JOÃO PAULO AZINHEIRA MARTINS MOITA

DANCE INJURIES AND MUSCULAR STRENGTH IN PRE-PROFESSIONAL DANCERS

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Faculdade de Educação Física e Desporto

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Tese apresentada para a obtenção do grau de Doutor em Educação Física e Desporto no ramo de Atividade Física e Saúde conferido pela Universidade Lusófona de Humanidades e Tecnologias.

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Dubito ergo cogito, cogito ergo sum

René Descartes

Para a Carla e para a Matilde

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DANCE INJURIES AND MUSCULAR STRENGTH IN PRE-PROFESSIONAL DANCERS

Abstract

The physical demands placed on dancers put them at a significant risk for injury, with similar rates as the ones sustained by athletes in sports at the same level of performance. Muscle strength has been suggested to play a preventive role against injury in dancers. Nevertheless, the nature of that relation is still unclear. The purpose of this thesis was therefore to examine the nature of the relation between muscular strength and injuries in the pre-professional setting. A systematic review of literature (Study I) was performed to determine the state of knowledge. Several gaps were found that needed to be bridged for advancing. The major limitations found concerned epidemiological data on injury surveillance. An epidemiological study (Study II) was conducted with the goal of describing the injury patterns within our population. After identifying jumps as the motor action mostly associated with injuries, Study III aimed to examine the relationship between lower extremity vertical jump power features and injury history. No differences were found between dancers with and without injury history with concern to vertical jump power. After detailed analysis of the results obtained along the course of the investigation, we preliminary conclude that the role of muscular strength in injury proneness may more likely be related with the strength production process than with the final product. Stronger dancers do get injured too.

Keywords: Dance injuries; Muscular strength; Pre-professional dancers.

Resumo

As exigências físicas impostas aos bailarinos na sua prática artística, representam um risco significativo de lesão com taxas de incidência semelhantes aquelas observadas em atletas no mesmo nível de desempenho. A força muscular tem sido sugerida como um potencial elemento preventivo a considerar contra as lesões. No entanto, a natureza dessa relação ainda não é clara. O objetivo desta tese foi o de examinar a natureza dessa relação no cenário pré-profissional. Uma revisão sistemática da literatura (Estudo I) foi realizada para determinar o estado do conhecimento. Várias lacunas foram encontradas no que dizia respeito à epidemiologia das lesões na dança. Pela necessidade das mesmas serem preenchidas, um estudo epidemiológico (Estudo II) foi realizado com o objetivo de descrever os padrões de lesão na nossa população. Depois de identificar os saltos como a ação motora mais associada às lesões, o Estudo III teve como objetivo examinar a relação entre as características da potência dos membros inferiores através do salto vertical e o histórico das lesões. Não foram encontradas diferenças entre bailarinos com e sem história de lesão, no que diz respeito à potência dos membros inferiores avaliada através do salto vertical. Após uma análise detalhada dos resultados obtidos ao longo do curso da investigação, concluímos preliminarmente, que o papel da força muscular na propensão para as lesões pode estar mais relacionado com o processo de produção de força do que com o produto final observado. Os bailarinos mais fortes também sofrem lesões.

Palavras-chave: Lesões; Força muscular; Bailarinos pré-profissionais.

Abbreviations

AdvL - Advanced level

BDI - Bilateral Deficit Index

BMI - Body mass index

CMJ - Counter-movement jump

$CMJ1^{st}$ - Counter-movement jump with feet in 1^{st} ballet position

CMJ^{left} - Counter-movement jump on the left leg

CMJ^{right} - Counter-movement jump on the right leg

DB - Downs and Black

DSLR - Double straight leg raise

DSV - Desempenho do salto vertical (vertical jump performance)

EMP - External mechanical power

EntL - Entry level

ERF - Extrinsic risk factors

ESLL - Explosive strength of the lower limb

$F1/Ext^{rat}$ – Flexion/Extension ratio

GOM - Gradual onset mechanism

GR - Grade of Recommendation

IADMS - International Association of Dance Medicine and Science

IC - Injury count

IIR - Injury incidence rate

IIRrg - Injury incidence rate range

IntL - Intermediate level

IPR - Injury prevalence rate

IPRrg - Injury prevalence rate range

IQR - Interquartile range

IRB - Institutional Review Board

IRF - Intrinsic risk factors

IRR - Injury rate ratio

LBP - Low back pain

LE - Lower extremity

LOE - Level of Evidence

Mdn - Median

MIC - Multiple injury count

MInf - Membros inferiores (lower limb)

MSK - Musculoskeletal

MVC - Maximal voluntary contraction

NvHab - Nível de habilidade

OCEBM - Oxford Centre for Evidence-Based Medicine

RFD - Rate of force development

ROM - Range of motion

RR - Risk ratio

RSI - Rapid Strength Index

SBJ - Standing broad jump

SCM - Salto com contra-movimento (counter movement jump)

SD - standard deviation

SHO - School Health-Care Office

SI - Symmetry Index

SkL - Skill level

SLR - Systematic Review of Literature

SOM - Sudden onset mechanism

SSC - Stretch–shortening cycle

SVJ - Standing vertical jump

TLR - Training load ratio

VJP - Vertical jump performance

1RM - One-repetition maximum

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Capítulo I - Introdução

"As lesões da dança não são um ato Divino"

Justin Howse

1.1. Organização e Estrutura da Tese

O presente trabalho encontra-se organizado de acordo com o disposto no regulamento de dissertações de Doutoramento da Universidade Lusófona de Humanidades e Tecnologias. Está escrito na sua maioria em língua Inglesa e compreende três manuscritos de investigação como núcleo central da Tese. A Tese encontra-se estruturada em cinco capítulos ao longo dos quais é descrito todo o trabalho desenvolvido. O Capítulo I, introduz a problemática que motivou a investigação, bem como as respetivas propostas e objetivos definidos. O Capitulo II, apresenta os constructos teóricos que suportam o racional seguido, bem como as limitações do estado atual do conhecimento identificadas na literatura. O Capitulo III, tem como propósito descrever o método desenhado para cada um dos estudos incluídos neste trabalho em função do seu objetivo. O Capitulo IV, representa a investigação na prática e compreende os três estudos correspondentes aos três manuscritos de investigação anteriormente mencionados: Uma Revisão Sistemática da Literatura, cujo propósito foi determinar o estado da arte no que concerne à relação entre a força muscular e as lesões em dança; Um estudo epidemiológico cujo objetivo principal foi o de identificar padrões de lesão dentro da população estudada; Um estudo transversal que se propôs a examinar a relação entre a potência do membro inferior o histórico de lesão. O Capitulo V, inclui a discussão dos resultados obtidos, as limitações encontradas no curso da investigação, direções futuras e conclusões.

1.2. O Problema

A Dança está entre algumas das atividades mais fisicamente exigentes para o sistema músculo-esquelético, equiparada ao desporto de alta intensidade, no qual podemos destacar o ballet como o estilo de dança mais exigente (Roberts, Nelson, & McKenzie, 2013). Nesse sentido, os bailarinos podem ser considerados atletas na medida em que são igualmente necessárias capacidades físicas sofisticadas para um desempenho de alto nível (Koutedakis & Jamurtas, 2004; Russel 2013). Os desempenhos de alto nível, tanto na dança como no desporto, requerem o desenvolvimento de capacidades atléticas como a força e a resistência muscular, velocidade e agilidade, flexibilidade, coordenação e controlo motor e, prontidão psicológica (Angioi, Metsios, Metsios, Koutedakis, & Wyon, 2009; Russel 2013). Tais requisitos, colocam as capacidades fisiológicas e de condição física no mesmo nível de importância que o desenvolvimento das habilidades técnicas. A exigência física imposta aos bailarinos devido aos elevados volumes do treino mais a natureza repetitiva dos padrões de movimento presentes nas aulas e ensaios, expõe os mesmos a um risco significativo de lesão, cuja incidência pode ser similar à incidência verificada no desporto ao mesmo nível de desempenho (Hincapié, Morton, & Cassidy, 2008; Jacobs, Hincapié, & Cassidy, 2012; Kenny, Whittaker, & Emery, 2015; Roberts et al., 2013).

No entanto, mesmo no auge da sua carreira profissional, os bailarinos podem exibir baixos níveis de condição física comparativamente com atletas. Frequentemente exibem valores semelhantes aos obtidos em sedentários saudáveis para componentes fundamentais de condição física, uma vez que o sistema de treino só-em-dança não promove estímulos suficientes para adaptações positivas significativas (Twitchett, Koutedakis, & Wyon, 2009).

Uma das principais características dos bailarinos é a flexibilidade (Malkogeorgos, Zaggelidou, Zaggelidis, & Christos, 2013). As amplitudes articulares extremas observadas, ultrapassam por vezes os requisitos de condição física sendo consideradas um indicador da capacidade artística especialmente no *ballet*. A flexibilidade está tão culturalmente enraizada na educação e formação em dança, que é frequentemente usada e promovida como um forte indicador de potencial sucesso sendo considerada um critério major para a seleção dos jovens bailarinos no momento da sua audição para as escolas pré-profissionais (Scheper et al., 2013). Por outro lado, temos a força muscular. Para que um/uma bailarino/a tenha controlo articular, deve existir um equilíbrio entre a flexibilidade e a força (Quarrier & Wightman, 1998). Quanto maior é a amplitude articular disponível mais a articulação precisa de força muscular para se manter estável durante o desempenho (Koutedakis, Stavropoulos-Kalinoglou, & Metsios, 2005; Malkogeorgos et al., 2013; Twitchett et al., 2009). Contudo, mesmo hoje em dia, para algumas seções do mundo da dança, a força continua a não ser considerado um ingrediente necessário para o sucesso e tem permanecido escondida do foco do conhecimento devido a crenças infundadas de que diminui a aparência estética do bailarino/a, a flexibilidade e por consequência o desempenho (Koutedakis & Jamurtas, 2004; Koutedakis et al., 2005; Malkogeorgos et al., 2013).

De modo inverso, estudos experimentais têm mostrado que o treino adicional de força nos bailarinos/as pode promover ganhos significativos de força muscular sem prejuízo para a linha estética e para a flexibilidade (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2012; Koutedakis et al., 2007; Twitchett, Angioi, Koutedakis, & Wyon, 2011). Além do efeito positivo sobre o desempenho, alguns autores sugerem que a força muscular pode ter um papel de relevo na prevenção de lesões e ser considerado como um indicador da propensão dos bailarinos/as para a lesão (Adam, Brassington, Steiner, & Matheson, 2004; Allen, Nevill, Brooks, Koutedakis, & Wyon, 2012; Ambegaonkar, Caswell, Winchester, Caswell, & Andre, 2012; Angioi et al., 2009; Caine, Goodwin, Caine, & Bergeron, 2015; Koutedakis, Frischknecht, & Murthy, 1997; Koutedakis, Khaloula, Pacy, Murphy, & Dunbar, 1997; Liederbach, Hagins, Gamboa, & Welsh, 2012; Mistiaen et al., 2012; Roussel et al., 2014; Russel 2013; Twitchett et al., 2010; Twitchett et al., 2009).

A força muscular no contexto do desporto assume um papel importante nos programas de prevenção de lesões, tendo demonstrado reduzir as taxas de incidência (Lauersen, Bertelsen, & Andersen, 2014; Soomro et al., 2015). Enquanto os mecanismos explicativos dessa relação continuam por identificar, uma revisão sistemática com meta-análise recente, sobre a eficácia das intervenções baseadas no exercício para prevenir lesões desportivas, descobriu que o treino de força mostrou estar associado com a redução das lesões em um terço (Lauersen et al., 2014). A força muscular está também associada com o estado de saúde auto-percebido (Hansen, Beyer, Flensborg-Madsen, Grønbæk, & Helge, 2013), o que significa que pode representar um indicador de saúde tal como o índice de massa corporal ou a pressão arterial (Ortega, Silventoinen, Tynelius, & Rasmussen, 2012). De modo geral, a condição física é aceite como um dos princípios fundamentais para a prevenção de lesões. A força muscular e os parâmetros que com ela se relacionam são elementos major da condição física que devem estar presentes tanto na saúde como no desempenho desportivo (Koutedakis & Jamurtas, 2004; Koutedakis et al., 2005; Naclerio, Colado, Rhea, Bunker, & Triplett, 2009; Twitchett et al., 2009). No contexto da dança porém, ainda não é claro se a força muscular se relaciona de forma positiva ou negativa com as lesões.

O nosso foco nos estudantes de dança pré-profissionais, prende-se com o facto de que para atingir elevados níveis e desempenho e alcançar uma carreira profissional, o treino começa em idades muito jovens num ambiente fisicamente exigente muitas vezes baseado apenas nos elementos técnicos da prática (Roberts et al., 2013; Yin, Sugimoto, Martin, & Stracciolini, 2016). Além do mais, os índices de lesão nesta população são bastante altos, não existe consenso sobre fatores de risco e o tema da força muscular permanece pouco estudado (Bowerman, Whatman, Harris, & Bradshaw, 2015; Caine et al., 2015; Ekegren, Quested, & Brodrick, 2014; Kenny et al., 2015).

1.3. Objetivos da Investigação

O principal objetivo deste trabalho residiu em examinar a natureza da relação entre as lesões da dança e a força muscular em bailarinos/as pré-profissionais, no que respeita ao potencial papel da força como indicador da propensão para a lesão. A nossa abordagem ao problema dentro do objetivo da investigação, iniciou-se com a revisão da literatura que forneceu a base para posteriormente delinear as outras metas de pesquisa para cada um dos estudos desenvolvidos.

- Objetivo de investigação 1, Estudo I – reunir e analisar toda a informação relevante sobre o tema de forma a determinar o estado atual do conhecimento.

Este objetivo foi cumprido através da revisão sistemática da literatura que realizou uma análise crítica e metodológica da informação disponível. Os resultados da revisão revelaram vários aspetos incontornáveis, particularmente relacionados com o campo da epidemiologia das lesões em dança, que precisavam de ser clarificados antes de avançar. Assim, como uma necessidade de maior importância, foi desenhado e realizado um estudo epidemiológico.

- Objetivo de investigação 2, Estudo II – determinar tendências e padrões de lesão específicos da nossa população através de um estudo longitudinal prospetivo.

O estudo supramencionado, permitiu obter informação precisa sobre o contexto e os mecanismos sob os quais ocorrem as lesões, discriminando género e nível técnico, fornecendo assim sólida informação base sobre os principais elementos da mecânica de lesões a serem relacionados com a força muscular ou qualquer outro fator em pesquisas futuras. De facto, era nesta temática que existiam as lacunas mais relevantes identificadas pela revisão da literatura. Nem todas as lesões resultantes da prática da dança se relacionam potencialmente com a força muscular. Se não obtivermos um mapa preciso do cenário da lesão, a identificação de fatores de risco como a força muscular ou outros, pode mostrar-se uma tarefa difícil de cumprir.

- Objetivo de investigação 3, Estudo III – examinar e analisar o produto do desempenho do salto vertical por intermédio da potência do membro inferior e da altura do salto, considerando as assimetrias bilaterais em estudantes de dança pré-profissionais, assimtomáticos, com e sem histórico prévio de lesão do membro inferior em função do género, tipo de lesão tendo em conta os saltos como mecanismo precipitante.

Os padrões de lesão identificados através do estudo epidemiológico, corroboram os da revisão sistemática onde os membros inferiores foram identificados como sendo a localização anatómica mais predominante para a lesão e os saltos como a ação motora mais prevalente na dança. A potência do membro inferior medida por intermédio do desempenho do salto vertical foi também identificado como uma das expressões de força mais avaliadas no contexto da dança. No entanto, a relação com as lesões é inconclusiva. Nesse sentido o Estudo III, teve como propósito clarificar essa relação.

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Chapter I - Introduction

"Dance injuries are not an Act of God"

Justin Howse

1.1. Thesis Structure and Organization

The present work is organized according to the predicted in the PhD dissertation regulation, from Universidade Lusófona de Humanidades e Tecnologias - ULHT. It is written mainly in English language and comprises three research manuscripts which constitute the core of the Thesis. The Thesis is structured in five chapters along which all the developed work is described. Chapter I, introduces the research problem as well as the reasons which motivated our research purpose and objectives. Chapter II presents the theoretical framework that provided the rational for approaching the problem as well as the limitations of current knowledge found in literature. Chapter III refers to the method designed for each of the developed studies concerning their design and purpose. Chapter IV concerns the research in practice presented in this work and comprises the three studies included in the Thesis: a Systematic Review of Literature (SRL) with the purpose of determining the state of the art on the relation between muscular strength and injuries; an Epidemiological study which main purpose was to identify injury patterns within the studied population; a cross-sectional study on the relation between lower limb power and injury history. Chapter V includes the reflexive discussion of the obtained results across studies as well as the limitations found, future research directions and conclusions.

1.2. The Problem

Dancing is among some of the most physically demanding activities for the musculoskeletal (MSK) system matching with high intensity sports, with ballet standing out as the most demanding style of dance (Roberts, Nelson, & McKenzie, 2013). In that sense, dancers may be considered athletes in a degree to which sophisticated physical capacities are required to perform at a high level (Koutedakis & Jamurtas, 2004; Russel 2013). High levels of performance both in dance as in sports, require the development of major athletic capacities such as muscular strength and endurance, flexibility, speed, agility, coordination, motor control, and psychological readiness (Angioi, Metsios,

Metsios, Koutedakis, & Wyon, 2009; Russel 2013). These requirements make physiologic and fitness capabilities just as important as dance technique skill development. The physical demands placed on dancers due to the high volume of the dance training system, plus the repetitive nature of dance movement patterns in classes and rehearsals, expose dancers to a significant risk for injury, featuring injury rates similar to the ones sustained by athletes in traditional sports at the same level of performance (Hincapié, Morton, & Cassidy, 2008; Jacobs, Hincapié, & Cassidy, 2012; Kenny, Whittaker, & Emery, 2015; Roberts et al., 2013).

However, even at the height of their professional careers, dancers' may present low levels of fitness when compared to athletes. They often exhibit values similar to those obtained from healthy sedentary individuals of comparable age in key fitness-related parameters, given that a dance-only training system elicits limited stimuli for positive and significant adaptations (Twitchett, Koutedakis, & Wyon, 2009).

One of the main characteristics of dancers is the flexibility (Malkogeorgos, Zaggelidou, Zaggelidis, & Christos, 2013). The extreme range of motion (ROM) exhibited by dancers go beyond physical fitness and is considered a hallmark of artistry, particularly in classical ballet. Flexibility is so culturally built-in in dance education that it is often used and promoted as a determinant marker in the selection of promising dance students (Scheper et al., 2013). On the other side of the coin lies strength. For a dancer to have control in a joint, a fine tuned balance between muscular strength and flexibility is required (Quarrier & Wightman, 1998). The larger the ROM, the more the joints need adequate muscular strength for maintaining stability through performance (Koutedakis, Stavropoulos-Kalinoglou, & Metsios, 2005; Malkogeorgos et al., 2013; Twitchett et al., 2009). Nevertheless, and even nowadays, for some sections of the dance world, muscle strength is not considered a necessary ingredient for success and have been hidden from the spotlight of knowledge due to unfounded assumptions that it would diminish dancers' aesthetic appearances and flexibility compromising performance (Koutedakis & Jamurtas, 2004; Koutedakis et al., 2005; Malkogeorgos et al., 2013).

Conversely, research has proven the opposite through growing evidence, that proper strength conditioning can increase strength levels in dancers and improve performance without interfering with their technical and aesthetic elements (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2012; Koutedakis et al., 2007; Twitchett, Angioi, Koutedakis, & Wyon, 2011). In addition to performance, some authors suggest that muscle strength may play a preventive role against injuries and may act as a predictive factor of dancers proneness to injury, once that in general they exhibit lower levels of strength when compared to other sport matching activities and weight-predicted norms (Adam, Brassington, Steiner, & Matheson, 2004; Allen, Nevill, Brooks, Koutedakis, & Wyon, 2012; Ambegaonkar, Caswell, Winchester, Caswell, & Andre, 2012; Angioi et al., 2009; Caine, Goodwin, Caine, & Bergeron, 2015; Koutedakis, Frischknecht, & Murthy, 1997; Koutedakis, Khaloula, Pacy, Murphy, & Dunbar, 1997; Liederbach, Hagins, Gamboa, & Welsh, 2012; Mistiaen et al., 2012; Roussel et al., 2014; Russel 2013; Twitchett et al., 2010; Twitchett et al., 2009).

Muscle strength in sport context has proven to play a key role in injury prevention programs reducing injury rates (Lauersen, Bertelsen, & Andersen, 2014; Soomro et al., 2015). While the underlying mechanisms explaining that relation, remain to be identified, a recent systematic review and meta-analysis on the effectiveness of exercise intervention to prevent sports injuries, found that strength training have reduced sports injuries to less than one-third (Lauersen et al., 2014). Plus, muscle strength was also found to be associated with self-rated health (Hansen, Beyer, Flensborg-Madsen, Grønbæk, & Helge, 2013) meaning that can be considered an hallmark of health just as body mass index (BMI) and blood pressure (Ortega, Silventoinen, Tynelius, & Rasmussen, 2012). In general, physical conditioning can be seen as one of the key principles for injury prevention, and muscular strength and strength related components are major physical conditioning elements required for both health and performance (Koutedakis & Jamurtas, 2004; Koutedakis et al., 2005; Naclerio, Colado, Rhea, Bunker, & Triplett, 2009; Twitchett et al., 2009). Within the context of dance practice, it remains unclear how it may positively or negatively be related with injuries.

Our focus of research on pre-professional dance students, relates to the fact that for achieving elite levels of performance and pursuit a professional career, dance practice starts at very early ages on a physically demanding environment often based only in the technical aspects of dance training (Roberts et al., 2013; Yin, Sugimoto, Martin, & Stracciolini, 2016). Furthermore, this population sustain high injury rates, consensus regarding risk factors remains unclear, and the issues surrounding muscle strength are understudied (Bowerman, Whatman, Harris, & Bradshaw, 2015; Caine et al., 2015; Ekegren, Quested, & Brodrick, 2014; Kenny et al., 2015).

1.3. Research Aims

The main purpose of this work lies on examining the nature of the relation between dance injuries and muscular strength in pre-professional dance students, concerning the potential role of muscular strength in injury proneness. Our approach to the problem within the research purpose, first started with the review of literature which provided the basis for subsequently outline the other research goals for each of the developed studies.

- Research goal 1, Study I - to gather and analyse all the relevant information on the theme to determine the current state of knowledge.

This goal was accomplished through an SRL which carried out a critical and methodological appraisal of the relevant literature available. The outcomes of the SLR revealed several ineluctable aspects (i.e. particularly concerning the dance injuries field) which needed to be clarified before addressing the muscular strength issue. Such made as a need of utmost importance, to design and perform a high-quality epidemiological study.

- Research goal 2, Study II - to determine injury trends and patterns within our population through a longitudinal prospective epidemiological study.

This study allowed to obtain accurate data on dance injuries context and mechanism, discriminating gender and skill levels, providing a strong background about key elements of injury mechanics to be related with muscular strength or any other factor in future research. In fact, this aspect was one of the major gaps found in literature, of the ones identified by the SRL. Not all injuries resulting from dance practice may potentially relate with muscular strength. If we do not get a precise map of the injury scenario, identifying associations with factors such as muscular strength or others, may remain a difficult task to attain.

- Research goal 3, Study III - to examine and analyse the product of vertical jump performance (VJP) by means of lower extremity (LE) Power and jump height, concerning bilateral asymmetries in asymptomatic pre-professional dance students with and without previous LE injury history regarding gender, injury type and jumps as a precipitating mechanism.

The injury patterns identified through the epidemiological study, corroborate the findings of the SRL which report the lower limb as being the most predominant location of injury and jumps one of the most prevalent motor actions in dance practice. Also, LE power assessed through VJP was found to be a recurrent strength related parameter assessed dancers. However, the relation with injuries remains unclear. In that sense Study III was structured with the purpose of clarifying that relation and adding new data which can be used for injury prevention.

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Chapter II - Theoretical Framework

"Science is a way of thinking much more than it is a body of knowledge".
Carl Sagan

This chapter provides the theoretical framework based upon which we developed our methodological approach as well as the support for the overall discussion of the obtained results.

2.1. Dance Injuries Epidemiology

The dance injuries theme is one of the major matters of concern for clinicians, researchers and dancers irrespectively of their skill level and dance style (Jacobs, Hincapié, & Cassidy, 2012; Malkogeorgos, Mavrovouniotis, Zaggelidis, & Ciucurel, 2011). The burden of injuries in dancers may range from temporary performance inhibition to career ending due to chronic physical disability and poor health quality later in life (Hincapié, Morton, & Cassidy, 2008; Kenny, Whittaker, & Emery, 2015; Smith et al., 2015; Smith et al., 2017). For those wishing to achieve elite levels and pursuit a professional career, dance practice, especially ballet, often starts at a very early age on a physical and psychological demanding environment fuelled by the strive for perfection through intense training (Roberts, Nelson, & McKenzie, 2013; Yin, Sugimoto, Martin, & Stracciolini, 2016). Such environment may act as a precursor for injury proneness particularly among young dancers (Bowerman, Whatman, Harris, & Bradshaw, 2015; Ekegren, Quested, & Brodrick, 2014; Kenny et al., 2015; Roberts et al., 2013), where the pre-professionals lead the chart of injury incidence rate (IIR) featuring ranges around 0.77 - 4,7 per 1000 dance hours (Ekegren et al., 2014; Gamboa, Roberts, Maring, & Fergus, 2008; Leanderson et al., 2011; Luke et al., 2002; Steinberg, Aujla, Zeev, & Redding, 2014) with up to 76% of injury risk (Smith et al., 2015). These injury rates are comparable with others aged matched high-risk athletic activities such as youth indoor soccer (4.5/1000 h), elite adolescent gymnastics (2.6/1000 h), ice skating (1.4/1000 h) (Kenny et al., 2015), or even with the incidence range observed in professional dancers (i.e. ballet and contemporary), 0.56 - 4.45 injuries per 1000 dance hours (Allen, Nevill, Brooks, Koutedakis, & Wyon, 2013; Nilsson, Leanderson, Wykman, & Strender, 2001; Shah, Weiss, & Burchette, 2012).

Epidemiological data should be able to provide the basis of understanding for injury management and prevention in both context of sports and dance by establishing injury determinants and extent (Liederbach, Hagins, Gamboa, & Welsh, 2012; Meeuwisse, Tyreman, Hagel, & Emery, 2007; Timpka et al., 2014). However, caution should be taken when interpreting some of the available epidemiological outcomes data. Heterogeneity in injury definition, injury data collection design and analysis, are known to influence epidemiological outcomes interpretation (Bronner, Ojofeitimi, & Mayers, 2006; Finch & Cook, 2014; Kenny, Palacios-Derflingher, Whittaker, & Emery, 2017; Liederbach et al., 2012; Timpka et al., 2014). In some cases the outcomes are just not comparable across studies, and in other cases they are highly prone to several bias factors (Hincapié et al., 2008; Kenny et al., 2017; Kenny et al., 2015; Liederbach et al., 2012; Timpka et al., 2014), which may also lead to a biased interpretation of the injury phenomenon. Furthermore, epidemiological data based on injury rates and frequencies without context specific information, is only able to report injury product benchmark metrics, which regardless of the usefulness in quantifying injuries on a given population, fail to reflect the nature of injury dynamics and their respective patterns.

When the research purpose is to study injury risk factors or markers for a particular condition, (i.e. muscle strength in the case of this work), epidemiological data should fit the purpose in order to provide the appropriate background for addressing the problem. The aforementioned concerns are, within the scope of injury surveillance, the pillars for robust study designs and will be presented in the following sections of this chapter.

2.1.1. Injury Definition

The first, injury definition, is perhaps the one that due to variability and lack of consensus, more may contribute to an impairment of data cross-checking amongst studies (Kenny et al., 2017; Liederbach et al., 2012; Timpka et al., 2014). The International Association of Dance Medicine and Science (IADMS) Standard Measures Consensus Initiative (Liederbach et al., 2012), reported six conventional ways of defining injury:

1) By tissue pathology and injury nature
2) By duration and nature of treatment
3) By time lost from a particular task

4) By time lost from work
5) By measure of permanent functional loss
6) By cost of care

The most used approach to define injury within sports and dance context is the one, or the ones, featuring time loss (Kenny et al., 2017; Liederbach et al., 2012), such as the purposed by the IADMS Standard Measures Consensus Initiative (Liederbach et al., 2012):

"*The term injury refers to an anatomic tissue-level impairment as diagnosed by a licensed health care practitioner that results in full time loss of activity for one or more days beyond the day of onset*".

Furthermore, it also states that:

"…*for events that fall short of this strict definition of injury the term musculoskeletal complaint should apply*".

Nevertheless, this injury concept may present some limitations in some scenarios. It is known that dancers often dance through most of their injuries (Gamboa et al., 2008; Kenny et al., 2017) and therefore time loss injury concept may underestimate the real impact of injuries within a given population. Although we accept that in determined non-optimal data collection scenarios, the use of retrospective procedures based on recall questionnaires and time-loss definitions may be more suitable for distinguishing MSK injuries from MSK complaints. However one should keep in mind that less severe cases and injuries resulting from overuse may go unnoticed (Timpka et al., 2014).

Injury definition coherency with study design and purpose, should be considered a key determinant for methodological consistency. In fact, longitudinal prospective studies (i.e. cohort) in order to capture all the relevant data, may benefit, apart from injury definition, to consider the concept of "health-related incident" (Timpka et al., 2014). The "health-related incident" concept was purposed by Timpka and colleagues (2014) (Timpka et al., 2014) in a Consensus Statement for epidemiological studies in athletics and is defined as:

"*Any physical or psychological complaint or manifestation experienced by an athlete, irrespective of the need for medical attention or time loss from Athletics activities*".

Using such conceptual definition in longitudinal designs, may reveal advantageous in many ways, since it considers all the reportable data. The main advantages relate with:

a) Having data on all the reportable incidents, including those that may not directly result from practice, but which may influence the athlete/dancer performance, having the opportunity of being posteriorly analysed.
b) Capturing syndromic context related pre-diagnostic data.
c) Allowing more accuracy in classifying injuries sub-categories and distinguishing between an injury and a MSK complaint.
d) Capturing overuse injuries occurrence.

Based on the previous and within dance context, we consider that any condition real or potential, which affects a dancer functional capacity presents itself as a complaint. When the complaint is significant enough to be reported by the dancer it should be registered irrespectively of being considered in advanced, an injury or not. For this same reason in what concerns to pre-diagnostic data, a complaint shouldn't be mistaken with an injury, and therefore pre-diagnostic data collection shouldn't be influenced by injury definitions, background formation and/or clinical expertise.

For the purpose of our epidemiological study design, we have considered the "health-related incident" definition by Timpka et al. (2014) (Timpka et al., 2014). The psychological element was not considered since it was out of the scope of interest of this research. Also, to be coherent with the previous, injury definition was adapted from IADMS Consensus Statement (Liederbach et al., 2012), by removing the time-loss element and staying as follows:

"The term dance injury should refer to an anatomic tissue-level impairment resulting from dance practice, diagnosed by a licensed health care practitioner and which implies full or partial dance activity impairment for one or more days beyond the day of symptoms onset".

As previously mentioned, the concepts and definitions used in injury surveillance studies should be coherent with study design and purpose allowing the collection and sub-sequent categorization of data to be used for determining injury patterns. Those aspects may represent a differentiating element, since, irrespectively of the methodological design employed, most studies on dance injuries report high rates and frequencies (Caine et al., 2016; Caine, Goodwin, Caine, & Bergeron, 2015; Kenny et al., 2015; Liederbach et al., 2012; Smith et al., 2015).

