physiology.

Resumen

Objetivo. Llevar a cabo una revisión integradora de toda la investigación relevante sobre los factores de riesgo físico de las lesiones en los bailarines de ballet preprofesionales para proporcionar una visión que pueda beneficiar a los profesionales de estas instituciones y resaltar las áreas para futuras investigaciones en esta población especializada.

Diseño. Los estudios se identificaron en las siguientes bases de datos electrónicas: MEDLINE vía PubMed, SPORTDiscus vía EBSCOhost y Web of Science Core Collection vía Web of Science. Se identificaron 8.415 títulos durante el proceso de búsqueda electrónica. Cinco estudios cumplieron los criterios de inclusión y se incluyeron en la revisión. Para evaluar la calidad de los estudios se utilizó la escala modificada de la Agency for Healthcare Research and Quality (AHRQ) para estudios observacionales.

Resultados. La revisión identificó que las siguientes características físicas pueden influir en el riesgo prospectivo de lesiones en los bailarines de ballet preprofesionales: edad y estado de maduración; antropometría y composición corporal; fuerza y potencia; movilidad articular y amplitud de movimiento; función específica de la danza; aptitud cardiorrespiratoria.

Limitaciones. La investigación identificada carecía de calidad metodológica. Esto, combinado con el bajo número de estudios identificados, hace que el diseño de protocolos de detección sea un reto para los profesionales.

Originalidad. Las revisiones anteriores no han utilizado una estrategia de búsqueda sistemática ni han investigado ambos sexos en esta cohorte. Debido a las exigencias únicas del ballet, la comprensión de la interacción entre las lesiones y las características físicas es un paso fundamental para reducir la carga de lesiones.

Conclusiones. Esta revisión logró determinar los factores de riesgo de lesiones dentro de esta población, pero debido a la insuficiencia de evidencia no pudo proporcionar recomendaciones sólidas de cribado.

Palabras clave. Danza, Lesiones, Factores de Riesgo, Ballet, Preprofesional, Revisión, Adolescente, Detección, Biomecánica, Fisiología.

Introduction

Ballet dancers specialise in ballet from an early age and enter pre-professional training schools from as young as 10 years old [1]. Whilst in these ballet schools, dancers train extensively alongside academic study to obtain sufficient physical and technical mastery to reach the professional level. They also mature and change physically during this intense training period [2–5]. Ballet is physically demanding, with dancers required to achieve high levels of neuromuscular control in extreme ranges of motion with performances punctuated by high-intensity activities such as jumping and turning [6]. These demands expose dancers to a significant risk of injury [7,8] which occur primarily in the lower extremities, in particular, the knees, ankles and feet [9,10] and are predominantly overuse in nature. Injury risk may be increased for young dancers who attend pre-professional schools due to the greater exposure to high training loads compared to recreational dancers of a similar age [5,11]. The reported injury incidence in this population varies within the literature, between 0.77 to 3.52 incidents per 1000 hours of training [9,12].

As retaining a place within pre-professional dance institutions is performance-dependent and competitive, time loss from training due to injury can negatively impact technical development and professional success [4,10,13,14] as well as health. Therefore, identifying physical characteristics of dancers that may be at a heightened injury risk can help to inform intervention strategies. For instance, Pilates or strength and conditioning sessions are modes of training that can be/are integrated into may influence the physical condition of the dancers and therefore could impact upon injury incidence [6,15,16]. Risk factor identification in this area is therefore crucial in informing the design of screening practices and guiding the practitioner towards conditioning methodologies may subsequently be implemented in dancers who present with these factors. It is also important to inform the design of research which needs to be implemented to allow robust recommendations to be provided to practitioners.

Screening is commonly used in practice to identify risk factors associated with injury risk [17]. However, there is a lack of consensus in the research over which factors to examine and how to effectively screen for these qualities, practitioners have questioned the value of

conducting injury risk screening [18]. To allow practitioners to implement screening strategies effectively and understand its value, the research must provide clear guidance to implement effective specific screening procedures for this unique population. It is also important that the methodological quality and limitations of existing research is examined so that researchers can critically evaluate current screening protocols to inform future study design and expand upon the available literature.

Systematic reviews have focused on injury risk factors within dance [17,19,20], aesthetic sports [21] and pre-professional dancers of varying styles [14]. Due to the unique demands of ballet such as performing “en pointe” (dancing with the feet fully plantarflexed using blocks in the shoes to support balance) and in a “turned out” position (with hips in external rotation), general dance/aesthetic sports research may not be applicable to a pre-professional ballet dancer. Bowerman et al. [22] conducted a narrative review investigating risk factors for lower limb injury within elite pre-professional female ballet dancers. They concluded that physical fitness characteristics such as strength and mobility, and genetic/epigenetic factors such as growth and maturation status, should be investigated alongside dance specific movement strategies to evaluate an individual’s injury risk. An integrative review can expand on this by using a more systematic search strategy focused on the population of interest to provide more specific guidelines to both researchers and practitioners.

This study aimed to undertake an integrative review of the literature that examined prospective injury risk factors in pre-professional ballet dancers aiming to provide practitioners with guidance to identify risk factors and the screening methods used to assess these factors. Furthermore, it will highlight areas for future research to guide the design of potential screening and intervention protocols in the future.

Methods

An integrative review search process was conducted following the methodological guidelines of Whitemore et al. [23].

Search Process

Studies were identified from the following electronic databases: MEDLINE via PubMed, SPORTDiscus via EBSCOhost and Web of Science Core Collection via Web of Science. The full search list of search terms can be found in Table 1. The specific strategy and pattern of searches conducted from the 28th of October 2020 can be seen in Table 2.

