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The science of biomechanics can promote dancers' injury prevention strategies

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ABSTRACT
Background: The most common sports activities leading to menisci injuries are tennis, jogging, gymnastics, and dancing. Menisci injuries in dancers most frequently occur due to rotational forces applied to the knee. **Objectives**: Since dancers' movement is of great biomechanical and rehabilitation interest, the purpose of this review is to explore the biomechanical approach of this issue as well as to identify any gap to this process and propose corresponding assessments.
A literature review search database of Pubmed, Medline, EMBASE, AMED, Scopus, Google Scholar, and CINAHL was conducted using relevant keywords and phrases.
Major Findings: The most common dance movement that can cause meniscus injury, is the grand plié, because of the excessive range of motion combined to compressive forces and axial rotations that occur during the execution of the movement.
Conclusions: A complete three-dimensional kinematic assessment of the lower limb joints from dynamic grand pliés or in intermidiate positions of the legs has not been made.
Thus, further research has to be done with the use of optoelectronic cameras and force plates, to accurately identify weather excessive knee rotation range of motion or moments could lead in medial or/and lateral meniscus tear during the grand plié.

KEYWORDS
Biomechanical analysis; dancers' knee injury; kinetic analysis; kinematic analysis; grand plié biomechanics

1. Introduction

The knee joint is a common field of research studies, because of its anatomical and biomechanical complexity. The need for prevention and rehabilitation of injuries in the knee leads to constant research about the type and frequency of injuries. According to a study carried out from Drosos and Pozo [1] with a sample of 17.397 people aged (20–29) and lasted more than a decade including 19.530 injuries, 6.434 patients (37%) suffered 7.769 injuries related to the knee joint. 10.8% of these concerned the medial meniscus lesion and 3.7% the lateral meniscus lesion. According to the researchers the most common activities leading to menisci injuries were tennis, jogging, gymnastics, and dancing.

1.1. Meniscus biomechanics and mechanism of injury

According to a model suggested by Shrive et al. [2] menisci under normal conditions follow the movement of the femour during knee flexion and extension. More specifically, during extension the vertical load exerted by the femoral condyles, force the menisci to move in the sagittal axis. During flexion, the condyles roll backward onto the tibial plateau, forcing the menisci to deform in the frontal axis and thus maximizing joint contact area. The external rotation of femur observed on knee flexion, provokes an anterior displacement of the medial meniscus. The significance of menisci, relies on their role in force transmission, load distribution, amount of contact force, and pressure distribution patterns [3].

The most frequent factor that can cause injuries of menisci, especially related to sports, is rotational force applied to the knee [4]. A common mechanism of injury is a varus or valgus force directed to a flexed knee. When the femur is internally rotated and the foot stabilized, a valgus force can cause a tear of the medial meniscus. Respectively, a varus force while the femur rotates externally, can lead to

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a lateral meniscus injury [5,6]. The firm attachment of medial meniscus on the tibial plateau compared to the relatively more mobile lateral meniscus, may be the reason behind the greater incidence of medial meniscus injury, according to Yeh et al. [4].

1.2. Analysis of forces and motion

Dancing, a sports activity related to lateral meniscus tear [1], is a particularly demanding activity that stresses the human body. It offers the opportunity to 'take advantage of' the biomechanical abilities of the body and transform them into art. A dancer should possess skills that can be the subject of study in the specific study-field: comprehension of motion, muscle action, dancer-surrounding interaction, motor control, and part movement.

During a training session the dancer performs repeated actions, such as specific steps, jumps, and movements that stretch particular muscle groups to the limit. While performing those movements, the body constantly receives various, both external and internal, forces like the gravity, weight, and the speed of the limbs, as well as the rotation of the joints [7–10]. These forces can either remain stable or multiply depending on the dancer's mass.

The external forces applied to a dancer's body can be determined through a motion analysis system combined with force plates [11–14]. All these data allow biomechanists to better understand the nature of the examined movement and propose interventions that can improve a dancer's technique and skills [15]. Injury prevention strategies can also be developed through this procedure [16].

Dancers' movement, being so complex and demanding for the human body, creates great biomechanical and rehabilitation interest. We hypothesized that an in depth systematic review of the literature could identify the biomechanical reason why dance is included at the most common sports activities leading to meniscus tear injuries. Thus, our purpose with this review is to explore the biomechanical approach of this issue as well as to identify any gap to this process and propose corresponding assessments.