2.1.2. Injury Data Collection Design

It is known that injury surveillance is the key stone for effective injury management and prevention in both context of sports and dance. Yet, and up to the present date there is still no consensus amongst the dance science community on a standard injury surveillance system. As suggested by Bronner (2006) (Bronner et al., 2006), and later on the IADMS Standard Measures Consensus Initiative (Liederbach et al., 2012), a robust injury surveillance system should possess three components: screening for intrinsic risk factors; tracking of extrinsic risk factors and injury occurrence reporting, being this last the field where greater confusion still lies. Furthermore, trends and patterns of injury as well as their inciting mechanisms, can only be identifiable through data obtained from appropriate and context specific reporting methods (Meeuwisse et al., 2007). Nevertheless, in terms of injury occurrence reporting models, literature is scarce and lacks in objectivity and context-specific systematization with several grey areas still existing. In fact, and from our perspective, dance science literature may be running a little ahead of understanding here. Much focus of attention has been given to injury risk factors identification (Caine et al., 2015; Kenny et al., 2015) but few less attention has been given to the data collection process, particularly concerning injury occurrence reporting designs with regard to the type of information to be included (Bronner et al., 2006; Liederbach et al., 2012). Injury data collection procedures vary widely, with some instruments and procedures being more prone to flaws than others (Bahr, 2009; Caine et al., 2015; Fuller et al., 2006; Goldberg, Moroz, Smith, & Ganley, 2007; Hincapié et al., 2008; Jacobs et al., 2012; Liederbach et al., 2012; Smith et al., 2015). Retrospective injury data collection procedures by means of recall questionnaires conducted by interview or through self-reported forms, are the ones more prone to recall bias and inaccuracy, once that less severe injuries may not be reported as well as the ones that occurred longer ago (Caine et al., 2015; Liederbach et al., 2012; Smith et al., 2015). On the other hand, prospective data collection designs are always preferential (Liederbach et al., 2012; Timpka et al., 2014). Still, even with prospective designs some issues must be considered.

Even though literature is quite consensual in relation to the ideal design (i.e. prospective) (Kenny et al., 2015; Liederbach et al., 2012; Meeuwisse et al., 2007; Timpka et al., 2014), it only gives answer to ”how” data should be collected. The “what type of data” should be collected is yet under discussion.

Epidemiological prospective data should be able to provide relevant and robust information, since by default, it provides a privilege position for such. It should be able to look beyond rates, risks and frequencies by frame them into the proper context in order to identify patterns. In that sense, the “what type of data” should be context-specific and, defined accordingly. The interdependence between data collection and analysis highlights this statement. If the right information is not captured, the outcomes and conclusions will be limited (Finch & Cook, 2014; Meeuwisse et al., 2007). Identifying injury patterns should be the first step to understand the injury phenomenon in a given population and underpin predictive studies. The “right data” should be based on individual assessment allowing to link all complaints within a person (Finch & Fortington, 2017) as well as the context on which they developed (Meeuwisse et al., 2007) and the respective consequences for practice. Prospective longitudinal studies offer the possibility to design injury surveillance methodological approaches able to capture both injury pre-diagnostic and post-diagnostic data. While diagnosis and post-diagnostic data should preferentially be collected and reported by qualified medical personnel, pre-diagnostic data does not have the same requirement since it concerns what the dancer/ athlete reports in the first person (Timpka et al., 2014). In what concerns to prevention, the lower the prevention level goal, the higher the importance of pre-diagnostic data. When properly designed, pre-diagnostic data collection, provide information which allows to identify “What happened”, “When did it happened” and the “How”.

This sort of information may allow to better define injury patterns concerning the recursive nature of injury aetiology and help to build a platform of knowledge for management and prevention.

2.2. Injury Multi-factorial Model

Dance injuries, as the ones in any other athletic activity, are multi-factorial in nature and result from a complex interplay of risk factors that when associated may compose a causal factor for injury (Liederbach et al., 2012; Meeuwisse et al., 2007). Tracking risk factors remains a challenge, and screenings often reveal inconsistent in their findings (Bahr, 2016; Kenny et al., 2015). One of the main reason for such may be related with the paucity of high quality studies (Kenny et al., 2015).

Risk factors by themselves do not cause injuries directly, they determine the susceptibility of an adverse event to occur (Faustman & Omenn, 2003). Risk factors act as predisposing agents and/or as facilitators which when combined turn the dancer/athlete more or less susceptible to injury (Liederbach et al., 2012; Meeuwisse et al., 2007). Still, an inciting event needs to happen for the injury to occur (Liederbach et al., 2012; Meeuwisse et al., 2007).

Meeuwisse purposed in 1994 (Meeuwisse, 1994) a multifactorial model for athletic injury aetiology (figure 2-1).

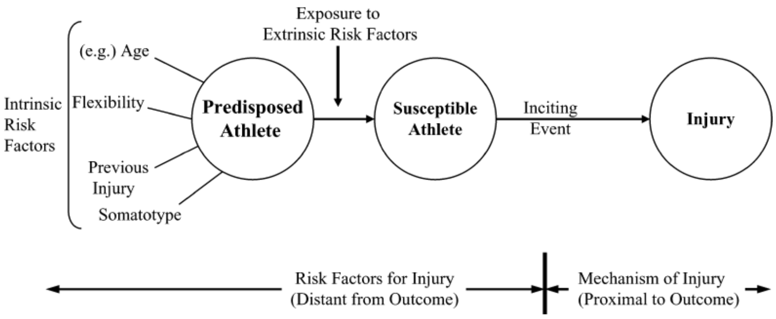

Figure 2-1: Multifactorial athletic injury model purposed by Meeuwisse (1994).

The model reflects the interrelation between intrinsic risk factors (IRF) and extrinsic risk factors (ERF), whereas the IRF concern the athlete individual-specific characteristics and the ERF concern the exposure to the practice environment. The interrelation between risk factors is recursive in nature, meaning that it changes frequently, where the predisposition level for injury may rise or diminish as a consequence of the dancer/athlete adaptive capacity to continuous exposure (Meeuwisse et al., 2007). Furthermore, each individual possesses is own set of IRF, divided in modifiable and non-modifiable factors (Bahr & Holme, 2003). While the non-modifiable IRF represent the baseline predisposition for injury and are mainly biological, the modifiable IRF are usually related with the individual functional capabilities and are responsive to external influence (Bahr & Holme, 2003; Bronner et al., 2006; Liederbach et al., 2012) such as ERF. Table 2-1 presents some of the main modifiable and non-modifiable IRF for pre-professional dance students.

Table 2-1: Examples of intrinsic risk factors for dance injuries

Intrinsic risk factors				
Non-modifiable	Modifiable			
Biological	Health & Physiological	Psychological	Physical Fitness	Skill Level
- Age - Growth and maturation - Gender - Gender specific - Bone and Joint architecture - Hypermobility	- Previous injury - Metabolic disorders - Hormonal disorders - Nutritional disorders - Somatotype	- Anxiety - Memory - Attention/Focus - Risk taking - Stress coping	- Aerobic condition - Anaerobic condition - Muscular Strength - Flexibility - Motor coordination	- Technique - Experience - Dance specific motor repertoire

In turn, ERF concern the external elements to which the dancer/athlete is exposed upon practice. They are usually activity-specific (Bahr & Holme, 2003; Bronner et al., 2006; Liederbach et al., 2012) and reflect the demands of practice. The inciting event is usually task-specific and concerns the mechanism under which the injury developed as consequence of ERF exposure (Bronner et al., 2006). Table 2-2 presents both the main ERF and inciting event.

Table 2-2: Examples of extrinsic risk factors and inciting events for dance injuries

Extrinsic risk factors	Inciting events
- Dance style	- Biomechanical stressors
- Technical and Choreographic demands	- Psychological stressors
- Aesthetic demands	- Faulty technique
- Training errors	- Work-to-rest ratio
- Performing conditions	
- Institutional and social	
- Environmental	
- Work planning and Schedule	

This constellation of risk factors interacts in multiple ways. It would be relatively easy to identify risk factors and determine causation if risk factors remained stable over time, which does not happen in a real case scenario (Meeuwisse et al., 2007). The linear paradigm approach implicit in classical cohort studies using screening programs to identify potential risk factors, often results in inconsistent findings because does not consider that for the same individual, injury may or may not occur under similar circumstances depending on the personal predisposition related with IRF change (Bahr, 2016; Bahr & Krosshaug, 2005; Meeuwisse et al., 2007). As an example, adolescence growth spurts are pointed as intrinsic risk factors for developing physeal injuries both in sports and dance (DiFiori et al., 2014; Hawkins & Metheny, 2001). However not all athletes/ dancers, develop physeal injuries during growth spurts, and although physeal injuries are more often related with overuse mechanism, the nature of their relation is unclear, being in fact, in some cases, also highly associated with acute traumatic fractures (DiFiori et al., 2014). Within the same growth and maturational stage, many other factors may combine. Both in sports and dance, literature is consensual that the strongest predictor of future injury is previous injury (DiFiori et al., 2014; Kenny et al., 2015; Liederbach et al., 2012). A recent systematic review on risk factors for musculoskeletal injury in preprofessional dancers (Kenny et al., 2015), identified previous injury as Level 2 evidence for future injury. Particularly foot and ankle injuries. One of the reasons for such association may relate to the fact that previous injury when not fully and properly recovered tend to recur principally on the return to the activity phase (Bahr, 2016). Although previous injuries are classified as modifiable IRF, their repercussions may permanently alter the baseline anatomical structure and not be fully modifiable changing the other IRF configuration and act as modulators for ERF exposure. This means that when determined markers stay stable and the events repeat enough, they may reveal more suitable to be identified through linear approaches. This recursive nature of risk and causation plus the constant interchangeability of risk factors, led to that in 2007, Meeuwisse and colleagues (Meeuwisse et al., 2007) had presented a new injury model featuring this cyclic nature of injury dynamics (figure 2-2.). An injury as an outcome, very much depends on the intrinsic features of the dancer/athlete and the way the body deals with exposure and the extrinsic elements under which is exposed. In dance literature, the majority of studies aiming for risk factors tracking, address to modifiable risk factors and most of the times in a non-context specific approach (Kenny et al., 2015). Also the dance injury model purposed from the IADMS Consensus Initiative (2012) (Liederbach et al., 2012) is based in Meeuwisse´s 1994 model instead of the 2007 which reflects a more linear approach to risk and causation (figure 2-3).

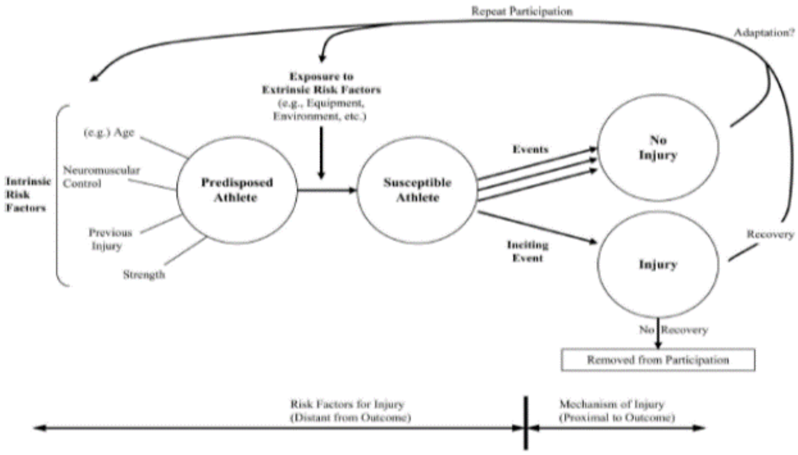

Figure 2-2: Dynamic, recursive model of aetiology in sport injury (Meeuwisse et al., 2007).

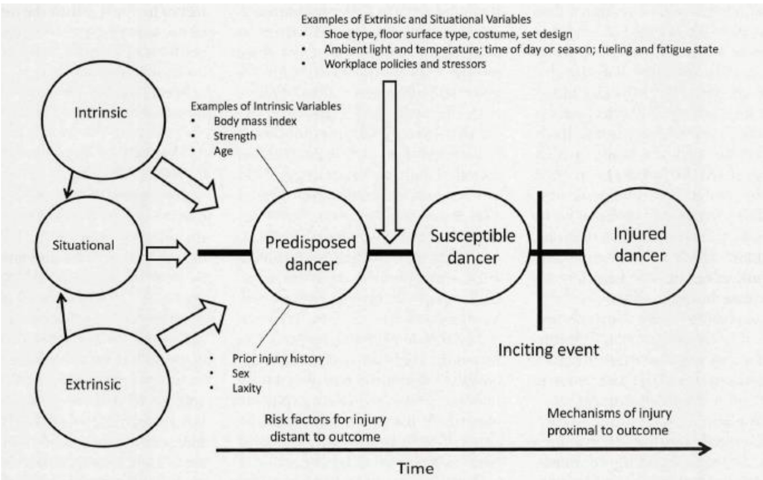

Figure 2-3: IADMS Consensus Initiative model of risk factors interaction (Liederbach et al., 2012).

Within dance science, this is an issue of recurrent interest but yet far from consistent results. Dance screenings are the main approach line but still inefficient.. Although we do believe that screenings are the path to follow, previous work needs to be done for them to function properly. In order to identify predictors, the strength of the association between the factor and risk needs to be confirmed (Bahr, 2016). Also, it should be identified how common is the condition and what is the respective context on which it occurs. The factors stability over time in a given context and population, also should be an issue to consider. Epidemiological studies may help to give answer to these issues. In sum, before addressing to risk factors, a better knowledge on injury dynamics concerning pre-injury environment is required.

2.3. Muscular Strength in Dance

Can the words flexible, lithe, willowy go hand in hand with strong, powerful, and explosive? While the first adjectives are often employed to describe dancers’ gracefulness and artistry, so are the seconds when addressing to some of the world's greatest dancers in their performances. Their common denominator: Muscular strength.

From motor complexity perspective, dancing may be seen as one of the most physically demanding activities for the musculoskeletal system, matching with high intensity sports (Malkogeorgos et al., 2013; Roberts et al., 2013; Russel & Jeffrey 2013). Sometimes dancers are referred as the “*Performing Athletes*” (Koutedakis, Stavropoulos-Kalinoglou, & Metsios, 2005), meaning that their performance excellence relies not only in their technical skill and aesthetics, but also in their physical capabilities (Koutedakis et al., 2005; Malkogeorgos et al., 2013; Twitchett et al., 2009). The main physiological attributes usually considered necessary for accomplishing with dance specific tasks, relate with coordination, strength, flexibility, good aerobic and anaerobic foundations and adequate body composition (Koutedakis & Jamurtas, 2004; Malkogeorgos et al., 2013; Twitchett, Angioi, Koutedakis, & Wyon, 2011; Wyon & Koutedakis, 2013). Nevertheless, it should not be forgotten that dance express itself through motion, and in order to that motion to occur, muscle tension is needed (Koutedakis & Jamurtas, 2004). In dance as in sports, muscles are required to produce tension under many circumstances, depending on the motor action being performed and the specificity of the task. From that tension results strength. Depending on the muscle action, velocity and type of contraction, motor task duration and movement pattern, muscular strength may assume different types and expressions (Atha, 1981; Bemben, Massey, Bemben, Misner, & Boileau, 1996; Bigland-Ritchie, 1984; Campos et al., 2002; Carvalho & Carvalho, 2006; Demura, Miyaguchi, & Aoki, 2008; Harris, Cronin, & Keogh, 2007; Rana et al., 2008; Rodrigues, 1999; Winter et al., 2016; Yamaji, Demura, Nagasawa, & Nakada, 2004). The wide motor repertoire in dance features an almost endless combination of motor actions through the different choreographic arrangements (Xarez, 1999), where the dancer needs to make use of those muscular strength types and expressions. Naming a few examples, dance is classified as an intermittent type of exercise in which acute bursts of exercise are followed by moments of high precision and skill (Twitchett et al., 2009). If on one side large reserves of power are needed for elevation during big explosive jumps (Malkogeorgos et al., 2013; Twitchett et al., 2009), the power output also needs to be maintained during small repetitive jumping sequences (Angioi, Metsios, Koutedakis, Twitchett, & Wyon, 2009). With concern to muscle actions, while eccentric control is required in the knee and ankle joint extensor muscles during the descending phase of the *demi plié*[1], strong isometric muscle work is required in female ballet dancers ankle joint for keeping balance while standing *en pointe*[2] (Khan et al., 1995).

The following sections of this chapter will address to the types of muscle strength and their respective expressions within dance context.

2.3.1. Muscular Strength Types and Expressions

A simple definition of strength may be the muscle ability to exert force (Harris et al., 2007; Koutedakis, Clarke, Wyon, Aways, & Owolabi, 2009; Mital & Kumar, 1998; Taber, Bellow, Abbott, & Bingham, 2016). Depending on the effort characteristics concerning muscle action, strength can be defined as static or dynamic (Mital & Kumar, 1998). In static muscular strength, force is developed but no movement occurs. The muscle is under isometric action and no mechanical work is performed (Mital & Kumar, 1998; Winter et al., 2016). In turn, dynamic muscle strength produces work, and occurs when the force point of application is displaced (Winter et al., 2016). This happens under concentric or eccentric muscle actions depending if the muscle respectively shortens or lengthens while exerting force. Nevertheless, in human motion, isolated forms of isometric, concentric or eccentric actions, are seldom found. Rather, they combine for efficiency. An example is the stretch–shortening cycle (SSC) where an eccentric action is immediately followed by a concentric one, as an economical way of movement enhancement (Bosco, Luhtanen, & Komi, 1983; Komi, 1984). Also, in most of dynamic motor tasks, stabilizers and fixator muscle actions tend be isometric or quasi-isometric (Winter et al., 2016). The aforementioned concepts, however, mainly refer to the mechanics of the muscle-tendon complex featuring muscle length in relation to the action performed. In the exercise context, such as sports and dance, force production also depends on task-specific effort features such as the load and speed range (i.e. force-velocity), and time (i.e. duration of the effort) (Atha, 1981; Harris et al., 2007; Taber et

[1] Bilateral knee flexion followed by extension.
[2] Full ankle-foot plantarflexion, weight bearing on toes.

al., 2016). In that sense, we may fall under three domains of strength type: Maximal strength; Speed-strength; Muscular-endurance. Each, with several expressions depending on the motor task demands (Bemben et al., 1996; Carvalho & Carvalho, 2006; Harris et al., 2007; Rana et al., 2008; Winter et al., 2016).

2.3.1.1. Maximal strength

Maximal strength represents the upper limit of force production (Taber et al., 2016). Strength, is also often defined as *"the peak force developed in a maximal, voluntary, isometric contraction, or as the maximum load that can be lifted for one repetition (1 RM)"* (Harris et al., 2007), regardless of time. Nevertheless, this definition only covers two dimensions of maximal strength (i.e. isometric and concentric). Muscles may develop maximal effort while performing isometric, concentric or eccentric actions, each, with different levels of force production for their respective maximum (Harbo, Brincks, & Andersen, 2012). While some exceptions may occur, in normal conditions and for the same motor task, maximal concentric strength scores are usually inferior to the ones obtained through a maximal isometric muscle action, whereas eccentric scores prove to be tendentially higher (Farthing & Chilibeck, 2003; Harbo et al., 2012).

Within dance context, jumps are perhaps the motor action where greater eccentric effort is required, especially during the landing phase for shock absorbing. At the same time and particularly in ballet, the most demanding isometric actions occur after concentric ones, where the dancer needs to hold steady in poise positions. Nonetheless, it should be referred that the maximal effort required of dance-specific motor actions, does not translate under a single set of motion, such as one-repetition maximum (1RM) or single maximal muscle contractions. First, because it is not the purpose of dance motion, and second, and as previously mentioned, maximal strength represents the upper limit of force production irrespectively of the time (Harris et al., 2007; Taber et al., 2016), and dance-specific motor tasks occur within specific speed and time frames (i.e. relative to the choreography). So, how may maximal strength benefit dancers' performance?

Maximal strength is a trainable skill which plays a major role in athletic performance. It is known to influence other strength types (Baker, Nance, & Moore, 2001b; Moss, Refsnes, Abildgaard, Nicolaysen, & Jensen, 1997; Taber et al., 2016; Østerås, Helgerud, & Hoff, 2002) even in activities where the force production needs to meet activity-task-specific time and speed constraints (Baker, Nance, & Moore, 2001a;

Baker et al., 2001b; Stone et al., 2004; Taber et al., 2016; Østerås et al., 2002) such as speed-strength and muscular-endurance.

Maximal strength influence in speed-strength force expressions (i.e. Power and Explosion) relies on the strong correlation with rate of force development (RFD) (Cormie, McGuigan, & Newton, 2010; Taber et al., 2016; Suchomel et al., 2016). As an example, RFD concerns the time-interval at which force is developed (Maffiuletti et al., 2016), and muscular power is the force-velocity product (Taber et al., 2016). If we consider that for a given task the athlete´s mass and the time-period over which force is applied are not immediate modifiable elements, the RFD time-interval needs to diminish to consequently increase the execution velocity (i.e. acceleration) (Taber et al., 2016). Furthermore, it is also known that human muscle shortening velocity is limited (Nyitrai et al., 2006; Sargeant, 2007), therefore, to enhance the force-velocity curve, muscular strength gains need to be achieved (Taber et al., 2016).

Conversely, muscular-endurance is the ability to repeatedly develop and/or maintain levels of force across prolonged periods of time. While it may seem more related with oxygen uptake features (e.g. VO_{2max} and VO_{2peak}) and subsequent work economy, than with maximal strength, some evidence suggests that heavy-resistance strength training improves work economy and enhances short and long-term endurance capacity (Aagaard & Andersen, 2010; Heggelund, Fimland, Helgerud, & Hoff, 2013; Stone et al., 2006; Østerås et al., 2002). A study by Aagaard and colleagues (Aagaard et al., 2011), purposed to examine the effect of heavy-resistance strength training on short/long-term endurance capacity, mechanical muscle output, skeletal muscle fibre size and type composition and muscle vascularization in top-level endurance athletes. Their results revealed an enhanced long-term endurance capacity through improvements registered in a 45-min time trial performance, an increased proportion of type IIa fibres and reduced proportion of type IIx fibres, elevated maximal muscle strength and increased RFD. It is also important to mention that in the aforementioned study (Aagaard et al., 2011), the training regimen did not result in cellular muscle hypertrophy. This finding is in line with other studies (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2012; Twitchett et al., 2011), which support the fact that strength training does not affect the aesthetic competence of dancers, and therefore misbeliefs and unfounded assumptions about this topic for keeping dancers away from strength training, should not be considered.

2.3.1.2. Speed-strength

The vast majority of athletic activities do not so much depend on maximal strength expressions, but rather, of their rapid production. This holds true not only in motor tasks such as kicking or throwing, but also whenever there is need of sudden direction changes and/or acceleration. This requires the neuro-muscular system to produce the greatest possible impulse in the shortest available time span (Suchomel et al., 2016; Taber et al., 2016; Winter et al., 2016). This phenomenon is under the domain of speed-strength, which manifests under the expressions of Power and Explosion. Both terms are often applied in research and professional practice, as synonyms for the same physical abilities (Carvalho & Carvalho, 2006; Winter et al., 2016). Although they are related, caution should be taken, because, in spite of both being expressions of the same strength type, they depend on very different factors and have distinct characteristics, thus, they are not synonyms and should not be employed indiscriminately (Carvalho & Carvalho, 2006; Winter et al., 2016). Explosive strength directly relates with the intra-muscular factors of muscle contraction, while Power concerns the inter-muscular speed of execution of a given motor action or sequence (Suchomel et al., 2016).

In order to better understand these two expressions of speed-strength, we must distinguish how they exist in time and human movement.

Strength can be expressed over a wide range of speeds and resistance levels. However, maximal force and maximal velocity are located at polar ends of the force-velocity continuum. Meaning that a negative correlation exists between maximal force and maximal velocity (Harris et al., 2007; Taber et al., 2016). For a given motor task, the higher the resistance the slower the execution velocity, which means that maximal strength is dominant in relation to speed. On the other hand, execution velocity (i.e. acceleration) dominance increases as the resistance decreases. Explosion or explosive strength represents the neuromuscular ability in overcoming high resistances as quick as possible. In other words, is to produce the maximum force within the shortest time period possible. Given the relation between force and time, it is measured in $N.s^{-1}$ (Bührle, 1986). and it may be analysed through the force-time curve (figure 2-4).

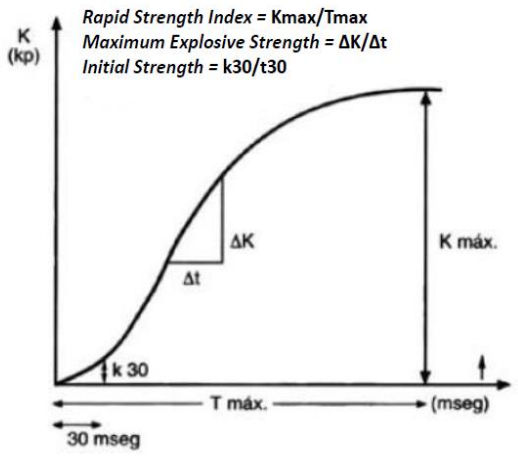

Figure 2-4: Isometric muscle contraction force-time curve featuring Rapid Strength Index; Maximum Explosive Strength, Initial Strength, adapted from Bührle (1986).

Explosive strength manifestations may be measured at any given point along the force-time curve. In most sports actions the available time for producing maximal strength locates around 250 milliseconds (ms) (Bührle, 1986). Explosive strength, however, concerns the initial stage of movement and reaches is maximum around 100 ms, particularly when the force development occurs against heavy load (more than 30% of max force) either dynamically or isometric (Schmidtbleicher, 1992). In the force-time curve, maximum explosive strength is identified through the maximum slope of the curve and calculated through the force (ΔK) and time (Δt) variation coefficient (i.e. ΔK/Δt). When, instead, the maximal strength peak (Kmax) and the maximum time needed to reach it (Tmax) are considered, we will obtain from their coefficient the Rapid Strength Index (RSI). This capability of developing high strength levels in the shortest time frame, heavily depends on muscle contraction velocity, which should not be mistaken with movement execution speed. It relies on a neurological substrate concerning intramuscular coordination, involving motor-unit recruitment, discharge frequency and synchronization of discharge. But again, and back to the maximum explosive strength development, it can only be observed when the resistance against which the force is developed is superior to 30% of max strength in isometric actions or at the static phase of dynamic actions. Whenever the resistance is inferior to the aforementioned percentage, movement starts to occur before maximum explosive strength being reached. The lower the resistance, the lower the maximal strength peak (figure 2-5).

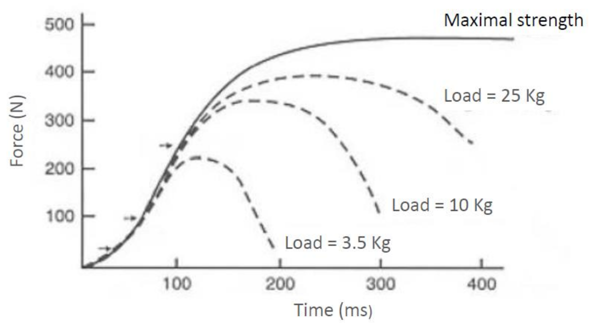

Figure 2-5: Force-time curve in dynamic actions with different resistance loads, adapted from Schmidtbleicher (1992).

Also, the lower the resistance the higher the movement speed (i.e. acceleration), and regardless of the maximum explosive strength not being reached, it influences initial strength (Taber et al., 2016). In the force-time curve, initial strength represents the highest muscle tension developed within the firsts 30ms to 50ms of muscle contraction and assumes particular importance in actions requiring high initial speed such as ballistic actions. The higher the level of force production in the static phase of movement, the earlier the acceleration may begin (Van Cutsem & Duchateau, 2005). In sum, explosive strength is an expression of speed-strength featuring fast force development at the static phase of movement and which relies on muscle contraction velocity per unit of time.

If within speed-strength, explosion expresses itself through the force-time curve, when force is associated with velocity (i.e. acceleration), in the force-velocity curve we find Power.

Power is defined as the product of force and velocity (*Power = Force x Velocity*), representing the rate at which mechanical work is performed and it is measured in Watts (W) (Abernethy & Jürimäe, 1996; Harris et al., 2007; Taber et al., 2016; Winter et al., 2016). Power is perhaps the most familiar expression of speed-strength used in the context of sports and conditioning, but also often inaccurately applied and interpreted. In order to understand how Power should be interpreted in the exercise context, we should pay close attention to the components from which it results, more exactly the impulse-momentum relationship (Taber et al., 2016; Winter et al., 2016). Most actions in sports and exercise involve acceleration of a mass (i.e. *Momentum*) and force acting on a mass over a given period of time (i.e. *Impulse*) (Taber et al., 2016). Meaning that, any change in *Momentum* must be obtained by altering the velocity, which requires a change in *Impulse*. Also knowing that the force applied during those actions is not constant across the time period, it is possible to state that in the Power equation, *Force* is associated with *Momentum* through *Impulse* (*Force x* Δ*Time*) whereas *Velocity* directly relates with *Momentum* (*Mass x* Δ*Velocity*) (Taber et al., 2016). The impulse-momentum relationship may therefore be represented as:

Force x Δ*Time = Mass x* Δ*Velocity*

This expression describes the reason why maximal power output is found in the middle of the force-velocity curve (figure 2-6). Overcoming high resistance loads require high force production but very low velocity, and ultimately no velocity when the muscle action is isometric, therefore Power equals zero. On the opposite end, without a resistance load, velocity will be maximum but with very few force production required, meaning that, in theory, Power production will be very low or even close to zero (Harris et al., 2007).

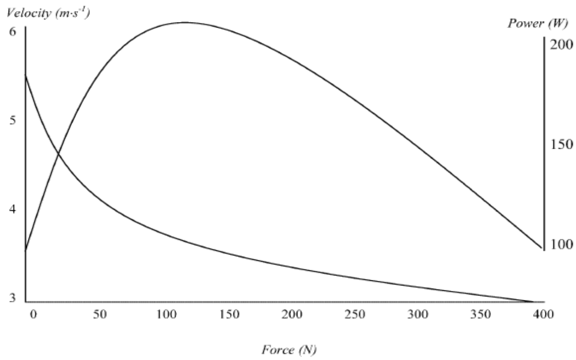

Figure 2-6: Interrelation between muscle force, velocity, and power. Adapted from Harris, Cronin & Keogh (Harris et al., 2007).

Although maximum power output is observed at intermediate movement speeds with intermediate loads, improvements in maximal strength though heavy loads training have proven to shift the force-velocity curve to the right (Harris et al., 2007; Taber et al., 2016), reinforcing the argument that maximal strength is a key element for Power enhancement at any level of execution speed and load (Taber et al., 2016). Nevertheless, the strength and speed ranges at which maximum power is reached also depend on the athlete/performer and performed work characteristics. Stronger and/or slower athletes/performers usually reach their maximum power output at lower execution speeds than faster athletes/performers (Carvalho & Carvalho, 2006).

Power gains are commonly associated with athletic performance enhancement (Harris et al., 2007; Taber et al., 2016; Winter et al., 2016; Young, 2006) in several motor tasks such as jumping (Cormie et al., 2010; Hori et al., 2008; McLellan, Lovell, & Gass, 2011; Newton, Kraemer, & Häkkinen, 1999), sprinting (Harris et al., 2007; Weyand, Sandell, Prime, & Bundle, 2010), quick direction changes (i.e. cutting) (Nimphius, McGuigan, & Newton, 2010; Salaj & Markovic, 2011), among others. However, caution should be taken when interpreting the relationship between these terms. Power is scalar, and it depends on factors of vector nature such as *Force*, *Impulse*, *Acceleration* and *Momentum*, which are also, to some extent, characteristics of performance (Winter et al., 2016). Understanding the integration of these factors is determinant for interpreting Power output assessments. One common misconception happens when Power output is defined as a determinant of athletic performance (Winter et al., 2016). Based on the impulse-momentum relationship from mechanics perspective, Power defines the dynamic characteristics of force application on a given task, not the performance outcome (Winter et al., 2016). This means that Power is a skill-related component of physical fitness (Caspersen, Powell, & Christenson, 1985), and rather, it should be seen as a characteristic of athletic performance instead of a determinant. Both Power and performance outcomes, are the consequence of a process, which share as a starting point the neuromuscular system ability to generate *Impulse* (Winter et al., 2016). The motor tasks associated with Power within performance, feature constant shifts in velocity with deliberate changes in both speed and direction. Those changes are determined by the generated *Impulse* (Winter et al., 2016). The same way, in order to that *Impulse* to be effective in accomplishing the task goals, it will also depend on the athlete/ performer skill proficiency level, particularly coordination (Carvalho & Carvalho, 2006). Coordination allows to optimise *Impulse* in the appropriate timing and direction for the movement task (Winter et al., 2016), assuming greater importance in activities of high motor complexity, such as dance (Malkogeorgos et al., 2013; Roberts et al., 2013; Russel & Jeffrey 2013). It plays a very important role in protecting the MSK system and in Power gains within a specific task. When the required forces are exceeded, and are too large, injury may occur to the muscle, tendon and in some extreme conditions to the bone. In what concerns to Power gains, the movement expressions in dance, as well as in sports, result from a set of motor actions, composed by motor gestures resulting from multi-joint muscle actions. Inter-muscular coordination will define the efficiency level of cooperation between agonists, antagonists and synergists, thus increasing the task specific Power. This process, however, being so task specific, possesses very little transference from one motor task to another (Carvalho & Carvalho, 2006), because the extent to which prime mover muscles are involved in one task is not the same in another (Flanagan & Salem, 2007; Riemann, Lapinski, Smith, & Davies, 2012; Swinton, Stewart, Agouris, Keogh, & Lloyd, 2011).