Table 1- List of search terms and groups

<u>Group A-Activity</u>		<u>Group B-Population</u>		<u>Group C-Injury</u>		<u>Group D-Risk</u>	
PM	WS/SD	PM	WS/SD	PM	WS/SD	PM	WS/SD
Dance [MeSH]	Danc*	Adolescent [MeSH]	Adolescen*	Wounds and Injuries [MeSH]	Injur*	Risk Factors [MeSH]	Risk
Ballet	Ballet	Pre-Professional	Pre-Professional	Athletic Injuries [MeSH]		Risk Assessment [MeSH]	Risk Assessment
		Pre Professional	Pre Professional			Screen* [tw]	Risk Factors
		Preprofessional	Preprofessional			Profil* [tw]	Screen*
		Elite	Elite			Predic*[tw]	Profil*
						Correlat*[tw]	Predic*
All terms combined in search with OR							Correlat*
Key: PM- PubMed (MEDLINE), WS- Web of Science (Web of Science Core Collection), SD- EBSCO Host (SPORTDiscus)							

Table 2-Full electronic search strategy.

	<u>Search Strategy</u>	PM	WS	SD
Preliminary Searches	1) A 2) A AND B 3) A AND C			
Searches used for Data Synthesis	4) 2 AND C 5) 1 AND D 6) 2 AND D 7) 3 AND D	30/11/20 8/12/20 20/12/20 28/10/20	1/12/20 14/12/20 20/12/20 8/11/20	2/12/20 8/12/20 21/12/20 27/11/20
Key: PM- PubMed (MEDLINE), WS- Web of Science (Web of Science Core Collection), SD- EBSCO Host (SPORTDiscus)				

Inclusion/exclusion criteria

Inclusion criteria were as follows: 1) original experimental research; 2) written in English; 3) investigating full time pre-professional ballet dancers.; 4) investigating physical characteristics and prospective associations with injury risk. Studies were excluded if they 1) were conference posters or proceedings. 2) included dancers who were only attending summer schools and not in full time programs. 3) investigated dancers who took part in balletic training as part of a wider dance curriculum, or if dancers that specialised in ballet were indistinguishable in the reporting of results from other dancers. 4) investigated physical screening tools that were considered invasive (e.g., blood tests were considered too invasive and therefore unlikely to occur in a standard screening review).

Data Collection

Following the initial searches, titles were screened (by author NM) using the eligibility criteria outlined above. Abstracts were then screened for potential inclusion. Additionally, reference lists were searched for additional studies not identified during the electronic database search. This process was then repeated to screen the remaining full texts before data extraction. A second independent reviewer (PP) replicated this process from the abstract stage, and the results were compared before the final study inclusion was agreed upon. Where there was no agreement the wider research team (RM, DC and CP) was consulted, and a consensus was reached on inclusion.