2. Methods

2.1. Literature search—strategy of the study design

The guidelines of PRISMA methodology [17] were used for this review in order to identify manuscripts relevant to the purpose of this study.

A literature review search on Pubmed, Medline, EMBASE, AMED, Scopus, Google Scholar, and CINAHL databases was conducted using the following keywords and phrases to identify relevant studies: biomechanical analysis, dancers' knee injury, menisci injury, kinetic analysis, kinematic analysis, force plates, optoelectronic cameras, motion analysis, grand plié biomechanics, common injuries in dancers, injury prevention in dancers, biomechanical assessment in dancers. The keywords opted to assess dancers' population, knee injuries to this population, and examine biomechanical parameters as risk factors for such injuries (kinematics or kinetics). The database search lasted for 9 months. First, each keyword was applied at the search engine of each database mentioned above, using quotation marks in each word to guarantee their existence in the manuscripts. All results were recorded, followed by an examination of titles, abstracts, and reference lists for relevant studies. Before the first level screening, all copies were removed from the recorded results of all databases. The manuscripts which met the eligibility criteria of the first level were recorded (6 months process) and passed to the second stage of the study selection process, where their full text was critically evaluated (4 months duration). The whole process was carried out by two independent reviewers, as mentioned in detail at the data collection process. The studies selected for this review were assessed for the risk of bias using the GRADE tool and critically discussed.

2.2. Inclusion and exclusion criteria

Articles met the inclusion criteria if: published in English, assessed dance biomechanics and kinesiology, discussed menisci injuries, studied grand plié kinematics, and kinetics. Manuscripts were excluded if they were case studies, they evaluated physical activity or spatiotemporal parameters (and not kinematic or kinetic data) of the performed dance movement or not evaluated the knee joint biomechanics. Although knee biomechanics during dance and particularly at grand plié is crucial for the development of injury prevention strategies for such athletes there is limited research evidence at the literature regarding this issue. For this reason, the date range of our research was extended, from 1965 till 2020, in order to collect all the significant data reported, for a complete review of this issue. All studies with the corresponding dates are presented at Table A1.

2.3. Study selection process

A first-level screening performed where the titles and abstracts of the bibliography search results were evaluated upon meeting the eligibility criteria. Articles were excluded according to the criteria set at the level of study design. During the second level of screening after reading and critically assessing the full text of each selected study passed the first screening process, we concluded to the studies that finally proceeded for analysis and discussion. Each study was evaluated based on meeting the purpose of this review and the inclusion criteria, present accurate results significant for this study, and applicable to dancers' population.

2.4. Data collection process

Titles and abstracts of the articles found in the searches were evaluated independently by two reviewers. The full text of potential articles was assessed based on the eligibility criteria by both judges individually. Disputes over inclusion or exclusion were resolved by consensus. Finally, the lists of included and excluded studies were discussed with the advisory group for the final decision. In order to identify the data of interest that should be extracted, a list of tables that will be included in the report was made. The category of data to be extracted was either fixed text such as yes/no, or free text in the cases where fixed text could not apply. All these data recorded to electronic forms—spreadsheets. One researcher extracted the data with the second, independently checking the data extraction forms for accuracy and details.

The general information used during the data extraction process was the recording of the researcher performing data extraction and the date of data extraction. Identification features of the study processed included the author's name, the article title, and the full citation, the type of publication (journal article) and the source of funding. Study characteristics, aim/objectives of the included studies, their design, and the inclusion and exclusion criteria applied were also taken under consideration. Characteristics of participants were recorded to meet the eligibility criteria of the examined dancers' population. The number of participants in each selected study, which discussed knee injury due to dance movements, and the kinematic and kinetic parameters assessed in each study to identify possible risk factors for knee injury in dancer athletes. Finally, the measurement tools and methodology used to measure the biomechanical parameters were recorded.

Data extraction forms were created on a sample of the included studies to ensure that the captured information was relevant and to avoid extracting unrequired data. The consistency of the obtained data was assessed to make sure that the reviewers were interpreting the forms, and the draft instructions and decision rules about coding data, in the same way.