2.3.1.3. Muscular-endurance

According to literature, dance is considered to be a high-intensity, intermittent form of exercise (Angioi, Metsios, Metsios, Koutedakis, & Wyon, 2009; Koutedakis & Jamurtas, 2004; Malkogeorgos et al., 2013; Twitchett et al., 2009). From class to performance, muscular endurance is a required physical attribute, either for maintaining the Power output (e.g. series of consecutive jumping usually between 30 and 60s), or muscle tension (e.g. *arabesque*[3] or holding a partner in a lift) in poise positions (Angioi et al., 2009; Koutedakis & Jamurtas, 2004; Malkogeorgos et al., 2013; Twitchett et al., 2009). The muscle or muscle groups ability in produce and maintain force overtime, before fatigue, is defined as muscular endurance (Bigland-Ritchie, 1984; Caspersen et al., 1985; Kanehisa & Miyashita, 1983). Fatigue represents the upper limit of muscular endurance, and is defined as a transient exercise-induced work capacity reduction, when the force or power output and/or exercise intensity cannot be maintained at the pre-set rate (Bigland-Ritchie & Woods, 1984; Liederbach, Schanfein, & Kremenic, 2013; Murgia, 2013; Vøllestad, 1997; Wyon & Koutedakis, 2013). It can be seen as safety mechanism for protecting the MSK system, and is a complex phenomenon caused by peripheral and central mechanisms overlapping and interaction (Liederbach, Schanfein, & Kremenic, 2013; Murgia, 2013; Wyon & Koutedakis, 2013). In fact, it is inevitably to address muscular endurance without taking fatigue into account. In literature several models have been developed in order to explain the fatigue response to exercise: cardiovascular/anaerobic; energy supply/energy depletion; neuromuscular; central; biomechanical; muscle trauma; thermoregulatory and psychological/motivational (Abbiss & Laursen, 2005). Although they are all interconnected and be quite important,

[3] Ballet body position in which a dancer stands on one leg (the supporting leg) with the other leg (the working leg) turned out and extended behind the body.

describing their respective mechanisms are out of the scope of the present work and can be found well describe elsewhere (Abbiss & Laursen, 2005; Liederbach et al., 2013; Murgia, 2013; Twitchett et al., 2009; Wyon & Koutedakis, 2013).

Irrespectively of the explanatory model and underlying substrate, peripheral fatigue, progressively influences the function of the muscle contractile process, by reducing the force generating capacity, whenever the activity requires prolonged holding or repetition of a high-force featuring isometric or isotonic contraction (Bigland-Ritchie, 1984; Bigland-Ritchie, Rice, Garland, & Walsh, 1995; Liederbach, Schanfein, & Kremenic, 2013; Vøllestad, 1997). As an example, during sustained or repeated maximal efforts, the muscle maximal voluntary contraction (MVC) capacity progressively starts to decline (figure 7) (Bigland-Ritchie & Woods, 1984). Within the same individual, the rate at which it happens will depend on the contraction intensity and/or on the contraction holding time (Bigland-Ritchie & Woods, 1984; Vøllestad, 1997). The time until task failure is defined as endurance time (Bigland-Ritchie & Woods, 1984) and is also represented in figure 7.

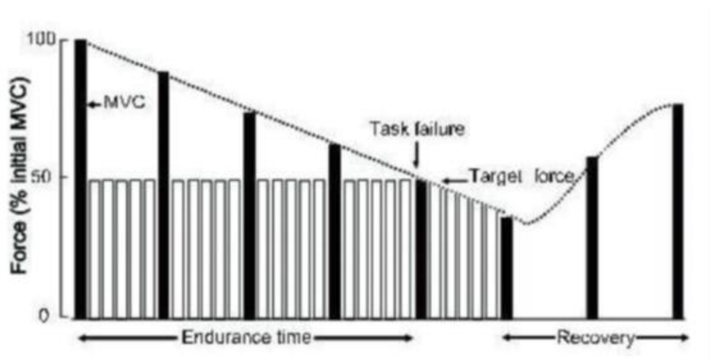

Figure 2-7. Changes in maximum force generating capacity through MVC during intermittent submaximal contractions. Adapted from Bigland-Ritchie & Woods (Bigland-Ritchie & Woods, 1984)

The endurance time is determined by the rate of maximum force generating capacity, concerning the duration and intensity of the exercise bout (Bigland-Ritchie & Woods, 1984). Within dance performance it is possible to observe several examples on which muscular-endurance assumes particular relevance. While big jump sequences with mid-air turns require maximal effort and just last a few seconds (e.g.15s) (Twitchett, Koutedakis, & Wyon, 2009), submaximal effort such as jump series sequences, allow to maintain the targeted intensity for a longer period (Vøllestad, 1997), more exactly between 30s and 60s (Twitchett et al., 2009).

Central fatigue relates to a reduced motor drive from brain motor centres, failing to maintain adequate muscle activation peripherally (Bigland-Ritchie & Woods, 1984; Froyd, Millet, & Noakes, 2013; Vøllestad, 1997). It often occurs when the work loads are not matched by adequate rest periods, and in many cases is preceded by a period of time during which a dancer or athlete is able to maintain his or her level of performance, but only with a sense of greater effort (Liederbach et al., 2013; Murgia, 2013). Central fatigue mechanism goes beyond muscle failure, and is often suggested to be associated with cognitive and emotional factors (Liederbach et al., 2013). Non-functional overreaching and Overtraining syndrome can be seen as good examples of central fatigue. They are long lasting and besides performance impairment have detrimental effects in the athlete/ dancer health (Kreher & Schwartz, 2012; Liederbach et al., 2013).

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Chapter III - Method

"It is not enough to say that we cannot know or judge because all the information is not in. The process of gathering knowledge does not lead to knowing"

John Steinbeck

This chapter provides the general description of the methodological approach used in the three studies presented in this work. Although the studies feature different designs, they are interconnected through an evolutionary line of thought worth being clarified in order to understand the choices that have dictated the path to follow throughout the research.

3.1. Developed Studies

The studies included in the present work, comprise: a Systematic review of literature, a Longitudinal prospective study and a Cross-sectional study. With regard to Study I, Systematic reviews and meta-analyses play a decisive role in research, since they may help determine whether planned studies for a given field are necessary and/or which path to follow based on the existing knowledge (Borenstein, Hedges, Higgins, & Rothstein, 2009; Liberati et al., 2009). They are often the starting point, and differ from other review types in reliability, since incorporate a set of procedures such as: specification of the question to be addressed; determination of methods to be used for searching the literature; studies inclusion and exclusion pre-determined criteria; specification of mechanisms to appraise the validity of the included studies; specification of methods to be used for performing the statistical analysis and a mechanism for disseminating the results (Borenstein et al., 2009). Meta-analysis concern the statistical synthesis of results from a series of studies. This allows to understand the results of any study in the context of all the other studies. (Borenstein et al., 2009). However, for a meta-analysis to be performed the required data must be available and the study design must be similar. Within our SRL, meta-analysis was not possible due to the included studies design heterogeneity. Within our knowledge this is the first systematic review on this subject.

Given the need of conducting an epidemiological study, Study II followed a longitudinal, prospective design. In sports and dance injuries epidemiology, longitudinal prospective designs are suggested as the most appropriate to define injury patterns and identify potential risk factors (Finch & Marshall, 2016; Fuller et al., 2006; Liederbach, Hagins, Gamboa, & Welsh, 2012; Meeuwisse, Tyreman, Hagel, & Emery, 2007; Timpka et al., 2014), since they are much more sensitive to changes overtime, and thus more powerful than cross-sectional studies.

In Study III a cross-sectional designed was used. Cross-sectional designs are quite valuable for describing the burden of long-term, particularly overuse-related conditions and identifying individual characteristics in population sub-groups (Levin, 2006; Meeuwisse et al., 2007; Timpka et al., 2014). Also, they are cost-effective and have no loss to follow-up (Levin, 2006).

3.2. Setting and Participants

Settings and participants are not applicable to Study I due to its design type. Nevertheless, within the inclusion and exclusion criteria defined for study appraisal, they were considered dance populations, irrespectively of dance style and level of practice (vocational, elite pre-professional and professional), and dancers of both genders with the age range set in accordance with the level and/or category of practice.

Studies II and III, were conducted on a full-time pre-professional dance school in Lisbon, Portugal featuring an eight-year full-time dance course from entry level to advanced level. Students range in age from 9 - 21 years old and their entrance in the school is made via audition only. Each school year lasts approximately 8.5 months (34 weeks) from September to June, with three interruptions in December (2 weeks), March/April (2 weeks) and from July to mid-September (10 weeks) respectively. The school repertoire features both classical and contemporary styles although contemporary is only introduced into de curriculum from the 3rd year on. Students also have classes of complementary dance practices (e.g. historical dances, character dance and tap dance), physical conditioning, Yoga and Pilates seminars. The average weekly amount of dance class participation, depending on the skill level (SkL), ranges between 9.75±3.59 hours for the entry level students and 20±7.32 for the advanced level students.

3.3. Instruments

The instruments used in Study I, mostly concern the included studies quality appraisal. The methodological quality assessment was done using the Downs and Black (DB) checklist (Downs & Black, 1998), whose detailed description is available in Appendix 2. The Level of Evidence and the Grade of Recommendation of the included studies were determined after methodological quality assessment and it was based on the Oxford Centre for Evidence-Based Medicine (OCEBM) recommendations (Howick et al., 2011) which is available in Appendix 3. Also, a data extraction form (Appendix 1) was created for allowing a blind analysis of the retrieved studies.

For Study II, there was the need of creating and developing a fit-for-purpose Individual Occurrence Report Form adapted to our setting and population. As previously described in Chapter II, injury occurrence reporting models, are scarce in literature, and the few found lack in objectivity and context-specific systematization with several grey areas still existing. The fields of the occurrence report comprised: Subject identification and demographic data; Occurrence identification; Occurrence description; Occurrence context. The details of the report form are exhibited in the Appendix 7 and described in the Chapter IV within the respective study.

In Study III, subjects´ height and weight were measured by means of a portable stadiometer and a digital scale, respectively. Ankle dorsi-flexion range of motion (ROM) was measured through weight-bearing lunge, using a metric tape with the ability to measure to 0.1 cm (Konor, Morton, Eckerson, & Grindstaff, 2012). For vertical jump tests assessment, it was used a Chronojump Boscosystem® Contact platform A2; Chronojump software 1.4.7.0., which has proven to be a reliable and valid equipment in field testing for estimating LE jump height and power through flight time (Bosco, Luhtanen, & Komi, 1983; Markovic, Dizdar, Jukic, & Cardinale, 2004).

3.4. Procedures

The present section summarizes the procedures followed in each study. The detailed description of each procedure is found on Chapter IV in the methods section of the respective studies. Studies II and III comply to the tenets of The Declaration of Helsinki of the World Medical Association (Association, 2013) and was approved by the *Comissão de Ética da Faculdade de Motricidade Humana da Universidade de Lisboa* (CEFMH, N25/2017). Participants aged 18 years or older provided written informed consent and those under the age of 18 years provided oral informed assent and a parent/legal guardian provided written informed consent.

3.4.1. Operational

Regarding Study I, the PRISMA statement for Reporting Systematic Reviews and Meta-Analysis of Studies That Evaluate Health Care Interventions: Explanation and Elaboration (Liberati et al., 2009) was consulted and provided the structure for the SLR.

The search strategy and identification of the relevant literature was conducted on five electronic databases (Cochrane Library, PubMed, Scopus, SportDiscus and Web of Science) from their year of inception up to October 2015, using the following search expression: dance* AND injur* AND (muscle strength OR muscle endurance OR muscle power). In order to ensure that all the available relevant data were considered, the search strategy was also extended to two specific dance science publication outlets (Journal of Dance Medicine and Science and Medical Problems of Performing Artists). The latter did not allow the use of the aforementioned search expressions, instead separate text words combinations with the indexed terms were used.

The inclusion criteria for study selection were: any observational or experimental study, within the scope of dance injury research involving dance populations irrespectively of dance style and level of practice (vocational, elite pre-professional and professional), of which the subject of research was the relationship between muscle strength and/or muscle power and/or muscle endurance and dance injury. Dancers of both genders were considered with the age range set in accordance with the level and/or category of practice; studies with mixed sample populations were considered if data concerning dancers were presented separately; studies where the object of research was the relation between other physical fitness components and injury were also considered if one or more of the selected parameters was included and objectively assessed; peer-reviewed studies published in English language.

Studies were excluded if they did not meet the inclusion criteria or if one of the following exclusion criteria were present: studies on special or disabled populations; studies on occasional dance practice; studies on retired dancers; editorials; conference proceedings and abstracts; book chapters; opinion and resource papers; review papers; methodological papers; descriptive survey studies; case studies; studies where injury data count as an independent variable.

The assessment of the methodological quality of the included papers, was made using the Downs and Black (DB) checklist which is a methodological quality assessment tool with high internal consistency (KR-20 = 0.89), good test–retest reliability (r = 0.88) and good interrater reliability (r = 0.75) (Downs & Black, 1998). It consists of 27 items across five sections, as follows: (i) Study quality (10 items) –the overall quality of the study based on data reporting; (ii) External validity (3 items) – the ability to generalize findings of the study through their representativeness; (iii) Internal validity concerning study bias (7 items) – to assess bias in the intervention and outcome measure(s); (iv) Internal validity concerning confounding and selection bias (6 items) – to determine bias from sampling or group assignment; and (v) Power of the study (1 items) – to determine if findings are due to chance (for more information see Appendix 2). After the methodological quality assessment, the Level of Evidence (LOE) and the Grade of Recommendation (GR) of the included studies were determined based on the Oxford Centre for Evidence-Based Medicine (OCEBM) recommendations (Howick et al., 2011).

In what concerns to studies II and III, injury-related data was collected on-site and on a daily basis, over the study time period. The physical location for data collection was the school health care office (SHO) were all the dance students visits due to health-related complaints were registered in an individual occurrence report form, featuring the following: Dance students' demographics; Physical complaint description concerning anatomical location; nature and type of physical complaint as well as symptoms onset type, based on the framework developed by Fuller et al. (Fuller, Bahr, Dick, & Meeuwisse, 2007; Fuller et al., 2006); Symptoms triggering mechanism description concerning the motor action (i.e. exercise being performed) (Xarez, 1999) and the respective context (Bahr & Krosshaug, 2005). In our sample the majority of dance students danced through most of their injuries. As such, no time-loss element could be included in injury definition due to the risk of underestimating injury burden (Kenny, Palacios-Derflingher, Whittaker, & Emery, 2017). Injury definition was adapted from Fuller et al. (2006) (Fuller et al., 2006) and described as "any physical complaint sustained by a dancer resulting from dance practice, diagnosed by a licensed health care practitioner and which irrespective of the need for medical attention, implies full or partial dance activity impairment for one or more days beyond onset". All the events falling short of this definition were considered musculoskeletal complaints.

For the purpose of Study II, only injury pre-diagnostic data were considered. In Study III, the study aimed for a retrospective analysis of the collected data concerning LE injuries only.

Given the epidemiological nature of Study II, measuring dance practice exposure time was determinant for calculating incidence and prevalence rates. As such, within our population, exposure referred to the time in hours spent in classes, rehearsals and performances. For each academic year, dance-time exposure was calculated based on weekly timetables from classes, rehearsals and performances concerning dance year, skill level (SkL) and gender. This allowed to most accurately obtain week, month and year dance-time, respectively. In addition, exposure was also used to determine if no differences existed between SkL groups which could justify defining sub-categories for analysis.

With respect to VJP assessment in Study III, the participants´ age, height (in cm) and mass (in kg) were recorded. The dynamic dominant leg was determined by the Ball kicking test (Brophy, Silvers, Gonzales, & Mandelbaum, 2010). Ankle dorsiflexion range of motion (ROM) was measured following the procedures described by Konor et al. (Konor, Morton, Eckerson, & Grindstaff, 2012) through weight-bearing lunge facing a wall and barefooted. Participants were given 3 trials to familiarize themselves with the procedure and precondition the tissues. Maximal dorsiflexion ROM was defined as the maximum distance in cm of the toe from the wall while maintaining contact between the wall and knee without lifting the heel. Before jump tests assessment, subjects completed a standardised warm-up that consisted of 5 min jogging at a self-selected pace followed by 10 squats, 10 heel raises and 5 min of their usual individual lower extremity stretching routine before dance classes. Additionally, each participant performed 3 practice trials for each of the jump types used in assessment. After the warm-up and practice trials, three jump test trials were performed, ordered according to the following jump types: Two-legged counter-movement jump (CMJ); Two-legged counter-movement jump using the technique for performing ballet jumps ($CMJ1^{st}$), (heels together, hips externally rotated with the feet in 1st ballet position, and pointed feet); One-legged counter-movement jump for left (CMJ^{left}) and right (CMJ^{right}) legs respectively. The subjects started all the jump tests within the contact mat, assuming the respective test position with the hands on their hips. They were instructed to sink as quickly as possible and then jump as high as possible, always keeping the hands on the hips, and not allowing the chest line to cross the knees during the sinking eccentric phase. It was also asked that at take-off, the subjects´ leave the mat with the knees and ankles extended, and land on a similar fashion (Young, 1995). For total recovering, a rest period of 1 min was given between trials and of 15 min between jump type (Markovic, Dizdar, Jukic, & Cardinale, 2004).

3.4.2. Data Analysis and Statistics

In Study I, data from the included studies was abstracted into evidence tables. When studies provided enough statistical data, effect size was calculated using the Open Meta Analyst software version 10.10 for Macintosh (Wallace et al., 2012) and interpreted according with Cohen (J. Cohen, 1988) recommendations. In studies that used statistical correlation analyses (i.e., Pearson or Spearman), when not provided, the coefficient of determination (r^2) was calculated for explaining the proportion of variance (Borenstein et al., 2009). Because of significant heterogeneity in study design, methodological procedures and quality, and outcomes of the selected studies, meta-analysis was not done, and data was analysed descriptively. After analysis, standardized summary of findings tables were created, concerning study descriptive characteristics (study first author/year, study design, population, dance style, study purpose and main outcome) and relevant statistical components (p-values, r-values, r^2-values, Cohen d). The strength of agreement between reviewers was determined through Cohen's kappa (Cohen & Jacob, 1960). Interpretation of Kappa values was established using standards proposed by Landis and Koch (Landis & Koch, 1977): 0=poor, 0.01–0.20=slight, 0.21–0.40=fair, 0.41–0.60=moderate, 0.61–0.80=substantial, and 0.81–1=almost perfect.

For both studies II and III, statistical analyses were performed using the Statistical Package for Social Sciences version 22.0 (SPSS Inc. Headquarters, 233s. Wacker Drive, 11th floor, Chicago, Illinois 60606. USA). Since within our data sets, a non-normal distribution was observed through the Kolmogorov-Smirnov test, non-parametric statistics were used.

In Study II, the significance level for all inferential analyses was set at $p < 0.05$. For all proportion comparisons Chi-square analysis was used. Kruskal-Wallis analysis was used for continuous variables comparison, such as incidence and prevalence rates. Poisson regression was applied to injured dancers' frequency across academic year months and injury mechanism categories in order to determine injury risk probability distribution and the most probable inciting event category. The month with less injured dancers and the inciting event category with less injuries registered were set as reference, respectively. Adjustment to covariates was also performed. The correlation between injury inciting event and onset mechanism was determined through Spearman test.

The risk ratio (RR) concerning the average probability of a dance student suffering at least one injury across one academic year was calculated through epidemiologic incidence proportion (Knowles, Marshall, & Guskiewicz, 2006) and reported as percentage (%95CI).

Injury rates were calculated using person-time as denominator and reported per 1000h (Knowles et al., 2006) for each injury category (i.e. index, local and re-injury for incidence and exacerbation for prevalence) (Fuller et al., 2007) based on multiple individual injury count number (IC) (Fortington, van der Worp, van den Akker-Scheek, & Finch, 2017). Rates were calculated separately for gender and SkL. Injury incidence rate range (IIRrg) and prevalence range (IPRrg) are reported. IIRrg was obtained through the sum of the respective incidence categories rate total within each year.

In Study III, the contact platform used records air time and determines the height of the jump using the formula: height of body centre of gravity = $(t^2 \times g)/8$, whereas g = 9.81 $m \cdot s^{-2}$ and t corresponds to air time (Leard et al., 2007). Power (watts) was calculated based on a previously published equation which accounted for participants´ body mass and height, thus reducing the effects of individual anthropometric variation (Ambegaonkar et al., 2018). The used equation was: Power (watts) = 78.5 × jump height (cm) + 60.6 × body mass (kg) - 15.3 × subject height (cm) - 1.308. For analysis purposes, only the best scores of each jump (i.e. jump height and Power) were considered. The bilateral deficit of jump performance was determined through Bilateral Deficit Index (BDI) using the following method: BDI% = 100 [(Bilateral$_{tot}$ / (Unilateral$_{dom}$ + Unilateral$_{ndom}$)] - 100 (Howard & Enoka, 1991). The Symmetry Index (SI) was calculated using the equation: (non-dominant leg / dominant leg) × 100 (Maulder & Cronin, 2005). The strongest side was defined as the side where jump height and Power scores were the highest within each participant. Injuries were grouped into injury type (i.e. acute and overuse) and mechanism (i.e. jumps), being respectively distributed by stronger and weaker side according to gender.

Descriptive statistics were expressed as median (Mdn) and interquartile range (IQR). For continuous variables Mann-Whitney *U* test and non-parametric Kruskal-Wallis tests were used. For nominal variables, Qui-square or Fisher exact test were used.

Bivariate non-parametric Spearman's correlation was performed for univariate analysis of continuous variables. Total sample analysis and gender stratified analysis were performed. Multivariate multinomial logistic regression was performed. Number of limb injuries, acute limb injuries and overuse limb injuries in the powerful limb were dependent variables. Ratio between ipsilateral and contralateral Power (w) and jump height (cm) were independent variables. Models were adjusted for gender. Poisson regression analysis was used for injury frequency distribution by gender concerning body side and adjusted to injury type. Alpha of 0.05 or less was considered for null-hypothesis rejection.

Because of multiple individual injuries, the most prevalent anatomical regions within the LE were determined through the percentage of male and female injured dancers by anatomical region concerning total LE injuries and LE injuries involving jumps.

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Chapter IV - The Developed Studies

4.1. Study I - The Relationship between Muscular Strength and Dance Injuries: A Systematic Review

A Relação entre a Força Muscular e as Lesões da Dança: Uma Revisão Sistemática

Final reference (see annex for the article in the published format):

Moita, J. P., Nunes, A., Esteves, J., Oliveira, R., & Xarez, L. (2017). The Relationship Between Muscular Strength and Dance Injuries: A Systematic Review. Med Probl Perform Art, 32(1), 40-50. doi:10.21091/mppa.2017.1002

4.1.1. Abstract

Background: The physical demands placed on dancers put them at a significant risk for injury, with similar rates as the ones sustained by athletes in sports at the same level of performance. Muscle strength has been suggested to play a preventive role against injury in dancers.

Objectives: To systematically search and examine the available evidence on the protective role of muscle strength in dance injuries.

Methods: Five electronic databases and two specific dance science publications were screened up to September 2015. Study selection was based on a priori inclusion criteria on the relation between muscle strength components and injuries. Methodological quality and level of evidence was assessed using the Downs and Black (DB) checklist and the Oxford Centre of Evidence-Based Medicine (OCEBM) 2011 model.

Results: From the 186 titles found only eight studies meet the inclusion criteria and were considered for review. Because of significant heterogeneity of the included studies, meta-analysis was deemed inappropriate. The DB quality assessment results presented as percentage scores ranged from 18.7% to 75% (mean 42.3±16.9) and the OCDEBM between 2b and 4. Some level 2b evidence from two studies suggest that pre-professional ballet dancers who get injured exhibit lower overall muscle strength scores on the lower extremity, and that lower extremity power gains may be associated with decreased bodily pain but not injury rate.

Conclusion: The findings of this review reveal that although there might be an association trend towards low muscle strength and dance injuries, the nature of that relation remains unclear and presently the state of knowledge does not provide solid basis for designing interventions concerning prevention.

Keywords: Dance injuries; Muscle strength; Injury prevention; Risk factor

4.1.2. Resumo

Contexto: As exigências físicas impostas aos bailarinos na sua prática artística, representam um risco significativo de lesão com taxas de incidência semelhantes aquelas observadas em atletas no mesmo nível de desempenho. A força muscular tem sido sugerida como um potencial fator preventivo a considerar contra as lesões.

Objetivos: Pesquisar e examinar de forma sistemática a evidência disponível sobre o papel protetor da força muscular na ocorrência de lesões na dança.

Método: Cinco bases de dados eletrónicas e dois jornais científicos específicos de ciência da dança foram analisadas até setembro de 2015. A seleção dos estudo baseou-se em critérios de inclusão definidos à priori, que considerassem a relação entre qualquer componente relacionado com a força muscular e as lesões da dança. A qualidade metodológica e o nível de evidência foram avaliados usando a escala de Downs e Black (DB) e o modelo do *Oxford Centre of Evidence-Based Medicine* (OCEBM) de 2011.

Resultados: Dos 186 estudos encontrados apenas oito corresponderam aos critérios de inclusão e foram considerados para revisão. Devido à heterogeneidade significativa dos estudos incluídos, não foi possível realizar meta-análise. Os resultados da avaliação da qualidade metodológica da escala DB foram apresentados em percentagem e variaram de 18,7% a 75% (média 42,3 ± 16,9). O nível de evidência segundo o OCDEBM situou-se entre 2b e 4. Alguma evidência de nível 2b observada em dois estudos, sugere que os bailarinos pré-profissionais que se lesionam apresentam valores mais baixos de força muscular na extremidade inferior, e que o aumento do nível de força nos membros inferiores podem estar associados à diminuição da dor corporal, mas não à taxa de lesão em si.

Conclusão: Os resultados desta revisão revelaram que, embora possa haver uma tendência de associação entre níveis mais baixos de força muscular e lesões na dança, a natureza dessa relação é pouco clara e atualmente o estado do conhecimento não permite ter uma base sólida para desenhar intervenções com vista à prevenção.

Palavras-Chave: Lesões; Dança; Força muscular; Prevenção; Fatores de risco

4.1.3. Background

Due to its motor complexity and technical requirements, dancing can be seen as a highly physically demanding activity for the musculoskeletal system, matching with high intensity sports (Malkogeorgos, Zaggelidou, Zaggelidis, & Christos, 2013; Roberts, Nelson, & McKenzie, 2013; Russel 2013) requiring high fitness levels and sophisticated physical capacities for excellence performance (Koutedakis & Jamurtas, 2004; Malkogeorgos et al., 2013; Russel 2013). The physical demands placed on dancers from choreography and performance schedules plus the repetitive nature of dance movement patterns in classes and rehearsals, place dancers at a significant risk for injury, with similar rates as the ones sustained by athletes in traditional sports at the same level of performance (Gamboa, Roberts, Maring, & Fergus, 2008; Roberts et al., 2013). However, even at the height of their professional careers, dancers may present low levels of fitness when compared to athletes, often exhibiting values similar to those obtained from healthy sedentary individuals of comparable age, given that a dance-only training system elicits limited stimuli for significant physical fitness adaptations (Twitchett, Koutedakis, & Wyon, 2009), particularly muscle strength.

Within some sections of the dance world, muscle strength is not considered a necessary ingredient for success and has been hidden from the spotlight of knowledge due to unfounded assumptions that it would diminish dancers' aesthetic appearances and flexibility, thus compromising performance (Koutedakis & Jamurtas, 2004; Koutedakis, Stavropoulos-Kalinoglou, & Metsios, 2005; Malkogeorgos, Mavrovouniotis, Zaggelidis, & Ciucurel, 2011). Conversely, research has proven the opposite through growing evidence, that proper strength conditioning can increase strength levels in dancers and improve performance without interfering with their technical and aesthetic elements (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2012; Koutedakis et al., 2007; Mistiaen et al., 2012; Twitchett, Angioi, Koutedakis, & Wyon, 2011). In addition to performance, some authors suggest that muscle strength may play a preventive role against injuries and may act as a predictive factor of dancers proneness to injury (Allen, Nevill, Brooks, Koutedakis, & Wyon, 2012; Ambegaonkar, Caswell, Winchester, Caswell, & Andre, 2012; Angioi, Metsios, Metsios, Koutedakis, & Wyon, 2009; Caine, Goodwin, Caine, & Bergeron, 2015; Koutedakis, Frischknecht, & Murthy, 1997; Koutedakis, Khaloula, Pacy, Murphy, & Dunbar, 1997; Koutedakis et al., 2005; Liederbach, Hagins, Gamboa, & Welsh, 2012; Malkogeorgos et al., 2013; Mistiaen et al., 2012; Reid, 1988; Roussel et al., 2014; Russel 2013; Twitchett, Brodrick, et al., 2010; Twitchett et al., 2009). In sports, muscle strength has proven to be a key determinant in injury prevention programs for reducing injury rates (Lauersen, Bertelsen, & Andersen, 2014; Soomro et al., 2015). While the underlying mechanisms remain to be accurately identified, a recent systematic review and meta-analysis on the effectiveness of exercise intervention to prevent sports injuries, found that strength training reduced sports injuries to less than one-third (Lauersen et al., 2014). Muscle strength has also been found to be associated with self-rated health (Hansen, Beyer, Flensborg-Madsen, Grønbæk, & Helge, 2013) meaning that it can be considered as a marker of health just as body mass index (BMI) or blood pressure (Ortega, Silventoinen, Tynelius, & Rasmussen, 2012).

In general, physical conditioning is a key principle for lowering injury risk, and muscle strength and strength related components such as muscle power and muscular endurance are major physical conditioning elements required for both health and performance (Koutedakis & Jamurtas, 2004; Koutedakis et al., 2005; Naclerio, Colado, Rhea, Bunker, & Triplett, 2009; Twitchett et al., 2009). The purpose of this review is to systematically search and examine the available evidence on the relationship between muscle strength and dance injuries concerning muscle strength potential protective role.

4.1.4. Methods

The PRISMA statement for Reporting Systematic Reviews and Meta-Analysis of Studies That Evaluate Health Care Interventions: Explanation and Elaboration (Liberati et al., 2009) was consulted and provided the structure for this review. Approval from Institutional Review Board (IRB) or Ethics Committee was deemed not required due to study design.

4.1.4.1. Search Strategy and Identification

Two reviewers (JPM and JE) created and run a systematic search of literature on five electronic databases (Cochrane Library, PubMed, Scopus, SportDiscus and Web of Science) from their year of inception up to October 2015, using the following search expression: dance* AND injur* AND (muscle strength OR muscle endurance OR muscle power). In order to ensure that all the available relevant data were considered, the search strategy was also extended to two specific dance science publication outlets (*Journal of Dance Medicine and Science* and *Medical Problems of Performing Artists*). The latter did not allow the use of the aforementioned search expressions, instead separate text words combinations with the indexed terms were utilized.

4.1.4.2. Selection

Because of the scarce number of scientifically acceptable studies found in literature, the following inclusion criteria were considered: any observational or experimental study, within the scope of dance injury research involving dance populations irrespectively of dance style and level of practice (vocational, elite pre-professional and professional), of which the subject of research was the relationship between muscle strength and/or muscle power and/or muscle endurance and dance injury. Dancers of both genders were considered with the age range set in accordance with the level and/or category of practice; studies with mixed sample populations were considered if data concerning dancers were presented separately; studies where the object of research was the relation between other physical fitness components and injury were also considered if one or more of the selected parameters was included and objectively assessed; peer-reviewed studies published in English language.