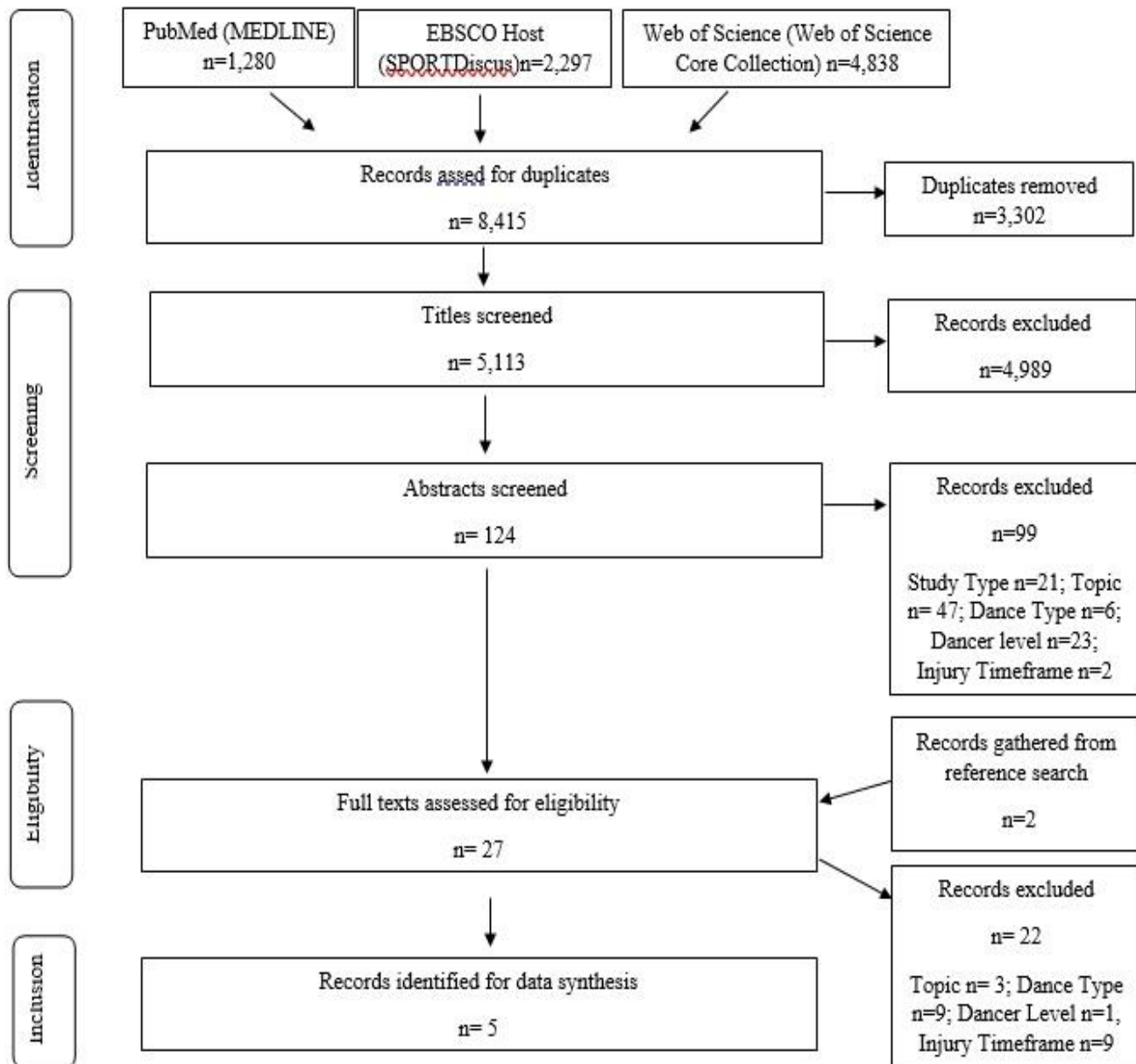
Data Synthesis and Risk of Bias

Methodological quality assessment was completed independently by two authors (NM and PP) following the same method. Disagreements were discussed and resolved by consensus within the wider research team (RM, DC and CP). Research quality and risk of bias were assessed using the modified Agency for Healthcare Research and Quality (AHRQ) scale for observational studies [24–27]. Criteria for grading was used based on the 1) study question (2 points); 2) study population (8 points); 3) comparability of subjects (22 points); 4) exposure or intervention (11 points); 5) outcome measures (20 points); 6) statistical analysis (19 points); 7) results (8 points); 8) discussion (5 points); 9) funding or sponsorship (5 points). A total quality score out of 100 was then calculated for each study [24]. Any differences in scoring from the first two reviewers were discussed and further analysed with the wider research team (RM, DC and CP) to gain consensus. Full scoring criteria can be found in [Appendix 1](#).

Results

In total 8,415 sources were identified during the electronic search process, reduced to 5,113 titles following the removal of duplicates, which were screened for eligibility. After the screening of abstracts, 25 studies were identified for full-text review from the initial identification process. A further 2 studies were identified from searching the reference lists of the selected abstracts. Of the 27 full texts, 5 were identified as fitting the selection criteria ([Figure 1 \[28\]](#)). In total 737 students were investigated in the studies. Study participant numbers varied from n=13 to n=359 with subject ages ranging from 9 years old to 19 years old. Study characteristics can be found in [Table 3](#).

Figure 1: Preferred reporting items for systematic review and meta-analyses (PRISMA) literature search flow diagram.



<u>Author</u>	<u>Population Description</u>	<u>N of Participants</u>	<u>Gender of Participants</u>	<u>Age of Participants (as reported)</u>	<u>Country of Training</u>	<u>N of Injuries</u>	<u>Injury Type Examined</u>	<u>Study Design</u>	<u>Injury Definition</u>	<u>Study Time Period</u>	<u>Students Training Schedule (as reported)</u>	<u>Risk Factor Examined</u>
Twitchett et al. 2010	Elite Vocational Ballet Students	13	Female	19 ± 7	Britain	11	All	Cohort Study	A physical or psychological problem deriving from stress or other causes to do with performance, rehearsal, training, touring or the circumstances of dance life.	15 weeks	1 class and 2 rehearsals daily on top of performances	Anthropometry & Body Composition, Strength and Power, Joint Mobility and ROM, Cardiorespiratory Fitness
Bowerman et al. 2014	Elite Adolescent Ballet Dancers (Australian Ballet School)	46	Mixed (29 female, 13 male)	16 ± 1.58	Australia	59	All	Cohort Study	Any physical harm resulting in pain or discomfort that required a dancer to modify their dance activity during one or more classes or cease all class.	6 months	19 hours per week	Age and Maturation Status, Specific Dance Function
Rudavsky et al. 2018	Young Ballet Dancers (Australian Ballet School and Vicotrian College of the Arts Secondary School)	57	Mixed (34 female, 23 male)	11-18 years	Australia	5	Patellar tendinopathy	Cohort Study	Tendon pathology diagnosed on ultrasound scan.	2 years	4-8 hours per day	Age and Maturation Status
Gamboa et al. 2008	Elite Preprofessional Ballet School Students	359	Mixed (288 female, 71 male)	9 to 20 years	United States of America	151	All	Cohort Study	Anything pain or discomfort requiring treatment from a physiotherapist.	5 years (annual analysis)	20 hours ballet, 2 hours cross training/pilates per week	Age & Maturation Status, Strength and Power, Joint Mobility and ROM, Specific Dance Function
Leanderson et al. 2012	Young Swedish Ballet Dancers (Royal Swedish Ballet School)	262	Mixed (130 female, 86 male)	9 to 21 years old	Sweden	216	All	Cohort Study	Anything pain or discomfort requiring treatment from a orthopaedic specialist.	7 years	6-11 hours per week	Hypermobility

Table 3- Study Characteristics

Results of Synthesis and Risk of Bias

Table 4 shows the research quality assessment data per study. Gamboa et al. [12] achieved the lowest score (40/100) whereas the Rudavsky et al. [29] study scored the highest of the studies assessed on all listed criteria (58/100). The research of Leanderson et al. [30] was presented as a section of a thesis, therefore isolating the introduction and discussion was particularly challenging. To address this, the research team agreed for 20 points to be removed from the potential total score for this research in areas where data was lacking due to the format of the research and a fair comparison could not be made (see Table 4). Based on the format of the research, the researchers concluded that it had undergone a less rigorous review process and therefore did not justify as high a score as the other studies included in this review. Overall, studies achieved the highest quality score in the discussion section. In contrast, there was a lack of comparability of the subjects recruited within each trial and the studies generally did not acknowledge funding and sponsorships sufficiently and therefore scored poorly in these areas.