2.5. Data items and risk of bias in individual studies

Following the data collection process, the studies included at this review were researches that assess the Dancers predisposition because of particular performance, the grand plié kinesiology, and biomechanics, the grand plié instant, muscle biomechanics and ROM, development of effective motor skills in dance, dance biomechanics, biomechanical analysis, and development of injury prevention strategies. The risk of bias assessed according to GRADE—Grading of Recommendations Assessment, Development, and Evaluation tool for a 'study-level'. The risk of bias in individual studies included in this systematic review is moderate.

3. Results

3.1. Selection of articles

The bibliographic search identified 513 potentially relevant articles with 15 articles identified by reports of related articles. After the copies had been removed 340 were examined at the first stage of screening. One hundred fifty articles went to the second next stage for further examination of full texts. After examining full texts, where the inclusion and exclusion criteria applied, 36 articles were used for writing this manuscript. Table A1 presents the studies indicated at the discussion and implications segment. The whole procedure is summarized in flow diagram 1.

3.2. Quality of revised articles

The overall quality of the studies was evaluated according to Ratcliffe et al. [18]. The final evaluation and discussion of the literature included studies whose quality was evaluated from medium to high level.

4. Discussion and implications

4.1. Dancers predisposition because of particular performance

Serious or repetitive injuries can complicate or in some cases, even, terminate a dancer's career [17,19]. Studies have shown that knee joint injuries are among the most frequent in dancers, because of the rotating loads that are applied to the joint. The elements, connective, or contractile, that surround and protect the knee are various and differ both in structure and function. An injury can include: stretching and/or irritation of the anterior cruciate ligaments, causing increased rotary instability of the joint and knee hyperextension; stretching and/or irritation of medial collateral ligaments, compromising the lateral stability of the joint; tearing or rupturing of the menisci; maltracking of the patella in the trochlear groove, resulting in grinding of the articular cartilage of the patellofemoral joint; increasing the incidence of chondromalacia patella and/or patellar tendonitis—'jumper's knee' and predispose the joint to patellar dislocation [20–24].

The most common dance movement that can reproduce the injury mechanism of the knee joint elements, is the plié and more specifically the grand plié, due to the associated compressive forces, longitudinal rotations that occur during the execution of the movement and excessive ROMs. The grand plié has been cited as being potentially harmful, because of the excessive range of motion combined to compressive forces and axial rotations that occur during the execution of the movement [25,26].

4.2. The grand plié kinesiology and biomechanics

In classical ballet the plié movement is performed in an upright position with the spine perfectly aligned with the rest of the body. The pelvis is bent, the hips rotated externally and hyperextended, the knees stretched and the feet fixed on the ground. The dancer's weight is equally divided on both legs. As the upper torso lowers, it must remain stable and the pelvis 'locked', while the hips bend externally by using back and pelvis placement. The knees flex and the feet remain fixed on the ground. Maintaining the upper torso position, the dancer returns to the starting position [8,27,28].

4.3. The grand plié instant

Barnes et al. [28], mention that during Grand Plié the dancer lowers the upper torso more than the demi plié (Figure B1).

Greater curve of the hips is noticed as well as feet hyperextension. According to Woodruff [29], 'the Grand Plié Instant is the instant at the bottom of the grand plié movement when the dancer alters the direction of their plié from descent to ascent with no pause'. That 'instant' was studied at the same leg every time concerning the flexion and the extension of the knee while performing the Grand Plié (Figure B2).

The execution of plié and Grand plié movements can be carried out from five different positions.

4.4. Dance biomechanics

A number of studies have been carried out regarding muscular recruitment patterns, vertical torso alignment, and 2 D joint ROMs, during both static and dynamic demi (1st position) and grand pliés (1st and 2nd positions) [30,23,26,27,31–33].

'Screw Home' describes the rotational mechanism that is necessary for the knee joint to achieve full flexion and extension. Tibia or femur must rotate 10° during the last 30° of extension of the knee due to the shape of the medial femoral condyle and the lateral pull of the quadriceps. During the grand plié, ballet dancers are taught to have the knees lined up over their foot to avoid excessive knee rotation as they bend and stretch their knees [22].

Serious or repetitive injuries, such as iliotibial band tightness (ITB) may result in patellofemoral pain. While ballet dancers tend to compensate the iliotibial band tightness they do excessive external rotation of the tibia, as a result the excessive knee rotation and the exacerbation of the patellofemoral pain [23].