Studies were excluded if they did not meet the inclusion criteria or if one of the following exclusion criteria were present: studies on special or disabled populations; studies on occasional dance practice; studies on retired dancers; editorials; conference proceedings and abstracts; book chapters; opinion and resource papers; review papers; methodological papers; descriptive survey studies; case studies; studies where injury data count as an independent variable.

After the identification of potentially relevant references, citations were imported to Reference Manager Software (Thompson Reuters) and duplicates removed. When titles and abstracts indicated potential for inclusion, full text articles were obtained and reviewed. A third-party (RO) consensus meeting was held if the two reviewers (JPM and JE) were not able to reach agreement on inclusion of an article. Additionally the review studies found in literature search and the studies included in review had their reference list hand-searched for additional relevant sources.

4.1.4.3. Data Extraction and Analysis

The extraction of relevant data was conducted by two other researchers (AN and LX) who were blinded to author and publication details. For that purpose, a previously data extraction form was created (Appendix 1). When disagreement occurred, a third researcher (RO) was consulted to provide clarification. When studies provided sufficient statistical data, effect size was calculated using the Open Meta Analyst software version 10.10 for Macintosh (Wallace et al., 2012) and interpreted according with Cohen(J. Cohen, 1988) recommendations. In studies that used statistical correlation analyses (i.e., Pearson or Spearman), when not provided, the coefficient of determination (r^2) was calculated for explaining the proportion of variance (Borenstein, Hedges, Higgins, & Rothstein, 2009). Because of significant heterogeneity in study design, methodological procedures and quality, and outcomes of the selected studies, meta-analysis was not done, and data was analysed descriptively. After analysis, standardized summary of findings tables were created, concerning study descriptive characteristics (study first author/year, study design, population, dance style, study purpose and main outcome) and relevant statistical components (*p*-values, *r*-values, r^2-values, Cohen *d*).

4.1.4.4. Quality Assessment

The assessment of the methodological quality of the included papers, was made in separate by two reviewers (JPM and AN), using the Downs and Black (DB) checklist which is a methodological quality assessment tool with high internal consistency (KR-20 = 0.89), good test–retest reliability (r = 0.88) and good interrater reliability (r = 0.75) (Downs & Black, 1998). It consists of 27 items across five sections, as follows: (i) Study quality (10 items) –the overall quality of the study based on data reporting; (ii) External validity (3 items) – the ability to generalize findings of the study through their representativeness; (iii) Internal validity concerning study bias (7 items) – to assess bias in the intervention and outcome measure(s); (iv) Internal validity concerning confounding and selection bias (6 items) – to determine bias from sampling or group assignment; and (v) Power of the study (1 items) – to determine if findings are due to chance (for more information see Appendix 2).

Due to the design heterogeneity of the studies included in the present review, the checklist was modified. From the original 27 items, 12 items were not applied to the included observational studies (4, 8, 9, 13–15, 17, 19, 23–24, 26–27) as they relate specifically to intervention studies, and items 5, 21 and 22 were omitted for studies that did not provide an independent control group. Accordingly, and taking into account the variation of the total item numbers of the checklist, the quality assessment results are presented as percentage scores, as previously suggested (Butterworth, Landorf, Smith, & Menz, 2012).

The strength of agreement between reviewers was determined through Cohen's kappa (Cohen & Jacob, 1960). Interpretation of Kappa values was established using standards proposed by Landis and Koch (Landis & Koch, 1977): 0=poor, 0.01–0.20=slight, 0.21–0.40=fair, 0.41–0.60=moderate, 0.61–0.80=substantial, and 0.81–1=almost perfect. The Level of Evidence (LE) and the Grade of Recommendation (GR) of the included studies were determined after methodological quality assessment and it was based on the Oxford Centre for Evidence-Based Medicine (OCEBM) recommendations (Howick et al., 2011). The details of CEBM recommendations are available in Appendix 3.

4.1.5. Results

Figure 4-1 shows a flow chart with the different phases of search and selection of the studies included in the review. The initial search identified 186 titles, of which 176 were identified through electronic database searching, and 10 identified through specialized dance science publications search. After duplicate removal, 118 titles and abstracts were screened for relevance, out of which 99 were excluded based on eligibility criteria and 19 were retrieved for in-depth full text review. After reference list hand search and full text review, 8 articles meet the inclusion criteria and were considered eligible for review (Angioi, Metsios, Koutedakis, Twitchett, & Wyon, 2009; Gamboa et al., 2008; Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997; Mistiaen et al., 2012; Roussel et al., 2014; Swain & Redding, 2014; Twitchett, Brodrick, et al., 2010) and 12 studies were rejected. The exclusion criteria are available in Appendix 5.

4.1.5.1. Description of the Included Studies

Table 4-1 provides the characteristics and a summary of findings of all studies included in this review. The eight studies included consisted of: 3 cross-sectional studies (Angioi et al., 2009; Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997) 1 longitudinal study (Twitchett, Brodrick, et al., 2010); 1 cohort study (Gamboa et al., 2008); 1 RCT (Roussel et al., 2014); 1 uncontrolled trial (Mistiaen et al., 2012); 1 case-control study (Swain & Redding, 2014).

Studies ranged from 13 participants in a longitudinal study (Twitchett, Brodrick, et al., 2010) to 359 in a cohort study (Gamboa et al., 2008). In total, data from 551 participants were included in this review, whereas 78.4% of the participants (*n*=432) were female dancers and 21.6% (*n*=119) male dancers. Three of the included studies featured only female dancers in their study population (Angioi et al., 2009; Swain & Redding, 2014; Twitchett, Brodrick, et al., 2010) and one study featured only male dancers (Koutedakis, Frischknecht, et al., 1997). The overall age range was 14.7±1.9 to 27.1±5.4 years old and the level of practice was mostly pre-professional, with only 2 studies addressing exclusively professional dancers (Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997).

The most frequently used strength related fitness component was lower extremity muscle power, assessed in four studies by means of field tests such as standing vertical jump (SVJ) (Angioi et al., 2009; Twitchett, Brodrick, et al., 2010) and standing broad jump (SBJ) (Mistiaen et al., 2012; Roussel et al., 2014). Three studies assessed muscle strength (Gamboa et al., 2008; Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997) using manual muscle testing and isokinetic dynamometry. Muscle endurance was assessed in three studies (Angioi et al., 2009; Swain & Redding, 2014; Twitchett, Brodrick, et al., 2010) using the press-up test for the upper extremity, and the Soresen and side plank test for core and trunk endurance.

Injury data-collection was mainly conducted by means of recall questionnaires (Angioi et al., 2009; Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997; Swain & Redding, 2014). The two experimental studies included, had an additional injury registration form used prospectively through the scope of the intervention (Mistiaen et al., 2012; Roussel et al., 2014) and two studies (Gamboa et al., 2008; Twitchett, Brodrick, et al., 2010) had their injury registration exclusively conducted by health care professionals. Injury data outcomes were expressed in terms of “days off activity”, as an indicator of injury and/or injury severity, and injury rates incidence concerning the anatomical distribution by tissue type and body location. Only two studies (Gamboa et al., 2008; Roussel et al., 2014) provided a clear definition of injury within their study purpose.

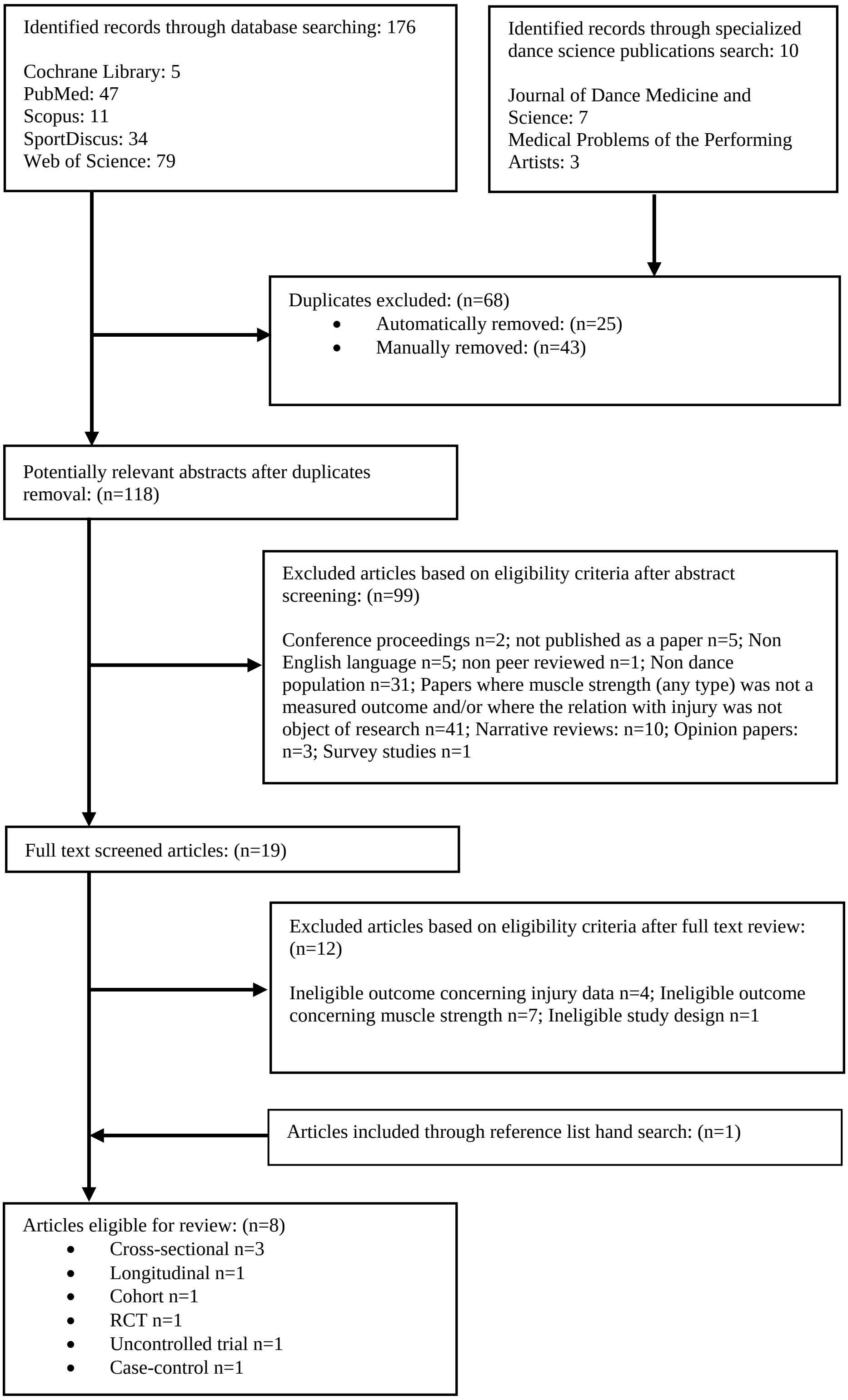

Figure 4-1: Flow chart of the identified and selected studies.

Table 4-1: Summary of findings of the included studies.

Study	Study design	Population (n)	Dance style	Study purpose	Main findings	p value	Effect size
Koutedakis et al. (1997)a	Cross-sectional	n=20M, mean age 26.6 ± 6.0; Professional	Ballet	To investigate the possible relationship between knee flexion to extension peak torque ratios ($F1/Ext_{rat}$) and low back injuries in active individuals	The lower the knee flexion to extension peak torque ratios ($F1/Ext_{rat}$) the greater the degree of low-back injury; Pearson product-moment negative correlation (r = -0.57)	$p < 0.05$	Large d = -1.38 ǂ r^2 = 0.32
Koutedakis et al. (1997)b	Cross-sectional	n=20M, mean age 26.6 ± 6.0; Professional; n=22F, age 27.1 ± 5.4; Professional	Ballet (M) and Contemporary (F)	To identify possible relationships between the sum of knee flexion and extension peak torques and the severity of lower-body injuries in professional dancers	The general trend would appear to be that the lower the sum of knee flexion and extension peak torques, the greater the severity of lower extremity injuries but not low-back injuries; Pearson product-moment negative correlation found in both female (r = -0.70) and male (r = -0.61) dancers	Female dancers: $p < 0.005$ Male dancers: $p < 0.01$	Large d = -1.96 ǂ r^2 = 0.49 d = -1.53 ǂ r^2 = 0.37
Gamboa et al. (2008)	5 years Cohort	n=288F, 71M elite pre-professional;14.7±1.9 years	Ballet	To examine the distribution and rate of injuries in elite adolescent ballet dancers and the the utility of musculoskeletal screening to distinguish between injured and non-injured dancers	Lower extremity isometric strength, was statistically different between injured and non-injured dancers; No significant differences were found for other muscle groups	Lower extremity: p = 0.045 Upper extremity: p = 0.864* Core stability: p = 0.128* Scapular stability: p = 0.160*	Small d = 0.33 No effect Small d = 0.30 Small d = 0.32
Angioi et al. (2009)	Cross-sectional	n=16, mean age 26 ± 4.7; 5 professional and 11 pre-professional female dancers	Contemporary	To investigate the association between physical fitness parameters and injury severity in female professional contemporary dancers and dance students	Significant negative correlation between days off and standing vertical jump (r = -0.66); The trend appear to be that the lower the muscular power, the greater the severity of injury; Moreover, backward regression analysis revealed that, from all studied parameters, the strongest predictor of total days off was standing vertical jump	p = 0.014	Large d = -1.75 ǂ r^2 = 0.43
Twitchett et al. (2010)	Longitudinal (15 weeks)	n=13 elite pre-professional female dancers, mean age 19 ± 0.7	Ballet	To investigate correlations between ballet injury and body fat percentage, active and passive flexibility, lower limb power, upper body and core endurance, and aerobic capacity	No correlations found between lower limb power, upper body and core endurance and ballet injury	No data displayed	UD

F, female; M, male;
*Not significant at p<0.05
Cohen d: 0.0 to 0.1: no effect, 0.2 to 0.4: small effect, 0.5 to 0.7: medium effect, >0.8: large effect; ǂ r^2 Coefficient of determination; UD, unable to determine

Table 4-1: (Continued)

Study	Study design	Population (*n*)	Dance style	Study purpose	Main findings	*p* value	Effect size
Mistiaen et al. (2012)	Uncontrolled trial	*n*=40 pre-professional dancers, mean age 20.3 ± 2.4; 38F, 2M	Mix: Ballet, Contemporary and others	To evaluate musculoskeletal injury rate and physical fitness before and 6 months after an endurance, strength, and motor control exercise program in pre-professional dancers.	Submaximal exercise tests significantly increase as well as ESLL; Injuries to lower extremities and lumbar spine were predominating in the present study; Of 35 dancers, 12 (34%) developed 1 or more injuries during a 6-month period; Health Status questionnaire SF-36 score remain unchanged, except for the physical pain item; No differences reported between injured and non-injured dancers	Lower limb explosive strength: $p = 0.04$ Physical pain item: $p = 0.009$	Small $d = 0.23$ Large $d = 0.84$
Roussel et al. (2014)	RCT	*n*=44 pre-professional dancers, both genders; Intervention group A *n*=23, 20F and 3M, mean age 19.9 ± 2.0; Intervention group B, *n*=21, 18F and 3M, mean age 19.6 ± 2.4	Mix: Ballet, Contemporary and others	To compare the effect of a 4 months conditioning program with a health promotion intervention on aerobic capacity, muscle strength and musculoskeletal injuries in pre-professional dancers	No significant differences were found between groups for aerobic capacity and muscle strength; Musculoskeletal injury incidence rate did not differ between both groups, except for lower back; No significant differences were observed for the results of the Health Status questionnaire SF-36, except for the bodily pain item	Explosive strength: $p = 0.630$ Injury incidence: $p = 0.635$ Lower back: $p = 0.019$ Bodily pain item: $p = 0.031$	Medium $d = 0.72$ UD UD Large $d = 3.17$
Swain & Redding, (2014)	Case-control	*n*=17, female dance students; LBP group, *n*=11, mean age 22.73 ± 0.65; No LBP, *n*=6, mean age 22.33 ± 0.49	Not specified	To examine differences in trunk muscle endurance among a sample of fulltime female dance students with and without LBP	The current study offers some evidence for the correlation of inadequate trunk muscle endurance with LBP in dancers; Female dance students with LBP exhibited lower levels of endurance than students without LBP	Difference between left and right side plank tests: $p = 0.004$ DSLR test: $p = 0.005$	Large $d = 5.18$ $d = 5.36$ Large $d = 4.86$

RCT, randomized control trial
F, female; M, male
ESLL, explosive strength of the lower limb; DSLR, double straight leg raise; LBP, low back pain
Cohen *d*: 0.0 to 0.1: no effect, 0.2 to 0.4: small effect, 0.5 to 0.7: medium effect, >0.8: large effect; UD, unable to determine

4.1.5.2. Quality Assessment

Table 4-2 presents the results of the methodological quality assessment for the included studies. The Cohen's kappa (Cohen & Jacob, 1960) for the strength of agreement between reviewers concerning study quality was k = 0.83, indicating a high agreement level. The DB quality scores ranged from 18.7% to 75% (mean 42.3±16.9). Although DB checklist does not provide specific instructions to classify studies according to the score obtained, a consensus meeting was held between researchers for determining interpretation criteria for the included studies quality assessment results. Thus, a cut-off point of 50% was established, and based on the overall quality percentage scores mean and standard deviation (SD) (42.3±16.9) we determined the intervals by calculating the mean minus one SD (25.4) and the mean plus one SD (59.2), for the average quality interval, where studies above 59.2 were considered of high quality and studies below 25.4 were considered to be of low quality. Based on these criteria, the quality assessment of the 8 included studies reveal: one high quality study (Gamboa et al., 2008); one average quality study above the 50% cut-off point (Roussel et al., 2014); five average quality studies below the 50% cut-off point (Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997; Mistiaen et al., 2012; Swain & Redding, 2014; Twitchett, Brodrick, et al., 2010); one poor quality study (Angioi et al., 2009).Table 4-3 displays the included studies LE and GR according with study design, based on the OCEBM guidelines (Howick et al., 2011). The majority of studies (5/8) were classified as 3b (ie, cross-sectional and longitudinal) and 4 (i.e., cross-sectional and case-control). The highest LE classification was 2b, obtained by two studies (i.e., cohort and low quality RCT), (Angioi et al., 2009; Gamboa et al., 2008; Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997; Mistiaen et al., 2012; Roussel et al., 2014; Swain & Redding, 2014; Twitchett, Brodrick, et al., 2010).

4.1.5.3. Muscle Strength and Injuries

One level 2 evidence cohort study (Gamboa et al., 2008) purpose to distinguish between injured and non-injured pre-professional dancers, using data from pre-season musculoskeletal screenings and prospective injury collection. From the strength parameters assessed (upper and lower extremity strength; trunk and scapular control), the lower extremity scores were the only ones statistically different between groups (p=0.045) (table 4-1). Although the size-effect was small (d=0.33), injured dancers exhibit lower strength values when compared to non-injured dancers. Still, the results may be questionable, since manual muscle testing was used for strength assessment, and besides the general non-functional nature of the method, the scores were averaged to facilitate the processing of the large amount of data.

Two other studies, both by Koutedakis et al., (Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997), addressed specifically to the relation between knee flexion and extension isokinetic strength assessment and injuries, respectively F1/Ext^{rat} and low-back injury (Koutedakis, Frischknecht, et al., 1997) and the sum of knee flexion and extension peak torques and the severity of lower-body injuries (Koutedakis, Khaloula, et al., 1997). In the first study, Koutedakis and colleagues (Koutedakis, Frischknecht, et al., 1997) found a significant negative correlation (r= -0.57; p<0.05) between knee F1/Ext^{rat} and the degree of low-back injury quantified through days off activity in professional male ballet dancers, meaning that the lower the F1/Ext^{rat} the greater the degree of low-back injury. On the other hand, despite of the large-size effect observed (d=-1.38), the coefficient of determination was small (r^2=0.32) and the sample size concerning dancers was also small (n=20). The second study by Koutedakis et al. (Koutedakis, Khaloula, et al., 1997) reveal a trend where the sum of knee flexion and extension peak torques was likely to be significantly associated with the severity of low extremity injuries, but not with low-back injuries, in both professional female contemporary dancers r=-0.70; p<0.005 and male ballet dancers r=-0.61; p<0.01, with a large-size effect for Pearson correlation coefficients (d= -1.96; d= -1.53) (table 4-1). Conversely, the variance of the association of the coefficient of determination was average to low (r^2=0.49; r^2=0.37), meaning that for female and male dancers 51% and 63% of the association variation remain unexplained. Despite of the results, both studies were classified with a 3b LE, and presented poor external validity and internal validity for confounding according with DB checklist (table 4-2).

Table 4-2: Included studies quality assessment scores (from modified Downs and Black checklist).

	Items																												
	Reporting										External validity			Internal validity (Bias)							Internal validity (Confounding)						Pwr		
Study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Score	%
Observational studies n=6; max. achievable score 16																													
Koutedakis et al. (1997)a	1	1	0	*	0	1	1	*	*	1	0	0	*	*	*	0	*	1	*	1	0	0	*	*	0	*	*	7	43.7
Koutedakis et al. (1997)b	1	1	0	*	0	0	1	*	*	1	0	0	*	*	*	0	*	1	*	0	0	0	*	*	0	*	*	5	31.2
Gamboa et al. (2008)	1	1	1	*	1	1	1	*	*	1	1	1	*	*	*	0	*	1	*	0	1	1	*	*	0	*	*	12	75
Angioi et al. (2009)	1	1	0	*	0	0	0	*	*	0	0	0	*	*	*	0	*	1	*	0	0	0	*	*	0	*	*	3	18.7
Twitchett et al. (2010)	1	1	0	*	0	0	0	*	*	1	0	0	*	*	*	0	*	1	*	0	1	1	*	*	0	*	*	6	37.5
Swain & Redding, (2014)	1	1	0	*	0	0	1	*	*	1	0	0	*	*	*	0	*	1	*	1	0	0	*	*	0	*	*	6	37.5
Experimental studies with no independent control group n=1; max. achievable score 28																													
Mistiaen et al. (2012)	0	1	0	1	*	1	1	0	1	1	0	1	1	0	0	0	1	1	0	0	*	*	0	0	0	1	0	11	39.2
Experimental studies n=1; max. achievable score 32																													
Roussel et al. (2014)	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	0	1	1	1	1	0	0	1	0	18	56.2
																												Mean % score	42.3

All questions were scored on the following scale: yes = 1, no = 0, unable to determine = 0; Question 5 is an exception, with scores allocated: yes = 2, partially = 1; no = 0; Question 27 is also an exception with scores ranging from 0 – 5; *Not applicable;.Pwr, power

Table 4-3: Level of Evidence and Grades of Recommendation CEBM.

Study	Level of Evidence		Grade of Recommendation
Koutedakis et al. (1997)a	Diferential diagnosis/Symptom prevalence	3b	C
Koutedakis et al. (1997)b	Diferential diagnosis/Symptom prevalence	3b	D
Gamboa et al. (2008)	Prognosis	2b	B
Angioi et al. (2009)	Diferential diagnosis/Symptom prevalence	4	D
Twitchett et al. (2010)	Diferential diagnosis/Symptom prevalence	3b	D
Mistiaen et al. (2012	Therapy/prevention, Aetiology/Harm	2c	D
Roussel et al. (2014)	Therapy/prevention, Aetiology/Harm	2b	B
Swain & Redding, (2014)	Diagnosis	4	C

4.1.5.4. Muscle Power and Injuries

Within the four studies that assessed lower extremity muscle power, only one cross-sectional study (Angioi et al., 2009) found a significant negative correlation (r= -0.66; p=0.014) between days off and SVJ (table 4-1) in professional and pre-professional contemporary dancers. Although a large-size effect was observed (d=-1.75) the study sample was small n=16, and the coefficient of determination (r^2=0.43) explains only 43% of the proportion of variance on the relation between lower extremity power assessed through SVJ and days off due to injury. Plus, the available data on injury only reported injury incidence according to typology where the highest percentage of injuries sustained by dancers was of muscular nature (46.6%), and no information on injury rate, type and/or anatomical location was provided. Also, the study obtained a score of 3 (18.7%) on the DB checklist and LE 4, according to the OCEBM guidelines, therefore the results should be interpreted accordingly.

A longitudinal study with a similar purpose but on female ballet dancers (Twitchett, Brodrick, et al., 2010) did not find any association between lower extremity muscle power, or other physical fitness parameter, except for aerobic capacity and injury. The two experimental studies in pre-professional dancers, also did not found any association between lower extremity muscle power assessed through SBJ and injury incidence (Mistiaen et al., 2012; Roussel et al., 2014). Nevertheless, one study (Mistiaen et al., 2012) showed that there were improvements on muscle power (p=0.04; small-size effect d=0.26) after the 6-months training program, and that the physical pain item of the health questionnaire assessment SF-36 significantly decreased (p=0.09; large-size effect d=0.84) despite of the frequent injuries observed during the intervention with particular incidence on the ankle, foot and hip (29%) followed by lumbar spine (21%) (table 4-1).

However, as stated by the authors, this study presented several methodological limitations such as not having a control group, the lack of standardization for test moments and procedures, subject drop outs in a relatively small sample size (n=40), which not allows to draw consistent conclusions based on their results (table 4-3).

4.1.5.5. Muscle Endurance and Injuries

Three of the included studies assessed muscle endurance. All the three studies used field tests in their measurements, being that two studies used the press-up test for upper limb endurance (Angioi et al., 2009; Twitchett, Brodrick, et al., 2010) and one study used isometric strength tests for trunk muscle endurance (Swain & Redding, 2014). No association between upper limb muscle endurance and injuries was found. In contrast the study by Swain & Redding (Swain & Redding, 2014) found some evidence that dancers with LBP history show reduced trunk muscle endurance (table 4-1). However, the sample size was small and non-representative (*n*=17) and the study presented a low level of evidence with some methodological constraints to consider (tables 4-2 & 4-3).

4.1.6. Discussion

The purpose of this review was to systematically search and examine the available evidence on the relation between muscle strength and muscle strength components and dance injuries, in order to clarify their potential protection role concerning injury proneness. To our knowledge this is the first systematic review addressing this theme.

Despite of the observed trend in dance science literature suggesting that muscle strength may play a preventive role against injuries and act as a predictive factor of dancers proneness to injury (Allen et al., 2012; Ambegaonkar et al., 2012; Angioi et al., 2009; Caine et al., 2015; Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997; Koutedakis et al., 2005; Liederbach et al., 2012; Malkogeorgos et al., 2013; Mistiaen et al., 2012; Reid, 1988; Roussel et al., 2014; Russel 2013; Twitchett, Brodrick, et al., 2010; Twitchett et al., 2009) the findings of this review reveal that although there might be an association trend towards low muscle strength and dance injuries, the nature of that relation remain unclear, since most of the information found is either limited or questionable. The reasons relate to the small number of studies found, particularly of high quality, and overall methodological weakness of the published papers. Specifically, only eight studies were considered eligible for review, from which only one was a high quality study (Gamboa et al., 2008). Three studies did not find any significant association between the assessed physical fitness parameters and injuries (Mistiaen et al., 2012; Roussel et al., 2014; Twitchett, Brodrick, et al., 2010) and four studies, the ones that yielded the most significant results (Angioi et al., 2009; Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997; Swain & Redding, 2014) (table 4-1), were classified as average to poor quality studies, with poor internal validity (table 4-2) and low level of evidence (table 4-3). Furthermore, the variability found in study design, research purpose and methodology made impossible to establish overall comparisons between results.

In the current review, injury data proved to be the main limiting factor for outline reliable conclusions based on the studies outcomes. Several issues were found concerning injury definition, collection and reporting. Specifically, only two studies provided a clear injury definition, prospective injury data collection and reporting concerning exposure (Gamboa et al., 2008; Roussel et al., 2014) which are the recommended methods by previous consensus statement (Liederbach et al., 2012). Injury definition diverse widely across literature both in dance as in sports, influencing the injury rates due to the different approaches (Bahr, 2009; Caine et al., 2015; Fuller et al., 2006; Goldberg, Moroz, Smith, & Ganley, 2007; Hincapié, Morton, & Cassidy, 2008; Jacobs, Hincapié, & Cassidy, 2012; Liederbach et al., 2012; Smith et al., 2015) particularly the ones that include "days-off" activity, since dancers many time dance through their injuries with underreporting estimated as high (Gamboa et al., 2008; Liederbach et al., 2012). Although there is still no consensus on a standard definition, one must be described within the study purpose to minimize interpretation bias.

Recent and previous literature also states that injury collection and reporting methods vary widely, with some instruments and procedures being more prone to flaws than others (Bahr, 2009; Caine et al., 2015; Fuller et al., 2006; Goldberg et al., 2007; Hincapié et al., 2008; Jacobs et al., 2012; Liederbach et al., 2012; Smith et al., 2015). Injury data collection procedures by means of recall questionnaires conducted by interview or through self-reported forms, are the ones more prone to recall bias and inaccuracy, once that less severe injuries may not be reported as well as the ones that occurred longer ago (Caine et al., 2015; Liederbach et al., 2012; Smith et al., 2015). This method also proves to lack in detailed information, concerning the nature and type of injury, underestimating the overall injury rates (Caine et al., 2015). Conversely, longitudinal data collection by a healthcare professional has proven to be the most reliable method (Caine et al., 2015; Fuller et al., 2006; Liederbach et al., 2012; Smith et al., 2015). In this review four studies (Angioi et al., 2009; Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997; Swain & Redding, 2014) collected injury data exclusively by means of recall questionnaires. The two experimental studies (Mistiaen et al., 2012; Roussel et al., 2014) besides questionnaires, also used during the time of their interventions a prospective injury data collection form. One longitudinal and one cohort study (Gamboa et al., 2008; Twitchett, Brodrick, et al., 2010) have their injury collection done prospectively by healthcare professionals.

As for reporting injury rates, literature recommends that these must account with the exposure element and be reported accordingly (Caine et al., 2015; Liederbach et al., 2012). Only two studies accomplished (Gamboa et al., 2008; Roussel et al., 2014) respectively, injuries reported by 1000 hours of dance and 1000 dance exposures.

In sum, from a methodological perspective, only two studies addressed adequately to injury data collection and reporting (Gamboa et al., 2008; Roussel et al., 2014). From a study design perspective, none of the studies discriminate the injury type, overuse or acute/traumatic. Since these two injury types present different mechanisms and relate differently with intrinsic risk factors, such as muscle strength (Bahr, 2009; Murphy, Connolly, & Beynnon, 2003), we suggest future research to take this issue into consideration.

The dance injury topic have received considerable focus of attention in scientific research and while the questions related with injury surveillance are of utmost importance, they are out of the scope of this review and further information can be found well described in literature (Bahr, 2009; Bronner, Ojofeitimi, & Rose, 2003; Caine et al., 2015; Fuller et al., 2006; Goldberg et al., 2007; Hincapié et al., 2008; Jacobs et al., 2012; Liederbach et al., 2012; Liederbach, Schanfein, & Kremenic, 2013; Negus, Hopper, & Briffa, 2005; Ojofeitimi & Bronner, 2011; Roberts et al., 2013; Smith et al., 2015; Thomas & Tarr, 2009; Timpka et al., 2014a; Timpka et al., 2014b).

Within the included studies, and similarly to sports, the lower extremity was the most used for strength related elements assessment, particularly lower extremity power (Lauersen et al., 2014). However, caution should be taken when assessing lower extremity power by means of field tests such as SVJ and SBJ in dancers. Unlike sports, the dance-only practice does not provide enough scope for significant physical fitness enhancements (Koutedakis et al., 2007; Twitchett et al., 2009). Thus, higher scores in SVJ or SBJ may not necessarily represent higher power related strength, but rather better inter-muscular coordination concerning pattern of force application, which is strongly related with skill proficiency in jump performance (Carvalho & Carvalho, 2006; Dowling & Vamos, 1993; Young, 2006) particularly in youth (Castro-Piñero et al., 2010). When assessing lower limb power in dance, one should consider that jump power adaptations are task and skill specific and have low transfer from one task to another (Bosco, Luhtanen, & Komi, 1983; Carvalho & Carvalho, 2006), (e.g. from single jump tasks to multiple or consecutive jump tasks, or the differences observed with regard to professional ballet dancers role in companies, soloists jump in general higher than artists) (Twitchett et al., 2009; Wyon et al., 2007). Young elite ballet dancers perform more than 200 jumps per 1.5-hour of technique class (Bowerman, Whatman, Harris, & Bradshaw, 2015), meaning that they require high reserves of lower extremity mechanical power (Twitchett et al., 2009). Lower extremity overuse injuries are also the most common type of injury in these populations often associated with increased exposure to repetitive jumping (Bowerman et al., 2015). This review found no studies addressing to lower limb mechanical power in order to assess repetitive jump capabilities in dancers and their relation with injury, and none of the included studies controlled dancer skill proficiency and task level of performance. In that sense, these findings may partially explain the absence of significant and conclusive results regarding this issue. We suggest that future research on this topic, besides SVJ and SBJ also consider the Bosco protocol for measuring lower limb mechanical power through vertical rebound jump series.