The selected studies' findings are presented around major themes of injury risk which emerged from the systematic review: age and maturation status, anthropometric and body composition, strength and power, joint mobility and ROM, specific dance function and cardiorespiratory fitness.

Age and Maturation

Age and maturation status were investigated in three studies. Both Gamboa et al. [12] and Bowerman et al. [22] did not find an association between chronological age and injury risk and no significant differences in sexual maturation (age at onset of menarche (AoM)) were observed between injured and non-injured female dancers. Rudavsky et al. [29] found that maturation level as estimated using the Mirwald level of proximity to peak height velocity was not significantly related to symptomatic patellar tendon pathology. Bowerman et al. [22] also found only *unclear* (greater than a 5% chance the true value of the rate ratio could substantially increase and decrease) links between injury risk and maturation assessed using the Tanner scale method but did find that another measure of maturity – a change of over 0.5cm in right foot length was associated with a moderately likely increase in injury risk (Rate Ratio (RR) = 1.41, Confidence Interval (CI): 0.9-2.1).

Anthropometric & body composition measurements

The majority of studies collected anthropometric measurements as part of their descriptive data for the participants. However, only two of the studies looked at the interaction between anthropometric/body composition variables and injury risk. Twitchett et al. [31] found that dancers with a lower body fat percentage had a higher severity of injuries. Bowerman et al. [22] found *unclear* (RR = 1.08, CI: 0.85 – 1.37) associations between body mass and injury risk.

Strength and power

Two studies examined associations with measures of muscular strength and power. Twitchett et al. [31] found no association between injury risk or injury severity and “lower body power” - defined as jump height in a ballet specific turned-out position.

Gamboa et al. [12] also investigated the upper body, core and scapular control but found no significant difference between those who suffered future injury and those that did not. However, a composite lower body strength score calculated using a combination of manual muscle testing scores across 16 different lower body movements did reveal that a significantly reduced injury risk in the stronger dancers (injured score = 4.4 ± 3.0 , non-injured score = 4.5 ± 0.3).

Joint Mobility and ROM

Several studies assessed joint mobility through a range of methods. Joint mobility can be assessed statically, passively, and actively. Static assessments of posture were conducted by Gamboa et al. [12], identifying that dancers who sustained an injury in the following year were 74% more likely to display excessive right foot pronation in these tests than non-injured dancers (RR=1.74). Indicators of hypermobility or joint laxities such as knee hyperextension and the knee integrity score were not significantly associated with injury risk. In contrast, hypermobility was assessed directly by Leanderson et al. [30] and students were categorised as normal, hypermobile, or as displaying generalised joint laxity (GJL). Students with GJL displayed a significantly greater injury risk than hypermobile or normal students. Leanderson et al. [30] also found that this risk was greater in older students. Gamboa et al. [12] assessed passive joint ROM in ankle plantarflexion, dorsiflexion, hip external and internal ROM, and in the quadriceps, hamstrings, hip flexors, latissimus dorsi and pectoralis major. Low levels of ankle plantar flexion on the right leg were associated with a significant increase in injury risk (Risk Ratio (RiR) = 1.50). Twitchett et al. [31] also assessed passive lower extremity flexibility in an assisted *développé* position but found no significant correlations with injury risk or severity.

Specific Dance Function

Four of the studies assessed active mobility using a two-dimensional analysis of ballet specific positions. Bowerman et al. [22] analysed pelvic angle and knee angle both in the *temps levé* and the *fondue* across both legs; finding that a decreased knee valgus angle of 10° during the right leg *fondue* indicated a *likely decreased* injury risk (RR = 0.68, CI: 0.5 - 1) and that a reduced pelvic tilt angle on the right leg also displayed a *likely decreased* injury risk (RR = 1.28 CI: 0.9 - 1.8). During the *temps levé*, an increased pelvic tilt angle on the left leg also indicated a *likely reduction* in injury risk (RR = 0.52, CI: 0.3 - 0.9) and there was a *small decrease* in injury risk for an increased knee valgus angle on the right leg (RR=0.72, CI:0.5 - 1). Gamboa et al. [12] assessed functional ROM in a turnout position both on the standing and gesture leg using a combination of “footprints” and an arthrodial goniometer, and also examined joint alignment in a *grand plie* in second position. All of these tests displayed no significant relationship with injury risk. Twitchett et al. [31] assessed ROM during an active *développé* position but did not find any significant correlations with injury risk or severity.

Cardiorespiratory Fitness

Only one study assessed the relationship between cardiorespiratory fitness and injury. Twitchett et al. [31] examined heart rate following the dance aerobic fitness test (DAFT). They found a significant positive correlation between heart rate at the end of the test ($r=.590$) and overall injury incidence, but no association with acute injuries.

