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Dance Medicine

Risk Factors For Dancers‘ Musculoskeletal Injuries

Judith-Elisa Kaufmann

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Dance Medicine

Risk Factors For Dancers‘ Musculoskeletal Injuries

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Chapter 1

General Introduction

1.1 The Background

For pre-professional, professional as well as amateur dancers, dance is a demanding high-performance activity. It requires great dedication and discipline from the dancers involved. In order to ensure overall wellbeing in the broadest sense, as well as at highest levels of performance, a healthy approach to dance teaching and training is vital. At best, injury-preventive approaches are evidence-based, drawing from biomechanically optimal dance technique and fitness levels which take the individual performing athlete into account.[1] Moreover, to ensure mental and psychological wellbeing, high quality of motivation based on an empowering work climate has shown to be vital.[2, 3]

1.2 Dance Medicine & Dance Science

In order to guide dancers and teachers to healthy training and working experiences dance medicine has evolved over the last decades. Dance medicine is part of performing arts medicine, dedicated to investigate, prevent, treat, and rehabilitate injuries while enhancing performance for all dance styles, genders, and age groups.[4] Dance medicine is sometimes considered to be a sub-discipline of sports medicine, stressing the important aspect of athleticism in this virtuous and demanding art form.[5] While sports medicine and science have a long history[6], a specific focus on dance medicine and dance science has evolved only in the late 20th century. Although, the first publications date back to as early as 1824[7], 1898[8], and 1935[9].

To date, dance medicine and dance science have provided an increasing body of research on several topics essential for injury prevention and performance enhancement of dancers, in which classical ballet is the dance style investigated most intensively.

Among the investigated topics are incidence, prevalence, risks, and causes of musculoskeletal injuries in dancers[10-16] as well as the psychological and financial burden of injuries for all stakeholders involved.[17-19] The importance of evidence based planning and scheduling of training[20-24] and the necessity to regard dancers as performing athletes who are supported and encouraged to train and have optimal dietary intake accordingly[20, 25-27] has received a lot of attention. (Neuro-) psychological aspects such as the prevention of eating disorders[28, 29] as well as the correct handling of pain and injury[30-32], the prevention of fatigue[23, 33] and overtraining[34, 35] have been researched.

1.3 The Important Synergy between Dance Medicine & Dance Pedagogy

In order to have dancers of all ages and all levels of expertise benefit from dance medical research, the proactive implementation of scholarly evidence into dance practice is vital. This bridge between scientific results and practical use on site has been discussed in sports medicine, and the coach or trainer has been described as the most important link for this synergy to be effective. [36-41] The coach's/teacher's motivation, compliance as well as their knowledge to implement evidence-based training methods into practice and thus inspire their athletes' compliance is vital for any injury preventive intervention.[39-42]

In dance or ballet, this role would be the ballet teacher's or ballet master's. Their task, teaching dance and guiding dancers, is also known as dance pedagogy, the art and science of teaching dance to students from early childhood to adulthood.[43] In children and adolescent pre-professional as well as amateur ballet dancers of all ages, the teacher is called dance pedagogue or ballet teacher. In professional ballet dancers, the term "ballet master" is used for the person who trains dancers in their every-day profession.

Repeatedly, the importance of a synergy between dance medicine and dance pedagogy – building dance education on the pillars of science – has been advocated by various authors as the most important solution to bringing dancers in touch with dance medicine in order to prevent their injuries.[44-46]

1.4 The Injury Panorama in Dancers

Injuries to dancers, ballet dancers as well as all dancer who include classical ballet as a major training focus such as modern and contemporary styles, can be acute (traumatic) or chronic (repetitive strain overuse). Acute injuries are linked to an identifiable event and a precise onset[47] during a dancer's performance, rehearsal, or training. Although prevalence and incidence of acute injuries are high in classical ballet, the majority of (ballet) dancers' injuries originate from chronic overuse and thus are non-traumatic in nature.[10] Defined as musculoskeletal complaints or injuries which cannot be linked to a clearly identifiable event or time of onset[47]. These overuse injuries usually have a rather complex etiology involving previous injuries which did not heal properly, overtraining, malnutrition, and a variety of other factors.[12, 48]

While the body of available scientific research on musculoskeletal injuries and prevention in dance medicine and science is increasing, the prevalence, incidence, and risks of these injury in dancers, including amateurs are still high.[11, 15, 17]. A systematic review on articles from 1966 to 2004 on professional ballet dancers' injuries, reported the lifetime prevalence to be ranging from 40% to 84%, with a point prevalence of 74%.[10] In a prospective study period of one season, Allen at al.[11] documented 4.4 injuries per 1000 working hours and a mean of 6.8 injuries in professional dancers. Of those injuries, 64% were overuse injuries. Fredrikson and Clarsen prospectively recorded injuries in another

world renowned ballet company.[49] Within 32 weeks, the average prevalence of injuries was 64%. These prevalences of injuries in ballet dancers are higher than in other elite performers, such as in the Olympics.[49]

Prospective studies in pre-professional adolescent ballet dancers with an average workload between 20 and 35 hours per week have shown high injury risk[17] and prevalence of injuries in the young.[50] With an incidence of 1.42 injuries per adolescent dancer per year and 76% of risk to sustain an injury within only one study year in ballet school, the risk for adolescent ballet dancers is higher than in most other sports.[17] Injury risks and rates increased throughout the three years of pre-professional training.[17] Already in the pre-professional adolescents, overuse injuries are prominent, most of them related to the joints (ankle, knee), as well as bones (predominantly stress fractures).

Further studies highlight the increase of injury risk proportionally to a commonly constant increase of workload throughout the season or school year of ballet dancers.[17, 51, 52] Furthermore, studies stress the risk of repetitive injury due to the high tendency of pre-professional, professional but also amateur ballet dancers and potential pathological changes if symptoms are ignored (i.e. work despite pain caused by an injury instead of treating it).[53-57] Dance science highlights these general aspects of medicine in ballet with respect to training, injuries as well as injury prevention throughout all levels of expertise.

Risk factors for these musculoskeletal injuries are part of ongoing research. Injury etiology and related factors have shown to be complex [58, 59], not only due to the fact that young ballet dancers are taught to dance through pain and injuries, regarding them as an integrating part of their profession.[50, 56] In the very traditional environment of classical

ballet, many aspects have been evaluated and be claimed to be linked to the etiology of injuries.[17, 60] Among them are erroneous dance technique [44, 60], deficits in individual fitness levels and certain, non-evidence based training methods [22, 61], but also the way teachers and ballet masters coach their dancers based on their knowledge and proactive effort to include dance scientific evidence into practice.[62, 63] These aspects will be addressed in this thesis. A short background on these risk aspects which could be associated with musculoskeletal injuries are given in 1.5 through 1.9.

1.5 The Role of Optimal Dance Technique for Injury Prevention

Erroneous dance technique has frequently been researched within the context of dance injuries. Among the many aspects of ballet technique, the technique of maximal leg-external rotation monitored by the hip joint, called “Turnout” or “En Dehors”, can be regarded as the basis of classical ballet technique which all other dance technical aspects but also dance styles such as modern and contemporary, built upon.[64, 65] In traditional approaches, dancers and teachers strive to achieve a turnout-angle of 180° between the two longitudinal axes of both feet (*Figure 1*). While turnout is supposed to be dominated by the hip joint's external rotation, the traditional approach has focused teachers and dancers onto the appearance of the feet. However, such unrealistic goals very often don’t take the dancer’s individual passive osseoligamentous and active myofascial (e.g., muscular endurance, neuromuscular control) capacities into account. There is evidence that even principal dancers display an average turnout angle of 134.6° in both legs.[64] Therefore, in striving for ideal total turnout of 180°, many dancers (have to) force their joints beyond optimal biomechanical abilities, which leads to compensatory movements along the kinetic chain of motion. The association between the dance technique of

“turnout” and ballet dancers’ injuries to the lumbar spine, knee joints, ankle and feet have been investigated throughout various studies [30, 66], but a scholarly conclusion has not yet been drawn.

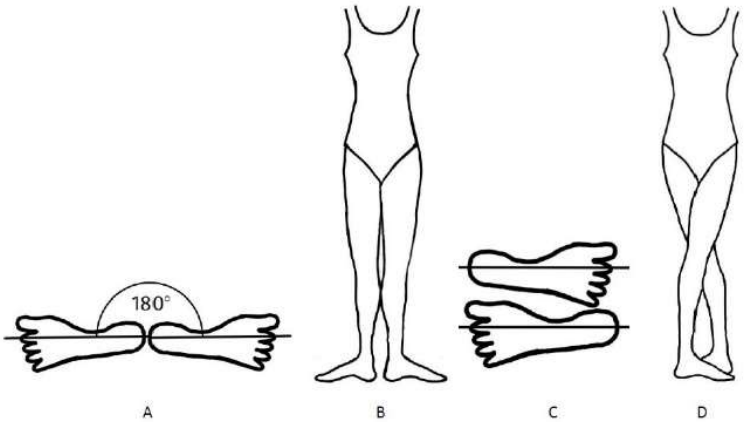

Figure 1: “ideal” functional turnout in 1st (A+B) and 5th (C+D) classical ballet position

1.6 The Role of the Ballet Teacher or Ballet Master for Injury Prevention

As previously introduced, in sports science the coach was identified as the most important person regarding injury prevention in athletes.[39] Not only with respect to implementing injury preventive measures [40, 41], but also for creating a safe motivational climate for such implementation of dance medicine into practice. The latter influences the athlete's learning, performance and overall health in general and also allows dancers to learn how to recognize early symptoms for injury or fatigue and how to deal with those. Such proceedings would include to learn how to deal with pain, to report injuries or complaints immediately, receive diagnosis and subsequent time for healing as well as evidence-based transition training to be ready to take up training again after rehabilitation.[67] Studies showed how negative motivational climates created by teachers were associated with a

negative affective state of dancers, which again affected their perception of wellbeing and performance. Although several studies evaluated the role of teachers'/masters' behavior and knowledge regarding dancers' health [16, 44, 62, 68, 69] as well as the resulting motivational environment associated to dancers' psychological wellbeing [2, 3], the association between teacher behavior and musculoskeletal injuries in dancers has not yet been evaluated. The latter has been found, however, in sports science.[70]

1.7 The Role of Warm-up for Injury Prevention

The workload of classical ballet dancers, especially pre-professionals and professionals, is very high, thus indicating that implementation of injury prevention measures is crucial.[17, 51]

Sports science has identified another aspect of science of training, through which injury prevention can be addressed in athletes: neuromuscular warm-up.[71-76] This type of warming-up in athletes aims at including fitness aspects which are not addressed during regular training of the athlete but were identified as risk factors for injuries such as sport specific strength, strength endurance, or power, as well as dynamic neuromuscular control of leg and arm alignment or core stability.[36, 74, 77-80].

In ballet research, however, neuromuscular warm-up has not been evaluated so far. Furthermore, neither in dance in general nor in classical ballet specifically, the warm-up habits of dancers have been documented in the first place, which would allow a first impression on how warm-up is being dealt with and facilitate future research.

1.8 The Role of Dance Medicine & Dancers Themselves for Injury Prevention

In order to prevent injuries, the nature of their cause needs to be evaluated. A possible method is to include dancers on this evaluation of perceived causes for their musculoskeletal injuries. Hence, dancers can give background information on circumstances leading to their injuries. In addition, asking dancers for their opinion empowers them and creates an awareness for the importance of their musculoskeletal injuries, thus facilitating their proactive compliance for preventive measures and easier implementation into dance practice later on.

Furthermore, no study has specifically aimed at investigating if dance medical research has been implemented into dance practice, first and foremost through the motivation of ballet teachers or ballet masters to base their dance pedagogy on dance medicine. In sports science it was shown that the sports coach's attitude towards injury prevention programs determines whether interventions reach their athletes. As such, dancers are highly depending on their teachers and masters, their knowledge and professional expertise, when trying to prevent injuries. Insight, if dance medicine is implemented is a necessity to be able to develop targeted injury prevention programs.

1.9 The Role of Injury as a Stressor for Injury Etiology & Injury Prevention

Originating from the realms of physics, the term "stress" as a neuropsychophysiological reaction was first described by Hans Seyle.[81-83] If exposed to mental or physical stress, the vegetative nervous system releases glucocorticoids and catecholamines, interacting with immune, cardiovascular, neuronal, and muscular systems.[84] Body adaptation and recovery functions can be negatively affected by intensity and duration of those

physiological and neuropsychological stress responses depending on how a person appraises the severity of a stressor, on their ability to cope with this stressor, and whether they perceive a stressor as an imminent threat to their life or career.[85] Especially chronic stress has been linked to illness[86-89], and in dancers and other athletes, psychosocial stress has been associated with injury risk.[90, 91] However, the injury as such might be regarded as a stressor as well.