Still with regard to lower extremity, two studies (Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997) using isokinetic dynamometry, found a significant association between low strength levels and injury severity (Table 4-1). Isokinetic dynamometers used to assess strength in terms of torque generated about a specific joint provide important and accurate information, nevertheless, one should consider that these tests are performed with the subject non-weight bearing, and cannot duplicate the speeds and range of motion of physical activity and injury mechanism (Murphy et al., 2003). Also, both studies used different isokinetic dynamometers, a LIDO and KIN-COM (Koutedakis, Frischknecht, et al., 1997) and a Cybex II and KIN-COM (Koutedakis, Khaloula, et al., 1997) which may arise some concerns when extrapolating data. In one study, Koutedakis and colleagues (Koutedakis, Frischknecht, et al., 1997) found that muscle imbalances represented through knee $F1/Ext^{rat}$ were associated with the severity degree of low-back injuries (Table 4-1). Although lower back seems to be the most frequently injured anatomical site in dancers (Koutedakis, Frischknecht, et al., 1997) the nature of the association between muscle strength imbalances represented through knee $F1/Ext^{rat}$ and the severity of low-back injuries was not clearly explored in the paper. Furthermore, the authors refer that other factors may play a role on the genesis of low-back injuries and should be examined to avoid confounding readings. Taking sports as an example, thigh muscle imbalances are often associated with injuries, but instead with the ones in the lower extremity rather than in the low-back (Cheung, Smith, & Wong, 2012; Croisier, Forthomme, Namurois, Vanderthommen, & Crielaard, 2002; Murphy et al., 2003; Söderman, Alfredson, Pietilä, & Werner, 2001).

In another study by Koutedakis et al. (Koutedakis, Khaloula, et al., 1997) they found that the sum of knee extension and flexion peak torques were associated with lower-extremity injury severity degree but not low-back (table 4-1). Within the previous study, the authors refer to the sum of knee flexion and extension peak torques as the thigh-power output, which may lead to some conceptual bias interpretation, since in literature the sum of knee flexion to extension peak torques is more widely accepted as representing the knee joint peak torque than the thigh power output (Krishnan & Williams, 2009). Another interesting question was found when analysing male dancer's data from the above studies (Koutedakis, Frischknecht, et al., 1997; Koutedakis, Khaloula, et al., 1997). In both studies male dancers present the same descriptive data (table 4-1) and the same isokinetic strength assessment outcomes. However, data from isokinetic dynamometers were considered differently within studies. In one study, knee $F1/Ext^{rat}$ was associated with low back injury severity (Koutedakis, Frischknecht, et al., 1997) while in the other, the thigh power output was associated with lower-extremity injury severity degree but not low-back (Koutedakis, Khaloula, et al., 1997). These findings may open up to discussion if different concepts in data treatment approach based on the same outcomes relate differently with injury. In that sense, and considering the limitations found, the reliability of the results may be found questionable.

Fatigue has been proposed as a risk factor for injuries both in sports and dance (Chappell et al., 2005; Grove, Main, & Sharp, 2013; Koutedakis et al., 1999; McLean et al., 2007; Murgia, 2013; Twitchett, Angioi, Koutedakis, & Wyon, 2010; Vetter & Symonds, 2010; Wyon & Koutedakis, 2013). Irrespectively of the underlying process that leads to it (i.e. physiological, cognitive, biomechanical), it can be defined as the inability to maintain a required or expected force or power output (Abbiss & Laursen, 2005; Bigland-Ritchie, 1984; Bogdanis, 2012). The strength component that most relates to fatigue is muscular endurance, since it represents the muscle capability to repeat a series of contractions or sustaining a prolonged contraction (i.e. isometric muscle endurance) (Caspersen, Powell, & Christenson, 1985; Kanehisa & Miyashita, 1983). The repetitive nature of dance movement patterns requires both types of muscular endurance, either on sustained isometric or repeated series of muscle contractions (Alexandros Malkogeorgos et al., 2013; Roberts et al., 2013; Wyon & Koutedakis, 2013). Two of the studies included in this review, used the press-up test for upper limb endurance (Angioi et al., 2009; Twitchett, Brodrick, et al., 2010) and found no association between upper limb muscle endurance and injuries. The mentioned studies subject sample, featured contemporary dancers (Angioi et al., 2009) and ballet dancers (Twitchett, Brodrick, et al., 2010). Some of the possible reasons for the lack of significant results, may relate to the fact that the press-up test is not a dance-specific test, and also injury patterns in both contemporary and ballet dancers, irrespectively of gender, are mainly located in the lower extremity followed by the trunk (i.e. low-back) (Caine et al., 2015; Shah, Weiss, & Burchette, 2012). In contrast, the study by Swain & Redding (Swain & Redding, 2014) found some evidence that dancers with LBP history exhibit reduced trunk muscle endurance (Table 1). Nevertheless, the authors report several limitations that may question the reliability of the results. The study only considered and association between LBP and trunk muscle endurance. Since LBP is multifactorial in nature, several other risk factors such as weak abdominal muscles, reduced range of motion, lumbar and hamstrings flexibility, spine hypermobility, among others that were neglected may have influenced the results as confounding elements. Moreover, reduced muscle trunk endurance may be influenced by prior LBP history and be a consequence not a cause. Although the results may found to be questionable, they shed some light into the specificity and need of field muscle testing in dance, which may reveal reliable in ecological approaches through appropriate study designs.

4.1.6.1. Limitations

The number of studies found and included in this review reveal low both in number and methodological quality meaning that evidence is scarce and heterogeneous. The heterogeneity of study design and methodologies used turn difficult to compare results, establish cause-effect relation between muscle strength and injury, and draw consistent conclusions. The eligibility of only English language publications in study selection may also represent a limiting factor by excluding potentially relevant studies.

4.1.7. Conclusion

The findings of this review reveal that the evidence on the potential preventive role of muscular strength and strength related components in dance injuries is scarce and heterogeneous, and presently the state of knowledge does not provide solid basis for designing interventions concerning prevention. Nevertheless, some level 2b evidence was found suggesting that pre-professional dancers who get injured exhibit lower strength values on the lower extremity when compared to non-injured dancers and that lower extremity power gains may be associated with decreased bodily pain but not injury rates. Future research should consider the functional aspects of muscle strength components within dance context.

4.1.8. References

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4.2. Study II – The Role of Pre-Diagnostic Data in Injury Epidemiology in Pre-professional Dancers

O Papel dos Dados Pré-diagnóstico na Epidemiologia das Lesões em Bailarinos Pré-profissionais

Moita, J.P., Xarez, L., Gomes, A., Coelho, C. (2018). The Role of Pre-Diagnostic Data in Injury Epidemiology in Pre-professional Dancers. Are We Missing the Wood for the Trees? *Submitted*

4.2.1. Abstract

Introduction: Pre-professional dance training starts at very early ages, on a highly demanding environment placing students at significant risk for injury. Injury management and prevention are a matter of concern. Given the constant interchangeability of risk factors, identifying injury patterns may prove to be equally as important. Data looking back from the time of injury through context-specific approaches, are missing.

Objectives: To identify activity-related injury patterns based on pre-diagnostic data.

Methods: Prospective, non-randomized, observational study, over a 3 years period on a full-time pre-professional dance school featuring both gender students aged 9 - 21 years old. Non-parametric statistics were used.

Results: A total of 625 dance injury records from 209 students, *n*=68 males, *n*=141 females, were analysed. Season injury risk probability was identified, proving different for each skill level (SkL). Multiple individual injuries revealed a trend towards prevalence rates in Advanced level, while Index injuries incidence become more noticeable in Entry level students. Overall incidence rates had no significant differences within SkL. Anatomical location was in line with previous research, although differences were found between gender and SkL. Most injuries occurred in classes, with Jumps standing out as the main motor action associated with injury symptoms of gradual onset mechanism.

Conclusion: Dance injuries happen because of dance practice. Knowing the context of injury history from the injured dancer perspective is determinant for management and prevention. Pre-diagnostic data is an umbrella term encompassing several aspects of injury background and represents fertile ground for research. Context-specific methodological approaches are recommended.

Keywords: Pre-professional; Dance; Injury patterns; Prevention.

4.2.2. Resumo

Introdução: O treino de bailarinos pré-profissionais começa por norma em idades muito jovens, num ambiente altamente exigente, constituindo um risco significativo de lesão. A gestão e a prevenção de lesões são um assunto de preocupação. Dada a constante permutabilidade dos fatores de risco, a identificação de padrões de lesão pode ser tão importante como os próprios fatores de risco. Abordagens específicas ao contexto, que permitam observar os eventos até à ocorrência da lesão estão ausentes na literatura disponível.

Objetivos: Identificar padrões de lesão específicos da atividade com base em dados pré-diagnóstico.

Método: Estudo prospetivo, não randomizado, observacional, durante um período de 3 anos numa escola de dança pré-profissional, com alunos de ambos os sexos, com idades entre 9 e 21 anos. Foi utilizada estatística não paramétrica.

Resultados: Um total de 625 registos de lesões de dança de 209 estudantes, n = 68 género masculino, n = 141 género feminino, foram analisados. Foi identificada a probabilidade de risco de lesão ao longo da temporada letiva, mostrando-se diferente para cada nível de habilidade (NvHab). Múltiplas lesões individuais mostraram uma tendência para um maior índice de prevalência no nível avançado, enquanto a incidência de primeiras lesões foi mais percetível em estudantes do nível iniciante. As taxas gerais de incidência não apresentaram diferenças significativas entre NvHab. A localização anatómica está de acordo com pesquisas anteriores, embora tenham sido encontradas diferenças entre géneros e NvHab. A maioria das lesões ocorreu nas aulas, com os Saltos em destaque como sendo a principal ação motora associada aos sintomas de lesão e ao mecanismo de início gradual dos sintomas.

Conclusão: As lesões na dança decorrem da prática da dança. Conhecer o contexto relativo à história da lesão a partir da perspetiva do dançarino é determinante para a gestão e prevenção. Dados pré-diagnóstico são um termo abrangente que engloba vários aspetos do histórico de lesões e representa um terreno fértil para pesquisa futura. Abordagens metodológicas específicas do contexto são recomendadas.

Palavras-Chave: Pré-profissionais; Dança; Padrões de lesão; Prevenção.

4.2.3. Introduction

In order to achieve elite levels and pursuit a professional career, dance practice often starts at very early ages, on a highly demanding environment (Caine et al., 2016; Ekegren, Quested, & Brodrick, 2014; Gamboa, Roberts, Maring, & Fergus, 2008; Kenny, Whittaker, & Emery, 2015; Roberts, Nelson, & McKenzie, 2013). The repetitive nature of dance training through long practice hours place dance students at significant risk for injury (Caine et al., 2016; Ekegren et al., 2014; Gamboa et al., 2008; Kenny et al., 2015; Roberts et al., 2013). In this population injury risk range between 32% and 86.2% (Ekegren et al., 2014; Gamboa et al., 2008; Lee, Reid, Cadwell, & Palmer, 2017; Luke et al., 2002; Yau et al., 2017) with incidence rates reaching up to 4.7/1000h (Bowerman, Whatman, Harris, Bradshaw, & Karin, 2014; Caine et al., 2016; Ekegren et al., 2014; Gamboa et al., 2008; Leanderson et al., 2011; Lee et al., 2017; Luke et al., 2002). Also, injury burden is known to vary from temporary dance practice limitation to full inhibition, as well as early career ending, chronic physical disability and poor health quality later in life (Hincapié, Morton, & Cassidy, 2008; Kenny et al., 2015; Smith et al., 2015; Smith et al., 2017). As such, injuries are a matter of concern for clinicians, dance teachers, researchers and dancers (Jacobs, Hincapié, & Cassidy, 2012; Malkogeorgos, Mavrovouniotis, Zaggelidis, & Ciucurel, 2011) with prevention being a recurrent topic of interest.

Within dance science literature, the traditional approach to this issue mainly focus on risk factors (Caine, Goodwin, Caine, & Bergeron, 2015; Kenny et al., 2015). Nevertheless, identifying injury predictors still remains a challenge with inconsistent results (Bahr, 2016; Kenny et al., 2015). Dance injuries, as the ones in any other athletic activity, are multi-factorial in nature and result from a complex interplay of risk factors that when associated may compose a causal factor for injury (Marijeanne Liederbach, Hagins, Gamboa, & Welsh, 2012; Meeuwisse, Tyreman, Hagel, & Emery, 2007). When an injury occurs, it represents the outcome of that interaction. Given the constant interchangeability of risk factors (Meeuwisse et al., 2007), particularly in young dancers during growth and skill development (Steinberg et al., 2011), identifying activity-related injury patterns, may prove to be equally as important in injury management and prevention as risk factors. In this particular aspect information is still insufficient. Most epidemiological studies in Pre-professional dancers (Bowerman et al., 2014; Caine et al., 2016; Ekegren et al., 2014; Gamboa et al., 2008; Leanderson et al., 2011; Lee et al., 2017;

Luke et al., 2002; Steinberg et al., 2011, 2013; Stracciolini, Yin, & Sugimoto, 2015; Wanke, Mill, & Groneberg, 2012; Yin, Sugimoto, Martin, & Stracciolini, 2016) feature an injury-centered approach based on "after-diagnosis" data, focusing on injury outcome and subsequent burden expressed through rates, risks and frequencies. Although those measures provide important quantitative metrics about the injury burden, they fail to reflect injury patterns dynamics and consequently possess little preventive applicability if not framed into the proper context. Data looking back from the time of injury (i.e. pre-diagnostic data) through context-specific approaches, are missing (Kenny et al., 2015; Meeuwisse et al., 2007). Pre-diagnostic data comprises the information reported by the dancer/athlete concerning injury (or any other health-related incident) reporting, before clinical judgement (Fortington, van der Worp, van den Akker-Scheek, & Finch, 2017; Jacobsson et al., 2013; Timpka et al., 2014). It is not influenced by injury definition, diagnosis or any other aspect of analytical character. When properly addressed may provide prime information about the "What", "When" and "How" of pre-diagnosis injury history, assuming particular importance in scenarios with multiple individual injuries and differentiated population features (i.e. gender and skill level) (Finch & Cook, 2014; Finch & Fortington, 2017; Finch & Marshall, 2016; Fortington et al., 2017). Although some studies in the Pre-professional population have already addressed some of these issues (Caine et al., 2016; Hiller, Refshauge, Herbert, & Kilbreath, 2008; Lee et al., 2017; Steinberg et al., 2011; Wanke et al., 2012), some limitations still exist. Caine et al. (Caine et al., 2016) focused on several aspects of injury background using a discriminative approach, however the study was of a cross-sectional nature, data was collected by means of questionnaire injury mechanism was not considered and data was not adjusted to multiple individual injuries. Lee and colleagues (Lee et al., 2017) failed to consider injury mechanism and multiple individual injuries. Two other studies of cross-sectional nature (Steinberg et al., 2011; Wanke et al., 2012) mainly focused on injury outcome and associated risk factors, only superficially addressing some temporal context elements.

Therefore, the purpose of the present study is bridging the gap in dance injuries epidemiology by identifying patterns of activity-related injury history based on pre-diagnostic data.

4.2.4. Methods

4.2.4.1. Study Design

Prospective, non-randomized, observational study (von Elm et al., 2007).

4.2.4.2. Setting

The study was conducted on a full-time pre-professional dance school in Lisbon, Portugal, as part of an ongoing initiative program for injury management and prevention carried out by the School Health-Care Office (SHO) that started in 2013. The school offers an eight-year full-time dance course from entry to advanced level in both classical and contemporary dance styles. The school population features both gender students with an age range between 9 - 21 years and whose entrance in the school is made via audition only.

4.2.4.3. Participants

All dance students who have reported health-related incidents to the SHO from September 2013 to June 2016, (3 academic years consisting of 34 weeks each) were considered. Participants aged 18 years or older provided written informed consent and those under the age of 18 years provided oral informed assent and a parent/legal guardian provided written informed consent at the first visit to SHO. This study complies to the tenets of The Declaration of Helsinki of the World Medical Association (Association, 2013) and was approved by the School of Human Kinetics, University of Lisbon, Ethics Committee Review Board (CEFMH, N25).

4.2.4.4. Data collection

Data were collected on a daily basis by the in-house health-care technician each time a dance student visited the SHO. All visits were registered in an individual occurrence report form (see appendix), featuring the following: Dance students' demographics; Physical complaint description concerning anatomical location; nature and type, based on the framework developed by Fuller et al. (Fuller, Bahr, Dick, & Meeuwisse, 2007; Fuller et al., 2006); Symptoms triggering mechanism description concerning the onset type were adapted from the nomenclature used by Jacobsson et al. (Jacobsson et al., 2012) (i.e. sudden and gradual onset); The motor action (i.e. exercise being performed) (Xarez, 1999) and the respective context (i.e. activity type) (Bahr & Krosshaug, 2005).

4.2.4.5. Definition of dance injury

Due to the risk of underestimating injury burden, no time-loss element could be included in injury definition (Kenny, Palacios-Derflingher, Whittaker, & Emery, 2017). Therefore, injury definition was adapted from Fuller et al. (2006) (Fuller et al., 2006) and described as "*any physical complaint sustained by a dancer resulting from dance practice*, *diagnosed by a licensed health care practitioner and which irrespective of the need for medical attention, implies full or partial dance activity impairment for one or more days beyond onset*". All the events falling short of this definition were considered musculoskeletal complaints.

4.2.4.6. Calculation of exposure

Within our population, exposure refers to the time in hours spent in classes, rehearsals and performances. For each academic year, dance-time exposure was calculated based on weekly timetables from classes, rehearsals and performances concerning dance year, skill level (SkL) and gender. This allows to most accurately obtain week, month and year dance-time, respectively.

Exposure was also used to determine if no differences existed within SkL groups which could justify defining sub-categories for analysis.

4.2.4.7. Statistical analysis

Statistical analyses were performed using the Statistical Package for Social Sciences version 22.0 (SPSS Inc. Headquarters, 233s. Wacker Drive, 11th floor, Chicago, Illinois 60606. USA). Non-parametric statistics were used. The significance level for all inferential analyses was set at $p < 0.05$. For all proportion comparisons Chi-square analysis was used. Kruskal-Wallis analysis was used for continuous variables comparison, such as incidence and prevalence rates. Poisson regression was applied to injured dancers frequency across academic year months and injury mechanism categories in order to determine injury risk probability distribution and the most probable inciting event category. The month with less injured dancers and the inciting event category with less injuries registered were set as reference, respectively. Adjustment to covariates was also performed. The correlation between injury inciting event and onset mechanism was determined through Spearman test.

The risk ratio (RR) concerning the average probability of a dance student suffering at least one injury across one academic year was calculated through epidemiologic incidence proportion (Knowles, Marshall, & Guskiewicz, 2006) and reported in percentage (%95CI).

Injury rates were calculated using person-time as denominator and reported per 1000h,(Knowles et al., 2006) for each injury category (i.e. index, local and re-injury for incidence and exacerbation for prevalence)(Fuller et al., 2007) based on multiple injury count number (MIC) (Fortington et al., 2017). Rates were calculated separately for gender and SkL. Incidence (IIRrg) and prevalence range (IPRrg) are reported. IIRrg was obtained through the sum of the respective incidence categories rate total within each year.

4.2.5. Results

Over the study period, from September 2013 to June 2016, 303 students were enrolled in the school (table 4-4). The SHO registered 1,081 visits from 234 students (figure 4-2). After exclusion of 456 records by not meeting inclusion criteria for analysis, a total of 625 records corresponding to dance injuries from 209 students, *n*=68 males, *n*=141 females, were considered.

Exposure analysis of variance found no significant intra-level differences, only inter-level differences ($p<0.001$). Therefore, three SkL have been considered: Entry (EntL), Intermediate (IntL) and Advanced (AdvL).

4.2.5.1. Injury risk ratio

The RR shown in table 4-4, revealed an injury risk ranging from 47.7% to 51.4% with 95% CIs [40.8–54.6] and [44.6–58.2] respectively. Chi-square analysis found no significant differences across injury risk range from 2013 to 2016. Nevertheless, a significant difference was found when the cumulative risk (2013-2016) was added for proportion comparison ($p<0.001$).

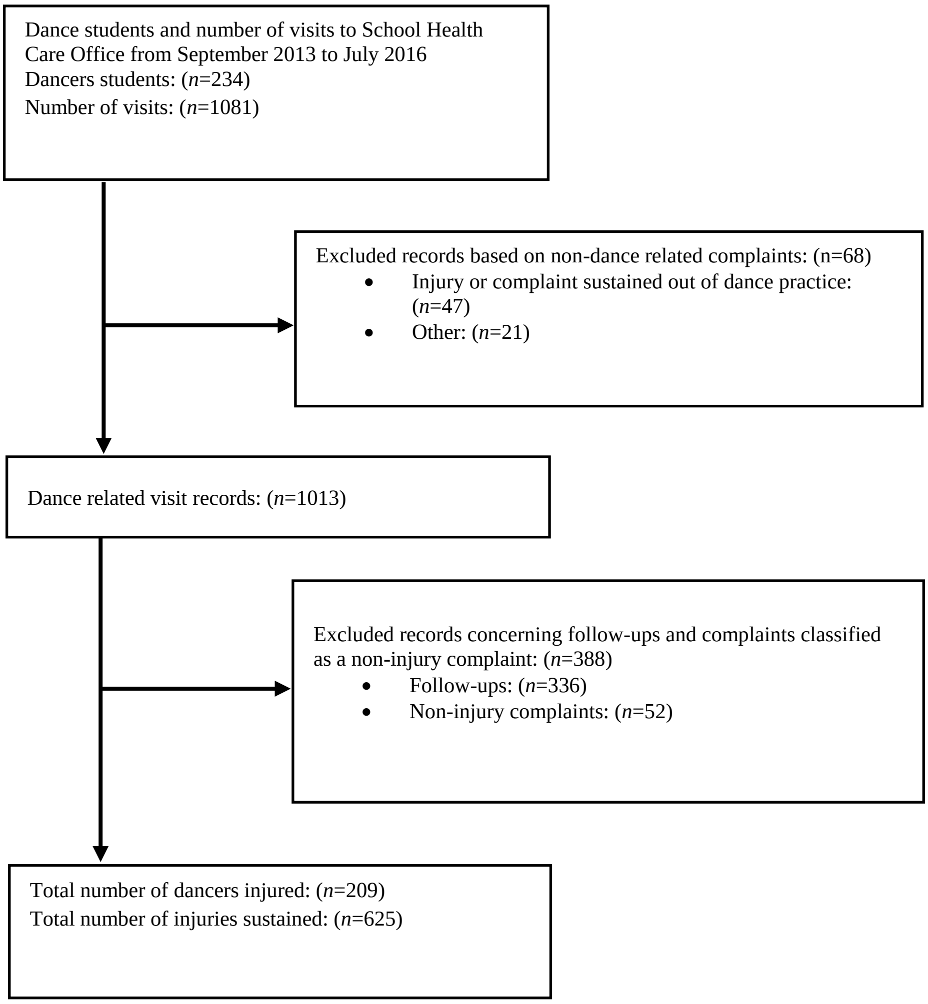


Figure 4-2: Flow chart of the dance injury records identification.

4.2.5.2. Injury risk probability distribution

Table 4-5 describes injured dancers' frequency patterns per month of practice across SkL, based on how often they have visited the SHO. December was found to be the month with less injured dancers. When using the year of the study and monthly exposure time as covariates, no significant association with injured dancers' distribution pattern was found.

January was identified as the month with higher injury probability for EntL with an IRR of 8.021 [95% CI 1.593–40.380] p=0.012. For IntL October was identified as the critical month, with an IRR of 3.382 [95% CI 1.096–10.436] p=0.034. In AdvL students several months exhibited significant added probability for injury. September stood out as the most significant, with an IRR of 3.131 [95% CI 1.570–6.244] p=0.001, followed by

October, February, April and May (p=0.021, p=0.022, p=0.039 and p=0.039, respectively).

Table 4-4: Dance students and injuries frequency and respective risk ratio (annual and cumulative over 3 years)

Year	Dance students (n)	Dance students injured (n)	Injuries sustained (n)	Risk ratio % [95% CI]
2013 - 2014	186	94	213	50.5 [43.4 , 57.6]
2014 - 2015	197	94	209	47.7 [40.8 , 54.6]
2015 - 2016	206	106	203	51.4 [44.6 , 58.2]
2013 - 2016*	303	209	625	68.9 [63.7 , 74.1]

**In order to more accurately report injury rates, the dance students' number was obtained through school enrolments consultation. Over the 3 years they were registered 589 school enrolments from which 94 correspond to students enrolled during the 3 years, 103 to students featuring 2 years of school enrolment and 89 corresponding to only 1 year. Therefore, after duplicates removed, 303 dance students remain as the ones which attended school over the 3 year period. As for the injured dance students, over the 3 years 32 dance students reported injuries consecutively each year, 53 dance students reported injuries over 2 of the 3 years and 124 students reported injuries only over 1 of the 3 years, featuring a total of 209 dance students with injuries.*

4.2.5.3. Injury incidence and prevalence rates

Table 4-6 presents the total number of injuries (n=625), with the respective incidence (IIR) and prevalence rates (IPR) concerning the MIC and the respective injured dancers' number across gender, SkL and year of study. In the academic year 2013/2014, EntL females featured a total of n=34 dance students from which n=23 (67.6%) suffered n=33 injuries. The Median (Mdn) exposure time of the 3rd, 4th and 5th dance years which integrate IntL, was 400.6h. The calculated 1 injury/1000h rate was (1 injury/[34x400.6])x1000=0.07. Nineteen dancers sustained 1 injury with a total of 19 injuries with 0.81/1000h for n=11 index injuries (IIR1), a 0.37/1000h concerning n=5 local injuries (IIR2), a 0.15/1000h for n=2 re-injuries (IIR3) and 0.07/1000h for n=1 exacerbation (IPR).

With the exception of EntL males, Chi-square analysis found no significant differences in injured dancers' proportion and injury frequency distribution across the three years within SkL and within the same gender. Conversely, inter-level distribution within the same gender exhibited significant differences (p<0.01). Depending on SkL, IIRrg oscillated between 0.23/1000h and 2.92/1000h and IPRrg between 0.11/1000h and 0.44/1000h for males, whereas for females IIRrg ranged between 0.54/1000h and 2.21/1000h and IPRrg between 0.00/1000h and 0.80/1000h.

Although Kruskal-Wallis analysis found no significant differences between IIR and IPR across gender and SkL, it was possible to observe that the higher the IC the lower the IIR1 and that IPR was higher towards AdvL.

4.2.5.4. Anatomical location

Figure 4-3 presents injury anatomical location patterns based on Mdn proportion of injured dance students according to anatomical location from 2013 to 2016, concerning SkL (i.e. intra-gender) and gender. In general, the lower limb was the most affected anatomical region, followed by the low back. The major inter-gender differences relate with: the higher proportion of Knee, Low-back and Pelvis and Hip injuries in AdvL males vs females. Ankle and Foot were the most common sites of injury for females. Also, the proportion of EntL female dance students who injured the Ankle (Mdn 15.3% IQR=5.5 - 32.3) or Foot (Mdn 12.8% IQR=5.5–23.5) was significantly higher when compared to same level males where no Mdn proportion was verified.

4.2.5.5. Triggering environment for injury symptoms

Within our study the majority of injury symptoms n=532 occurred during classes. The central tendency across SkL concerning classes across the three years of the study was of 94.1% Mdn [IQR=93.7–96.6] for EntL students, 92.9% Mdn [IQR=83.6–93.0] for IntL students and 86.1% Mdn [IQR=69.3–88.8] for AdvL students. Rehearsals had some expression in AdvL, with 11.5% Mdn [IQR=5.1–15.3] and Performances were marginal with only 1.7% also in AdvL. Other environments accounted for around 4% for all skill levels.

Amongst dance classes, classical ballet stood out as the most representative dance style with injury symptoms ranging from a Mdn of 88.9% [IQR=82.7–93.7] and 84.9% [IQR=75.0–87.5] in EntL and IntL, respectively, to a Mdn of 73.3% [IQR=67.3–77.8] in AdvL. Also, contemporary dance style had some expression ranging from 10.4% to 26.7% in IntL and AdvL, respectively.

Table 4-5: Increased injury risk month across the 3 years of the study (2013-2016) based on Poisson distribution.

	Skill Level								
	Entry			Intermediate			Advanced		
Month	IRR	95%CI	*p*	IRR	95%CI	*p*	IRR	95%CI	*p*
Adjusted to hours of practice and year of study									
	Hours of practice: p=0.868			***Hours of practice: p=0.939***			***Hours of practice: p=0.091***		
	Year of study: p=0.180			***Year of study: p=0.231***			***Year of study: p=0.880***		
September	2.016	[0.368 , 11.039]	0.419	1.852	[0.737 , 4.655]	0.190	**3.131**	**[1.570 , 6.244]**	**0.001**
October	4.563	[0.710 , 29.337]	0.110	**3.382**	**[1.096 , 10.436]**	**0.034**	**2.773**	**[1.163 , 6.612]**	**0.021**
November	5.525	[0.928 , 32.899]	0.060	2.197	[0.727 , 6.637]	0.163	1.869	[0.793 , 4.408]	0.153
December	*Ref.*(1)	-	-	*Ref.*(1)	-	-	*Ref.*(1)	-	-
January	**8.021**	**[1.593 , 40.380]**	**0.012**	1.757	[0.567 , 5.445]	0.329	1.787	[0.781 , 1.787]	0.169
February	4.729	[0.905 , 24.719]	0.066	2.340	[0.800 , 6.839]	0.120	**2.524**	**[1.145 , 2.524]**	**0.022**
March	1.916	[0.325 , 11.287]	0.472	2.176	[0.815 , 5.810]	0.121	2.039	[0.934 , 2.039]	0.074
April	**4.873**	**[1.034 , 22.960]**	**0.045**	1.888	[0.688 , 5.179]	0.217	**2.172**	**[1.039 , 2.172]**	**0.039**
May	5.500	[0.897 , 33.710]	0.065	2.957	[0.862 , 10.144]	0.085	**2.432**	**[1.044 , 2.432]**	**0.039**
June	0.505	[0.046 , 5.588]	0.578	0.865	[0.283 , 2.644]	0.800	1.598	[0.756 , 1.598]	0.219

IRR, Incidence Rate Ratio

Table 4-6: Injury incidence and prevalence rates adjusted to skill level, gender and multiple injuries across the three years of study.