Table 5-Intergrative Review Summary

<u>Findings</u>	<u>Recommendations for future research</u>
<ul style="list-style-type: none"> • Various studies have attempted to investigate the links between physical characteristics and injury risk in pre-professional ballet dancers. • 5 studies were identified that investigated physical characteristics and the prospective injury risk associated with these factors. • The following physical characteristics have been investigated and linked to injury risk in the literature. Age & maturation status (3 studies) Measures of anthropometrics and body composition. (2 studies) Strength and power (2 studies) Joint mobility and ROM (3 studies) Specific dance function (4 studies) 	<ul style="list-style-type: none"> • There is very little research that examines the links between physical characteristics and future injury. This is necessary to establish and inform screening protocols and injury prevention strategies. • There is a need for greater subject numbers in the literature. Very few studies included large numbers of male dancers, and many excluded them entirely. • There is low methodological quality in all the literature identified. • There are very few studies that look at each of the physical characteristics identified. This demonstrates a lack of depth in the literature, and it cannot provide robust recommendations for practitioners • There is a need for more research that investigates the interactions between the various genetic and modifiable physical characteristics and how they influence balletic performance to further improve our understanding in this area. • Physical capacities should be investigated using methodology and practice that is used in the wider scientific literature which can then be compared with a detailed analysis of dance specific actions and practice. This will provide higher levels of evidence and increase the robustness of the research findings.

Cardiorespiratory fitness (1 study)	
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Discussion

Data Extraction

The present integrative review aimed to investigate potential associations between physical characteristics and prospective injury risk for pre-professional ballet dancers. [Table 5](#) shows the main findings of this review with recommendations for future research. Only 5 studies met our inclusion criteria, demonstrating a scarcity of both population specific and high-quality research. During the final full-text review stage, the primary reason for exclusion was due to studies not distinguishing between ballet dancers and other dance styles. This is problematic as ballet training involves unique movements and characteristics that combine to produce a training load that is not replicated in other dance styles [\[32,33\]](#). The other key reason for exclusion was that many of the studies identified were cross-sectional or retrospective and therefore didn't examine injury risk prospectively. Within the five studies a large number of potential injury risk factors are assessed, demonstrating the notion that injury risk is multifactorial for young dancers. This complexity combined with the limited evidence available reaffirms the challenges for practitioners working with these dancers.

Methodological Quality

The modified AHRQ scale identified various areas in which methodological quality was limited. This may have influenced the findings and interpretations of the studies identified. One of the key areas that the studies performed badly on was the comparability of subjects. For instance, none of the studies matched different age groups and the studies that included male and female participants did not have an equal split of genders. Only one study collected medical history before participation in the study and included this as part of the analysis [\[29\]](#) and differences in training schedule/repertoire and training experience of the participants were not accounted for in any of the studies. Only one of the studies detailed the subject recruitment process and none detailed how they managed data for participants that dropped out from the study or what the criteria for this were. This increases the potential for the characteristics of the participants to influence the study's findings and is a particularly important consideration when exploring injury risk in ballet dancers as the training demands of different genders and dancers performing different pieces can vary significantly [\[32,34\]](#).

Age and Maturation

Three of the studies included assessments of age and maturation with two studies investigating chronological age and finding no relationship with injury. Of the studies included in this review, Bowerman et al. [\[22\]](#) found a likely increased risk of injury for individuals with a growth rate of more than 0.5cm in the right foot during a six-month period. This measure of increase in the length of the bones was used as a marker of maturation. However, this methodology can be questioned as validation studies have not been performed in adolescents [\[35\]](#).

Both Gamboa et al. [\[12\]](#) and Bowerman et al. [\[22\]](#) assessed associations with sexual maturation. Gamboa et al. [\[12\]](#) investigated AoM but didn't find any significant interactions with injury risk. However, assessing the menstrual cycle may be less reliable in adolescent dancers with later AoM and an irregular menstrual pattern observed in these populations [\[36–38\]](#). The Tanner scale used by Bowerman et al. [\[22\]](#) does provide a reliable assessment of sexual maturation [\[39\]](#), however their analysis

which involved grouping the students using Tanner stages may have some limitations. . For example, stages two and three were classified as “less mature” and four and five as “more mature”. This may have limited the sensitivity of these measures and the ability to detect associations, since large changes can occur in relatively small-time frames which may increase injury risk. For example, stages 4 and 5 were placed together which typically represents 2 to 3 years of development in which both peak height and weight velocity may occur.

Rudavsky et al. [29] used the Mirwald method [40] to estimate proximity to peak height velocity and found no correlation with tendon pathology. However, these findings should be treated with caution due to the limited number of participants and because it is suggested that the Mirwald method may be unreliable in later and earlier developers [41]. Alternative methods to predict the stage of maturation such as the Khamis-Roche method have been widely adopted in other adolescent sporting contexts which have been shown to display a lower error rate [42] and could therefore provide a useful alternative for future research.

Interestingly, none of the studies reported longitudinal growth in stature to indicate maturation levels, which presents a reliable, non-invasive technique for understanding maturation levels. Bowerman et al. [22] collected results over 6 months and Gamboa et al. [12] only used the first year of assessment for each participant and acute changes in growth patterns that may lead to heightened injury risk may therefore have been difficult to collect during this timeframe [43]. Rudavsky et al. [29] collected data for 2 years and used measurements of stature as part of the Mirwald maturity offset calculations but changes in stature was not investigated. Inclusion and analysis of more longitudinal measures of changes in growth in future research would assist in conducting analysis around maturation levels.