In injury-response-models, such as Brewer's[92], it is suggested that injury is first appraised cognitively, followed by an emotional and behavioral response. However, injury responses are depending on the individual. The personality of the injured (e.g., trait anxiety, motivation, hardiness, locus of control), their coping behavior (e.g., coping skills, goal setting), history of stressors (e.g., previous injuries) and perceived social support play important roles.[85, 93, 94] For that matter, and thus highlighting the complexity of injury as well as the individual's neuropsychological appraisal, Mainwaring and colleagues suggested a person-to-situation-model. They described injury-response to be a more complex, multidimensional interaction between factors related to the affected individual and their environment rather than a linear process of events.[95] In Mainwaring's model, the individual's psychological, physical, behavioral and social responses act as moderators, affecting and being affected by intrinsic and extrinsic determinants. Intrinsic factors could be demographics, traits, coping behavior, identity, nutritional aspects, knowledge, or other stressors, while the dance environment, financial situation, social support, dance culture and identity, and treatment can be named as extrinsic factors.[96] As such, Mainwaring's model stresses a holistic approach to injury appraisal and injury rehabilitation.

Dancers show a high prevalence and incidence of injuries for which mental stress has shown to be a risk factor.[48] Since injury is perceived as stressful, threatening careers as well as identities[95, 97, 98], injuries might increase dancers' stress levels and thus their risk for consecutive injury. Moreover, in sports science it has been described that athletes cope better with consecutive injury than with first-time-injury, being more accepting of the injury and less anxious.[99] In dancers, those aspects have not yet been investigated. However, since dancers are known to be working through injury and pain[32, 97], it might be interesting to know if injury could intensify dancers' fear of more severe and/or consecutive injury so much that their stress levels upon second- or further injury are increased instead of lower, as it had been shown in other athletes.

For that matter, we aimed to investigate whether 1) injuries are associated with increased stress levels, and 2) if consecutive injuries are related to higher perceived stress levels than first injury in first-year dance students.

1.10 The Aim of this Thesis

At present, the above-mentioned topics have not specifically been studied. Therefore, this thesis aims to evaluate aspects of the synergy between dance medicine and dance pedagogy with the aim to prevent musculoskeletal injuries in classical ballet dancers and to provide the basis for future research.

As such we investigated some important aspects on the etiology and prevention of ballet dancers' musculoskeletal injuries. Specifically, this thesis looked into aspects which have not yet been studied before, such as warm-up or motivational climate in order to provide the basis for future research. Also we evaluated effects of erroneous dance technique,

the causes that dancers perceived for their injuries and their perceived implementation of dance medicine into dance practice by their ballet master or ballet teacher.

For that purpose, this thesis is based on four studies which all are the first of their kind to investigate the respective topic in dance medicine and science.

1) A systematic literature review is performed to investigate the association between the dance technique of “turnout” and musculoskeletal injuries in ballet dancers, studying the various approaches that have been conducted over the previous decades.

2) The association between musculoskeletal injuries and motivational climate created by the ballet teacher or ballet master is researched.

3) A documentation of warm-up habits in ballet dancers is provided. Furthermore, the association between warm-up routines and musculoskeletal injuries is investigated.

4) Dancers’ perceptions of causes for their injuries and their teachers'/masters' level of implementation of preventive dance medicine is investigated, asking which factors dancers perceive to be important when it comes to their injuries and injury prevention.

5) A prospective longitudinal study investigated the role of injury as a stressor for dancers. The study assessed first and consecutive injuries and compared stress levels during injury to baseline stress levels dancers had reported before they entered an educational dance program at a university for arts and dance.

1.9 The Outline of this Thesis

Chapter 2 is dedicated to a systematic literature review on the association between the dance technique of “turnout” and musculoskeletal injuries. Moreover, the review aimed to investigate the scientific background of forcing and compensating turnout, which has not yet been done in science.

The first study investigating the relationship between motivational climate created by the ballet teacher or ballet master and dancers’ musculoskeletal injuries is presented in Chapter 3.

Chapter 4 aims to document ballet dancers’ warm-up habits and a possible link between warm-up routines and physical injuries to dancers.

Chapter 5 clarifies dancers’ perceptions of causes for their acute and overuse injuries and investigates the support from ballet teachers and ballet masters dancers perceive for their injury prevention and wellbeing.

Chapter 6 is dedicated to a prospective longitudinal assessment of stress dancers perceived during and after injuries and thus, whether injury in itself can be regarded as stressor for dancers.

A general discussion of results and summary are being presented in Chapter 7, followed by a list of publications and acknowledgements.

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Chapter 2

Dance Technique & Turnout

Does forced or compensated turnout lead to musculoskeletal injuries in dancers? A systematic review on the complexity of causes

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Abstract

Injury prevalence in dancers is high, and misaligned turnout (TO) is claimed to bear injury risk. This systematic review aimed to investigate if compensating or forcing TO leads to musculoskeletal injuries.

A systematic literature review was conducted according to the PRISMA Guidelines using the databases of PubMed, Embase, Emcare, Web of Science, Cochrane Library, Academic Search Premier, and ScienceDirect. Studies investigating the relationship between compensated or forced TO and injuries in all genders, all ages, and levels of dancers were included. Details on misaligned TO measurements and injuries had to be provided. Screening was performed by two researchers, data extraction and methodological quality assessment executed by one researcher and checked by another.

7 studies with 1293 dancers were included. Methodological quality was low due to study designs and a general lack of standardised definition of pathology and methods of assessment of misaligned TO. The studies investigating the lower extremities showed a hip-focus only. Non-hip contributors as well as their natural anatomical variations were not accounted for, limiting the understanding of injury mechanisms underlying misaligned TO. As such no definite conclusions on the effect of compensating or forcing TO on musculoskeletal injuries could be made.

Total TO is dependent on complex motion cycles rather than generalised (hip) joint dominance only. Objective dual assessment of maximum passive joint range of motion through 3D kinematic analysis in combination with physical examination is needed to account for anatomical variations, locate sites prone to (overuse)injury, and investigate underlying injury mechanisms.

Keywords: turnout, dance, injury prevention, musculoskeletal injuries, biomechanics

2.1 Introduction

Injury rates in dancers are high, ranging from 0.62 to 5.6 per 1000 dance exposure hours [1], mainly sustained to the lower limbs and spine, and overuse in nature [1-10]. One of the commonly cited risk factors is a misaligned or poorly controlled turnout (TO) [2, 11-16]. TO can be described as the external rotation of the leg [12, 17] with the aim of increasing overall range of motion (ROM) especially in abduction, as well as stability in static and dynamic balance.

Turnout is considered to be the most important technical, stylistic, and aesthetic characteristic of classical ballet and is also used in other dance styles, i.e., modern, contemporary, or jazz dance [18]. Active aspects of TO ask for high levels of inter- and intra-muscular coordination, finetuned proprioception, strength, and strength endurance to allow functional dynamic alignment.

Individual passive anatomical capabilities determine the amount of TO a dancer is maximally able to present while maintaining efficient alignment. Professional ballet dancers display an average functional TO of 133.6° with a passive hip external rotation capability of 50.2° and an active hip external rotation of 35.2° [19].

However, especially in classical ballet TO has become a search for perfection with dancers trying to achieve an ideal total TO (TTO) of an 180° angle between the bilateral longitudinal axes of the feet (*Figure 1*) [12]. In the attempt to achieve the ideal 180° many dancers need to force joints or draw from compensatory mechanisms.

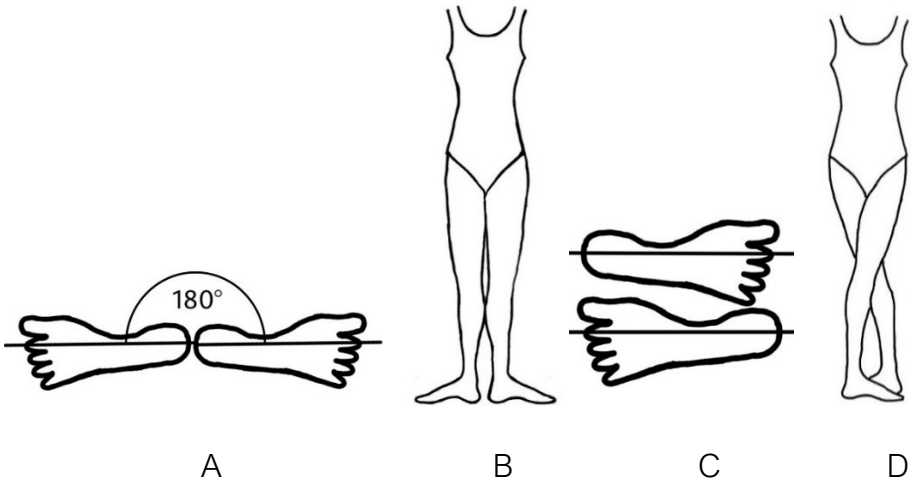

Figure 1: "ideal" functional turnout in 1st (A+B) and 5th classical ballet position (C+D)

When trying to achieve ideal TO, three different possibilities of compensating or forcing TO are possible: lumbar hyperlordosis, forced tibial external rotation ("screwing the knee"), and hyperpronation/abduction of the feet [13, 14, 16, 20-37]. It is claimed that these mechanisms lead to injuries within the kinetic chain. However, there is a lack of overview on existing research, in which the effects of compensating or forcing TO are presented. Thus, this systematic review aims to investigate the association between aspects of forced or compensated TO and dancers' musculoskeletal injuries [5, 15, 24].

2.2 Methods

2.2.1 Search strategy

A systematic literature search was conducted on September, 23rd, 2019, assisted by a librarian, using the databases of PubMed, Embase, Emcare, Web of Science, Cochrane Library, Academic Search Premier, and ScienceDirect, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The research used three basic groups of keywords (ballet, and/or dance, turnout and/or pre-identified synonyms, and injury and/or pre-defined synonyms) in different Boolean combinations, including filters and MESH terms (*Appendix 1*). Additional hand search of reference lists and manual search of the journal "Medical Problems of Performing Artists" was conducted.

2.2.2 Inclusion & exclusion criteria

Original studies investigating the relationship between compensated or forced TO and musculoskeletal injuries in dancers, males and/or females, as well as all levels of dancers from the dance styles ballet, modern, contemporary, and jazz were included. These styles are chosen as they are mainly or to a certain degree using TO as part of their dance technique. Age was not used as an exclusion criterium. Details on measurements of compensated or forced TO and musculoskeletal injuries had to be provided. Studies, which only described and compared TO and related measurement techniques were excluded, as were case studies and reviews.

2.2.3 Data extraction

Regular references and meeting abstract references were screened independently by two researchers (J.E.K. and M.G.J.G.), with any disagreements resolved by consensus. Data was extracted using a data-extraction table by J.E.K and checked by M.G.J.G. The following data was extracted: Study design, participants, inclusion/exclusion criteria, exposure, outcome, assessment procedures, and results.

2.2.4 Methodological quality assessment

The methodological quality of retrieved studies was assessed independently by two researchers (J.E.K. and M.G.J.G.) through questions specifically designed for the purpose of this review. The categories included injury outcome, exposure assessment, selection bias, and handling of confounders. Exposure assessment was subdivided into the categories definition, methods, and measurements, resulting in a mean outcome score. The COSMOS-E (Conducting Systematic Reviews and Meta-Analyses of Observational Studies of Etiology) Guidance was used as a template [38].

Table 3: Methodological quality assessment

	Cimelli	Coplan	Drężewska	Jenkins	Negus	Steinberg	Merkensteijn
INJURY OUTCOMES	DEF	DEF	DEF	*HIGH*	DEF	SUFF	DEF
EXPOSURE ASSESSMENT	SUFF	*HIGH*	SUFF	DEF	SUFF	*HIGH*	*HIGH*
SELECTION BIAS	DEF	DEF	DEF	DEF	DEF	DEF	DEF
CONFOUNDER ADJUSTMENT	DEF	DEF	DEF	N.A.	DEF	DEF	DEF

DEF: deficiencies SUFF: sufficient *HIGH*: high standard approach N.A. Not applicable

2.3 Results

2.3.1 Search

387 articles and 32 abstract references were retrieved. Through the first screening of titles and abstracts (J.E.K., M.G.J.G.) 34 studies and 2 conference abstracts were identified. Additional manual search of "Medical Problems of Performing Artists" as well as retrieved reference lists yielded one additional study and one additional conference abstract. Full text reading and application of exclusion and inclusion criteria resulted in 7 original studies (*Figure 3)*.