	2013/2014						2014/2015						2015/2016					
Skill level and Gender	IC (*n*)	Injured dancers (*n*)	IIR1/ 1000h	IIR2/ 1000h	IIR3/ 1000h	IPR/ 1000h	IC (*n*)	Injured dancers (*n*)	IIR1/ 1000h	IIR2/ 1000h	IIR3/ 1000h	IPR/ 1000h	IC (*n*)	Injured dancers (*n*)	IIR1/ 1000h	IIR2/ 1000h	IIR3/ 1000h	IPR/ 1000h
Entry level Male	***Total dance students n=18***						***Total dance students n=21***						***Total dance students n=24***					
	Total injured dancers n=5 (27.7%)						***Total injured dancers n=2 (9.5%)***						***Total injured dancers n=3 (12.5%)***					
	Total injuries n=15						***Total injuries n=3***						***Total injuries n=3***					
IIRrg/1000h:	***Exposure(Mdn)/h: 396.3***						***Exposure(Mdn)/h: 405.6***						***Exposure(Mdn)/h: 367.7***					
0.23 – 1.96	1	1	0.14	-	-	-	1	1	0.12	-	-	-	1	3	0.23	-	-	0.11
	2	1	0.28	-	-	-	2	1	0.12	-	-	0.12						
IPRrg/1000h:	3	1	0.14	0.14	-	0.14												
0.11 – 0.14	4	1	0.14	0.42	-	-												
	5	1	0.14	0.42	0.14	-												
		Total	0.84	0.98	0.14	0.14		Total	0.23	-	-	0.12		Total	0.23	-	-	0.11
Entry level Female	***Total dance students n=34***						***Total dance students n=36***						***Total dance students n=39***					
	Total injured dancers n=23 (67.6%)						***Total injured dancers n=10 (27.8%)***						***Total injured dancers n=21 (53.8%)***					
	Total injuries n=33						***Total injuries n=14***						***Total injuries n=27***					
IIRrg/1000h:	***Exposure(Mdn)/h: 400.6***						***Exposure(Mdn)/h: 407.9***						***Exposure(Mdn)/h: 369.2***					
0.84 – 2.21	1	19	0.81	0.37	0.15	0.07	1	8	0.34	0.14	0.07	-	1	16	0.63	0.42	0.07	-
	2	1	0.07	0.07	-	-	2	1	0.07	0.07	-	-	2	4	0.14	0.35	0.07	-
IPRrg/1000h:	3	1	0.22	-	-	-			-	-	-	-	3	1	-	0.14	0.07	-
0 – 0.22	4	1	0.07	0.07	-	0.15	4	1	0.07	0.07	0.07	0.07						
	5	1	0.07	0.29	-	-			-	-	-	-						
		Total	1.25	0.81	0.15	0.22		Total	0.48	0.27	0.14	0.07		Total	0.76	0.90	0.21	-

IIRrg, injury incidence rate range; IPRrg, injury prevalence rate range; IC, injury count; IIR1, injury incidence rate concerning new index injuries; IIR 2, injury incidence rate concerning new local injuries; IIR3, injury incidence rate concerning re-injuries; IPR, injury prevalence rate concerning exacerbation of existent injury

Table 4-6: (continued)

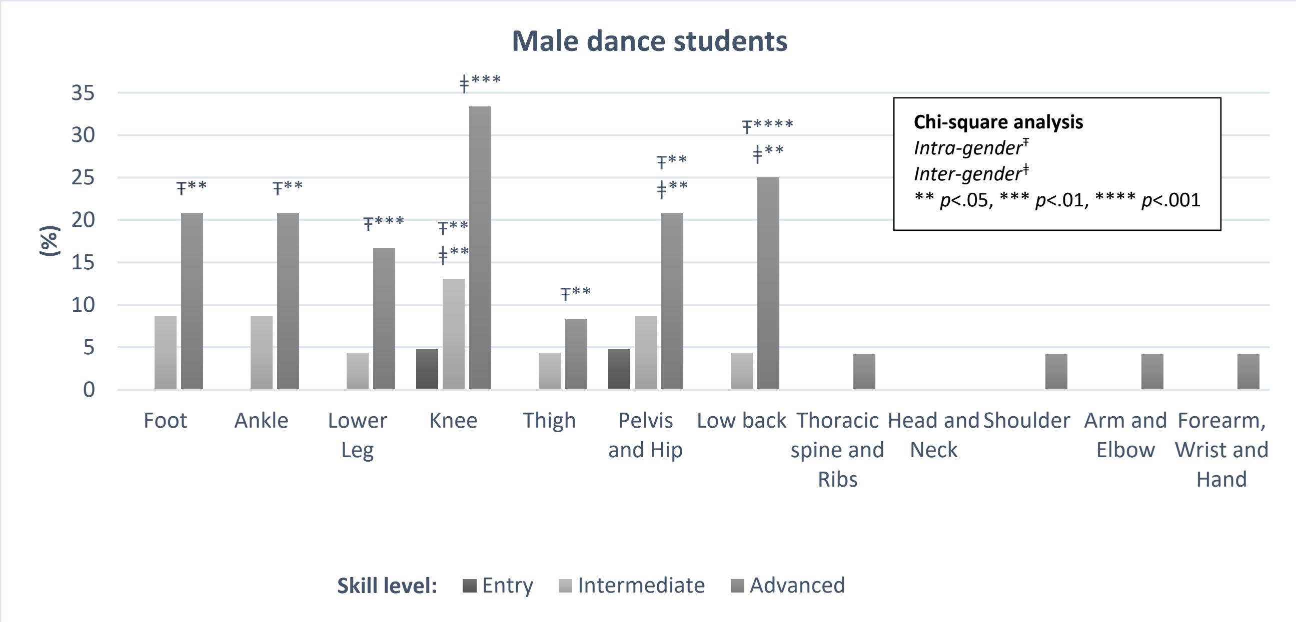
Skill level and Gender	2013/2014 IC (*n*)	Injured dancers (*n*)	IIR1/ 1000h	IIR2/ 1000h	IIR3/ 1000h	IPR/ 1000h	2014/2015 IC (*n*)	Injured dancers (*n*)	IIR1/ 1000h	IIR2/ 1000h	IIR3/ 1000h	IPR/ 1000h	2015/2016 IC (*n*)	Injured dancers (*n*)	IIR1/ 1000h	IIR2/ 1000h	IIR3/ 1000h	IPR/ 1000h
Intermediate level Male	***Total dance students n=22*** ***Total injured dancers n=11 (50.0%)*** ***Total injuries n=18*** ***Exposure(Mdn)/h: 613.6***						***Total dance students n=25*** ***Total injured dancers n=8 (32.0%)*** ***Total injuries n=11*** ***Exposure(Mdn)/h: 626.3***						***Total dance students n=23*** ***Total injured dancers n=9 (39.1%)*** ***Total injuries n=15*** ***Exposure(Mdn)/h: 574.6***					
IIRrg/1000h: 0.68 – 1.18	1	7	0.15	0.22	0.07	0.07	1	5	0.32	-	-	-	1	6	0.15	0.30	-	-
	2	1	-	0.15	-	-	2	3	0.13	0.26	-	-	2	1	0.15	-	-	-
	3	3	0.07	0.22	0.30	0.07							3	1	-	-	0.08	0.15
IPRrg/1000h: 0 – 0.15													4	1	0.08	0.15	0.08	-
		Total	0.22	0.59	0.37	0.15		Total	0.45	0.26	-	-		Total	0.30	0.30	0.08	0.15
Intermediate level Female	***Total dance students n=64*** ***Total injured dancers n=17 (26.6%)*** ***Total injuries n=25*** ***Exposure(Mdn)/h: 620.1***						***Total dance students n=50*** ***Total injured dancers n=24 (48.0%)*** ***Total injuries n=44*** ***Exposure(Mdn)/h: 627.8***						***Total dance students n=56*** ***Total injured dancers n=25 (44.6%)*** ***Total injuries n=41*** ***Exposure(Mdn)/h: 575.6***					
IIRrg/1000h: 0.54 – 1.18	1	13	0.05	0.05	0.18	0.05	1	13	0.35	0.03	0.03	-	1	16	0.22	0.09	0.16	0.03
	2	2	-	0.05	0.05	-	2	6	0.13	0.19	0.03	0.03	2	4	0.09	0.12	-	-
	3	1	0.03	0.03	-	0.03	3	4	0.13	0.10	0.06	0.10	3	3	-	0.09	0.12	0.06
IPRrg/1000h: 0.10 – 0.25						-							4	2	-	-	0.09	0.16
	5	1	-	0.05	0.05	0.03												
							7	1	0.03	0.03	0.06	0.10						
		Total	0.08	0.18	0.28	0.10		Total	0.64	0.35	0.19	0.22		Total	0.31	0.31	0.37	0.25

IIRrg, injury incidence rate range; IPRrg, injury prevalence rate range; IC, injury count; IIR1, injury incidence rate concerning new index injuries; IIR 2, injury incidence rate concerning new local injuries; IIR3, injury incidence rate concerning re-injuries; IPR, injury prevalence rate concerning exacerbation of existent injury

Table 4-6: (continued)

Skill level and Gender	2013/2014 IC (*n*)	Injured dancers (*n*)	IIR1/ 1000h	IIR2/ 1000h	IIR3/ 1000h	IPR/ 1000h	2014/2015 IC (*n*)	Injured dancers (*n*)	IIR1/ 1000h	IIR2/ 1000h	IIR3/ 1000h	IPR/ 1000h	2015/2016 IC (*n*)	Injured dancers (*n*)	IIR1/ 1000h	IIR2/ 1000h	IIR3/ 1000h	IPR/ 1000h
Advanced level Male	***Total dance students n=21*** ***Total injured dancers n=21 (100%)*** ***Total injuries n=69*** ***Exposure(Mdn)/h: 981.7***						***Total dance students n=24*** ***Total injured dancers n=19 (79.2%)*** ***Total injuries n=59*** ***Exposure(Mdn)/h: 1009.5***						***Total dance students n=25*** ***Total injured dancers n=19 (76.0%)*** ***Total injuries n=45*** ***Exposure(Mdn)/h: 897.3***					
IIRrg/1000h:	1	10	0.10	0.19	0.15	0.05	1	5	0.08	0.12	-	-	1	9	0.13	0.27	-	-
1.69 – 2.92	2	1	-	-	0.10	-	2	7	0.17	0.17	0.21	0.04	2	1	0.04	-	0.04	-
													3	4	-	0.36	0.09	0.09
IPRrg/1000h: 0.31 – 0.44	4	4	-	0.39	0.34	0.05	4	2	-	0.21	0.08	0.04	4	3	0.09	0.22	0.09	0.13
	5	1	0.05	0.10	0.05	0.05	5	2	0.04	0.12	0.21	0.04	5	2	-	0.27	0.09	0.09
	6	3	0.10	0.10	0.49	0.19												
							7	2	0.08	0.12	0.21	0.17						
	8	1	0.10	0.15	0.10	0.05	8	1	-	0.08	0.08	0.17						
	10	1	0.05	0.19	0.19	0.05												
		Total	0.39	1.12	1.41	0.44		Total	0.37	0.83	0.78	0.45		Total	0.27	1.11	0.31	0.31
Advanced level Female	***Total dance students n=27*** ***Total injured dancers n=17 (62.9%)*** ***Total injuries n=53*** ***Exposure(Mdn)/h: 972.3***						***Total dance students n=41*** ***Total injured dancers n=31 (75.6%)*** ***Total injuries n=78*** ***Exposure(Mdn)/h: 1010.8***						***Total dance students n=39*** ***Total injured dancers n=29 (74.4%)*** ***Total injuries n=72*** ***Exposure(Mdn)/h: 900.8***					
IIRrg/1000h:	1	4	0.08	-	0.08	-	1	10	0.17	0.02	0.02	0.02	1	9	-	0.14	0.03	0.09
1.25 – 1.60	2	6	0.04	0.04	0.23	0.15	2	9	0.12	0.17	0.14	-	2	8	-	0.14	0.14	0.17
							3	6	0.05	0.12	0.12	0.14	3	6	0.03	0.17	0.06	0.26
IPRrg/1000h: 0.34 – 0.80	4	3	0.04	0.19	0.11	0.11	4	1	0.02	0.02	0.02	0.02	4	2	-	0.06	0.11	0.06
	5	1	-	0.04	0.04	0.11	5	3	0.05	0.17	0.10	0.05	5	3	-	0.11	0.11	0.20
	6	1	-	0.04	0.15	0.04	6	1	-	0.05	0.05	0.05	6	1	0.03	0.09	0.03	0.03
	7	2	0.08	-	0.46	-	7	1	-	0.05	0.07	0.05						
		Total	0.23	0.30	1.07	0.42		Total	0.41	0.60	0.53	0.34		Total	0.06	0.71	0.48	0.80

IIRrg, injury incidence rate range; IPRrg, injury prevalence rate range; IC, injury count; IIR1, injury incidence rate concerning new index injuries; IIR 2, injury incidence rate concerning new local injuries; IIR3, injury incidence rate concerning re-injuries; IPR, injury prevalence rate concerning exacerbation of existent injury



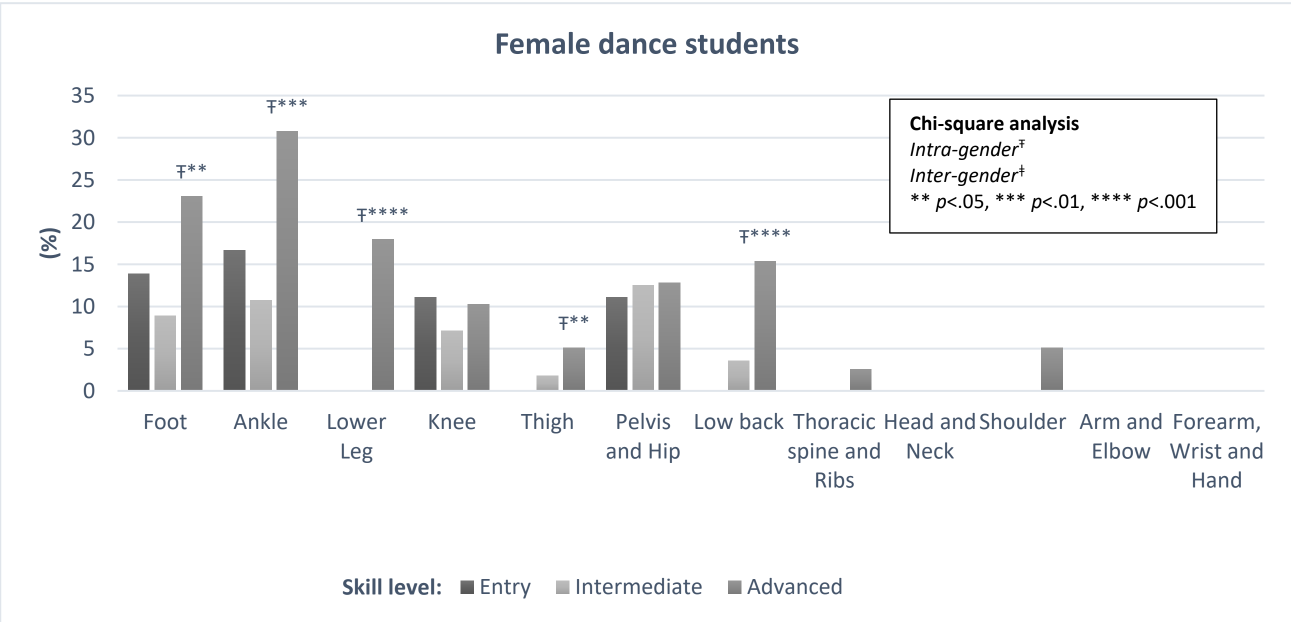


Figure 4-3: Median based proportion (%) of injured dance students per anatomical location (2013-2016), concerning gender and skill level.

4.2.5.6. Dance classes inciting event and onset mechanism

Table 4-7 shows the Poisson regression concerning injury inciting event in dance classes. All the covariates, except year of study in females, were found to have a significant effect (p<0.001) on injury frequency distribution. Higher SkL was also associated with an increasing effect in injury distribution of 69% for males and 30.8% for females. The number of injured dancers also had a similar effect of 18.7% and 16.8% for males and females, respectively. Concerning the year of the study a decreasing effect of 31.7% was observed in injury distribution for male dance students.

Table 4-7: Injury related dance class inciting event according to Poisson distribution across motor actions by gender.

	Male			Female		
Injury mechanism	IRR	95%CI	*p*	IRR	95%CI	*p*
Adjusted to skill level, number of injured dancers and year of study						
	Skill level: p<0.001			***Skill level: p<0.001***		
	Number of injured dancers: p<0.001			***Number of injured dancers: p<0.001***		
	Year of study: p<0.001			***Year of study: p=0.054***		
Jumps	**5.878**	**[2.000 , 17.270]**	**0.001**	**2.910**	**[1.431 , 5.916]**	**0.003**
Falls	**3.707**	**[1.269 , 10.826]**	**0.017**	1.643	[0.758 , 3.561]	0.208
Displacements	1.140	[0.306 , 4.248]	0.845	1.797	[0.841 , 3.841]	0.130
Steps	0.504	[0.092 , 2.750]	0.428	0.798	[0.303 , 2.098]	0.647
Postures	1.683	[0.506 , 5.602]	0.396	0.880	[0.347 , 2.231]	0.787
Gestures	**4.905**	**[1.594 , 15.093]**	**0.006**	**2.724**	**[1.274 , 5.823]**	**0.010**
Balance	0.528	[0.097 , 2.885]	0.461	**2.675**	**[1.320 , 5.421]**	**0.006**
Turns	3.136	[1.045 , 9.413]	0.052	**2.620**	**[1.298 , 5.291]**	**0.007**
Unidentified	*Ref.*(1)	-	-	*Ref.*(1)	-	-

IRR, Incidence Rate Ratio

From the 532 injuries occurred in classes, *n*=173 (32.5%) were on the sequence of a sudden (SOM), and *n*=359 (67.5%) a gradual onset mechanism (GOM). Jumps were found to be the motor action with the highest probability for developing injury symptoms in both genders, being also strongly correlated with GOM, r_s=0.755 (*p*<0.001) for males and r_s=0.703 (*p*<0.001) for females, respectively. Gestures also proved to have a similar pattern in both genders, with an GOM correlation of r_s=0.849 (p<0.001) for males and r_s=0.621 (*p*<0.001) for females. Falls were only significantly associated with SOM in male dance students, r_s=0.834 (*p*<0.001). Balance and Turns were only significantly associated with symptoms onset in females, being the first strongly correlated with GOM, r_s=0.872 (*p*<0.001).

4.2.6. Discussion

4.2.6.1. Injury risk ratio

Our population exhibits a 47.7%–51.4% IRR. Previous studies in identical population samples reported IRRs between 32.0% and 86.2% (Ekegren et al., 2014; Gamboa et al., 2008; Lee et al., 2017; Luke et al., 2002; Yau et al., 2017). This variability may relate with study design heterogeneity, data analysis (Meeuwisse et al., 2007), and injury definition (Kenny et al., 2017). Nevertheless, in the majority of those studies, IRR lies between 75.4% and 86.2% (Ekegren et al., 2014; Lee et al., 2017; Luke et al., 2002; Yau et al., 2017). Only a study by Gamboa et al.,(Gamboa et al., 2008) reported an annual range (32.0%–51.0%) similar to ours. The exception in the Gamboa study was the cumulative IRR (42.0%) that was considerably lower than in our study (68.9%) perhaps due to the way dancers' frequencies were considered for calculating the cumulative score.

4.2.6.2. Injury risk probability distribution

Identifying injury distribution patterns across a season may reveal a useful tool in the management and prevention by anticipating the moments where injury risk is the greatest. The few studies found in Pre-professional dancers, only considered injury frequency per month of training (Gamboa et al., 2008; Lee et al., 2017; Wanke et al., 2012) which may not be truly representative due to the skewedness effect of multiple individual injuries (Fortington et al., 2017). For that reason, we have considered injured dancers' frequency per month and used regression analysis. Within our findings, covariates such as monthly exposure time and year of study were not associated with frequency distribution, revealing a fairly consistent pattern across the 3 years. Also in the study by Lee et al. (2017) (Lee et al., 2017), no association between total exposure time in hours and injury frequency was found. These findings may suggest that, irrespectively of the exposure time, training load ratio (TLR) may also play a role in injury occurrence (Soligard et al., 2016). Gamboa and colleagues (Gamboa et al., 2008) associated monthly variation in injury frequency to the increases in training intensity. Wanke et al. (Wanke et al., 2012) found no significant variations in distribution. In our study, the time-period for increased injury risk varied according to SkL. The reasons for such may relate with curricular structure, annual planning, performance schedules, previous injury and others (Bronner, Ojofeitimi, & Mayers, 2006; S. J. Kenny et al., 2015). EntL curricular structure is organized progressively, the students' participation in performances is scarce and for many it is the first contact with a systematic training system. As such, January may represent their cumulative TLR exertion peak. IntL and AdvL have a different annual planning schedule. Their first presentation moment occurs in early November, and preparation starts in September/ October. Furthermore, factors such as non-full recovery from a previous injury during academic vacations, or physical deconditioning may amplify a *too-much-too-soon* effect giving little room for adaptation and thus facilitating injury when TLR increases(Soligard et al., 2016).

4.2.6.3. Injury incidence and prevalence rates

IIRs in pre-professional dancers vary widely across studies (0.54/1000h–4.7/1000h) (Bowerman et al., 2014; Caine et al., 2016; Ekegren et al., 2014; Gamboa et al., 2008; Leanderson et al., 2011; Lee et al., 2017; Luke et al., 2002) and can be as high as other aged matched high-risk athletic activities (1.4/1000h–4.5/1000h) (S. J. Kenny et al., 2015) or even to the incidence range observed in professional dancers (0.56/1000h–4.45/1000h) (Allen, Nevill, Brooks, Koutedakis, & Wyon, 2013; Nilsson, Leanderson, Wykman, & Strender, 2001; Shah, Weiss, & Burchette, 2012). However, rates may reveal of limited interpretation when multiple individual injuries are not considered (Finch & Marshall, 2016) and studies concerning prevalence rates are lacking. Our IIRrg for males (0.23/1000h–2.92/1000h) and females (0.54/1000h–2.21/1000h) were found to be similar to studies also considering gender differences (Bowerman et al., 2014; Ekegren et al., 2014; Leanderson et al., 2011): 0.80/1000h–2.80/1000h for males and 0.08/1000h–2.19/1000h for females, respectively. Caine et al. (Caine et al., 2016) discriminated IIR by technique level (1.32/1000h–4.55/1000h) which was higher than in our sample whose maximum was 2.92/1000h. Interestingly, and although AdvL students have a higher injury frequency, no significant differences were found in injury rates amongst SkL. This may be explained by using the person-time as a denominator in the rate calculation, whereas, although injury frequency is higher in AdvL so is the exposure time. Furthermore, the increasing IPR trend towards AdvL also may attenuate IIR outcome scores in AdvL.

4.2.6.4. Anatomical location

Identifying the anatomical locations most likely to be injured is of the utmost importance for prevention and one of the most described patterns across the literature. Our findings are in line with previous research where the lower extremity is identified as the most affected body region in pre-professional dancers (Caine et al., 2016; Caine et al., 2015; Lee et al., 2017; Steinberg et al., 2011, 2013; Yau et al., 2017; Yin et al., 2016). Still, in what concerns to specific anatomical locations, some differences exist among studies. Within dance training formation, and particularly in classical ballet, the technique and the repertoires have differences between genders, evolving according to SkL. It is therefore important to discriminate between both. In our study, to minimize the potential distortion effect of multiple individual injuries we have considered the Mdn proportion of injured dancers per anatomical location, by gender and by SkL, instead of injury frequency per anatomical location. Significant differences were found. AdvL and IntL males exhibited a higher proportion of knee injured dancers when compared to females. This finding is in contrast with the studies of Yin et al. (Yin et al., 2016), Steinberg et al. (Steinberg et al., 2011, 2013) and Stracciolini et al. (Stracciolini et al., 2015), where the knee was found to be the most prevalent site for injury in females. It is worth mentioning, however, that these studies' sample featured almost exclusively females. Also, some studies in sports literature report that adolescent female athletes are more prone to knee injuries than male athletes (Louw, Manilall, & Grimmer, 2008; Myer et al., 2010). Concurrently, a study in professional ballet dancers by Nilsson et al. (Nilsson et al., 2001) reported a similar observation concerning a higher knee injury incidence in male dancers. With concern to the low back, the lifts performed by AdvL males while partnering, may explain the higher proportion observed. The study by Caine et al. (Caine et al., 2016), also found a higher prevalence of low back injuries in males when compared with females, although not significant. As expected, and according with previous literature (Nilsson et al., 2001; Yau et al., 2017), a higher proportion of female dancers exhibited ankle and foot injuries in comparison with male dancers. Interestingly, both EntL and AdvL were the ones registering the higher proportion of injured dance students, perhaps because of the early start of point shoes training (EntL) and the increasing time of point shoes work (AdvL).

4.2.6.5. Triggering environment for injury symptoms

Although very few studies address to the activity type where injuries occur, our findings were similar to the ones reported by Caine et al. (Caine et al., 2016) where the majority of injuries (86.1%–94.1%) occurred in classes, compared with rehearsals and performances probably because pre-professional dance training relies mostly in classes.

4.2.6.6. Dance classes onset mechanism and inciting event

In the present study, from the 532 injuries that occurred in classes, *n*=173 (32.5%) concerned an SOM, and *n*=359 (67.5%) an GOM. These results are within the range found across literature regarding gradual onset injuries (53.6%–85%) and acute injuries (12%–45%) (Caine et al., 2016; Ekegren et al., 2014; Gamboa et al., 2008; Leanderson et al., 2011; Lee et al., 2017; Yau et al., 2017). With respect to the motor action as inciting event, up to the present date we found no studies in the literature addressing such issue in the pre-professional setting. Irrespective of gender, Jumps were the motor action with more probability of developing symptoms with a strong correlation with GOM r_s=0.755 (p<0.001) for males and r_s=0.703 (p<0.001) for females, respectively. This is not surprising since according to the literature, elite pre-professional dancers may perform more than 200 jumps in a 1.5h class (Bowerman, Whatman, Harris, & Bradshaw, 2015). Also, in a study conducted in a professional ballet company (Allen, Nevill, Brooks, Koutedakis, & Wyon, 2012) found that the largest proportion of injuries were sustained during jumping exercises. The wide variety of gestures vocabulary used in dance (i.e. lower limb, trunk and upper limb) also makes Gestures significantly predisposing for non-acute injuries in both genders. The significant association between Falls and acute mechanism in male dancers may justify the high rates of knee injuries, and the ankle and foot high rates in female dancers may be associated with the extreme range of motion required of those anatomical structures to perform during Balance and Turns.

4.2.7. Conclusion

The present work represents an update contribution on the epidemiology of injuries affecting pre-professional ballet dancers. Dance injuries happen because of dance practice. Given the recursive nature of risk and causation, knowledge on activity-related injury patterns, may reveal of added value for management and prevention. With regard to data analysis, and because of the potential distorting effect of multiple individual injuries, we must underline the importance of determining whether to use injured dancers' frequency or injury frequency. While the injured dancers' frequency may more reliable for describing risk probability distribution and anatomical location, injury frequency may be more representative of activity type, injury inciting event and onset mechanism. In that sense, some of the general findings of the present work are in line with those of previous research, such as injury anatomical location, activity type and onset mechanism. Nevertheless, a more in-depth analysis revealed gender and SkL specific patterns asymmetries. Some other results, disclosed information that was heretofore unreported or inconsistent with prior research. These relate with injury risk probability distribution, incidence and prevalence rates adjusted to multiple individual injuries and injury inciting event.

4.2.8. Perspective

Pre-diagnostic data is an umbrella term encompassing several aspects of injury background and represents fertile ground for research. To be able to look beyond rates, risks and frequencies in dance injuries epidemiology, context-specific methodological approaches are recommended, particularly with concerns to multiple individual injuries. Also, injury risk factors research may strongly benefit from such approaches for targeted tracking of specific risk factors associated with gender, skill level and activity type, so that injuries may be timely prevented.

4.2.9. References

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4.3. Study III – Vertical Jump Performance and Lower Extremity Injuries in Pre-professional Dancers

O Desempenho do Salto Vertical e as Lesões da Extremidade Inferior em Bailarinos Pré-profissionais

Moita, J., Gomes, A., Xarez, L., Madeira, R., Coelho, C. (2018). Vertical Jump Performance and Lower Extremity Injuries in Pre-professional Dance Students. *Submitted*

4.3.1. Abstract

Context: Jumps are an integral aspect of dance practice being quite often pointed out as one of the major identifiable mechanisms associated with injury. Both in dance as in sports, vertical jump performance (VJP) is one of the lower body´s most used strength-related parameter associated with performance and injury. Nevertheless, in dance, the nature of the relation with injury remains inconclusive, particularly in the pre-professional setting.

Objective: To examine and analyse VJP performance features, concerning lower extremity (LE) bilateral asymmetries in asymptomatic pre-professional dance students with and without previous LE injury history.

Design: Cross-sectional study.

Setting: Full-time pre-professional dance school.

Participants: A total of 94 dance students volunteered for this study: 60 females and 34 males.

Results: From the 94 participants, *n*= 24 males and *n*= 50 females exhibited LE injury history, while 20 dancers, respectively *n*=10 males and *n*=10 females, did not. Males jumped 9.9 Mdn [IQR=1.1] cm higher than female dancers in double leg counter movement jump (CMJ), and 5.6 Mdn [IQR=1.4] cm in single leg CMJ jumps. It was observed a trend in male dancers concerning injury distribution, towards a higher LE injury incidence rate ratio (IRR) involving jumps on the stronger side when compared to the weaker side. Also, injury frequency in male dancers regarding jump-related overuse injuries revealed higher on the stronger side. No differences were observed on the assessed parameters between dancers with and without injury history.

Conclusions: VJP assessment product through double and single leg CMJ, proved ineffective in distinguishing between injured and non-injured dancers. Stronger dancers do get injured too. The relationship between VJP and injuries in dancers, may more likely be related with the dancer intrinsic features involved in the lower body external mechanical power (EMP) production process to meet the demands of dance practice, than with the VJP final product.

Key words: Pre-professional; Dance; Lower extremity injuries; Power; Jump height.

4.3.2. Resumo

Contexto: Os saltos são um elemento integrante da prática da dança, sendo muitas vezes apontados como um dos principais mecanismos identificáveis associados às lesões. Tanto na dança como no desporto, o desempenho do salto vertical (DSV) é um dos parâmetros relacionados com a força, mais utilizados na parte inferior do corpo, associado ao desempenho e também às lesões. No entanto, na dança, a natureza dessa relação permanece inconclusiva, particularmente no cenário pré-profissional.

Objetivo: Examinar e analisar as características do DSV, no que diz respeito às assimetrias bilaterais dos membros inferiores (MInf) em estudantes de dança pré-profissionais assintomáticos, com e sem histórico prévio de lesão do MInf.

Desenho: Estudo transversal.

Ambiente: Escola de dança pré-profissional.

Participantes: Um total de 94 estudantes de dança voluntariaram-se para este estudo: 34 do género masculino (GM) e 60 do género feminino (GF).

Resultados: Dos 94 participantes, n = 24 GM e n = 50 GF exibiram histórico de lesão do MInf, enquanto que 20 bailarinos, respetivamente n = 10 GM e n = 10 GF, não o fizeram. Os participantes do GM saltaram 9.9 Mdn [IQR=1.1] cm mais alto do que o GF no salto com contramovimento (SCM) em duas pernas, e 5.6 Mdn [IQR=1.4] cm nos SCM numa perna. Nos bailarinos do GM observou-se uma tendência relativa à distribuição de lesões, no sentido de um maior rácio de incidência de lesões (RIL) do MInf no lado mais forte respeitante às lesões associadas aos saltos e por sobre-uso. Não foram observadas outras diferenças nos parâmetros avaliados entre bailarinos com e sem histórico de lesão.

Conclusões: O produto de avaliação do DSV através de SCM bilateral e unilateral, mostrou-se ineficaz na distinção entre bailarinos com e sem histórico de lesão. Os bailarinos mais fortes também sofrem lesões. A relação entre o DSV e as lesões, pode mais provavelmente estar associada às características intrínsecas do executante envolvidas no processo de produção de potência para atender às exigências da prática de dança, do que com o produto final do DSV.

Key words: Pré-profissional; Dança; Lesões do membro inferior; Potência; Altura do salto.

4.3.3. Context

Within the scope of epidemiological literature, lower extremity injuries, particularly the ones associated with overuse, are suggested as the most predominant type of injury in dance (Allen, Nevill, Brooks, Koutedakis, & Wyon, 2012; Caine et al., 2016; Caine, Goodwin, Caine, & Bergeron, 2015; Kenny, Whittaker, & Emery, 2015; Roberts, Nelson, & McKenzie, 2013; Smith et al., 2015). Jumps are an integral aspect of dance practice (Ambegaonkar et al., 2018; Malkogeorgos, Zaggelidou, Zaggelidis, & Christos, 2013; Twitchett, Koutedakis, & Wyon, 2009; Wyon, Allen, Angioi, Nevill, & Twitchett, 2006) being quite often pointed out as one of the major identifiable mechanisms associated with injury (Allen et al., 2012; Bowerman, Whatman, Harris, & Bradshaw, 2015). Some authors state that dancers may perform more than 200 jumps in a 1.5h class, with more than half of those involving one-legged landings (Bowerman et al., 2015; Liederbach, Dilgen, & Rose, 2008). For these reasons, LE Power is often considered to be one of the major requirements for jumping performance in dance (Koutedakis et al., 2007; Koutedakis, Stavropoulos-Kalinoglou, & Metsios, 2005; Malkogeorgos et al., 2013; Twitchett, Angioi, Koutedakis, & Wyon, 2011). In fact, both in dance as in sports, vertical jump performance (VJP) through LE Power and/or jump height, are some of the lower body most used strength-related parameters associated with performance and injury (Lauersen, Bertelsen, & Andersen, 2014; Suchomel, Nimphius, & Stone, 2016). Nevertheless, in dance, the nature of the relation with injury remains inconclusive, particularly in the pre-professional setting.