Comparing and contrasting muscle function in grand-plié and demi-plie, Trepman concluded that grand-plié is not simply a deeper demi-plie. Electromyographic activity of lower extremity muscle activity focuses on vastus lateralis and medialis which have a peak during the lowering and the following rising phase. Tibialis anterior presented a continuous activity during grand-plié and a variation of electromyographic activity was observed for gluteus maximus, hamstrings, and lateral and medial gastrocnemius. Grand-plié is a unique, varied movement that is characterized from dancer's different dance idioms, personal habit, balance, and training background [30].

Two different systems have been combined and studied for their influence on dance performance and body alignment for dance, the imagery system and the conditioning system. With 'Performance Competence Evaluation Measure' (PCEM) and 'Dynamic Alignment Measure' (DAM), as evaluating tools, Krasnow et al. [34] ended up that the combination of both systems (conditioning-with-imaging) was the most efficient method to improve dance skills.

Skrinar (1988) suggests that material taught at the floor, barre or practicing a task at a very slow tempo may be insufficient and too far removed from the actual neural patterns during real performance. Dance sciences challenge is to provide teachers with knowledge and special tools in order to develop more effective motor skills exercises in a beneficial and safe atmosphere for dancers [35–37].

Biomechanics is the science of human movement that studies the body's mechanical structure and function, providing data on muscular activation, and its motion characteristics [38–42]. Kneeland introduced dancing principles and techniques in the early 1960s and researchers of 1970s first created specific tools and research methodology which have evolved to the present training strategy and up-to-date measurement equipment [31]. Several investigations have studied different interest fields included jumping efficiency [43] alignment in movements such as 'demi and grand plié releve, passé, degage, rond de jambe, grand battement, arm movements, turns, elevation work and falls'. Every movement was examined for its closed and opened kinetic chain, separately for each lower extremity, pelvic, and spine muscles [26,44,45].

Other topics of interest were the comparison of elite professional dancers with amateur, beginner or nondancers, [46,47] or with professional athletes in other sports, or comparing abilities between normal and postoperative dancers, or female and male dancers [48,49]. Other researchers analyzed traditional methods of ballet teaching and training, or proposed new and more effective motor strategies and techniques by focusing on anatomical features and biomechanical factors [50,51]. This procedure provided a correlation between anatomical-biomechanical structures and injuries and gradually led to the implementation of preventive measures [52].

Relevant dance articles including electromyography (EMG), force plates, motion analysis using videography, and/or physics analysis have been researched from current literature and involved in order to ensure the broadest scope [53,54] Three-dimensional kinematic and kinetic analysis provides scope for the biomechanical study of knee joint and its related injuries [55]. These important data correlated to functional data analysis could allow rehabilitation professionals to possibly identify the etiology of different motion patterns and plan more specific rehabilitation protocols [42,50,51]. Although, high anatomical and technique variability between participants must be considered, because generalizing results may be unreliable or hypothetical.

5. Conclusions

A complete three-dimensional kinematic assessment of the lower limb joints from dynamic grand pliés or in intermidiate positions of the legs has not been made.

While in classical ballet plies have been 'incriminated' due to the intense rotational loads that cause to the knee [26], yet, it would be useful to study the movement of the dancer in unstable-real conditions so as to form a complete picture of the nature of the plié move. Taking into account the number of grand pliés often performed in a ballet class, it is rather surprising that very few is known about the move.

Injury prevention requires the implementation of a full spectrum of proven effective strategies based on accurate and adequate data [52]. Injury prevention strategies should be an important part of every physical activity, because it not only helps athletes to achieve their training goals but also gives essential guidance on injury avoidance thus prolonging and maintaining a healthy career. Biomechanical data would be of great importance to rehabilitation scientists in their effort to develop injury prevention protocols for dancers.

Thus, further research has to be done with the use of optoelectronic cameras and force plates so as to accurately identify weather excessive knee rotation range of motion or moments could lead in medial or/and lateral meniscus tear during the grand plié.