Despite the inconclusive findings in the reviewed literature, the researchers all suggested more detailed investigation with more participants and longitudinal measures of maturation related changes might provide a better insight. The wider literature provides the rationale for this, whereby injuries affecting the apophysis which are directly influenced by adolescent growth and maturation [44,45] are often identified within pre-professional dancers [5]. incidence could therefore potentially be reduced by managing dancers during periods when dancers are at heightened risk. Despite the complexities of analysing these factors, this area also warrants further investigation due to the potential influence maturation may have on modifiable physical risk factors which may mediate injury risk such as strength and ROM [46]. For example, Kolokythas et al. [46] found that male pre-professional dancers showed age related increases in jump height whereas female dancers did not. This was accompanied by an age-related increase in injury incidence in the female dancers. This might indicate a mediating effect of male puberty on muscle characteristics and therefore injury. The measurement of longitudinal changes in size and physique alongside sexual maturation is required to understand how adolescent maturation can be accurately assessed and provide further insight into potential injury mechanisms.

Anthropometric & Body Composition Measurements

Ballet dancers typically have slender physiques with low body fat [47]. Individuals that have the lowest body fat percentages within this cohort may therefore be at risk of having an unhealthy body composition which may increase the risk of injury [48]. Associations between injury risk and anthropometric and body composition variables were investigated in two studies, one of these observing significant results. Twitchett et

al. [31] found dancers with a lower body fat percentage had significantly increased injury severity ($r=-0.614$). The limited number of injuries ($n=8$) observed prevented an analysis of incidence and means findings may need confirming in larger cohorts before generalising to all ballet dancers. However, these findings are somewhat supported by the work of Benson et al. [49] who investigated the links between Body Mass Index (BMI) and injury in young professional ballet dancers and found that dancers with a BMI of 19 or lower were more time-restricted from dance through injury. However, as BMI can be influenced by both lean body mass and fat mass these findings could also be linked to a lack of muscle and therefore strength.

For the practitioner, anthropometric information can be obtained with varied levels of detail and ease. Sophisticated measures such as Dual-energy X-ray absorptiometry can identify bone density, lean body mass and body fat percentage, but are expensive and expose students to radiation can be contrasted with measurements of height and weight using a stadiometer and scales which can be easily obtained but lack precision. A wide variety of these measures have been recommended by the researchers identified both in this review [11,31] and in the wider dance literature [49–51] due these measures being used to identifying dancers with inadequate energy availability [52]. This link between energy consumption, body weight and injury has been indicated by Frusztajer et al. [51] in professional ballet dancers, who found that after controlling for age, weight and height that dancers that consumed less energy and had weight fluctuations that dropped to a lower percentage of ideal body weight, had a higher incidence of stress fractures. This study was also interesting in that it investigated longitudinal changes in body weight as well as current anthropometric status which could provide further insight if adopted with pre-professional dancers. Despite the potential benefits these measures might provide, due to the heightened risk of eating disorders and body consciousness among dancers [53] examining anthropometric and body composition factors may present an ethical dilemma for a practitioner and so appropriate care safeguarding should be taken before considering the investigation of these factors or inclusion in screening processes.

Strength and Power

Overuse injuries are the most common mechanism for injury among pre professional ballet dancers [9,10]. Despite the evidence that increasing force production capabilities may be effective in reducing the risk of overuse injuries in athletic activity [54] we found only two studies that examined relationships between strength or power and injury risk. A total of 6 strength measures were taken across the two studies, however the only significant finding was that lower manual muscle testing across a range of lower body movements was related to injury risk [12]. Balletic injuries primarily occur in the lower body. Upper body and trunk strength measures examined in these studies may therefore not correspond with these types of injuries, suggesting screening lower body strength may be more valuable for practitioners [9,10,12]. Despite this, the use of manual muscle testing has been questioned in the literature due to a lack of sensitivity [55,56] and intra-tester reliability [57]. Moreover, there is a lack of ecological validity when using manual muscle testing as the positions in which an individual muscle group is tested do not replicate the multi-joint nature of dancing or the muscle activation patterns for the specific muscle groups tested. Measurement of lower extremity biomechanics during more dynamic assessments of dance movements using equipment such as force plates, 3D motion capture and Inertial Measurement Units (IMU) may enable practitioners to examine dance in a more specific context. These techniques can

be utilised to combine standardised measures of strength and power assessments with more dynamic dance activity.

Twitchett et al. [31] attempted to investigate a correlate of power output in a more ballet specific context by measuring height achieved in a ballet specific jump but found no relationship with prospective injury risk. Jumping using ballet specific techniques may modify jump strategy and limit dancers' ability to express their maximum physical output [58] which may have influenced this finding of no relationship between jump height and injury risk. It may be more appropriate when measuring a physiological capacity such as power or force output, to use measurement strategies that have been used consistently and validated in the wider scientific literature. Analysis of these recognised qualities can then be cross validated with dance specific movements using more bespoke equipment for biomechanical analysis, such as those listed in the preceding paragraph. This enables researchers and practitioners to then determine relationships between these underlying capacities and performance in dance specific activities and providing a more holistic analysis of how various capacities influence dance performance and injury risk.

Joint Mobility and ROM

To achieve the desired aesthetic of ballet performance dancers must have high levels of joint mobility and move through an extreme ROM. Briggs et al. [59] suggest that while the ability of hypermobile dancers to achieve extreme ROM may benefit dance aesthetic, these dancers are more likely to suffer from more severe injuries and incur a greater number of tendon injuries, a concept corroborated by Leanderson et al. [30]. General Joint Laxity (GJL) has been linked to various neurophysiological deficits that can affect proprioception, joint stability, inflammatory response, and psychology [60]. However the range and manifestation of these deficits differ significantly between individuals [61]. Furthermore, hypermobility assessment criteria such as the Beington assessment tool are not precise enough to identify more complex interactions with physical attributes. Further research is needed to investigate specific relationships between hypermobility, GJL, physical characteristics and injury due to the prevalence of these conditions within ballet.