2.3.2 Study designs and study population

1 study was a longitudinal observational cohort study, while 6 studies had a cross-sectional observational design. The studies included a total of 1293 dancers representing 4 dance styles: classical ballet (n=4), modern dance (n=2), contemporary dance (n=2), and jazz dance (n=1). The smallest study presented 12 professional contemporary dancers [39], the largest included 1082 amateur dancers from ballet, modern, and jazz [40]. The youngest participants were 8-16 years old in 1 study [40], while the other studies focused on adolescents and young adults with a mean age ranging from 16,5 [41] to 26,8 [39] years (*Table 1).*

2.3.4 Turnout measurements & terminology

The terminology used for TO was heterogeneous as were its definitions and assessments (*Table 2*). *Figure 2* and *Appendix 2* provide an overview of terms, acronyms, and definitions used in research on turnout to support the understanding of our results. The

studies investigating the lower extremities used “CTO” (“compensation of TO”), “CTO difference”, and “muscular value” to label the misalignment associated with TO and injury. The authors studying hyperpronation of the foot or lumbar hyperlordosis used “forcing”, “compensation in the TO position”, and “incorrect TO technique” in their exposure terminology. Measurement techniques varied with regard to positions of the dancer, tools used, as well as the calculations applied for exposure assessment.

2.3 5 Injury definition & assessment

Injury definitions included “timeloss with respect to training, exam, or performance” [42, 43], or “timeloss to completion of class” [44], “current pain in the ankle or foot region, that is, movements or exercises that evoke pain or pain that disturbed her dance practice and daily life activity“[40], “pain intensity regardless of effect on performance” [41], injuries preventing the executing of functional turnout [39], or “any pain, discomfort, or musculoskeletal problem that would cause modification of technique or time away from dance class, rehearsal, or performance” [45]. Injury assessment was executed once via interview in combination with professional diagnosis [40], in 3 studies by self-report with a questionnaire [39, 42, 45], once by interview [43], in 1 study by questionnaire and additional evaluation of medical history forms [41], and in another by questionnaire and additional report of the physiotherapist [44]. Injury mechanisms included overuse injuries [42] as well as overuse and traumatic injuries [43, 45], but this was not always specified [39-41]. Reported injury locations were the lower extremities in 5 studies [39, 41-43, 45], the low back in 4 studies [41-43, 45], and isolated reports were given on the foot in 2 studies [39, 40]. One study only mentioned the number of injuries, but did not include any details on the injury location [44].

2.3.6 Methodological quality assessment

The methodological quality of the studies was medium to low *(Table 3)*. Overall assessment for outcome showed a retrospective approach based on self-report of most of the studies, which could have introduced information bias. In only three studies injuries were objectively scored by medical professionals. Outcome for exposure assessment showed manual measurements (as opposed to 3D kinematic analysis or comparable techniques) and isolated approach to TO, i.e., the focus on the hip, spine, or foot only instead of assessment of the spine, pelvis, and lower extremities as an entity of TO. Information on missing data was not reported, and apart from Jenkins et al., where confounder adjustment was not applicable as they focused on prediction and not on etiology, none of the other studies addressed handling of confounders, although dancing style [46, 47], expertise [48, 49], or age [46, 50] might have led to confounding. Selection bias and small sample sizes were also likely to have had an impact on the validity of the presented results. One study used their exposure in the definition of the outcome, which is equally likely to have influenced the results [39].

2.3.7 Detailed results

Different anatomical foci and a variability of methods of TO assessment (measurement and calculation) of the studies prevented pooling of results and generalizability.

2.3.7.1 Misaligned Turnout – Focus on spine and feet

3 studies investigated the relationship between specific body parts and/or specific injuries, and misaligned TO. Steinberg et al. focused on tendinopathies of the ankle and foot in 1082 young female amateur dancers and found a relationship between hyperlordosis and

paratenonitis, but no correlation with “sickling” or “rolling” of the foot. Cimelli et al. investigated change in foot posture in relationship to TO angle and injury in 5 female and 7 male contemporary dancers. The authors found relationships between the foot’s tendency towards pronation with increasing angle of TO, as well as the number of reported injuries and amount of pronation of the (right) foot in TO. Drężewska et al. studied lumbosacral pain in 45 female and 26 male pre-professional ballet students and reported a correlation between the degree of TO and low back pain through a compensatory anterior pelvic tilt. A sacral bone inclination angle of ≥30° was related to an increase of risk and intensity of low back pain in dancers.

2.3.7.2 Compensated Turnout – Focus on the lower extremities

In general, CTO was defined as the difference in degrees between the bilateral angle of (active or passive) hip external rotation and the angle of (active or passive) total turnout in the dancer. However, 4 studies used various calculations of “compensated TO” (“CTO”) to investigate the lower extremities (Table 2). Coplan found that 90% of the college level ballet dancers and instructors with CTO >25° were injured, van Merkensteijn et al. confirmed that modern dancers with CTO <26° had no injury, whereas dancers with 2 or more injuries had CTO of >43°. Negus et al. showed that poor dynamic control of functional TO and compensated TO in pre-professional ballet dancers were linked to severity of (overuse) injuries and a history of injuries in 100% of the dancers. CTO ranged from 68.9° in 1st to 86.9° in 5th position. Jenkins et al. investigated if TO measurements can be used to predict physiotherapist-reported injuries in 47 female contemporary dance students. For every 1% of CTO-increase they reported a 9% increase in the odds to sustain 2 or 2+ injuries. Their second variable correlating with injury risk showed that with

every increase of 1% in this so-called “muscular value” (i.e., the total active TO as a ratio of passive hip external rotation) the odds to be among the 2+ injury group increased for 8.4%. The authors aimed to quantify the injury risk through CTO in a longitudinal prediction study.

2.4 Discussion

The purpose of this review was to find out if there is conclusive evidence for the often-claimed relationship between misaligned TO and the incidence of injuries of the lower back and lower extremity. In our systematic review, 1 longitudinal and 6 cross-sectional studies reported that compensated or forced TO can be linked to musculoskeletal injuries in dancers. However, a cross-sectional study design cannot allow conclusions on a causative relationship between exposure and outcome. Both occur at different points in time and thus cannot be identified if only one point in time (the cross-sectional study design) is investigated. For that matter, current injuries [39, 43], injuries reported in the dancers' injury histories prior to testing [40, 42, 45], or which occurred during longitudinal study procedures [44] may also have led to misaligned TO and confounded the exposure measurements. Thirdly, none of the studies evaluated the overall musculoskeletal system involved in TO (i.e. spine and the lower extremity as an entity), but focused on isolated anatomical aspects only. The methodological quality of the reviewed articles stress the need for better research methods on a potential association between forced TO and occurrence of injuries.

2.4.1 The complexity of dynamic turnout and related misalignment

In efficient motion, optimal movements need the least amount of force. In any other case overstrain and injuries might occur. The amount of TO a dancer is maximally able to present ("functional TO") when maintaining efficient alignment is determined by passive anatomical structures (i.e. bony-cartilage articulations and ligaments), the dancer's "total passive TO", regardless of strength and motor control (i.e., the dancer's "total active TO").

On average, functional TO-values of 134° have been found in professional dancers [19]. The difference between these values and the "desired 180°" is regarded as compensating or forcing TO. This can be achieved by 3 mechanisms: lumbar hyperlordosis, forced shank external rotation ("screwing the knee"), and hyperpronation/abduction of the feet ("rolling-in-phenomenon") [51], most probably employed in various combinations (*Figure 2).*

Individual anatomical predispositions as well as reasons for forcing or compensating can be manifold. They may range from neuropsychological aspects, such as personal motivation and perfectionistic striving, (lack of) knowledge and awareness, stress, or poor coping skills, to faulty technique, lack of inter- and intramuscular co-ordination and strength endurance, poor dynamic motor control, especially in end range co-ordination, or general fatigue [52-54]. Hence, concise definition of compensating or forcing is essential for analysis of injury mechanisms and locations, especially because both entities describe differently related aspects (*Figure 2).*

The high prevalence of low back pain as well as injuries to the knee, lower leg, foot, and ankle in dancers are commonly attributed to compensating and forcing of TTO [15, 24, 29, 39, 40, 55]. However, the reviewed studies present large heterogeneity in their outcome measures, i.e., numbers and locations of injuries, as well as underlying mechanisms, i.e., overuse and traumatic injuries. Since compensation might be present at one or several locations simultaneously (lumbar spine, lower extremity: knee joints, ankle, or foot), the association between the occurrence of compensation and the locations of misalignment leading to injury is poorly understood. When forcing TO, dancers may employ 1, 2, or all 3 compensatory mechanisms. One body part might be the location of forcing, another region the one to become injured, while both are compensating for yet a

third anatomical part. The complexity is even greater since these in- and extrinsic factors have an intricate interplay as well. These complex interactions remain unaddressed, become generalized, or are labelled in a variety of ways. However, they have to be taken into account in order to locate and prevent injuries.

2.4.2 A simplified approach – hip versus non-hip contribution

Heterogeneity existed on TO assessment and the interpretation of compensating or forcing of TO. For instance, the 4 studies on compensation of the lower extremities used 4 different methods of assessment (2 based on functional TO, 1 on total passive TO, and 1 study based on functional TO, which was equalled to and measured like total active TO). All studies focused on the hip joint only, which is supposed to be responsible for about 60-70° (58-60%) of TTO [56, 57]. Although the hip joint is the most efficient monitor of the leg axis, the non-hip contributors (i.e., lower spine, innate femoral torsion, end range rotation of the knee, innate tibial torsion, and pronation of the subtalar complex) add 20-30° or 40% to total TO [51, 54, 56, 58]. However, none of these factors were accounted for in the studied articles with a focus on hip external rotation *versus* non-hip-contributors.

The reduction of "compensation of TO" to the non-hip contributors presents too simplified a model of this complex interplay between spine and all joints and ligaments of the lower extremity. Non-hip contributors play a far greater and more complex role than previously established [19, 53, 60]. Lower spine, knee, ankle, and foot are all part of the overall kinetic chain of TO. Hence, these contributors should be considered in correctly aligned as well as forced or compensated TO. Their anatomical variations may further determine [52], why some dancers are more likely to become injured than others, after the hip *and* non-hip-contributions are exceeded. Studies on isolated anatomical aspects of TTO [39-

41] highlight the importance to account for anatomical variations in the search for objective overall assessment. Thus, a hip-only focus limits the understanding of underlying mechanisms leading to compensation or forcing, resulting in overuse and injury.

2.4.3 Dynamic- and multiple-position-assessment

TO is a complex dynamic concept, dependent on an intricate interplay of multiple joints, all contributing with different angular velocities, when the dancer moves through TO. Especially in classical ballet, the 5th position (*Figure 1*) is the position most often used. But in the reviewed articles the assessment of TO was mainly focused on 1st position and on static measurements. Only Negus et al. stressed the importance of crossed-leg-positions, such as the 5th position, and dynamic assessment through pliés and jumps [12]. The reported compensation in 5th position-TO was characterised by nearly 20° more external rotation of the lower limb compared to 1st position. Other authors showed the coinciding increase in sacral inclination [61]. Moreover, in 5th position the dancer can fix the heel of the front foot against the forefoot of the back leg, which allows the subtalar structures to achieve more hyperpronation and more external rotation in the knee compared to the 1st or other open positions [62]. Dynamic knee-motion capture analysis showed that despite a dancer's full knee extension, the thigh and lower leg did not move as one segment in TO, as was previously assumed [19, 52, 60]. Results indicate that the knee is not protected against shear forces when locked. The dancer's strive for ideal total TO requires intense, yearlong training to achieve the adjustments needed in joints and soft-tissues [53, 63]. Those can lead to injuries (e.g., pes anserinus, meniscus, osteoarthritis [64], subtalar joints, etc.), depending on anatomical variations. Extrinsic factors, such as the need to employ a variety of possibilities of faulty dance technique to be able to accomplish the

necessary adaptations (e.g., an incomplete locking of the front knee in the closing of the 5th position [65], or the use of plié to force a greater TO angle of the feet [39, 42]) play further important roles. Thus, an analysis of non-hip-contributors throughout dynamic alignment in all positions and not only in the static 1st position is essential when analysing injury risk of (ballet) dancers.

Validated methods of assessing maximum passive ROM of hip and knee joint as well as lumbosacral and subtalar motion exist. For that matter, in prevention of injuries and the planning of training the dancer's phenotype (e.g., monitoring passive range of motion of joints, etc.) and (dynamic) kinematic data (e.g., motion capture) should both be taken in consideration [66, 67]. The difference between summative TTO and the "ideal TO" of 180° can be used as reference guides for assessment, prevention, treatment, and rehabilitation of (overuse) injuries related to TO, accounting for anatomical variations in the dancer. Active "misaligned-TO-measures" during health screenings or auditions can be used to screen for a higher likelihood of injury using the difference between functional TO (FTO) and total active TO (TAT) as reference for individual dancers, employing goniometer [52], plurimeter [68], and/or rotator discs. The "FTO minus TAT"-difference may alert the teacher to start preventive measures, such as abstaining from certain positions during ballet, unless all necessary criteria in the individual dancer are met. Finally, neuropsychological aspects, i.e., the constant motivation (perfectionistic striving and external pressure) to achieve ideal TTO of 180° as well as acknowledging that and why injuries are occurring through misaligned TO in practice, need to be discussed as part of a prevention of injuries.