Within dance science, several studies already addressed the potential relationship between VJP and injury (Ambegaonkar et al., 2018; Angioi, Metsios, Koutedakis, Twitchett, & Wyon, 2009; Mistiaen et al., 2012; Roussel et al., 2014; Twitchett et al., 2010; Wyon, Koutedakis, Wolman, Nevill, & Allen, 2014). While some studies found no relation (Mistiaen et al., 2012; Roussel et al., 2014; Twitchett et al., 2010), others have reported some significant associations such as: a negative correlation (r= - 0.66) between LE power and injury severity (Angioi et al., 2009) in contemporary dancers; a significantly higher injury incidence (p <0.01) in ballet dancers with lower LE power (Wyon et al., 2014); and an association (χ^2=5.9, p=0.02) between LE single leg hop horizontal distance and LE injury risk in collegiate female dancers (Ambegaonkar et al., 2018). However, different populations, study designs, settings and methodological approaches, make it difficult to establish overall comparisons and draw conclusions.

Furthermore, injuries are multifactorial in nature (Liederbach, Hagins, Gamboa, & Welsh, 2012; Meeuwisse, Tyreman, Hagel, & Emery, 2007), meaning that finding a statistically significant association between a specific test outcome and injury, only identifies the existence of a potential relation not who is at risk of injury (Bahr, 2016). Also, it is known that the physiological variables associated with performance do not remain stable over time (Meeuwisse et al., 2007), and that dancers quite often dance through most of their injuries across the season (Gamboa, Roberts, Maring, & Fergus, 2008). Thus, studies assessing VJP in dancers should consider the hypothesis that jumping performance is shaped by the dancer intrinsic features plus the result of dance practice exposure adaptative process (Twitchett et al., 2009; Wyon et al., 2007). In that sense, it may either represent a contributing factor for injury, or a consequence of injury history associated with practice. It may therefore be of benefit, to identify LE injury patterns associated with VJP based on dancers' previous injury history.

The primary aim of the present study was to examine and critically analyze the product of VJP by means of LE Power and jump height, concerning bilateral asymmetries in asymptomatic pre- professional dance students with and without previous LE injury history. The secondary aim was to examine intra-subject lateral differences concerning injury history. Gender, injury type and precipitating mechanism were discriminated.

4.3.4. Methods

This study was conducted on a full-time pre-professional dance school in Lisbon, Portugal. A cross-sectional design was employed. VJP was assessed by means of one and two-legged jump tests, performed in a single session for each participant at the end of the academic year. LE Power (w) and jump height (cm) were considered. Injury history was retrospectively assessed through consultation of the school health care office individual reports concerning the respective year´s occurrences. For the purpose of the present study only LE injuries were considered. Injury data included: injury location (i.e. anatomical region and body side) and injury type (i.e. acute and overuse), classified according with Fuller et al. (Fuller et al., 2006) framework; injury precipitating mechanism referring to the exercise being performed at the time of injury (when identified), in order to identify injuries occurred during jumps (Xarez, 1999). This study complied to the tenets of The Declaration of Helsinki of the World Medical Association (Association, 2013) and was approved by the School of Human Kinetics, University of Lisbon, Ethics Committee Review Board (CEFMH, N25/2017).

4.3.4.1. Participants

Participants were recruited from a pre-professional dance school in Lisbon, Portugal. The school features an 8-year dance course with both ballet and contemporary dance styles and whose access is made via audition only. The weekly time of dance class participation range between 9.75 Mdn [IQR=3.59] hours for the entry level students and 20.00 Mdn [IQR=7.32] hours for the advanced level students. Participants were excluded if they presented any active symptoms of pain and disability within the last 4 weeks prior to LE power assessment and/or any other kind of physical impairment for conducting the tests. Participants aged 18 years or older provided written informed consent and those under the age of 18 years provided oral informed assent and a parent/legal guardian provided written informed consent.

4.3.4.2. Instruments

Subjects´ height and weight were measured by means of a portable stadiometer and a digital scale, respectively. Ankle dorsi-flexion range of motion (ROM) was measured through weight-bearing lunge, using a metric tape with the ability to measure to 0.1 cm (Konor, Morton, Eckerson, & Grindstaff, 2012). For vertical jump tests assessment a Chronojump Boscosystem® Contact platform A2 and the respective Chronojump software 1.4.7.0., which has proven to be a reliable and valid equipment in field testing for estimating LE jump height and power through flight time were used (Bosco, Luhtanen, & Komi, 1983; Markovic, Dizdar, Jukic, & Cardinale, 2004).

4.3.4.3. Procedures

Prior to VJP assessment, the participants´ age, height (in cm) and mass (in kg) were recorded. The dynamic dominant leg was determined by the Ball kicking test (Brophy, Silvers, Gonzales, & Mandelbaum, 2010). Ankle dorsiflexion ROM was measured following the procedures described by Konor et al. (Konor et al., 2012) through weight-bearing lunge facing a wall and barefooted. Participants were given 3 trials to familiarize themselves with the procedure and precondition the tissues. Maximal dorsiflexion ROM was defined as the maximum distance in cm of the toe from the wall while maintaining contact between the wall and knee without lifting the heel. Before jump tests assessment, subjects completed a standardised warm-up that consisted of 5 min jogging at a self-selected pace followed by 10 squats, 10 heel raises and 5 min of their usual individual lower extremity stretching routine before dance classes. Additionally, each participant performed 3 practice trials for each of the jump types used in the assessment. After the warm-up and practice trials, three jump test trials were performed, ordered according to the following jump types: Two-legged counter movement jump (CMJ); two-legged counter movement jump using the technique for performing *sautés* jumps ($CMJ1^{st}$; heels together, hips externally rotated with the feet in 1^{st} ballet position, and pointed feet); one-legged counter movement jump for the left (CMJ^{left}) and right (CMJ^{right}) legs respectively. The subjects started all the jump tests within the contact mat, assuming the respective test position with the hands on their hips. They were instructed to sink as quickly as possible and then jump as high as possible, always keeping the hands on the hips, and not allowing the chest line to cross the knees during the sinking eccentric phase. It was also asked that at take-off, the subjects´ left the mat with the knees and ankles extended, and land on a similar fashion (Young, 1995). For total recovering, a rest period of 1 min was given between trials and 15 min between jump type (Markovic et al., 2004).

4.3.4.4. Data analysis

The contact platform records air time and determines the height of the jump using the formula: height of body centre of gravity = $(t^2 \times g)/8$, whereas g = 9.81 $m \cdot s^{-2}$ and t corresponds to air time (Leard et al., 2007). Power (watts) was calculated based on a previously published equation which accounted for participants´ body mass and height, thus reducing the effects of individual anthropometric variation (Ambegaonkar et al., 2018). The used equation was: Power (watts) = 78.5 × jump height (cm) + 60.6 × body mass (kg) - 15.3 × subject height (cm) - 1.308. For analysis purposes, only the best scores of each jump (i.e. jump height and Power) were considered. The bilateral deficit of jump performance was determined through Bilateral Deficit Index (BDI) using the following method: BDI% = 100 $[(Bilateral_{tot} / (Unilateral_{dom} + Unilateral_{ndom})]$ - 100 (Howard & Enoka, 1991). The Symmetry Index (SI) was calculated using the equation: (non-dominant leg / dominant leg) × 100 (Maulder & Cronin, 2005). The strongest side was defined as the side where jump height and Power scores were the highest within each participant.

For intra-gender analysis concerning only dancers with injury history, injuries were grouped into injury type (i.e. acute and overuse) and mechanism (i.e. jumps), being respectively distributed by stronger and weaker side according to gender.

4.3.4.5. Statistical analysis

The normality of continuous data distribution was assessed by the Kolmogorov-Smirnov test. Descriptive statistics are expressed as median (Mdn) and interquartile range (IQR). For continuous variables the Mann-Whitney *U* test and the Kruskal-Wallis tests were used. For nominal variables, χ^2 or the Fisher exact test were used. Bivariate Spearman's correlations were performed for univariate analysis of continuous variables. Total sample analysis and gender stratified analysis were performed. Multivariate multinomial logistic regressions were performed. The number of LE injuries, concerning acute and overuse injuries in relation to body side power were the dependent variables. Regression analysis also considered the subjects grouped in accordance with the number of individual injuries sustained: a) no injuries; b) 1 injury; c) 2 injuries; d) 3 or more injuries. The ratio between ipsilateral and contralateral Power (w) and jump height (cm) were independent variables. Models were adjusted for gender. Poisson regression analysis was used for injury frequency distribution by gender concerning body side and adjusted to injury type. An $\alpha<0.05$ was considered for null-hypothesis rejection.

Due to multiple individual injuries, the most prevalent anatomical regions within the LE were determined through the percentage of male and female injured dancers by anatomical region concerning total LE injuries and LE injuries involving jumps.

4.3.5. Results

4.3.5.1. Participants

A total of 94 dance students were included in this study: 60 females (age Mdn=16 , IQR=4 years; height Mdn=163.7 , IQR=15.4 cm; mass Mdn=51.1 , IQR=17.2 kg) and 34 males (age Mdn=16 , IQR=4 years; height Mdn=164.6 , IQR=15.8 cm; mass Mdn=51.1 , IQR=17.7 kg). From the 94 participants, 24 males and 50 females exhibited LE injury history, while 20 dancers, respectively 10 males and 10 females, did not. In what concerns to the intrinsic variables associated with VJP (table 4-8), participants´ age, body mass and height were found to be positively correlated with LE Power but not with jump height in males. In females, correlations with jump height were found across jump types, except in CMJ1st. Additionally, ankle ROM was also found to be positively correlated with jump height and Power in single leg CMJ. For both genders, body weight proves to be the variable which more strongly correlates with LE Power. In female dancers, age was the one more associated with jump height except in CMS1st.

Table 4-8: Spearman correlation of intrinsic variables associated with vertical jump performance.

	CMJ		CMJ1st		CMJleft		CMJright		BDI (%)		SI (%)	
Gender and intrinsic variables	Jump height (cm)	Power (w)	Jump height (cm)	Power (w)	Jump height (cm)	Power (w)	Jump height (cm)	Power (w)	Jump height	Power	Jump height	Power
Males												
Age (yrs)	0.318	**0.370***	0.169	0.312	0.272	**0.359***	0.219	**0.419***	-0.328	**-0.471****	0.006	0.025
Body mass (Kg)	0.242	**0.741****	0.217	**0.681****	0.175	**0.795***	-0.008	**0.774****	-0.036	**-0.570****	0.185	0.216
Height (cm)	0.058	**0.487****	0.027	**0.429***	0.146	**0.607****	-0.059	**0.534****	-0.172	**-0.567****	0.242	0.273
Left Ankle ROM (cm)	-	-	-	-	0.324	0.369	-	-	-	-	-	-
Right Ankle ROM (cm)	-	-	-	-	-	-	0.172	0.229	-	-	-	-
Females												
Age (yrs)	**0.425****	**0.757****	0.228	**0.708****	**0.378****	**0.769****	**0.297***	**0.752****	-0.216	**-0.701****	0.095	0.107
Body mass (Kg)	**0.328***	**0.860****	0.154	**0.857****	**0.311***	**0.935****	0.253	**0.904****	-0.156	**-0.828****	0.142	0.158
Height (cm)	**0.366****	**0.730****	0.248	**0.754****	**0.372****	**0.798****	**0.295***	**0.759****	-0.148	**-0.669****	0.187	0.201
Left Ankle ROM (cm)	-	-	-	-	**0.385***	**0.534***	-	-	-	-	-	-
Right Ankle ROM (cm)	-	-	-	-	-	-	**0.448***	**0.537***	-	-	-	-

CMJ, counter movement jump; BDI, bilateral deficit index; SI, symmetry index; ROM, range of motion
* *p*<.005; ** *p*<.05

Table 4-9: Vertical jump performance, Bilateral Deficit Index (BDI) and Symmetry Index (SI) by gender and injury history status.

	Jump type					
Gender and Injury history status	CMJ Mdn±[IQR]	CMJ1st Mdn±[IQR]	CMJleft Mdn±[IQR]	CMJright Mdn±[IQR]	BDI (%) Mdn±[IQR]	SI (%) Mdn±[IQR]
M non-injured n= 10						
Jump height max (cm)	34 ± [9] ǂ**	32,6 ± [10.9] ǂ**	19,0 ± [6.6] ǂ**	20,2 ± [5.3] ǂ**	-0,3 ± [21.6)	95,9 ± [11.6]
Power max (w)	4029.1± [1570.1] ǂ**	3930,7 ± [1746.6] ǂ**	2588,1 ± [1214.5] ǂ**	2658,2 ± [1097.9] ǂ**	-23,4 ± [14.7]	97,5 ± [5.3]
M injured n= 24						
Jump height max (cm)	34.8 ± [7.6] ǂ**	34.6 ± [7.1] ǂ**	18 ± [6.6] ǂ**	19.2 ± [5.7] ǂ**	-1.3 ± [21.6]	97.4 ± [17.1]
Power max (w)	4046 ± [676.8] ǂ**	4118.4 ± [750.7] ǂ**	2818.9 ± [567.4] ǂ**	2711.8 ± [747] ǂ**	-24.9 ± [8] ǂ**	98.6 ± [10.29
F non-injured n= 10						
Jump height max (cm)	24.7 ± [7]	24.2 ± [5.2]	12.3 ± [3.6]	11.8 ± [5]	-3.6 ± [10]	106.6 ± [10]
Power max (w)	2168.6 ± [960]	2008.7 ± [795]	1256 ± [1110.6]	1201 ± [712.5]	-18.8 ± [46.4]	104.6 ± [8.1]
F injured n= 50						
Jump height max (cm)	26.4 ± [6.3]	26.8 ± [5.7]	13.3 ± [3.2]	13.2 ± [3.2]	-1.5 ± [17.7]	94.3 ± [17.4]
Power max (w)	2581.6 ± [755.7]	2585.5 ± [716]	1470.2 ± [751.3]	1462.8 ± [605.9]	-14 ± [21.7]	95.6 ± [16.4]

M, male; F, female; CMJ, counter movement jump; BDI, bilateral deficit index; SI, symmetry index

ǂ Mann-Whitney U test performed for inter-gender differences significant at ** p<0.05

4.3.5.2. Injury History and VJP

Table 4-9 describes VJP by jump type according to gender and injury history. No differences were found in VJP between dancers with and without injury history. Jump height and LE power were significantly higher in male dancers for all jump types when compared to females. Males jumped Mdn=9.9 , IQR=1.1 cm higher than female dancers in double leg CMJ, and Mdn=5.6 , IQR=1.4 cm in single leg CMJ jumps. Also, BDI and SI revealed no differences between genders, except for BDI concerning power in injured males. Although CMJ1st corresponds to a dance-specific feet position, no differences were found when comparing with the obtained scores on normal CMJ.

4.3.5.3. Body Side Power and Injuries

Table 4-10 presents injury distribution by gender according to injury type and mechanism in relation to body side power. χ^2 analysis found no significant differences except for LE overuse injuries involving jumps where it was observed a higher injury percentage on the stronger side for male dancers when compared to females. In fact, the same trend, although not significant, was observed in injury distribution following a Poisson regression analysis (table 4-11), whereas male dancers exhibited a tendency for higher LE injury incidence rate ratio (IRR) involving jumps on the stronger side when compared to the weaker side. Conversely, and also not significant, female dancers showed a tendency for having a lower IRR of LE overuse injuries involving jumps on the stronger side (table 4-11).

Table 4-10: Injury distribution by gender according to injury type and mechanism in relation to body side power.

Gender	Injury frequency by injury type and mechanism	Body side power Stronger side Injury *n* (%)	 Weaker side Injury *n* (%)
Male dancers with LE injuries n= 24			
	Total LE injuries *n*= 106	55 (51.8)	51 (48.1)
	Acute *n*= 45	23 (51.1)	22 (48.8)
	Overuse *n*= 61	33 (54.1)	28 (45.9)
Male dancers with LE injuries involving jumps n= 18			
	Total LE injuries involving jumps *n*= 51	36 (70.5)	15 (29.4)
	Acute *n*= 20	14 (70)	6 (30)
	Overuse *n*= 31ǂ*	23 (74.1) ǂ*	8 (25.8) ǂ*
Female dancers with LE injuries n= 50			
	Total LE injuries *n*= 165	79 (47.8)	86 (52.1)
	Acute *n*= 21	7 (33.3)	14 (66.6)
	Overuse *n*= 144	72 (50)	72 (50)
Female dancers with LE injuries involving jumps n= 24			
	Total LE injuries involving jumps *n*= 51	25 (49)	26 (50.9)
	Acute *n*= 22	13 (59)	9 (40.9)
	Overuse *n*= 29	11 (37.9)	18 (62)

LE, Lower extremity
ǂChi-square analysis performed, significant at *p<.05, for inter-gender differences in LE overuse injury distribution involving jumps

Table 4-11: Lower extremity injuries by gender according to Poisson distribution concerning body side power and adjusted to injury type and mechanism.

	Males			Females		
Body side power	IRR	95%CI	*p*	IRR	95%CI	*p*
LE injuries adjusted to injury type						
	Injury type: p=0.184			***Injury type: p=0.333***		
Stronger side	1.045	[0.583 , 1.896]	0.882	0.997	[0.544 , 1.827]	0.992
Weaker side	*Ref.*(1)	-	-	*Ref.*(1)	-	-
LE injuries involving jump adjusted to injury type						
	Injury type: p=0.254			***Injury type: p=0.024***		
Stronger side	1.644	[0.889 , 3.041]	0.113	0.852	[0.631 , 1.149]	0.293
Weaker side	*Ref.*(1)	-	-	*Ref.*(1)	-	-

IRR, Incidence Rate Ratio; LE, lower extremity

4.3.5.4. Injury Anatomical Location

The most prevalent anatomical regions for total LE injuries were the knee (58.3%) for males and the ankle (56.0%) for females. With respect to LE injuries involving jumps, the lower leg was the most prevalent in both genders with 55.6% and 58.3% of injured males and females respectively.

Multivariate analysis found no differences in VJP between injured and non-injured dancers on the assessed parameters.

4.3.6. Discussion

The purpose of the present study was to examine VJP product through LE Power and jump height in pre-professional dancers with and without LE injury history. While in some athletic activities the ability to jump higher or farther (i.e. jump task product) may determine who performs the best (Suchomel et al., 2016), within the dance context, jumping performance mostly depends on how (i.e. process) the lower body generates Power to meet task-specific requirements of time and space (Xarez, 1999). This means that some caution is recommended when interpreting this type of data in the context of performance and injury and may partially explain the absence of evidence on the relation between VJP and injuries in our study. Although jump height is found to be directly proportional to Power output in max VJP within the same individual, it is also true that inter-individually, we may find similar Power outputs associated with different jumps heights and similar jumps heights associated with different Power outputs. Therefore, when comparing different subjects, the ones with the highest jump scores may not necessarily be the most powerful as well as the ones exhibiting higher LE Power may not necessarily be the ones jumping higher (Wyon et al., 2006). Furthermore, also several factors are suggested to influence the process of external mechanical power (EMP) production and subsequently VJP (Carvalho & Carvalho, 2006; Sharma, Gandhi, Meitei, Dvivedi, & Dvivedi, 2017; Suchomel et al., 2016; Taber, Bellow, Abbott, & Bingham, 2016; Winter et al., 2016; Wyon et al., 2006). Some may relate with anthropometric factors (Sharma et al., 2017; Wyon et al., 2006), others with physiological factors such as muscular strength (Suchomel et al., 2016; Taber et al., 2016) and others with task-related skill-proficiency factors (Carvalho & Carvalho, 2006; Winter et al., 2016). The results of our study found high correlations between body mass and LE Power across all jump types in both genders, but only low correlations with jump height in females and none in male dancers. Also, ankle dorsi-flexion ROM was found to correlate to single leg CMJ in females but not in males. Previous literature report that many of the jumps performed in dance involve one-legged landings (Bowerman et al., 2015; Liederbach et al., 2008) and that jump performance may present differently among genders (Wyon et al., 2006). Our findings suggest that different jump strategies may exist among male and female dancers in what concerns to joint participation in jump performance, supporting also the recommendation of future research assessing VJP, to consider bilateral differences and Power outputs instead of only jump height. Most of the previous research in the dance context assessing VJP mainly considered jump height assessed by means of two legged vertical jumps tasks (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2012; Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2009; Twitchett et al., 2010; Wyon et al., 2014), therefore when Power is not calculated, classifications using the terms weaker or stronger or powerful, based only in jump height may reveal inaccurate. No body side discrimination may also be a limiting element. A study by Wyon et al. (2014) (Wyon et al., 2014) although not considering LE Power, assessed knee extension maximal isometric strength. Maximum muscular strength is known to be the physiological parameter that has more influence on external mechanical power (EMP) production (Carvalho & Carvalho, 2006; Suchomel et al., 2016; Taber et al., 2016; Winter et al., 2016), and with the exception of Wyon´s study, research on lower body maximum strength relation with LE Power and injuries are a clear limitation in the current state of knowledge including the present study. Future research examining VJP may benefit of including maximum muscular strength assessments as well as determining the force-time and force-velocity curves associated with EMP production (Suchomel et al., 2016). The first because greater muscular strength may modify the force-time characteristics of an individual (Suchomel et al., 2016; Taber et al., 2016). Specifically it is known that stronger individuals may exhibit distinct force-time curve characteristic such as unweighted phase duration, jump phase shape and net impulse forces when compared to weaker individuals (Suchomel et al., 2016). The second, because the dynamic features of Power production concerning strength and velocity may possess different proportional contributions among individuals (Carvalho & Carvalho, 2006; Taber et al., 2016). In addition, studies using prospective designs concerning injury data collection and pre-season assessment of muscular strength and strength related parameters such as Power, must take into considerations that those parameters may not remain stable across a season (Meeuwisse et al., 2007) and therefore may not be the same at the time of injury.

LE Power is a skill-related component of physical fitness (Caspersen, Powell, & Christenson, 1985) which defines the dynamic characteristics of force application (i.e. impulse-momentum relationship) on a given task (Carvalho & Carvalho, 2006). In what concerns to Power gains, the movement expressions in dance, as well as in sports, result from a set of motor actions, composed by motor gestures resulting from multi-joint muscle actions. Inter-muscular coordination will define the efficiency level of cooperation between agonists, antagonists and synergists. This process, however, is highly task-specific and possesses very little transference from one motor task to another (Carvalho & Carvalho, 2006), because the extent to which muscles are involved in one task is not the same as in another (Flanagan & Salem, 2007; Riemann, Lapinski, Smith, & Davies, 2012; Swinton, Stewart, Agouris, Keogh, & Lloyd, 2011). A recent study by Ambegaonkar et al. (Ambegaonkar et al., 2018) found that single leg hop horizontal performance was associated with LE injury risk in collegiate female dancers χ^2=5.9, *p*=0.02, with a predictive cut-off value of 78.2%. In the same study, no relations were found between VJP and injury. Although it is an important finding it may be conditioned by the context since the study population featured only female modern dancers. In what concerns to classical ballet, the jump type more often associated with injury mainly implies a vertical and repetitive component (Allen et al., 2012; Bowerman et al., 2015), meaning that the findings of the aforementioned study may not translate to classical dance style. Skill proficiency association with VJP and injury is lacking and also may represent a fertile ground for future research within dance literature.

In the present work multivariate regression analysis found no association between the selected VJP parameters and injury history, meaning that in our population no predictive factor was able to be identified. With concern to jump type, male dancers jump significantly higher and develop more Power than females which is consistent with previous studies in dance (Wyon et al., 2006) and sports (Quatman, Ford, Myer, & Hewett, 2006). For all participants, body side asymmetries regarding BDI and SI proved to be similar and inferior to 10%, thus not representing an added risk factor for injury (Gustavsson et al., 2006).

One of the major gaps found in current knowledge concerning this topic, is the lack of information on male dancers and study designs considering injury type and mechanism related with VJP. Within the dance repertoire, and especially in classical ballet, male dancers are the most required for jumping tasks (Wyon et al., 2006). Identifying gender pattern distribution may reveal useful in future research and in injury management and prevention. With concern to injury location, previous studies pointed the knee as one potential location in male dancers (Nilsson, Leanderson, Wykman, & Strender, 2001) and the foot and ankle for females (Nilsson et al., 2001; Yau et al., 2017). Our results are in line with some of the previous data for total LE injuries in our population. With respect to the injuries involving jumps, the lower leg was the most dominant anatomical region in both genders. Within the dance context, lower leg injuries are found to be associated with overuse mechanism (Khan et al., 1995; Negus, Hopper, & Briffa, 2005). In our study, male dancers have demonstrated a trend towards the strongest side with respect to injury frequency. This may suggest that the strongest side in male dancers is the most exposed during practice increasing the probability of sustaining an injury.

Summarizing, the product of VJP assessment (LE Power and jump height) through double and single leg CMJ, proved ineffective in distinguishing between injured and non-injured dancers when asymptomatic and in identifying injury risk proneness. The potential role of VJP in injury dynamics requires future research to examine the determinants of EMP under different conditions associated with dance-specific jumping tasks process and how do they relate with injury history and/or with other risk factors.

4.3.7. Limitations

We acknowledge several limitations in the present study. The number of participants without LE injury history was low for both genders, which may not be truly representative of the respective sub-group. In addition, and despite of our sample being mostly composed by advanced level students over the age of 16, it also featured students from beginner and intermediate levels with an inferior age range. Different skill levels and given the age range, the maturational status, both may influence the injury pattern distribution and VJP outcome within genders. Nevertheless, due to the sample distribution characteristics such discriminative analysis was not possible. Future studies with a larger sample and pre-defined sub-groups concerning skill level and maturational status may be of benefit to clarify this issue.

4.3.8. Conclusions

The present study results elicited a critical analysis regarding the several potential reasons why the state of knowledge concerning the relationship between VJP and injuries is still so limited. Although the nature of that relation may still reveal a complex matter for future research, the overall conclusion can be quite straightforward: stronger dancers get injured too. The relation between VJP and injuries in dancers, may more likely be related with the dancer intrinsic features involved in the lower body EMP production process to meet the demands of dance-specific tasks, than with the VJP final product. In that sense future research may benefit of study designs aiming to assess dance-specific jump tasks and the associated determinants of EMP production such as the force-velocity curve, the force-time curve, skill proficiency and reactive strength.

4.3.9. References

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Chapter V - General Discussion

"The absence of evidence is not the evidence of absence"

Carl Sagan

The present work comprises three studies featuring the course of the investigation: a systematic review of literature; a prospective, non-randomized, observational study; a cross-sectional study. The discussion of the results of the aforementioned studies can be found described in detail in Chapter IV on the respective sections. Along the following chapter, there will be presented the link between studies, based on main conclusions according to the stages of the investigation.

5.1. Linking the Studies

Whenever a research project is designed, several approaches and paths to follow are considered possible. The background for this research started with the assumption that muscle strength could have some type of relation with musculoskeletal (MSK) injuries in dancers. But what would it be? At a first glance, it would seem relatively straightforward to draw a hypothesis from some current literature suggestion. According to some authors, dance, particularly ballet, is a high intensity activity requiring high reserves of muscular power and strength (Koutedakis, Clarke, Wyon, Aways, & Owolabi, 2009; Malkogeorgos, Zaggelidou, Zaggelidis, & Christos, 2013; Twitchett, Koutedakis, & Wyon, 2009). Moreover, the dance-only technical training system, typical of pre-professional dance teaching, elicits limited stimuli for positive and significant adaptations concerning muscular strength (Malkogeorgos et al., 2013; Twitchett et al., 2009). Based on the previous, it would be expected that in what concerns to muscular strength, "weaker" dancers would be more prone for sustaining musculoskeletal (MSK) injuries than "stronger" dancers. However, the relation between strength and injuries revealed far more complex than expected. Through a closer look at the problem and after an in-depth review of literature corresponding to Study I presented in the Chapter IV of this work, we were compelled to question the potential validity of the aforementioned preliminary hypothesis. Despite of the observed trend in dance science literature suggesting that muscle strength may play a preventive role against injuries and may be considered a predictive factor for injury proneness (Allen, Nevill, Brooks, Koutedakis, & Wyon, 2012; Ambegaonkar, Caswell, Winchester, Caswell, & Andre, 2012; Angioi, Metsios, Metsios, Koutedakis, & Wyon, 2009; Caine, Goodwin, Caine, & Bergeron, 2015; Koutedakis, Frischknecht, & Murthy, 1997; Koutedakis, Khaloula, Pacy, Murphy, & Dunbar, 1997; Koutedakis, Stavropoulos-Kalinoglou, & Metsios, 2005; Liederbach, Hagins, Gamboa, & Welsh, 2012; Malkogeorgos et al., 2013; Mistiaen et al., 2012; Reid, 1988; Roussel et al., 2014; Russel & Jeffrey 2013; Twitchett et al., 2010; Twitchett et al., 2009) the findings of our review of literature, reveal that although there was observed an association trend towards low muscle strength and dance injuries, the nature of that relation remains unclear. Most of the information found was either limited or questionable. The reasons concerned the small number of studies found and the overall methodological weakness. In fact, the current state of knowledge seemed more supported by grey literature opinions and beliefs than by high quality scientific evidence.

Nevertheless, the absence of evidence may not be the evidence of absence. The gaps found in literature needed to be bridged before addressing to the muscular strength role in injury dynamics. In fact, the biggest challenge of this work was to build a logic background, which could allow to look at the problem through the right perspective. First, it was required a deeper understanding of the injury phenomenon. Dance injuries, as the ones in any other athletic activity, are multi-factorial in nature and result from a complex interplay of risk factors that when associated may compose a causal factor for injury (Liederbach et al., 2012; Meeuwisse, Tyreman, Hagel, & Emery, 2007). Meaning that, when an injury occurs, it represents the outcome of that interaction. In second, not all injuries may relate with muscular strength issues. This scenario led to some questions: how do injuries distribute in our population? What type of injuries may more likely relate with muscular strength issues? And with what type of muscular strength? A glimpse of certainty crossed our minds. Before addressing to the muscular strength issue, there was the need of identifying injury patterns within our population. And for that purpose, an epidemiologic study needed to be carried out.

Epidemiological data should be able to provide the basis of understanding for injury research, management and prevention by establishing injury determinants and extent (Liederbach et al., 2012; Meeuwisse et al., 2007; Timpka et al., 2014). In this particular aspect information was still insufficient. Most epidemiological studies in Pre-professional dancers (Bowerman, Whatman, Harris, Bradshaw, & Karin, 2014; Caine et al., 2016; Ekegren, Quested, & Brodrick, 2014; Gamboa, Roberts, Maring, & Fergus, 2008; Leanderson et al., 2011; Lee, Reid, Cadwell, & Palmer, 2017; Luke et al., 2002; Steinberg et al., 2011, 2013; Stracciolini, Yin, & Sugimoto, 2015; Wanke, Mill, & Groneberg, 2012; Yin, Sugimoto, Martin, & Stracciolini, 2016) feature an injury-centered approach based on "after-diagnosis" data, focusing on injury outcome and subsequent burden expressed through rates, risks and frequencies. Although those measures provide important quantitative metrics about the injury burden, they fail to reflect injury patterns dynamics and consequently possess little preventive applicability if not framed into the proper context. Study II addressed several aspects of dance injuries epidemiology that were found to be insufficient, inconclusive or limited across literature. Inevitably, at a certain point, it overlapped the strength issue, going far beyond the outcomes of interest that could be related with muscular strength. Nevertheless, it allowed to build a platform of knowledge for future research in injury management and prevention.