Across the studies examining ROM, only passive plantarflexion ROM in the right foot/ankle was identified as having any relationship with injury risk [12]. Plantarflexion is needed to achieve the “pointe” of the foot required in both closed and open chain movements in ballet and is a key aesthetic of balletic performance [62]. Attempting to achieve this position without the passive flexibility to underpin the technique may lead to increased stress on the foot itself or around the structures trying to compensate for this lack of mobility [62,63]. For instance, certain dancers may have bony restrictions such as an os-trigonum or Steida's process which might limit the ability to fully plantarflex the foot. This increases the demands on, not just the ankle and foot joints, but also further up the chain, particularly in closed chain positions such as standing “on pointe” [64]. ROM like strength is a small factor of overall functional performance. Due to this, ROM measures should be studied alongside more dynamic dance activities to understand these relationships and identify potential associations with injury risk.

Specific Dance Function

Both Gamboa et al. [12] and Bowerman et al. [22] found associations between postural factors of the turnout position and injury risk. Bowerman et al. [22] examined the *temps levé* and *fondue* movement's and identified an association between excessive pronation

of the foot during those movements and injury. Researchers within ballet have identified that greater foot pronation can be associated with “rolling” the feet and “forcing” turnout which may then influence injury risk [65]. These turnout positions are unique to ballet and therefore these findings may not be replicated in non-balletic populations. Changes in dance biomechanics may be influenced by changes in limb length, tissue properties and coordination that can occur during maturation and therefore this process may exacerbate the impact of these findings.

Despite this, neither Bowerman et al. [22] nor Gamboa et al. [12] replicated these results on the left limb. Interestingly despite the range of more global measures of turnout examined by Gamboa et al. [12], none showed any relationship with injury risk. Anatomical structure, passive joint mobility, muscular strength and coordination of all of these elements throughout various ballet movements underpin a dancer’s functional turnout [65,66]. Potentially because of the highly complex interrelationships between these factors and functional performance, researchers have failed to identify screening strategies that accurately measure a dancer’s turnout. Once screening measures have been validated against in-class balletic performance potential associations between lower limb biomechanics and injury can be explained. Tools such as IMUs and 3D motion capture that could allow more dynamic pictures of these relationships should be used so that inter- and intra-individual differences can be explored in the required detail.

Cardiorespiratory Fitness

Twitchett et al. [31] found that dancers with higher DAFT heart rates displayed a higher injury risk. They suggested that this may be explained by a lower fitness level leading to a loss of neuromuscular control whilst dancing resulting in an increase in injury risk. However, these findings are based on a small number of study participants ($n = 13$) and relatively high number of injuries ($n=8$) and therefore should be interpreted with caution. Furthermore, whilst the DAFT is a dance specific test, it is difficult to ascertain how performance in this test replicates responses to daily and weekly ballet training. Longitudinal measures of cardiorespiratory responses to training can be obtained during dance practice using heart rate and respiratory frequency monitoring devices and could be used to corroborate the findings of the DAFT and further investigate relationships with injury risk.

Practical implications

Many of the modifiable physical characteristics highlighted by this review may influence one another and interact in various ways with balletic performance to influence injury risk. They are also influenced by non-modifiable factors such as growth and maturation and stature. In addition to the lack of evidence for the associations between each factor and injury risk, there is also a lack of depth in the available research due to the methodologies characterising these factors often being sub-optimal.

Russell et al. [67] suggests that screening for injury risk forms the first of five essential categories for providing effective healthcare provision. Despite this, there is a lack of evidence on how to design effective screening protocols within pre-professional ballet schools and a lack of understanding of how physical characteristics affect dance performance and injury risk. In other elite sporting environments screening is used in conjunction with performance data to provide a more holistic approach to injury prevention. For instance, within association football, aerobic capacity can be measured during screening [68] and then cross-referenced with a player’s real-time training and match data collected via Global Positioning Systems [69]. This allows practitioners to

be proactive in intervention strategies that might reduce injury risk, either by increasing physical capacities or reducing training demands [70]. Despite the elite training requirements of young ballet dancers, there is currently not enough guidance in the literature with which to develop and apply a similar model.

Limitations

This review was limited in that only 5 studies were found that matched the inclusion criteria. Furthermore, a wide range of factors were identified and examined but the specific factors and way they were measured was not consistent across studies and varied methods of data analysis were used. This meant that comparing the studies directly was challenging and robust statistical comparisons of the existing research was therefore not possible.

Conclusion

Despite the rigorous and exhaustive search performed, there is a paucity of research investigating risk factors for injury for pre-professional ballet dancers. This review identified characteristics that may influence prospective injury risk but could not provide specific tools for screening these factors based on current evidence. This presents a challenge for practitioners working within these environments. Various important considerations for further investigation are suggested within this review. For instance, using standardised and replicable screening measures, understanding longitudinal changes in both modifiable and non-modifiable physical characteristics, and investigating how dancers with specific characteristics perform during their regular dance activity.