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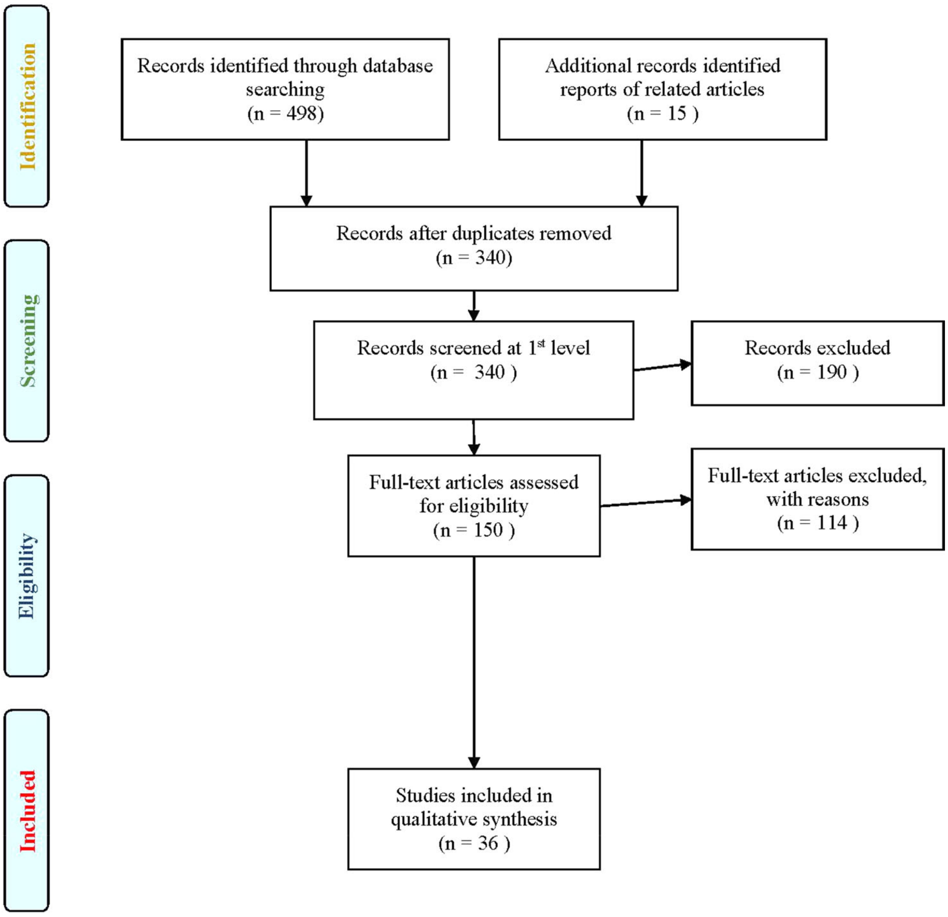
Appendix A. Tables

Table A1. Studies that assess biomechanical issues of dancers.

Biomechanical issue	Research team	Year
Dancers predisposition because of particular performance	• Chmelar et al.	1988
	• Gelabert et al.	1980
	• Ryman et al.	1980
	• Hamilton et al.	1978
	• Malcom et al.	1996
	• Wislow et al.	1995
	• Zarins et al.	1983
	• Myers et al.	1982
	• Krasnow et al.	2011
The grand plié kinesiology and biomechanics	• Thullier et al.	2004
	• Wilson et al.	2008
	• Barnes et al.	2000
The grand plié Instant	• Myers et al.	1982
	• Krasnow et al.	2011
Muscle biomechanics and ROM	• Wislow et al.	1995
	• Kneeland et al.	1966
	• Lessard et al.	1980
	• Trepman et al.	1998
	• Krasnow et al.	2011
	• Wilson et al.	2008
Development of effective motor skills in dance	• Clippinger et al.	1988
	• Minton et al.	1981
	• Gamboian et al.	1999
	• Clippinger et al.	1986
	• Clippinger et al.	1985
Dance Biomechanics	• Papagiannis et al.	2018
	• Papagiannis et al.	2016
	• Papagiannis et al.	2016
	• Johnstone et al.	1996
	• Bronner et al.	2003
	• Kneeland et al.	1966
	• Harley et al.	2002
	• Woodhull et al.	1990
	• Nichols et al.	1979
	• Krasnow et al.	2011
Biomechanical Analysis and development of injury prevention strategies	• Minton et al.	2000
	• Raney et al.	1988
	• Papagiannis et al.	2019
	• Clippinger et al.	1986
	• Clippinger et al.	1985
	• Bronner et al.	2003
	• Wislow et al.	1995

Appendix B. Figures



Flow diagram of the selection procedure.

Figure B1. Demi plie position.

Figure B2. grand plié position.