Some limitations have to be addressed: First, only 7 studies, relating injuries to compensated or forced turnout could be found, despite a thorough search strategy. Second, due to the large heterogeneity in methodology and presentation of results, no conclusions can be based on the presented articles, highlighting the need for a standardised methodology for assessing TO. As TTO is strongly associated with a complex interaction of dynamic motion of spine, lower extremity joints, ligaments and soft tissue, analysis will be complex. Nevertheless, all these aspects have to be taken into account, rather than generalising isolated anatomical approaches, if an adequate analysis of complaints in these high-performing artistic athletes is executed.

Conflict of interest statement: The authors have no conflicts of interest to declare.

Figure 2: Compensating and forcing turnout: definitions, analysis and related injuries

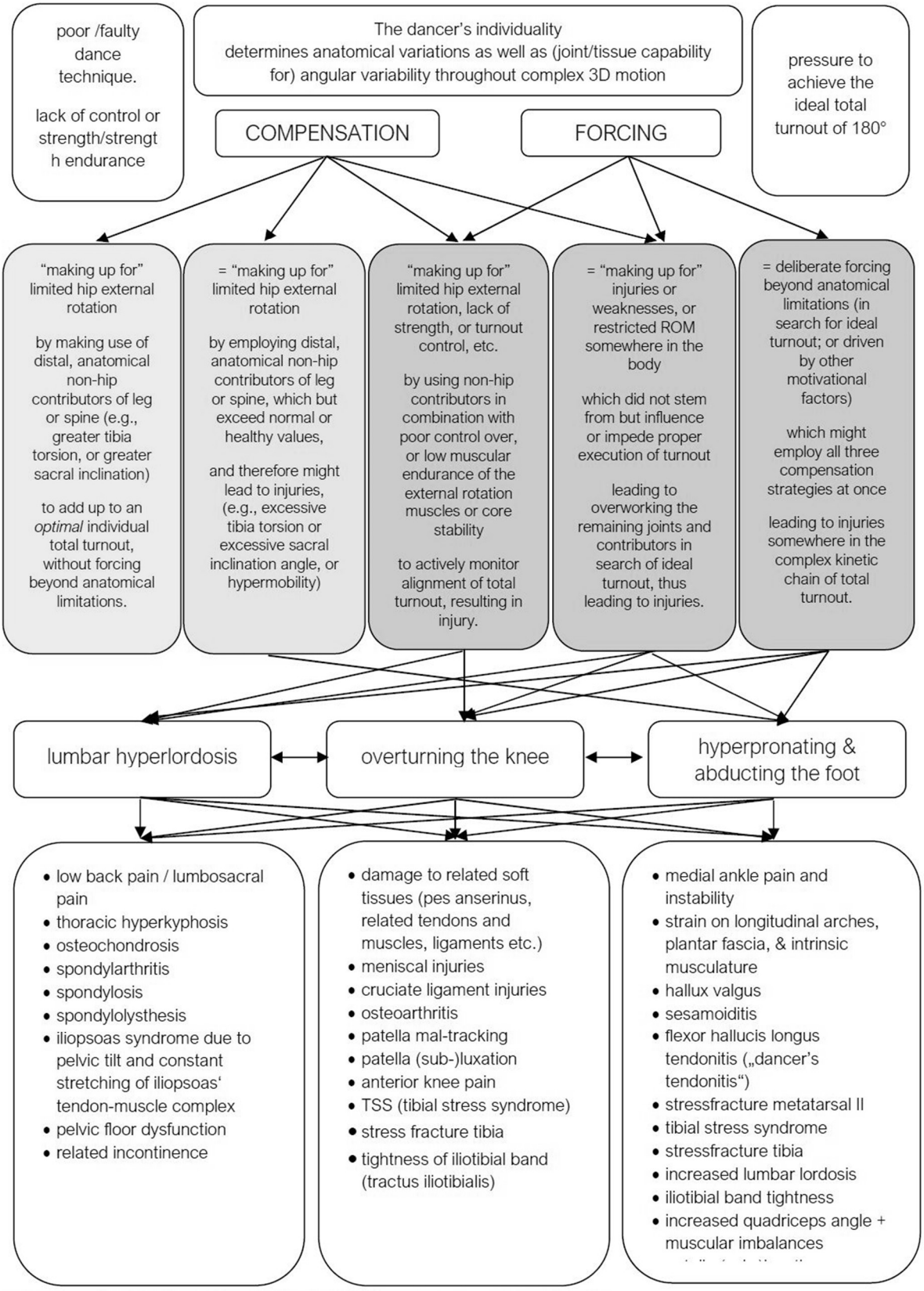

Figure 3: Search documentation Flowchart

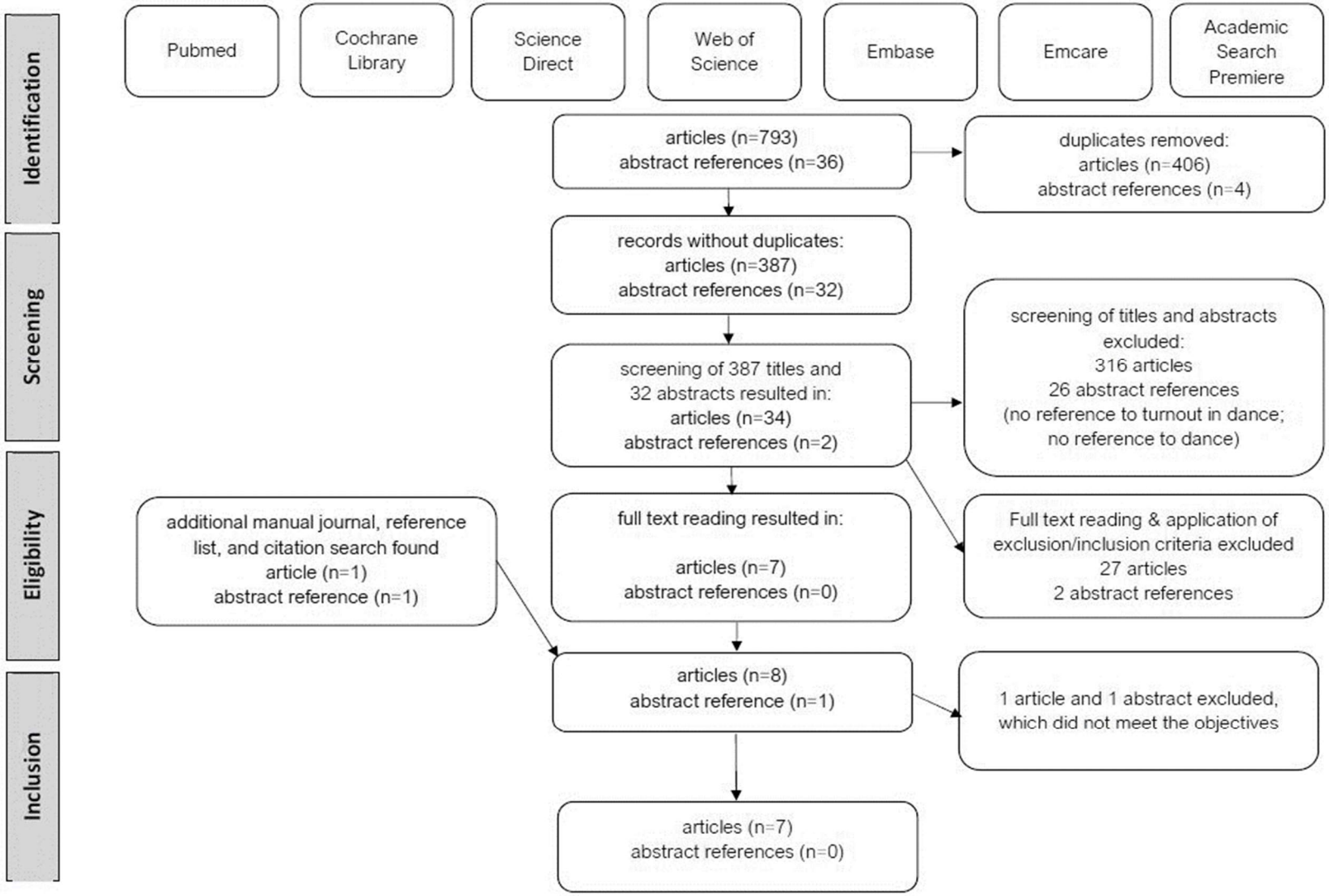

Table 1: Data Extraction

Author, Year	Publication	Study design	Participants	Inclusion/Exclusion Criteria
Cimelli, S. N., & Curran, S. A., 2012	Influence of turnout on foot posture and its relationship to overuse musculoskeletal injury in professional contemporary dancers: a preliminary investigation. Journal of the American Podiatric Medical Association, 102(1), 25–33.	cross-sectional observational cohort study	**number:** 12 dancers **sex:** 5 female **dance style:** contemporary **level:** professional **Ø age:** 26.8 years (range: 21-36 years)	**Inclusion criteria**: aged 20-40 years; a current traumatic injury that renders him/her unable to assume a functional turnout position; a minimum of 3 years of contemporary and ballet dance training; a minimum of 1 year as professional contemporary dancer. **Exclusion criteria**: not provided
Coplan, 2002	Ballet dancer's turnout and its relationship to self-reported injury. The Journal of Orthopaedic and Sports Physical Therapy, 32, 579–584.	cross-sectional observational cohort study	**number:** 30 dancers & instructors **sex:** 27 female **dance style:** ballet **level:** college level & teaching experience **Ø age:** 22 years (range: 16-50 years)	**Inclusion criteria**: not provided. Ballet students and their teachers were recruited from 3 colleges offering ballet training (in Baltimore) **Exclusion criteria**: not provided.
Dręże wska, M., & Śliwiński, Z., 2013	Lumbosacral pain in ballet school students. Pilot study. Ortopedia, Traumatologia, Rehabilitacja, 15, 149–158.	cross-sectional observational cohort study	**number:** 71 dancers **sex:** 45 females **dance style:** ballet **level:** ballet school students **Ø age:** 16.5 years (range: 15-18 years)	**Inclusion criteria:** not provided. **Exclusion criteria**: dancers with back injury and discontinuation of dance practice due to any injury longer than 3 weeks within the preceding 6 months.
Jenkins, J. B., Wyon, M., & Nevill, A., 2013	Can turnout measurements be used to predict physiotherapist-reported injury rates in dancers? Medical Problems of Performing Artists, 28(4), 230–235.	longitudinal observational cohort study	**number:** 47 dancers **sex:** all female **dance style:** contemporary **level:** university level **Ø age:** 19.9 years (range: 17-22 years)	**Inclusion criteria**: not provided. All participants were enrolled in a BA Dance Theatre at a United Kingdom contemporary dance conservatoire. **Exclusion criteria**: not provided.

Table 1: Data Extraction

Author, Year	Publication	Study design	Participants	Inclusion/Exclusion Criteria
Negus, V., Hopper, D., & Briffa, N. K., 2005	Associations between turnout and lower extremity injuries in classical ballet dancers. The Journal of Orthopaedic and Sports Physical Therapy, 35, 307–318.	cross-sectional observational cohort study	**number:** 29 dancers **sex:** 24 female **dance style:** ballet **level:** pre-professional **Ø age**: 18 years (range: 15-22 years)	**Inclusion criteria:** not provided. All participants were students in the first- and second year groups of the Advanced Diploma of Dance programme in an Academy for Performing Arts **Exclusion criteria**: inclusion was restricted to the programme only to optimize homogeinity of current and previous dance training.
Steinberg, N., Hershkovitz, I., Peleg, S., Dar, G., Masharawi, Y., & Siev-Ner, I., 2011	Paratenonitis of the foot and ankle in young female dancers. Foot & Ankle International, 32, 1115–1121.	cross-sectional observational cohort study	**number:** 1082 dancers **sex:** all female **dance style:** ballet, jazz, modern **level:** non-professional **Ø age:** not provided. (range: 8-16 years)	**Inclusion criteria**: positive diagnosis by MD on site: Non-professional female dancers (8-16 years old) were screened over the previous 15 years in a Performing Arts medicine Center (Tel Aviv), active in a variety of dance styles. **Exclusion criteria**: dancers were excluded from the paratenonitis group if they had concomitant injury or pathology of other ankle/foot structures (e.g., ankle sprain, shin split), a history of ankle/foot surgery, or ankle/foot dislocation or subluxation.
van Merkensteijn, G. G., & Quin, E., 2015	Assessment of Compensated Turnout Characteristics and their Relationship to Injuries in University Level Modern Dancers. Journal of Dance Medicine & Science, 19(2).	cross-sectional observational cohort study	**number:** 22 dancers **sex:** 20 female **dance style:** modern **level:** university level **Ø age**: 21.27 years (range: not provided)	**Inclusion criteria**: not provided. Modern dancers undertaking a university level modern dance core curriculum were included. **Exclusion criteria:** not provided