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Appendix 1. Modified AHRO Quality Assessment Criteria for Observational Criteria

Area of study assessment	Focus of assessment	Reviewer mark allocation focus	Mark allocated per area	Weighted score	
Study Question	Clearly Focussed and Appropriate Question	Study Question: Title Quality (clarity of subject)	1	2	2
		Study Question: Title Quality (indicate study methodology)	1		
Study Population	Description of Study Population	Study Population: Characteristics	1	5	8
		Study Population: Gender	1		
		Study Population: Age	1		
		Study Population: Variability and characteristics	2		
	Sample Size Justification	Study Population: Sample size calculations	1	3	
		Study Population: Explanation of sample number	1		
		Study Population: Statistical Power	1		
Comparability of Subjects	Specific inclusion/exclusion criteria for all groups	COS: Mention of inclusion-exclusion criteria	1	5	22
		COS: Specific population clarified	1		
		COS: Did they volunteer or were they recruited? Was this process clearly indicated	1		
		COS: Clarity of overall numbers of subjects included and original and adapted numbers	1		
		COS: Inclusion exclusion criteria considered all factors	1		
	Criteria applied equally to all groups	COS: Inclusion exclusion criteria are equal for both groups.	2	3	
		COS: All subjects completed all screenings.	1		
	Comparability of Groups at Baseline with disease status and prognostic factors?	COS: Injury history the same for all subjects	1	3	
		COS: Comp of groups in terms of injury risk exposure due to prognostic demands	1		
		COS: Currently injured status is the same for all subjects	1		
	Study groups comparable and non-participants in relation to confounding factors	COS: Groups comparable in age	1	3	
		COS: Groups comparable in gender	1		
		COS: Groups comparable in training experience	1		
	Did the study include a concurrent control?	COS: Control Group	5	5	
	Comparability of follow up for all groups at each assessment.	COS: Follow up conducted over the same time frame	1	3	
		COS: Follow conducted by the same people	1		
		COS: Follow up injury measure the same for all participants	1		
Exposure or Intervention	Clear definition of exposure.	Exposure: Clear definition of the risk factors looked at	2	5	11
		Exposure: Clear description of the methods of measurement	2		
		Exposure: Clear introduction for why looking at the risk factors is necessary	1		
	Exposure method standard, valid and reliable	Exposure: Methods standard	1	3	
		Exposure: Methods valid	1		
		Exposure: Methods reliable	1		

	Exposure measured equally in all subject groups	Exposure: Risk factor assessment at the same time for all participants	1	3		
		Exposure: Risk factor measurement procedure is the same for all participants	1			
		Exposure: Risk factors were assessed the same for all participants	1			
Outcome Measures	Primary/Secondary Outcomes Clearly Defined	Outcome Measures: Clear definition of primary outcome and calculation steps	2	5	20	
		Outcome Measures: Are there any secondary measures for injury measurement clearly explained and defined in the same way	2			
		Outcome Measures: Introduction explains the form of injury measurement	1			
	Outcomes assessed blind to exposure or intervention	Outcome Measures: Measurement conducted by the same people that measured the risk factor	3	5		
		Outcome Measures: Could knowledge of the results influence the outcome measure	2			
	Length of follow up adequate for the question?	Outcome Measures: The reason for follow up period is clearly stated	2	5		
		Outcome Measures: Appropriate follow up period from risk factor measurement to injury diagnosis.	3			
	Method of the outcome, standard, valid & reliable?	Outcome Measure: Standard	1	5		
		Outcome Measure: Valid	2			
		Outcome: Reliable	2			
Statistical Analysis	Where the statistical tests appropriate?	Statistical analysis: Missing data reported	1	5	19	
		Statistical analysis: Standard statistical methods used	1			
		Statistical analysis: Do the methods chosen minimise Type 1 Error	1			
		Statistical analysis: Do the methods chosen minimise Type 2 Error	1			
		Statistical analysis: Are these appropriate for the number of subjects	1			
	Multiple comparisons taken into consideration?	Statistical analysis: Could there be a multiple comparison error using the statistical methods selected	1	3		
		Statistical analysis: Have they used a multiple comparison test	1			
		Statistical analysis: Was the multiple comparison test selected appropriate	1			
	Model and Multivariate testing appropriate?	Statistical analysis: Was the statistical model/multivariate analysis described clearly	1	2		
		Statistical analysis: Was the statistical model or multivariate analysis chosen appropriate	1			
	Power Calculation Provided?	Statistical analysis: Have they provided the information required to generate a power calculation	1	2		
		Statistical analysis: Is a power calculation and the results provided	1			
	Assessment of Confounding	Statistical analysis: Were relationships between the variables studied investigated	2	5		
		Statistical analysis: Were regression models that investigated more than one factor at once used	2			
		Statistical analysis: Were potentially confounding statistics accounted for in the analysis	1			
	Dose-Response Assessment	Statistical analysis: Dose-response assessment used if appropriate	2	2		
Results	Measure of Effect for Outcome?	Results: Measure of effect for outcome used	1	5	8	
		Results: Measure of effect for outcome model appropriate	1			
		Results: Confidence intervals were provided for a measure of effect for outcome	1			
		Results: Measure of Effect for Outcome provided a significant value	1			

	Adequacy of follow up for each study group?	Results: Measure of Effect for Outcomes used of significant value and CI's appropriate	1	3	
		Results: Follow up on the time period for the injuries reported	1		
		Results: Mean or median follow up times from risk factor measurement to injury diagnosis provided	1		
		Results: Standard deviation and confidence intervals of injury distribution provided	1		
Discussion	Conclusions supported by results with potential biases and limitations are taken into consideration?	Discussion: Brief summary of results and findings	1	5	5
		Discussion: Consideration and mechanisms explanation provided	1		
		Discussion: Comparisons with other published studies provided	1		
		Discussion: Limitations of the study provided	1		
		Discussion: A study of the research and clinical applications of the work provided	1		
Funding or Sponsorship	Type and sources of support for study	Funding and Support: Mention	2	5	5
		Funding and Support: Specific role of funding and support considered	1		
		Funding and Support: Processes that the funders were involved in described	1		
		Funding and Support: External bodies who might be influenced described	1		
		Total Score	100	100	100