Within the injury patterns identified through Study II, jumps stood out as the motor action mostly associated with injury incidence on the lower extremity (LE) for both genders. Being jumps an integral aspect of dance practice (Ambegaonkar et al., 2018; Malkogeorgos et al., 2013; Twitchett et al., 2009; Wyon, Allen, Angioi, Nevill, & Twitchett, 2006) previous studies also pointed out this motor action as one of the main identifiable mechanisms associated with injury (Allen et al., 2012; Bowerman, Whatman, Harris, & Bradshaw, 2015). Moreover, some authors state that dancers may perform more than 200 jumps in a 1.5h class, with more than half of those involving one-legged landings (Bowerman et al., 2015; Liederbach, Dilgen, & Rose, 2008). For these reasons, LE Power is often considered to be one of the major requirements for jumping performance in dance (Koutedakis et al., 2007; Koutedakis et al., 2005; Malkogeorgos et al., 2013; Twitchett, Angioi, Koutedakis, & Wyon, 2011). In fact, both in dance as in sports, vertical jump performance (VJP) through LE Power and/or jump height, are some of the lower body most used strength-related parameters associated with performance and injury (Lauersen, Bertelsen, & Andersen, 2014; Suchomel, Nimphius, & Stone, 2016). Nevertheless, in dance, the nature of the relation between VJP and injury remains inconclusive, particularly in the pre-professional setting. In that sense, Study III was for us the logical step to be taken upon the course of research. Although some studies within dance science already addressed this issue (Ambegaonkar et al., 2018; Angioi, Metsios, Koutedakis, Twitchett, & Wyon, 2009; Mistiaen et al., 2012; Roussel et al., 2014; Twitchett et al., 2010; Wyon, Koutedakis, Wolman, Nevill, & Allen, 2014) some limitations were found concerning, different populations, study designs, settings and methodological approaches, being therefore, the respective outcomes and conclusions of heterogeneous nature. One of the main limitations concerns study design. The physiological variables associated with performance, such as muscular strength or in this particular case VJP through Power and jump height, may not remain stable over time (Meeuwisse et al., 2007). Also, dancers quite often dance through most of their injuries across a season (Gamboa et al., 2008). Thus, studies assessing VJP, should consider the hypothesis that jumping performance is shaped by the dancer intrinsic features plus the result of dance practice exposure adaptative process (Twitchett et al., 2009; Wyon et al., 2007), either representing a contributing factor for injury, or a consequence of injury history associated with practice. In that sense, it may be of benefit, to identify LE injury patterns associated with VJP based on dancers' previous injury history, instead of using a prospective only design whereas the current status of dancers concerning VJP at the time of injury may not be exactly the same if the injuries occur more towards the end of the season and the jumping tasks assessment has taken place at the beginning.

In our population the product of VJP assessment (LE Power and jump height) through double and single leg CMJ, proved ineffective in distinguishing between injured and non-injured dancers when asymptomatic and in identifying injury risk proneness. Even when regression analysis was performed concerning the number of individual injuries sustained no differences were verified. This may suggest that when asymptomatic, training at the same level with no restrictions, the product of VJP is similar between dancers with and without injury history. Several reasons may explain such findings. In our third study, only the product of VJP expressed through Power and jump height were considered for both double and single leg jump tasks. While in some athletic activities the ability to jump higher or farther (i.e. jump task product) may determine who performs the best (Suchomel et al., 2016), within the dance context, jumping performance mostly depends on how (i.e. process) the lower body generates Power to meet task-specific requirements of time and space (Xarez, 1999). This means that some caution is recommended when interpreting this type of data in the context of performance and injury and may partially explain the absence of evidence on the relation between jumping performance and injuries in our study and in some previous published literature (Mistiaen et al., 2012; Roussel et al., 2014; Twitchett et al., 2010). Although jump height is found to be directly proportional to Power output in max VJP within the same individual, it is also true that inter-individually, we may find similar Power outputs associated with different jumps heights and similar jumps heights associated with different Power outputs. Therefore, when comparing different subjects, the ones with the highest jump scores may not necessarily be the most powerful as well as the ones exhibiting higher LE Power may not necessarily be the ones jumping higher (Wyon et al., 2006). Furthermore, also several factors are suggested to influence the process of external mechanical power (EMP) production and subsequently VJP (Carvalho & Carvalho, 2006; Sharma, Gandhi, Meitei, Dvivedi, & Dvivedi, 2017; Suchomel et al., 2016; Taber, Bellow, Abbott, & Bingham, 2016; Winter et al., 2016; Wyon et al., 2006). Some may relate with anthropometric factors (Sharma et al., 2017; M. Wyon et al., 2006), others with physiological factors such as muscular strength (Suchomel et al., 2016; Taber et al., 2016) and others with task-related skill-proficiency factors (Carvalho & Carvalho, 2006; Winter et al., 2016). In sports, stronger athletes exhibit higher muscular strength levels and low injury rates when compared to weaker athletes (Lauersen et al., 2014; Suchomel et al., 2016). Conversely, within dance context, the dancers with the higher performance capabilities are also the most requested and consequently more exposed to practice, which may increase the probability of sustaining an injury. Also, within our results, male dancers have demonstrated a trend towards the strongest side with respect to injury frequency incidence, suggesting that the strongest side may be the most exposed during practice thus increasing injury probability.

The potential role of VJP in injury dynamics requires future research to examine the determinants of EMP under different conditions associated with dance-specific jumping tasks process and how do they relate with injury history and/or with other risk factors.

5.2. Limitations

The present work comprises two kinds of limitations: the limitations inherent to the developed studies and the limitation in giving a full answer about the nature of the relation between dance injuries and muscular strength.

With regard to Study I, the number of studies found and included prove to be low both in number and methodological quality. The heterogeneity of study designs and methodologies used made difficult to compare results, establish cause-effect relation between muscle strength and injury, and draw consistent conclusions. The eligibility of only English language publications in study selection may also have represented a limiting factor by excluding other potentially relevant studies.

The main limitation of Study II was the inability in controlling injury underreporting, which may have omitted some injury cases recording. Furthermore, with regard to motor actions analysis concerning the inciting event for injury, it should be mentioned that “Jumps” and “Gestures” encompass several different motor tasks such as two-legged jumps, one-legged jumps, trunk gestures, lower and upper extremity gestures, among others. For analysis purposes it was not possible to discriminate those motor tasks sub-categories. Therefore, they were grouped into an umbrella motor action category corresponding to the ones presented in Study II. Future research should consider discriminating these motor actions sub-categories associated with specific injury types and mechanism.

In Study III, there were acknowledged several limitations. The number of participants without LE injury history was low for both genders, which may not be truly representative of the respective sub-group. In addition, and despite of our sample being mostly composed by advanced level students over the age of 16, it also featured students from beginner and intermediate levels with an inferior age range. Different skill levels and given the age range, the maturational status, both may influence the injury pattern distribution and VJP outcome within genders. Nevertheless, due to the sample distribution characteristics such discriminative analysis was not possible. Future studies with a larger sample and pre-defined sub-groups concerning skill level and maturational status may be of benefit to clarify this issue.

When the state of the art was defined through the systematic review of literature in Study I, several gaps were found in the body of knowledge. Those gaps needed to be bridged before advancing. The efforts made to fulfil that purpose have dictated the path of research. Although the goal of building a solid platform of knowledge for addressing the research problem adequately, has been accomplished, the state of knowledge at this point of the investigation does not allow to provide an in-depth clarification about the role of muscular strength in dance injuries.

5.3. Future directions

As previously mentioned, it is important to note that due to the complexity of the theme, the research is still ongoing, and the studies comprised in this work, reflect the course of research so far. The several questions raised by the developed studies undoubtedly represent fertile ground for future research. Many of those questions are highlighted in the discussion and conclusion sections of Study I and can be consulted in Chapter IV. The future directions hereby presented represent the work in progress resulting from the link between studies.

With respect to the elements of muscular strength involved in jumping performance, it is suggested that greater muscular strength may modify the force-time characteristics of an individual (Suchomel et al., 2016; Taber et al., 2016). Specifically, stronger individuals may exhibit distinct force-time curve characteristic such as unweighted phase duration, jump phase shape and net impulse forces when compared to weaker individuals (Suchomel et al., 2016). Furthermore it should be considered that Power is a skill-related component of physical fitness (Caspersen, Powell, & Christenson, 1985) which defines the dynamic characteristics of force application (i.e. impulse-momentum relationship) on a given task (Carvalho & Carvalho, 2006). The movement expressions in dance, as well as in sports, result from a set of motor actions, composed by motor gestures resulting from multi-joint muscle actions. Inter-muscular coordination may define the efficiency level of cooperation between agonists, antagonists and synergists. This process, however, is highly task-specific and possesses very little transference from one motor task to another (Carvalho & Carvalho, 2006), because the extent to which muscles are involved in one task is not the same as in another (Flanagan & Salem, 2007; Riemann, Lapinski, Smith, & Davies, 2012; Swinton, Stewart, Agouris, Keogh, & Lloyd, 2011). Within dance science most of the approaches assessing LE Power mainly focus on the product of jumping tasks performance such as Power and/or jump height or distance (Ambegaonkar et al., 2018; Angioi et al., 2009; Mistiaen et al., 2012; Roussel et al., 2014; Twitchett et al., 2010; Wyon et al., 2014). Since the dynamic features of Power production concerning strength and velocity may possess different proportional contributions among individuals (Carvalho & Carvalho, 2006; Taber et al., 2016). Future research may benefit in including maximum muscular strength and EMP production process assessments in order to determine the force-time and the force-velocity curves (Suchomel et al., 2016; Taber et al., 2016). Also, and still in what concerns to Power production by the LE, the repetitive nature of dance training often requires of dancers the capability to maintain the Power output through sequences of jump series. As mentioned in Study I, studies assessing repetitive jump capabilities are missing and should be considered in future studies, particularly the ones focusing in overuse injuries associated with jumps.

Study I also suggested that the functional aspects of muscle strength within dance context to be taken into consideration. Quite often, we hear dance teachers saying: *you are using the wrong muscles*! In fact, within the dance world, the mastery of technique is so important that faulty technique is considered to be one of the major causes of injury, creating undesired movement patterns and subsequently muscular imbalances. Nonetheless, we should also highlight that even within dance technique when correctly performed, the extreme ranges of motion required are in themselves, promoters of muscular imbalances, such as: strong hip external rotators vs weak internal rotators, strong hip abductors vs weak hip adductors and strong ankle plantar flexors vs weak ankle dorsi flexors.

In Study II, the incidence of lower leg injuries was found to be of particular relevance in advanced level dancers. Also, in Study III, the lower leg was the most prevalent anatomical location with respect to LE injuries involving jumps for both genders with 55.6% and 58.3% of injured males and females respectively. Based on the previous line of thought, the Medial Tibial Stress Syndrome (MTSS) is a common clinical condition on the lower leg caused by repetitive loading stress during running and jumping activities, occurring in 4% to 35% of athletic and military populations (Kudo & Hatanaka, 2015; Verrelst et al., 2014). In dance, MTSS was found to be one of the most prevalent overuse injuries in the lower leg particularly in ballet dancers (Khan et al., 1995; Negus, Hopper, & Briffa, 2005). MTSS is associated with underlying periostitis of the tibia secondary to tibial strain as well as a spectrum of tibial stress injuries, including tendinopathy, periostitis, periosteal remodelling, and stress reaction of the tibia (Kudo & Hatanaka, 2015; Verrelst et al., 2014).

In general, risk factors are commonly divided into two categories: intrinsic and extrinsic factors. The main extrinsic risk factor is strongly associated with mechanical overload of the lower leg induced by repetitive strain from loading forces during weight-bearing activities (Willems et al., 2006). From amongst the intrinsic risk factors for developing MTSS, greater external knee adduction moments, greater knee valgus, hip internal rotation and hip adduction during landing, were found to be significantly related (Verrelst et al., 2014). In one study featuring professional ballet dancers, it was found that the number and severity of non-traumatic injuries were associated with reduced functional turnout (p<05) (Negus et al., 2005). Also, excessive foot pronation has been described as a link in the development of numerous lower limb pathologies, including MTSS (Chuter & Janse de Jonge, 2012; Willems et al., 2006).

Nevertheless the role of a proximal-to-distal directed mechanism in lower extremity injuries has not been fully described, meaning that risk factors for MTSS are not well understood (Reinking, 2007) and there is still a lack of objective evidence to support the use of existing interventions to prevent medial tibial pain (Thacker, Gilchrist, Stroup, & Kimsey, 2002). One study hypothesised that female athletes who develop MTSS, may exhibit lower strength levels of the hip abductors and external rotators muscles, when compared with individuals who not develop MTSS (Verrelst et al., 2014). It was found that decreased hip abductor concentric strength is a predictive parameter for the development of MTSS in females. More specifically, total work (p=0.010) and average power (p=0.045) for concentric abduction strength were found to be significant predictors for this clinical condition. Similar studies found significantly lower hip abduction and external rotation strength in athletes sustaining lower limb injuries (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004; Niemuth, Johnson, Myers, & Thieman, 2005). However, no specific mechanism could be described on the role of hip strength parameters in the development of MTSS, since general lower limb injuries were included in the studies and the role of context and task specific technique were not considered. Although we should keep in mind that the aforementioned studies aimed to athletic populations on which the movement patterns are essentially executed in the sagittal plane without the technical demand of keeping the lower limb aligned in external rotation. When addressing to this particular question in dancers the hip external rotation should be tested functionally concerning the context requirements of practice. Therefore, within our line of research, we hypothesized that dancers more prone to develop MTSS may have lower hip turnout muscular strength when compared to dancers that do not develop MTSS.

Conclusions

"It is not the strongest species that survive, nor the most intelligent, but the ones most responsive to change"

Charles Darwin

This work focused in the study of the relationship between dance injuries and muscular strength in the pre-professional setting. Whenever the research theme concerns injuries resulting from a specific activity, such as dance or sports, irrespectively of the elements that potentially might be associated as risk factors, it is determinant to know the injury context and the respective patterns. Through the course of research, several limitations were found in this field related with inconsistent or unreported information. Dance injuries happen because of dance practice. Throughout the pre-professional training period, the dancers technical and artistic repertoire evolve and differs according to gender and skill level. Defining injury patterns and their respective background, may help to differentiate the ones most likely to be related with determined risk factors, such as muscular strength, in those sub-groups.

This work represents only the tip of the iceberg with respect to the knowledge on the relationship between dance injuries and muscular strength. Not all dance injuries relate with muscle strength issues. Beyond that, stronger dancers do get injured too. The role of muscular strength in injury proneness may more likely be related with task-specific strength production processes to meet the demands of dance practice, than with the final observed product within the concept of "stronger" or "weaker".

Conclusões

“Não são as espécies mais fortes que sobrevivem, nem as mais inteligentes, mas as que melhor se adaptam à mudança”

Charles Darwin

O foco deste trabalho centrou-se na relação entre as lesões da dança e a força muscular no cenário pré-profissional. Sempre que o tema da pesquisa diz respeito a lesões decorrentes de uma atividade específica, como dança ou o desporto, independentemente dos elementos que potencialmente possam estar associados como fatores de risco, é determinante conhecer o contexto da lesão e os respetivos padrões. Ao longo do curso da investigação, foram encontradas várias limitações neste campo relacionadas com informações inconsistentes ou não reportadas. As lesões da dança acontecem por causa da prática da dança. Ao longo do período de formação pré-profissional, o repertório técnico e artístico dos bailarinos evolui e difere de acordo com o gênero e o nível de habilidade. A definição dos padrões de lesão e seus respetivos antecedentes, podem ajudar a diferenciar aquelas com maior probabilidade de estarem relacionados com determinados fatores de risco, como a força muscular, nesses subgrupos.

Nesse sentido, este trabalho representa apenas a ponta do iceberg no que diz respeito ao conhecimento sobre a relação entre lesões de dança e força muscular. Nem todas as lesões da dança poderão estar relacionadas com problemas de força muscular. Além disso, os bailarinos/as mais fortes também sofrem lesões. O papel da força muscular na propensão para as lesões, pode mais provavelmente estar relacionado com o processo de produção de força num contexto específico da tarefa em função das exigências da prática, do que com o produto final observado dentro do conceito de "forte" ou "fraco".

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Appendix

Appendix 1 - Data extraction form

Article title:
Main reason for inclusion in the review:
Study design:
Study purpose:
Subject details (age/gender/other)
Inclusion and exclusion criteria:
Dance style:
Recruitment/Selection:
Sample size:
Study variables:
Instruments:
Main outcomes:

Appendix 2 - Description of the quality assessment tool: Downs & Black (1998)

Items	
Reporting	**Score**
1. Is the hypothesis/aim/objective of the study clearly described?	Yes: 1 No: 2
2. Are the main outcomes to be measured clearly described in the Introduction or Methods section?	Yes: 1 No: 2
3. Are the characteristics of the patients included in the study clearly described?	Yes: 1 No: 2
4. Are the interventions of interest clearly described?	Yes: 1 No: 2
5. Are the distributions of principal confounders in each group of subjects to be compared clearly described?	Yes: 2 Partially: 1 No: 0
6. Are the main findings of the study clearly described?	Yes: 1 No: 2
7. Does the study provide estimates of the random variability in the data for the main outcomes?	Yes: 1 No: 2
8. Have all important adverse events that may be a consequence of the intervention been reported?	Yes: 1 No: 2
9. Have the characteristics of patients lost to follow-up been described?	Yes: 1 No: 2
10. Have actual probability values been reported (e.g. 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?	Yes: 1 No: 2
External validity	
11. Were the subjects asked to participate in the study representative of the entire population from which they were recruited?	Yes: 1 No: 0 Unable to determine: 0
12. Were those subjects who were prepared to participate representative of the entire population from which they were recruited?	Yes: 1 No: 0 Unable to determine: 0
13. Were the staff, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive?	Yes: 1 No: 0 Unable to determine: 0
Internal validity (Bias)	
14. Was an attempt made to blind study subjects to the intervention they have received?	Yes: 1 No: 0 Unable to determine: 0
15. Was an attempt made to blind those measuring the main outcomes of the intervention?	Yes: 1 No: 0 Unable to determine: 0
16. If any of the results of the study were based on “data dredging”, was this made clear?	Yes: 1 No: 0 Unable to determine: 0
17. In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls?	Yes: 1 No: 0 Unable to determine: 0
18. Were the statistical tests used to assess the main outcomes appropriate?	Yes: 1 No: 0 Unable to determine: 0
19. Was compliance with the intervention/s reliable?	Yes: 1 No: 0

	Unable to determine: 0
20. Were the main outcome measures used accurate (valid and reliable)?	Yes: 1 No: 0 Unable to determine: 0
Internal validity (Confounding)	
21. Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?	Yes: 1 No: 0 Unable to determine: 0
22. Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?	Yes: 1 No: 0 Unable to determine: 0
23. Were study subjects randomised to intervention groups?	Yes: 1 No: 0 Unable to determine: 0
24. Was the randomised intervention assignment concealed from both patients and health care staff until recruitment was complete and irrevocable?	Yes: 1 No: 0 Unable to determine: 0
25. Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?	Yes: 1 No: 0 Unable to determine: 0
26. Were losses of patients to follow-up taken into account?	Yes: 1 No: 0 Unable to determine: 0
Power	
27. Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?	$<n_1$ =0 n_1-n_2 =1 n_3-n_4 =2 n_5-n_6 =3 n_7-n_8 =4 n_8+ =5
Max achievable score	32

Appendix 3 - Level of Evidence and Grades of Recommendation based on the Centre for Evidence Based Medicine (CEBM), (Howick et al., 2011)

Level of Evidence

Level	Application context	Study design
1A	- Therapy/Prevention, Aetiology/Harm - Prognosis - Diagnosis - Differential diag./symptom prevalence - Economic and decision analyses	SR (with homogeneity) of RCTs SR (with homogeneity) of inception cohort studies SR (with homogeneity) of Level 1 diagnostic studies SR (with homogeneity) of prospective cohort studies SR (with homogeneity) of Level 1 economic studies
1b	- Therapy/Prevention, Aetiology/Harm - Prognosis - Diagnosis - Differential diag./symptom prevalence - Economic and decision analyses	Individual RCT (with narrow Confidence Interval) Individual inception cohort study with > 80% follow-up Validating cohort study with good reference standards Prospective cohort study with good follow-up Analysis based on clinically sensible costs or alternatives; systematic review(s) of the evidence; and including multi-way sensitivity analyses
1c	- Therapy/Prevention, Aetiology/Harm - Prognosis - Diagnosis - Differential diag./symptom prevalence - Economic and decision analyses	All or none All or none case series Absolute SpPins and SnNouts All or none case-series Absolute better-value or worse-value analyses
2a	- Therapy/Prevention, Aetiology/Harm - Prognosis - Diagnosis - Differential diag./symptom prevalence - Economic and decision analyses	SR (with homogeneity) of cohort studies SR (with homogeneity) of either retrospective cohort studies or untreated control groups in RCTs SR (with homogeneity) of Level >2 diagnostic studies SR (with homogeneity) of 2b and better studies SR (with homogeneity) of Level >2 economic studies
2b	- Therapy/Prevention, Aetiology/Harm - Prognosis - Diagnosis - Differential diag./symptom prevalence - Economic and decision analyses	Individual cohort study (including low quality RCT; e.g., <80% follow-up) Retrospective cohort study or follow-up of untreated control patients in an RCT validated on split sample Exploratory cohort study with good reference standards Retrospective cohort study, or poor follow-up Analysis based on clinically sensible costs or alternatives; limited review(s) of the evidence, or single studies
2c	- Therapy/Prevention, Aetiology/Harm - Prognosis - Diagnosis - Differential diag./symptom prevalence - Economic and decision analyses	"Outcomes" Research; Ecological studies "Outcomes" Research Ecological studies Audit or outcomes research
3a	- Therapy/Prevention, Aetiology/Harm - Prognosis - Diagnosis - Differential diag./symptom prevalence - Economic and decision analyses	SR (with homogeneity) of case-control studies SR (with homogeneity) of 3b and better studies SR (with homogeneity) of 3b and better studies SR (with homogeneity) of 3b And better studies
3b	- Therapy/Prevention, Aetiology/Harm - Prognosis - Diagnosis - Differential diag./symptom prevalence - Economic and decision analyses	Individual Case-Control Study Non-consecutive study or without consistently applied reference standards Non-consecutive cohort study, or with very limited population Analysis based on limited alternatives or costs, poor quality estimates of data, but including sensitivity analyses incorporating clinically sensible variations.
4	- Therapy/Prevention, Aetiology/Harm - Prognosis - Diagnosis - Differential diag./symptom prevalence - Economic and decision analyses	Case-series (and poor quality cohort and casecontrol studies) Case-series (and poor quality prognostic cohort studies) Case-control study, poor or non-independent reference standard Case-series or superseded reference standards Analysis with no sensitivity analysis
5	- Therapy/Prevention, Aetiology/Harm* - Prognosis* - Diagnosis* - Differential diag./symptom prevalence* - Economic and decision analyses[#]	Expert opinion without explicit critical appraisal, or based on physiology, bench research or "first principles"* Expert opinion without explicit critical appraisal, or based on economic theory or "first principles"[#]

Grades of Recommendation

Grade	Description
A	Consistent level 1 studies
B	Consistent level 2 or 3 studies or extrapolations from level 1 studies
C	Level 4 studies or extrapolations from level 2 or 3 studies
D	Level 5 evidence or troublingly inconsistent or inconclusive studies of any level

Appendix 4 - Included studies

Main author	Title	Year	Journal
Koutedakis	Knee Flexion to Extension Peak Torque Ratios and Low-Back Injuries in Highly Active Individuals	1997	*International Journal of Sports Medicine*
Koutedakis	Thigh Peak Torques and Lower-Body Injuries in Dancers	1997	*Journal of Dance Medicine and Science*
Gamboa	Injury Patterns in Elite Preprofessional Ballet Dancers and the Utility of Screening Programs to Identify Risk Characteristics	2008	*Journal of Orthopaedic and Sports Physical Therapy*
Angioi	Physical Fitness and Severity of Injuries in Contemporary Dance	2009	*Medical Problems of the Performing Artists*
Twitchet	Does Physical Fitness Affect Injury Occurrence and Time Loss Due to Injury in Elite Vocational Ballet Students?	2010	*Journal of Dance Medicine and Science*
Mistiaen	Effects of Aerobic Endurance, Muscle Strength, and Motor Control Exercise on Physical Fitness and Musculoskeletal Injury Rate in Preprofessional Dancers: An Uncontrolled Trial	2012	*Journal of Manipulative and Physiological Therapeutics*
Roussel	Effect of a physical conditioning versus health promotion intervention in dancers: A randomized controlled trial	2014	*Manual Therapy*
Swain	Trunk Muscle Endurance and Low Back Pain in Female Dance Students	2014	*Journal of Dance Medicine and Science*

Appendix 5 - Excluded studies after full text assessment

Main author	Year	Reason for exclusion
Agopyan	2013	No injury data assessed
Ambegaonkar	2012	No injury data assessed
Askling	2006	Muscle strength as a dependent variable of functional status during injury recovery
Echegoyen	2013	Muscle strength as a dependent variable of technique execution
Lee	2012	Muscle strength not objectively assessed
McCabe	2013	Muscle strength not objectively assessed
Parnianpour	1994	No injury data assessed
Schmitt	2005	Injury data used as an independent variable
Shan	2005	Muscle strength not objectively assessed
Shippen	2010	Muscle strength as a dependent variable of technique execution
Twitchett	2011	Muscle strength as an independent variable related with aesthetics and performance and not with injury
Kline	2013	Ineligible study design

Appendix 6 - Informed Consent

Consentimento Informado Livre e Esclarecido para Investigação Científica com Seres Humanos

Título do projeto ou estudo:

Força Muscular e Lesões em Dança em Bailarinos Pré-Profissionais

(Dance Injuries and Muscle Strength in Pre-Professional Dancers)

Pessoa responsável pelo projeto:

Luís Miguel Xarez Rodrigues

Instituição de acolhimento:

Faculdade de Motricidade Humana – Universidade de Lisboa (Laboratório de Comportamento Motor)

Este documento, designado **Consentimento, Informado, Livre e Esclarecido**, contém informação importante em relação ao estudo para o qual foi abordado/a, bem como o que esperar se decidir participar no mesmo. Leia atentamente toda a informação aqui contida. Deve sentir-se inteiramente livre para colocar qualquer questão, assim como para discutir com terceiros (amigos, familiares) a decisão da sua participação neste estudo.

Informação geral
O objetivo deste projeto de investigação é caracterizar a potencial relação entre os vários tipos e expressões de força muscular e as lesões músculo-esqueléticas decorrentes da prática artística da dança em bailarinos pré-profissionais. Para isso serão avaliados parâmetros de força considerados fundamentais dentro do contexto da prática artística da dança atendendo às suas exigências técnicas e coreográficas bem como dados referentes ao tipo e etiologia da lesão.
Qual a duração esperada da minha participação?
As tarefas nas quais irá participar não ultrapassarão os 20 minutos de duração por tarefa executada. As mesmas serão executadas em dias diferentes de acordo com a disponibilidade e condição física do participante.
Quais os procedimentos do estudo em que vou participar?
Todas as tarefas serão precedidas de um aquecimento. As tarefas a realizar incluem: • Avaliação antropométrica: massa corporal; altura; comprimento dos segmentos corporais • Avaliação das amplitudes articulares dos membros inferiores • Execução de saltos máximos e saltos consecutivos • Movimentos de força máxima direcionados aos músculos com ação motora na articulação coxo-femoral.

A minha participação é voluntária?
A sua participação é voluntária e pode recusar-se a participar. Caso decida participar neste estudo é importante ter conhecimento que pode desistir a qualquer momento, sem qualquer tipo de consequência para si. No caso de decidir abandonar o estudo, a sua relação com a Escola de Dança do Conservatório Nacional (EDCN) não será afetada não sofrendo nenhuma consequência da sua não-participação ou desistência.
Quais os possíveis benefícios da minha participação?
Para além de ficar com um registo detalhado dos parâmetros avaliados, será possível identificar fatores de risco para a lesão relacionados com esses mesmos parâmetros caso existam, podendo atuar sobre eles se necessário e/ou desejável.
Quais os possíveis riscos da minha participação?
Em todas as tarefas motoras podem existir riscos de ordem física associados às tarefas de teste nomeadamente os saltos, que se podem resumir essencialmente a quedas ou má receção do salto ao solo por parte do participante. Em caso de acidente ou desconforto físico, os testes serão prontamente interrompidos e o participante assistido de imediato por um elemento com formação clínica e experiência. Caso se justifique será encaminhado para o serviço de saúde adequado.
Como é assegurada a confidencialidade dos dados?
Os dados recolhidos serão guardados no computador pessoal do investigador responsável pelos dados e apenas esse investigador terá acesso à identificação dos participantes. A confidencialidade do processo garante-se através da utilização de códigos para a identificação dos participantes de forma a garantir que outros elementos da equipa de investigação possam aceder aos dados mantendo sempre a confidencialidade e o anonimato dos participantes.
O que acontecerá aos dados quando a investigação terminar?
Após o término da investigação os dados serão guardados pelo investigador responsável, utilizando códigos para a identificação dos participantes, garantindo-se sempre a confidencialidade e o anonimato.
Como irão os resultados do estudo ser divulgados e com que finalidades?
Os resultados serão divulgados em formato de artigo científico em revistas/jornais científicas/os, garantindo-se sempre o anonimato dos participantes e da instituição envolvida.
Em caso de dúvidas quem devo contactar?
Para qualquer questão relacionada com a sua participação neste estudo, por favor, contactar: Luís Xarez, **Tlm:** 966002168, **Email:** lxarez@gmail.com João Paulo Moita, **Tlm:** 966884620, **Email:** jp_moita@hotmail.com

Assinatura do Consentimento Informado, Livre e Esclarecido

Li (ou alguém leu para mim) o presente documento e estou consciente do que esperar quanto à minha participação no estudo *Dance Injuries and Muscle Strength in Pre-Professional Dancers*. Tive a oportunidade de colocar todas as questões e as respostas esclareceram todas as minhas dúvidas. Assim, aceito voluntariamente participar neste estudo. Foi-me dada uma cópia deste documento.

Nome do participante **Assinatura do participante**

Data

Nome do representante legal do participante
(se aplicável)

Grau de relação com o participante

Investigador/Equipa de Investigação

Os aspetos mais importantes deste estudo foram explicados ao participante ou ao seu representante, antes de solicitar a sua assinatura. Uma cópia deste documento ser-lhe-á fornecida.

Nome da pessoa que obtém o consentimento **Assinatura da pessoa que obtém o consentimento**

Data

Appendix 7 - Study II, Injury Reporting Framework

Item	Information type
Subject identification	
Name:	*For research purposes the name was coded*
Age:	*Years old*
Dance year:	*From 1º to 8º*
Skill level:	*Entry/ Intermediate/Advanced*
Academic year enrolment:	
Occurrence identification	
Reason for visit number:	
Date:	*Day – Month – Year*
Occurrence description	
Anatomical location:	*Foot/ Ankle/ Leg/ Knee/ Thigh/ Pelvis and Hip/ Low back/ Thoracic spine and Ribs/ Head and Neck/ Shoulder/ Arm and Elbow/ Forearm, Wrist and Hand*
Reason for visit:	*New complaint/ Recurrent complaint/ Follow up from previous complaint/ Technical advice/ Other*
Symptoms onset chronometry:	*Aims to identify the first onset and should be described in #days or #months from first time symptoms manifest*
Complaint type:	*Index/ Local/ Early Recurrence (< 2 months)/ Late recurrence (2-12 months)/ Delayed recurrence (> 12 months)/ Exacerbation*
Onset type:	*Insidious/ Acute*
Context	
Activity type:	*Class/ Rehearsal/ Performance/ Other (i.e. Non-dance related activity or Don´t know/remember)*
Style:	*Classic/ Modern/ Other (i.e. Traditional dance; Tap dance; Creative expression)*
Class type:	*Technique/ Repertoire/ Pas-de-Deux/ Other (i.e. Physical conditioning; Yoga; Pilates)*
Inciting event:	*Identify the exercise being performed at the time symptoms arise and/or self-perceived mechanism/ If the subject can't identify or don't remember it should be reported as "Unidentified"*
Inciting event motor action category:	***Jumps:** Actions with a total aerial phase without support/ **Falls:** Actions carried out in the direction of the ground, with weight transference between supports and without aerial phase/ **Displacements:** Actions of cyclic and consecutive weight transference between supports/ **Steps:** Actions of weight transference between two supports/ **Postures:** Actions of immobility performed on stable support/ **Gestures:** Actions*

	of segmental movements performed on fixed support(i.e. lower limb anatomical segment; trunk segment; upper limb segment) / ***Balance:*** *Actions of immobility performed on reduced support/* ***Turns:*** *Actions of change of direction performed through rotation on the support/* ***Unidentified***

Annexes

Annex 1 - Study I in the published version