Table 2: Data Extraction

Author, Year	Exposure	Outcome	Measurement Procedures	Results	Results
				Injuries	*Turnout*
Cimelli et al., 2012	CTO = increase of foot pronation with increasing TO (compensation = "forcing" or "excessive pronation")	**location:** injuries to the spine, hip, thigh, knee, lower leg, ankle, foot **mechanism:** not stated **definition:** All injuries that prevented execution of a functional TO	**turnout:** angle of TO and angle of gait on tracing paper and via Foot Posture Index **injuries:** self-reported occurence before the previous 12 months, and during the previous 12 months via dance history and injury questionnaire no details on questionnaire provided	**number of injuries:** 28 injuries reported in 12 dancers 7 male dancers: 2.86 SD ± 0.55 5 female dancers: 1.6 SD ± 0.55 of which 11 injuries occured in the previous 12 months **injury location:** spine (n=5) hip (n=6) thigh (n=2) knee (n=6) ankle (n=5) foot (n=4)	relationships found between 1) Foot Posture Index and angle of TO (ρ = 0.933-0.968, P < 0.01) and 2) the number of reported injuries and change in foot posture in the angle of TO for the right foot only (ρ = 0.789, P < 0.01) Dancers showed a tendency toward pronation when moving into TO.
Coplan, 2002	CTO = FTO – bilateral pHER (compensated TO = functional TO minus bilateral passive hip external rotation) "TO was considered compensated when FTO was greater than total passive hip external rotation"	**location:** low back and/or lower extremity **mechanism:** non-traumatic/overuse injuries **definition:** Any pain or dysfunction of the low back or lower extremities that impacted the dancer's ability to practice or perform.	**turnout:** CTO values for injured and non-injured dancers derrived from: 1) passive hip external and internal rotation (prone, hips in neutral position) goniometer 2) total passive hip external and internal rotation ROM (sum of left and right hip values) 3) FTO in 1st position (standing on a sheet of paper, tracing footprints with pen) **injuries:** self-reported throughout the dance career via questionnaire no details on questionnaire provided	**number of injuries:** 22 injuries reported in 14 dancers (47%) 23.5% (n=7) reported more than 1 injury **injury location:** low back: 13.6% (n=3) knee 36% (n=8) shin 22.7% (n=5) ankle 13.6% (n=3) hip 4.5% (n=1) foot 4.5% (n=1)	CTO differences found between injured dancers: Ø 25.4° ± 21.3 (P = 0.006) and non-injured dancers: Ø 4.7° ± 16.3 (P = 0.006) Ø CTO-angle was 20.8° greater for injured group than non-injured group (95% CI, CTO range: 7.0° - 34.5°)

Table 2: Data Extraction

Author, Year	Exposure	Outcome	Measurement Procedures	Results	Results
				Injuries	*Turnout*
Dręże wska et al., 2013	CTO = increasing sacral inclination in relationship to increasing TO in 1st position ("Compensation in the TO position")	**location:** low back pain **mechanism:** pain intensity **definition:** Pain intensity regardless of its effect on physical performance	**turnout:** 1) angle of sacral bone inclination (baseline mechanical inclinometer) in standing parallel and maximum TO 1st position **pain:** 1) details on occurence, duration, intensity retrieved from medical history forms 2) on-site assessment of pain intensity via Visual Analogue Scale (VAS scale). 3) source for co-existing complaints not clearly stated.	**number of injuries:** 44 dancers reported low back pain (62%) **injury location:** co-existing complaints reported: talo-crural pain (n=10) knee pain (n=10) hip pain (n=7) groin pain (n=6) right thigh pain (n=3) right hallux valgus (n=3)	relationship found between angle of sacral inclination in TO position and pain: subjects with ≥ 30° of sacral inclination showed higher Ø pain scores than those with ≤ 29°. < 29° sacral inclination in TO: VAS 4.86; range 2-8 (P < 0.05) ≥ 30° sacral inclination in TO: VAS 6.32; range 3-9 (P < 0.05) Relationship between sacral inclination angle in parallel position and pain was similar between subjects: ≤ 25° sacral inclination in parallel: VAS 5.25; range 2-8; (P > 0.05) > 25° sacral inclination in parallel: VAS 5.74; range 2-8; (P > 0.05)
Jenkins et al., 2013	CTO = TPT – pER (compensated TO difference = total passive TO minus passive hip external rotation) muscular-value = TAT/pER (Total active TO as a ratio of passive hip external rotation)	**location:** not provided **mechanism:** traumatic and overuse injuries **definition:** physical damage to the body or a body part, which prevented completion of one or more entire curriculum class.	**turnout:** 1) FTO (measured like, equalled to, and further referred to as Total Active TO = TAT): Functional Footprints® 2) Total passive TO (TPT): goniometer (supine, hip neutral) 3) Passive hip ER (pER): goniometer (supine, hip flexed 90°) 4) CTO: TPT – pER (total passive TO minus bilateral passive hip external rotation) 5) Active external rotation lag: TPT – TAT 6) Muscular-value: TAT/pER (Total active TO as a ratio of passive hip external rotation) **injuries:** 1a) records of physiotherapist-reported injuries (used for assessment) 1b) self-reported over a 10 months period via Dance UK Injury Questionnaire	**number of injuries:** total of 47 injuries physiotherapist-reported: 0 injuries (12%) 1 injury (24%) 2 injuries (6%) 3 inuries (4%) 4 injuries (1 %) **location of injuries:** no further information provided due to a lack of consistent information	CTO and muscular-value were found positively predictive for physiotherapist-reported injuries. CTO and muscular values are predictive of more than 2 injuries (2+): CTO difference odds ratio 1.090, 95% CI (1.002-1.186) for every 1% increase in CTO, there is a 9% increase in the odds that the dancer will be in the 2+ injury group (compared to the 0 - 1 injury groups) Muscular-value odds ratio: 1.084, 95% CI (1.021-1.151) for every 1& increase in the muscular-value, there is an 8.4% increase in the odds that the dancer will be in the 2+ injury group (compared to the 0 - 1 injury groups)

Table 2: Data Extraction

Author, Year	Exposure	Outcome	Measurement Procedures	Results	Results
				Injuries	*Turnout*
Negus et al., 2005	CTO = static FTO – bilateral aHER (compensated TO = static functional TO minus bilateral active hip external rotation)	location: low back, lower extremity mechanism: non-traumatic/overuse and traumatic definition: any pain, discomfort, or other musculoskeletal problem, which required modification of, or time away from, dance training, examinations, or performance in the previous 2 years.	turnout: 1) Passive and active hip external rotation; supine, hip extended, knee flexed; goniometer 2) static FTO (sFTO): standing 1st position, both 5th positions paper trace dynamic FTO (dFTO): tracings after 3 jumps (1st + 5th position) 3) Active external rotation lag: total passive hip external rotation – total active hip external rotation 4) CTO: static FTO – total active hip external rotation 5) Static-dynamic TO difference: sFTO – dFTO injuries: self-reported via interview to assess lower extremity non-traumatic and traumatic injury history over the previous 2 years	number of injuries: 100% (n=29) reported injuries over the previous 2 years overuse: 93.1 % (n=27) traumatic: 41.4% (n= 12) 27 participants (93.1%) reported to be currently injuried: 86.2% (n=25) overuse injuries 24.1% traumatic injuries location of injuries (non-traumatic; traumatic): hip: 23.5% (n=16); 35.7% (n=5) ankle: 22.0% (n=15); 42.9% (n=6) lower leg: 23.5% (n=16); 0.0% (n=0) foot: 10.3% (n=7); 14.3% (n=2) low back: 11.8% (n=8); 0.0% (n=0) knee: 7.4% (n=5); 7.1% (n=1) thigh: 1.5% (n=1); 0.0% (n=0)	correlation found between the number and severity of overuse injuries, which were associated with reduced FTO (r = > 0.38; P < 0.04) but not with hip ROM. The number of overuse injuries was positively correlated with 6 TO variables: CTO in all 3 positions and static-dynamic FTO in all 3 positions: r = 0.39-0.55, P < 0.039 Severity of non-traumatic injuries was positively correlated with 3 TO variables: static-danymic TO difference in all 3 positions: r = 0.38-0.47, P < 0.043 CTO was correlated between all 3 positions (1st, 5th right foot, 5th left foot): r > 0.88, P < 0.001
Steinberg et al., 2011	"Incorrect TO technique" (anterior pelvic tilt and sickling of the feet in plié) as a risk factor for paratenonitis	location: paratenonitis of the ankle and foot mechanism: no details provided definition: current pain in ankle or foot region, movements or exercises that evoke pain or pain that disturbed her dance practice and daily life activity.	turnout: no measurements provided; results based on clinical examination and observation of technique injuries: medical examination records on current foot or ankle paratenonitis	number of injuries: 8.6% (n=93) paratenonitis of foot or ankle joints location of injuries: paratenonitis of the joints of foot or ankle	lumbar hyperlordosis: attempt to increase TO resulted in higher risk for paratenonitis compared to dancers with correct technique (no numbers provided) dancers with paratenonitis had greater hip external rotation ROM compared to dancers without (OR, 1.048, 95%; CI 1.014-1.083) 38% of dancers with hyper hip external rotation were injured compared to 20% of non-injured dancers with hyper hip external rotation (P = 0.001) (no numbers provided)

Table 2: Data Extraction

Author, Year	Exposure	Outcome	Measurement Procedures	Results	
				Injuries	*Turnout*
van Merkensteijn et al., 2015	CTO = FTO – aHER (compensated TO = functional TO in 1st position minus total active hip external rotation)	**location:** low back, lower extremities **mechanism:** traumatic and non-traumatic/ injuries **definition:** any pain, discomfort, or musculoskeletal problem, that would cause modification of technique or time away from dance class, rehearsal, or performance in the previous 2 years.	**turnout:** active hip external rotation (AHER): prone; goniometer FTO: foot tracing on white paper in standing 1st position **injuries:** self-reported via questionnaire over the pevious two years; injury questionnaire was referenced to Trepman, E., et al. (2005) Spinal problems in dancers. In: R. Solomon, J. Solomon, & S.C. Minton: Preventing Dance Injuries. Champain, Human Kinetcs, p.85-97.	**number of injuries:** non-traumatic/overuse: 68% (n=15) traumatic: 36% (n=8) **location of injuries:** foot/ankle: (n=16) knee: (n=7) low back: (n=6) hip pain: (n=5) shin splints: (n=1)	correlation found between CTO with 1+ traumatic injury: r = 0.45, (n=22), P = 0.04 correlation found between CTO Ø 43° with 2+ injuries: *r* = 0.45, (n= 22), P = 0.04 no correlation found between CTO and nontaumatic/overuse injuries: *r* = 0.20, (n=22), P = 0.36 relationship found between increased CTO and low back pain (*r* = 0.50, (n=22), P = 0.02) but not between CTO and other injuries All participants compensated TO (3°-72°) Ø CTO: 36° ± 17° Ø FTO: 113° ± 14° Ø active hip external rotation: 78° ± 16°

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Medline, Embase:

((("ballet dancer"/ OR "classical ballet".mp OR "ballet".mp OR ballet*.mp OR "ballerina".mp OR ballerina*.mp OR "ballerino".mp OR ballerino*.mp OR "Dancing"/ OR "dancer".mp OR "dancers".mp OR "dancing".mp OR "dance".mp OR "dances".mp OR danc*.mp) AND ("turnout".mp OR turnout*.mp OR "turn out".mp OR turn out*.mp OR "leg external rotation".mp OR (leg ADJ4 external ADJ rotation).mp OR "external rotation".mp OR external rotat*.mp OR "en dehors".mp OR "Demi-Plie".mp OR "Demi-Plies".mp OR "Grand Plie".mp OR "Grand Plies".mp OR "Fondu".mp OR "pirouette".mp OR "pirouettes".mp OR "pirouetting".mp OR pirouett*.mp OR "jump".mp OR "jumps".mp OR "jumping".mp OR "jumped".mp OR jump*.mp OR "land".mp OR "lands".mp OR "landing".mp OR "landed".mp OR land*.mp OR "standing position".mp OR "standing positions".mp) AND (exp "Injury"/ OR "injury".mp OR "injuries".mp OR "injured".mp OR injur*.mp OR "fracture".mp OR "fractures".mp OR "fractured".mp OR fractur*.mp OR "trauma".mp OR trauma*.mp OR nontraum*.mp OR "overuse".mp OR overuse*.mp OR "rupture".mp OR "ruptured".mp OR ruptur*.mp OR "leg alignment".mp OR "leg alignments".mp OR "extremity alignment".mp OR "extremity alignments".mp)) OR ((*"ballet dancer"/ OR "classical ballet".ti OR "ballet".ti OR ballet*.ti OR "ballerina".ti OR ballerina*.ti OR "ballerino".ti OR ballerino*.ti OR "Dancing"/ OR "dancer".ti OR "dancers".ti OR "dancing".ti OR "dance".ti OR "dances".ti OR danc*.ti) AND ("turnout".ti OR turnout*.ti OR "turn out".ti OR turn out*.ti OR "leg external rotation".ti OR (leg ADJ4 external ADJ rotation).mp OR "external rotation".ti OR external rotat*.ti OR "en dehors".ti)))

(ts=(("ballet dancer" OR "classical ballet" OR "ballet" OR ballet* OR "ballerina" OR ballerina* OR "ballerino" OR ballerino* OR "Dancing" OR "dancer" OR "dancers" OR "dancing" OR "dance" OR "dances" OR danc*) AND ("turnout" OR turnout* OR "turn out" OR "turn out*" OR "leg external rotation" OR (leg NEAR/4 external NEAR/4 rotation) OR "external rotation" OR "external rotat*" OR "en dehors" OR "Demi-Plie" OR "Demi-Plies" OR "Grand Plie" OR "Grand Plies" OR "Fondu" OR "pirouette" OR "pirouettes" OR "pirouetting" OR pirouett* OR "jump" OR "jumps" OR "jumping" OR "jumped" OR jump* OR "land" OR "lands" OR "landing" OR "landed" OR land* OR "standing position" OR "standing positions") AND ("Injury" OR "injury" OR "injuries" OR "injured" OR injur* OR "fracture" OR "fractures" OR "fractured" OR fractur* OR "trauma" OR trauma* OR nontraum* OR "overuse" OR overuse* OR "rupture" OR "ruptured" OR ruptur* OR "leg alignment" OR "leg alignments" OR "extremity alignment" OR "extremity alignments")) OR ti=(("ballet dancer" OR "classical ballet" OR "ballet" OR ballet* OR "ballerina" OR ballerina* OR "ballerino" OR ballerino* OR "Dancing" OR "dancer" OR "dancers" OR "dancing" OR "dance" OR "dances" OR danc*) AND ("turnout" OR turnout* OR "turn out" OR "turn out*" OR "leg external rotation" OR (leg NEAR/4 external NEAR/4 rotation) OR "external rotation" OR "external rotat*" OR "en dehors")))

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Chapter 3

Motivational Climate & Teacher/Master

Perceptions of motivational climate and musculoskeletal injuries in ballet dancers

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Abstract

Sports science identified the trainer-athlete-relationship in the etiology of injuries. We aimed to investigate 1. the association between empowering (EMC) and disempowering (DMC) motivational-climate and musculoskeletal injuries in ballet, 2. if EMC moderates the association between DMC and injuries.

A cross-sectional cohort survey-study was conducted among ballet dancers (>18 years) reporting acute and overuse injuries of the previous two years. Motivational climate was assessed with the Empowering-and-Disempowering-Motivational-Climate-Questionnaire (1-5-Likert). The Oslo-Sports-Trauma-Research-Centre-Overuse-Injury-Questionnaire assessed severity of overuse injuries. Linear regression was performed adjusted for the confounders age, sex, expertise, experience, and initiation-age with an interaction term between EMC and DMC to assess effect modification.

189 dancers (26.7±7.9 years; 130 professionals, 27 nations) reported 197 acute and 465 overuse injuries (previous two years). Mean EMC was 3.1±1.07, DMC 3.3±1.08. EMC was associated with less acute (β=-0.22; 95%CI -0.40 to -0.04) and overuse injuries (β=-0.74; 95%CI -0.99 to -0.50), while DMC was associated with more injuries (acute: β=0.30; 95%CI 0.13 to 0.47; overuse: β=0.74; 95%CI 0.50 to 0.98). When tested together and adjusted for confounders, EMC lost its protective effect (acute: β=-0.15; 95%CI -0.19 to 0.49; overuse: β=-0.34; 95%CI -0.81 to 0.13). DMC was positively associated with injuries throughout all settings (acute: β=0.43; 95%CI 0.10 to 0.76; overuse: β=0.46; 95%CI 0.00 to 0.91). EMC showed no moderating effects on DMC in the adjusted models.

To avoid injuries, it is not enough to create an EMC, because any disempowering nuances may negatively affect empowering climates. Teachers should avoid DMC altogether to prevent injuries in dancers.

3.1 Introduction

As in many high performance sports, vocational, professional, but also amateur ballet dancers experience musculoskeletal injuries, which have been reported to range from 0.6 to 5.6 injuries per 1000 hours of dance (1, 2) The majority of ballet dancers' injuries are overuse injuries and sustained to the lower extremities and spine (3), with a number of different risk factors involved in their development.

Comparable to any other athlete or performer, the psychological environment surrounding the ballet dancer could account for such a risk factor. Among other influences, the behavior of the ballet teacher or ballet master creates a certain motivational climate. The motivational climate has been identified as a predictor for health and wellbeing of athletes, influencing their performance, engagement, and adherence (4-10). Fusing the concepts from self-determination-theory (11) and achievement-goal-theory (12), Duda (2013) described the resulting motivational climate to be more or less empowering or disempowering (13, 14). Based on the tenets of self-determination-theory, achievement-goal-theory and previous research, empowering motivational climates are characterized as task-involving as well autonomy- and socially-supportive, while disempowering climates as more ego-involving, controlling, and relatedness-thwarting. Moreover, in Duda's approach, empowering and disempowering climates are not fundamentally two ends on a continuum, but instead are conceptualized as coexisting (6, 15).

In an empowering motivational climate (EMC), individuality, the dancer's perspectives and self-referenced development are supported. The dancer's reflection on the presence and handling of physical complaints through an empowering atmosphere could contribute to

reduce the number of injuries by fighting the idea that pain and injuries are an integrating part of the dance world. (16, 17) An acceptance of individual anatomical limitations instead of a focus on the need to employ compensatory strategies to fulfil ideal dance technical demands could further contribute to avoid many injuries.(18) The focus on social interaction and task-orientation satisfies basic psychological needs for autonomy, competence, as well as relatedness and facilitates co-operative learning. The resulting focus on teamwork could reduce injuries, because there is less need to compete with peers or live up to teachers' expectations, while dancing through pain and injury. In such a climate, mistakes are seen as a chance to learn, while physical complaints and their need to heal is acknowledged. In task-involving climates, trying hard in skill development is appreciated and dancers' are offered meaningful choices and opportunities to input. Hence, empowering climates can foster self-efficacy (19), perceived ability and enjoyment (20, 21) as well as self-worth (22). Studies have found performance- and personality enhancing effects of empowering teacher behavior, which provides rationale, supports meaningful choice and fosters self-referenced perception of competence (23). This nurtures psychological health mirrored in positive affective states or self-esteem, and enhances performance in athletes (9, 13) and dancers (7, 8, 10), while harm or illness can be prevented (24).

A disempowering motivational climate (DMC), in the contrary, stresses an ego-involving view of competence, in which high levels of intra-competition between dancers (performance orientation) and punishment of mistakes are perceived. Disappointment in the dancer expressed by the teacher as well as unequal recognition are examples of controlling teacher behavior, which can result in feelings of humiliation, pressure,

intimidation, and control in the dependent person, e.g., the dancer (25). Such a climate does not offer an environment in which dancers can acknowledge or report physical complaints, accept their anatomical individuality or are encouraged to speak out in case of pain or shortcomings. Thus, such an atmosphere is disempowering, fostering maladaptive behavior such as perfectionistic concerns or anxiety (26, 27), forcing the dancer to suppress physical or psychological discomfort, which could support development of stress, illness, or injury.

In a study involving 406 English athletes from various team and individual sports, EMC could be linked to more positive outcomes, such as enjoyment in sports participation, while DMC was associated with reduced accomplishment as well as physical symptoms.(6) In 112 female and male adolescents football players, perceived coach-created empowering motivational climate positively was associated with the children's autonomous motivation. (28) It was positively related to their enjoyment of daily physical activity and negatively related to their percentage of body fat. In female elite football as well as female youth football, empowering features of the climate (e.g., task-involving, autonomy- and social support) and the relationship with or behavior of the coach were negatively related to injuries. Disempowering aspects (e.g., ego-orientations, perceived performance climates, the coach as a source of distress) have shown to be positively associated with overuse or previous injuries. (29, 30)

To our knowledge, no study has investigated the relationship between the motivational climate and musculoskeletal injuries in ballet dancers. Hence, the primary aim of this study was to investigate ballet dancers' perceptions of teacher created empowering and

disempowering motivational climates and their association with musculoskeletal injuries. It is hypothesized that an EMC can be positively related to the prevention of musculoskeletal injuries and that DMC can be associated with injuries and ill-health. Second, given EMC and DMC coexist, this study aimed to test whether the EMC moderated the effects of DMC and its association with injuries, i.e., if EMC has a buffering effect on the hypothesized debilitating effects of DMC (6).

3.2 Methods

3.2.1 Study design

A cross-sectional cohort study was performed, using a survey based on 90 questions. The METC-LDD (Medical-Ethic Committee Leiden│Den Haag│Delft) waived METC approval as it did not subject to the WMO (Medical Research Involving Human Subjects act) (N19.082/RM/fIT1). Informed consent was obtained electronically.

3.2.2 Participants

3.2.2.1 Inclusion & exclusion criteria

Participants were professional, pre-professional/vocational, and amateur ballet dancers over 18 years of age, with regular classical ballet training and experience for at least 3 years. Insufficient data (i.e., <75% of the questionnaire answered) were regarded as exclusion criteria. Since the survey was composed in English to serve international purpose, sufficient English language skills were an inclusion criteria for participation.

3.2.2.2 Recruitment method

The link to the survey was presented via social media (Facebook, Instagram), embedded in a short explanation, in which the dancers were asked to further distribute and share the information through their personal contacts, within theatres, ensembles, dance panels, blogs, and other contact options. The survey was executed anonymously and no personal data, through which dancers could be identified, was recorded. 188 ballet ensembles and

51 dance organizations from around the world were informed via email and through contact forms on their website.

3.2.3 Assessments

3.2.3.1 Demographics

General questions assessed baseline demographics such as sex, nationality, age at starting to dance ballet and workload of the previous two years. Workload was assessed as dancer exposure (DE), which equals a dancer's event (irrespective of duration of exposure), i.e., participation in a class, rehearsal, or performance as recommended in dance science literature (31), as well as per athlete exposure hour (AE), i.e., 60 minutes. Level of expertise, i.e., pre-/professional or amateur dancer, was derived from the reported AE: professionals included professional and pre-professional dancers in vocational institutions and were defined as dancers with 16+ hours exposure per week, whereas amateurs had a maximum of 15 hours of dancing per week.(32-35)

3.2.3.2 Injuries

Primary outcome measures were the number of acute and overuse musculoskeletal injuries of the previous two years (36). Overuse injury (37) was defined as any ongoing or recurrent musculoskeletal pain, ache, stiffness, instability, giving away, swelling, locking etc., sustained within the previous two years from dance related activities (i.e., performance, rehearsal, or technique class), which could not be linked to a clearly identifiable event but which affects the dancer's ability to dance, forces to perform and train with pain or functional disability, modify technique, reduce workload, or stop dancing altogether. Acute Injury (37) referred to any acute injury, whose onset could be linked to

a specific injury event, in the course of dance related activities (i.e., performance, rehearsal, or technique class) within the previous two years, which affects the dancer's ability to dance, forces to perform and train with pain or functional disability, modify technique, reduce workload, or stop dancing altogether.

Self-reported acute injuries within the previous two years were recorded through 17 items representing 16 body parts and an additional item as possibility to report other injuries than those associated to the given locations. Within each item the following was asked: diagnosis, time loss, pain, the necessity to modify training or technique, and instability to assess the severity of the injury.

Overuse injuries and their severity were assessed based on three sets of questions from the *Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire* (37) adapted for dancers. The items recorded participation in training, rehearsals, or performance by 4 options (i.e., '*full participation without pain'*, '*full participation but with pain during dancing*', '*reduced participation*', and '*I could not participate at all'*), reduction of dancing volume/load through 5 options (i.e., '*No reduction*', '*to a minor extent*', '*to a moderate extent*', '*to a major extent*', and '*I could not dance at all*'), as well as how the overuse injury affected the dancer's performance through 5 items (i.e., '*no effect*', '*to a minor extent*', '*to a moderate extent*', '*to a major extent*', and '*I could not perform at all*').

Moreover, the mode of diagnosis was recorded for both injury mechanisms, i.e., whether the diagnosis was done by a medical professional, the teacher, or the dancers themselves.

3.2.3.3 Motivational Climate

The two high-order dimensions of motivational climate mirroring teacher's behavior, namely empowering and disempowering climate, were assessed through the *(Empowering and Disempowering Motivation Climate Questionnaire)* (38), which was adapted for dancers for the purpose of this study. The dancers were asked to think of their primary ballet teacher of the previous two years, whom they had spent most of their training time with. 33 items were based on a 1-5-Likert-Scale, ranging from 'Strongly disagree" (1) to 'Strongly agree' (5) resulting in mean scores for each subscale, i.e., EMC and DMC. 17 items represented dimensions of EMC, defined by its three lower-order domains, namely task-involving (e.g., '*My Ballet Master/Teacher/Pedagogue/Trainer makes sure dancers feel/felt good when they improve/improved*'), autonomy-supporting (e.g., '*My Ballet Master/Teacher/Pedagogue/Trainer gives dancers choices and options*'), and social-supporting behavior (e.g., '*My Ballet Master/Teacher/Pedagogue/Trainer really cares for me no matter what happens*') with 9, 5, and 3 items, respectively. 16 items assessed DMC, with 7 items for lower-order ego-involving climate (e.g., '*My Ballet Master/Teacher/Pedagogue/Trainer gives most attention to the best dancers*') and 9 items for controlling behavior (e.g., '*My Ballet Master/Teacher/Pedagogue/Trainer shouts at dancers in front of others to make them do certain things*').

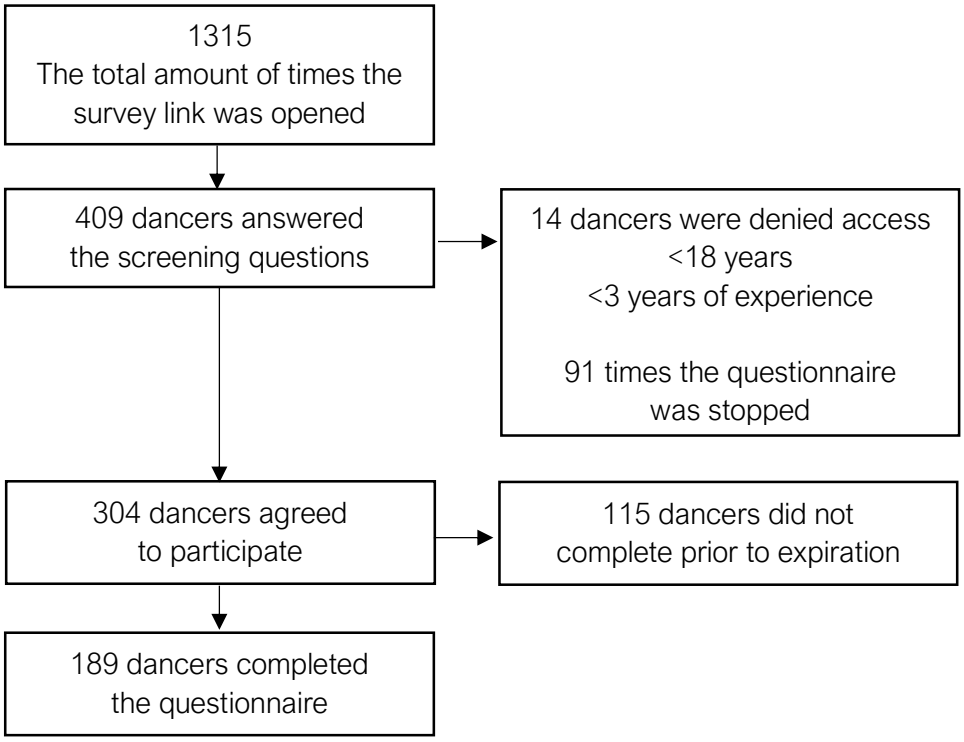
3.2.3 Statistical analysis

SPSS 25 for windows was used for statistical analysis. Normality assumptions were neglectable due to sufficient sample size (39). Multicollinearity was assessed between all *Empowering and Disempowering Motivation Climate Questionnaire*-items (cutoff VIF

<5.0, tolerance >0.2) (40). Cronbach's α was applied to test internal reliability of the *Empowering and Disempowering Motivation Climate Questionnaire*-subscales, and explorative factor analysis (EFA) was used to identify the underlying structure of the scale (Extraction method: Maximum Likelihood; Rotation method: Equamax with Kaiser Normalization; Kaiser-Meyer-Olkin Measure of Sampling Adequacy and Bartlett Test).

Uni- and multivariate linear regression served to determine the extent of the relationship between the perceived teacher created higher-order climates and acute or overuse injuries, respectively. The association was assessed in 8 models. In model 1, a univariate regression, we assessed the effect of EMC on acute and overuse injuries, respectively. Model 2 was model 1 with adjustment for the confounders age, sex, years of ballet training, age at ballet initiation, and level of expertise (i.e., professional or amateur dancer). Model 3 evaluated the effect of DMC on both injury mechanisms, in model 4, model 3 was adjusted for confounders. Model 5, a multivariate regression, tested the effect of both, EMC and DMC on acute as well as overuse injuries, and the equivalent model 6 again adjusted for confounding variables. Model 7 evaluated the moderating effect of EMC on DMC (EMC x DMC), for both injury mechanisms with adjustment for confounders in model 8. For this interaction, Hayes' PROCESS v3.5 for SPSS (41) was applied. PROCESS offers the adoption of the Johnson-Neyman-technique, which identifies points in the range of the moderator (EMC) in which the interaction effect of X (DMC) on Y (injuries) becomes statistically significant. When no Johnson-Neyman-Score is reported the output indicates that the effect of DMC on the outcome is significant throughout the whole range of DMC (1-5 Likert Scale) with no buffering effect of EMC.

Figure 1: Flowchart participant documentation



3.3 Results

3.3.1 Population

189 ballet dancers, 156 females and 33 males with a mean age of 26.7 ±7.9 years were included *(Figure 1)*, representing 27 nations (Appendix 1). Most dancers were professional dancers (70%). 5 dancers could not be identified according to level of expertise because their athlete exposure hours were identified as outliers (i.e. > 100 up to 4000 athlete exposure hours). For details see table 1.

Table 1: Demographics: the values are given as the mean ±standard deviation, N (%) of the population
DE: Dancer exposure (= per event, irrelevant of duration of exposure)
AE: Athlete exposure (= per hour, i.e., 60 minutes)

	All N=189	Females N=156	Males N=33
Age at participation (years)	26.7 ±7.86	26.6 ±7,96	27.2 ±7.47
Ballet experience (years)	14.5 ±6.97	14.6 ±7.25	14.0 ±5.51
Age at ballet initiation (years)	8.0 ±5.78	7.4 ±4.61	11.0 ±9.06
Athlete exposure AE (N) (hours/week)	185 26.8 ±15.24	152 25.1 ±15.45	33 34.2 ±11.73
Dancer exposure DE (N) (events/week)	184 12.3 ±9.60	151 11.5 ±9.52	33 16.2 ±9.09
Dancing level Professional AE N(%) (hours/week) Amateur AE N(%) (hours/week)	 130 (70.3) 35.5 ±8.19 55 (29.7) 6.2 ±3.94	 100 (65.8) 34.9 ±8.53 52 (34.2) 6.3 ±3.99	 30 (90.9) 37.3 ±6.73 3 (9.1) 3.7 ±1.52
Empowering climate Professional Amateur	3.1 ±1.07 2.8 ±.1.03 3.8 ±0.75	3.2 ±1.04 2.8 ±1.02 3.8 ±0.76	2.7 ±1.11 2.5 ±1.05 4.1 ±0.65
Disempowering climate Professional Amateur	3.3 ±1.08 3.6 ±.1.03 2.7 ±0.89	3.3 ±1.06 3.6 ±1.01 2.7 ±0.86	3.5 ±1.19 3.7 ±1.10 2.1 ±1.37

3.3.2 Injuries

A total of 197 acute injuries (table 2) were reported by 116 dancers, resulting in 1.0 ±1.16 acute injuries per dancer, of which 161 (81.7%) were diagnosed by a medical professional. The ankle was the body part that was most often affected. 20% of all dancers

had an acute ankle injury. When looking at severity acute injuries often resulted into *'timeloss'* and *'pain'* (table 3a and 3b), suggesting that these injuries were substantial. Acutely pulled muscles and acute bone blockage in foot, wrist, shoulder, and hamstrings were reported as 'other acute injuries'.

A total of 465 overuse injuries were reported by 162 dancers (85.7%), 2.5 ±1.9 per dancer and 317 (68%) diagnosed by a medical professional, (table 2). Again the ankle was most often affected by overuse injuries (table 4a and 4b). Muscle soreness until numbness and pain, chronic respiratory diseases, and anorexia were reported as 'other injuries'. Appendix 2 provides an overview of the reported acute and overuse injuries.

For severity, most injuries resulted in *'Full participation but with pain during dancing'* . In combination with *'no reduction of dancing load'* and *'moderate'* to *'major effect on performance'*, substantial burden for the dancers can be noted. Timeloss could not be assessed conclusively for overuse injuries.

3.3.3 Empowering and disempowering motivational climate

Multicollinearity analysis showed acceptable levels of correlation between all items of EMC and DMC. Cronbach's α suggested good internal reliability between items of the *Empowering and Disempowering Motivation Climate Questionnaire* (EMC α = 0.946; DMC α = 0.96). Explorative factor analysis (KMO = 0.97; Bartlett Test p = 0.00) showed clear loading onto 2 factors, which was additionally verified in a Scree Plot. As intended, items of the EMC loaded most strongly onto one factor (range of factor loading: 809 – 515), whilst variables of the DMC loaded onto the second factor (range of factor loading: 853 – 251). The DMC (3.3 ±1.08) and the EMC (3.1 ±1.07) mean scores were moderate.

3.3.4 Motivational climate and injuries

Higher EMC scores were associated with less injuries (acute: β -0.25, 95%CI -0.40 to -0.10; overuse: β -0.92, 95%CI -1.13 to -0.71). After adjustment for confounders in Model 2, these associations remained similar (acute: β -0.22, 95%CI -0.40 to -0.04; overuse: β -0.74, 95%CI -0.99 to -0.50). Higher DMC scores were associated with more acute injuries in model 3 (unadjusted: β 0.31, 95%CI 0.16 to 0.46; adjusted: β 0.30, 95%CI 0.13 to 0.47) and more overuse injuries (unadjusted: β 0.90, 95%CI 0.68 to 1.11; adjusted: β 0.74, 95%CI 0.50 to 0.98) in models 3 and 4. When including both EMC and DMC in one regression model (models 5 and 6), EMC lost its protective effects for both acute (unadjusted: β 0.10, 95%CI -0.22 to 0.41; adjusted: β -0.15, 95%CI -0.19 to 0.49) and overuse injuries (unadjusted: β -0.53, 95%CI -0.97 to -0.09; adjusted: β -0.34, 95%CI -0.81 to 0.13), while the negative effects of DMC remained for acute injuries (unadjusted: β 0.39, 95%CI 0.08 to 0.70; adjusted: β 0.43, 95%CI 0.10 to 0.76) as well as overuse injuries (unadjusted: β 0.44. 95%CI 0.00 to 0.87; adjusted: β 0.46, 95%CI 0.00 to 0.91).

3.3.5 Effect modification of EMC on DMC and injuries

In model 7 and 8 we assessed whether EMC had a moderating effect on DMC and its association with injuries (table 5). EMC only moderated the relationship between the DMC and acute injuries in the unadjusted model (DMC x EMC β 0.15, 95%CI 0.01 to 0.28). The Johnson-Neyman score indicated that only when the EMC score was higher than 3.28, did it buffer the debilitating effects of DMC on acute injuries. However, when adjusting for confounders in Model 8, the moderating role of EMC disappeared (acute: β 0.14, 95%CI -.01 to 0.29; overuse: β -0.15, 95%CI -0.35 to 0.06).

Table 2: Prevalence, frequency, diagnosis of injuries as mean ±standard deviation and N (%) of the population
acute injuries: sudden onset caused by high-intensity forces, i.e., accidents resulting in sprains, strains, contusions, fractures etc.
overuse injuries: result from repetitive micro-traumata of submaximal mechanical loading, also called "chronic injuries".

	Acute injuries	Overuse injuries
Total sum of injuries in 189 dancers	197	465
Injuries per dancer	1.0 ±1.16	2.5 ±1.86
Injuries per female dancer	1.0 ±1.17	2.3 ±1.78
Injuries per male dancer	1.1 ±1.13	3.3 ±2.05
Injuries per professional dancer	1.2 ±1.25	2.9 ±1.94
Injuries per amateur	0.7 ±0.89	1.5 ±1.20
Injuries per dancer		
0	73 (38.6)	27 (14.3)
1	65 (34.4)	42 (22.2)
2	33 (17.5)	31 (16.4)
3	12 (6.3)	44 (23.3)
4	1 (0.5)	18 (9.5)
5	4 (2.1)	14 (7.4)
6	1 (0.5)	8 (4.2)
7		3 (1.6)
8		0 (0)
9		2 (1.1)
Injuries diagnosed by medical professional	161 (81.7)	317 (68.0)
Injuries diagnosed by the ballet teacher/master	8 (4.1)	24 (5.2)
Injuries diagnosed by the dancers themselves	28 (14.2)	124 (26.7)

Table 3a: Locations and severity of acute injuries: Dancers who experienced acute injuries to the upper extremities and torso
Injury locations are calculated as N(%) of the whole study population; severity is calculated as n(%) of the number of dancers affected.
Legend:
acute injuries: sudden onset caused by high-intensity forces, i.e., accidents resulting in sprains, strains, contusions, fractures etc.

	Head	Shoulder	Arm	Thorax	Cervical	Thoracic	Lumbar	Sacroiliac
Total N (%)	11 (5.8)	9 (4.8)	6 (3.2)	3 (1.6)	5 (2,7)	0 (0)	8 (4,2)	5 (2,7)
Timeloss n(%)	9 (81.8)	8 (88.9)	4 (66.7)	2 (66.7)	2 (40.0)	0 (0)	6 (75.0)	5 (100.0)
Modifying technique n(%)	2 (18.2)	5 (55.5)	2 (33.4)	1 (33.3)	3 (60.0)	0 (0)	3 (37.5)	3 (60.0)
Dancing with pain n(%)	3 (27.3)	7 (77.8)	3 (50.0)	1 (33.3)	3 (60.0)	0 (0)	7 (87.5)	3 (60.0)
Dancing with instability n(%)	1 (9.1)	6 (66.7)	2 (33.3)	0 (0)	1 (20.0)	0 (0)	2 (25.0)	1 (20.0)

Table 3b : Locations and severity of acute injuries: Dancers who experienced acute injuries to the lower extremities and 'other injuries'.
Injury locations are calculated as N(%) of the whole study population; severity is calculated as n(%) of the number of dancers affected.
Legend:
acute injuries: sudden onset caused by high-intensity forces, i.e., accidents resulting in sprains, strains, contusions, fractures etc.

	Hip	Thigh	Knee	Shin	Calf	Ankle	Foot	Toes	Other Injuries
Total N (%)	15 (7,9)	17 (9,0)	33 (17,5)	4 (2,1)	4 (2,1)	37 (19,6)	20 (10,6)	10 (5,3)	10 (5,3)
Timeloss n(%)	8 (53.3)	11 (64.7)	26 (78.8)	2 (50.0)	3 (75.0)	28 (75.7)	17 (85.0)	4 (40.0)	8 (80.0)
Modifying technique n(%)	6 (40.0)	8 (47.1)	17 (51.5)	1 (25.0)	3 (75.0)	16 (43.2)	7 (35.0)	5 (50.0)	5 (50.0)
Dancing with pain n(%)	9 (60.0)	13 (76.5)	21 (63.6)	1 (25.0)	4 (100.0)	21 (56.8)	6 (30.0)	7 (70.0)	4 (40.0)
Dancing with instability n(%)	5 (33.3)	3 (17.6)	15 (45.5)	2 (50.0)	0 (0)	20 (54.1)	6 (30.0)	1 (10.0)	2 (20.0)

Table 4a: Locations and severity of overuse injuries: Dancers who experienced overuse injuries to the upper extremities and torso
Injury locations are calculated as N(%) of the whole study population; severity is calculated as n(%) of the number of dancers affected.
Legend:
overuse injuries: result from repetitive micro-traumata of submaximal mechanical loading, also called "chronic injuries".

	Head	Shoulder	Arm	Thorax	Cervical	Thoracic	Lumbar	Sacroiliac
Total N (%)	10 (5.3)	28 (14.8)	5 (2.6)	5 (2.6)	9 (4.8)	10 (5.3)	57 (30.2)	20 (10.6)
Participation in training, rehearsals, performance n(%)								
Full participation without pain	-	2 (7.1)	-	1 (20.0)	-	1 (10.0)	2 (3.5)	-
Full participation but with pain during dancing	6 (60.0)	22 (78.6)	3 (60.0)	3 (60.0)	8 (88.9)	7 (70.0)	49 (86.0)	19 (95.5)
Reduced participation	2 (20.0)	4 (14.3)	-	1 (20.0)	-	1 (10.0)	4 (7.0)	1 (5.0)
I could not participate	2 (20.0)	-	2 (40.0)	-	1 (11.1)	1 (10.0)	2 (3.5)	-
Reduction of dancing volume/load n(%)								
No reduction	4 (40.0)	17 (60.7)	2 (40.0)	4 (80.0)	6 (66.7)	4 (40.0)	44 (77.2)	11 (55.5)
To a minor extent	3 (30.0)	10 (35.7)	-	-	2 (22.2)	2 (20.0)	6 (10.5)	6 (30.0)
To a moderate extent	-	-	1 (20.0)	1 (20.0)	-	1 (10.0)	5 (8.8)	2 (10.0)
To a major extent	-	1 (3.6)	-	-	-	2 (20.0)	-	1 (5.0)
I could not dance at all	3 (30.0)	-	2 (40.0)	-	1 (11.1)	1 (10.0)	2 (3.5)	-
Affect performance n(%)								
No effect	1 (10.0)	7 (25.0)	2 (40.0)	1 (20.0)	-	2 (20.0)	6 (10.5)	2 (10.0)
To a minor extent	3 (30.0)	11 (39.3)	-	2 (40.0)	3 (33.3)	3 (30.0)	14 (24.6)	3 (15.0)
To a moderate extent	4 (40.0)	6 (21.4)	-	1 (20.0)	4 (244.4	3 (30.0)	23 (40.4)	10 (50.0)
To a major extent	1 (10.0)	3 (10.7)	1 (20.0)	1 (20.0)	1 (11.1)	1 (10.0)	12 (21.1)	4 (20.0)
I could not perform at all	1 (10.0)	1 (3.6)	2 (40.0)	-	1 (11.1)	1 (10.0)	2 (3.5)	1 (5.0)

Table 4b b: Locations and severity of overuse injuries: Dancers who experienced overuse injuries to the lower extremities and 'other injuries'.
Injury locations are calculated as N(%) of the whole study population; severity is calculated as n(%) of the number of dancers affected.
Legend:
overuse injuries: result from repetitive micro-traumata of submaximal mechanical loading, also called "chronic injuries".

	Hip	Thigh	Knee	Shin	Calf	Ankle	Foot	Toes	Other injuries
Total N (%)	40 (21.2)	14 (7.4)	68 (36.0)	28 (14.8)	7 (3.7)	73 (38.6)	44 (23.3)	26 (13.8)	21 (11.1)
Participation in training, rehearsals, performance n(%)									
Full participation without pain	3 (7.5)	1 (7.1)	3 (4.4)	-	-	4 (5.5)	4 (9.1)	-	1 (4.8)
Full participation but with pain during dancing	20 (50.0)	7 (50.0)	46 (67.6)	16 (57.1)	5 (71.4)	46 (63.0)	33 (75.0)	19 (73.1)	17 (81.0)
Reduced participation	14 (35.0)	5 (35.7)	13 (19.1)	10 (35.7)	2 (28.6)	11 (15.1)	5 (11.4)	3 (11.5)	2 (9.5)
I could not participate	3 (7.5)	1 (7.1)	6 (8.8)	2 (7.1)	-	12 (16.4)	2 (4.5)	4 (15.4)	1 (4.8)
Reduction of dancing volume or load n(%)									
No reduction	15 (37.5)	8 (57.1)	32 (47.1)	15 (53.6)	2 (28.6)	36 (49.3)	22 (50.0)	16 (61.5)	17 (81.0)
To a minor extent	11 (27.5)	4 (28.6)	12 (17.6)	4 (14.3)	3 (42.9)	12 (16.4)	12 (27.3)	3 (11.5)	2 (9.5)
To a moderate extent	7 (17.5)	1 (7.1)	14 (20.6)	4 (14.3)	1 (14.3)	8 (11.0)	6 (13.6)	1 (3.8)	1 (4.8)
To a major extent	4 (10.0)	1 (7.1)	5 (7.4)	3 (10.7)	-	5 (6.8)	2 (4.5)	2 (7.7)	-
I could not dance at all	3 (7.5)	-	5 (7.4)	2 (7.1)	1 (14.3)	12 (16.4)	2 (4.5)	4 (15.4)	1 (4.8)
Affect performance n(%)									
No effect	6 (15.0)	2 (14.3)	4 (5.9)	-	-	3 (4.1)	5 (11.4)	4 (15.4)	2 (9.5)
To a minor extent	12 (30.0)	5 (35.7)	14 (20.6)	8 (28.6)	3 (42.9)	12 (16.4)	15 (34.1)	2 (7.7)	1 (4.8)
To a moderate extent	15 (37.5)	1 (7.1)	19 (27.9)	7 (25.0)	3 (42.9)	30 (41.1)	10 (22.7)	4 (15.4)	11 (52.4)
To a major extent	3 (7.5)	6 (42.9)	27 (39.7)	12 (42.9)	-	18 (24.7)	12 (27.3)	12 (46.2)	6 (28.6)
I could not perform at all	4 (10.0)	-	4 (5.9)	1 (3.6)	1 (14.3)	10 (13.7)	2 (4.5)	4 (15.4)	1 (4.8)

Table 5: The association between empowering and disempowering climates and acute as well as overuse injuries
Legend:
Models 2, 4, 6, and 8 were adjusted for the confounders age, sex, level of expertise, years of ballet, and age at ballet initiation.
Models 7 and 8 show the interaction between EMC and DMC (DMC x EMC)

Parameters acute injuries	β	95% CI for β		Parameters overuse injuries	β	95% CI for β	
		Lower	Upper			Lower	Upper
Model 1: EMC	-0.250	-0.402	-0.099	Model 1: EMC	-0.919	-1.132	-0.705
Model 2: EMC adjusted	-0.220	-0.400	-0.041	Model 2: EMC adjusted	-0.741	-0.986	-0.496
Model 3: DMC	0.307	0.160	0.455	Model 3: DMC	0.896	0.684	1.108
Model 4: DMC adjusted	0.300	0.127	0.472	Model 4: DMC adjusted	0.741	0.503	0.979
Model 5: EMC	0.095	-0.215	0.405	Model 5: EMC	-0.531	-0.970	-0.092
DMC	0.389	0.083	0.695	DMC	0.437	0.004	0.870
Model 6: EMC adjusted	0.154	-0.185	0.493	Model 6: EMC adjusted	-0.342	-0.809	0.125
DMC adjusted	0.428	0.097	0.758	DMC adjusted	0.456	0.001	0.912
Model 7: EMC	0.027	-0.313	0.367	Model 7: EMC	-0.449	-0.982	0.085
DMC	0.293	-0.040	0.626	DMC	0.554	0.027	1.081
Interaction (DMC x EMC)	0.145	0.007	0.283	Interaction (DMC x EMC)	-0.176	-0.375	0.023
Model 8: EMC	0.096	-0.264	0.456	Model 8: EMC	-0.282	-0.814	0.250
DMC	0.336	-0.018	0.690	DMC	0.551	0.030	1.073
Interaction adjusted	0.140	-0.007	0.287	Interaction adjusted	-0.145	-0.345	0.055

3.4 Discussion

This study evaluated the association between ballet dancers' perceptions of teacher created motivational climate and musculoskeletal injuries. In a cross-sectional study including 189 professional and amateur dancers we found that motivational climate was perceived as moderate to low as well as more disempowering than empowering. In our population, DMC was associated with acute and overuse injuries. While EMC had potential to prevent injuries, it lost its effect when DMC was included in the analysis. The stronger association between EMC and DMC, respectively, and overuse injuries is probably related to the fact that acute injuries occur un-anticipated, as sudden macro trauma, while overuse injuries result from more subtle submaximal overload leading to micro-traumata over a longer period of time. Thus, overuse injuries are more strongly depending on the psychological environment surrounding the dancer.

3.4.1 Injuries

The dancers sustained approximately 2.5 times more overuse than acute injuries in the previous two years. This was the case in our whole population as well as in the two levels of expertise, i.e., amateurs and professionals. The prevalence and anatomical locations of injuries found in our dancers are consistent with recent studies (1, 42-44). The lower extremities were the body parts most affected. The highest numbers of acute as well as overuse injuries were sustained to the ankle and the knee, followed by overuse injuries to the lumbar spine.

In order to show the burden of injuries we displayed the items reporting severity for each anatomical injury location instead of aggregating mean scores for overall severity assessment. Overuse injuries result from repetitive micro-traumata instead of one acute

macro-trauma (45, 46). Working through those traumata instead of curing complaints renders the athlete at a high risk to sustain further harm. This was documented in sports science and mirrors the difficulty of managing overuse injuries (37). Our tables on the anatomical locations of overuse injuries display patterns, which confirm these tendencies in dancers, who tend to work with pain and/or instability but without reduction of training load. After (or when dancing through micro-) trauma, neuromuscular control might be impaired through alterations in injured tissues responsible for proprioception, sensorimotor control, and strength (47), increasing the risk of overuse and re-injury. Moreover, the stress related to an injury, levels of pain, and perceived lack of recovery has been shown to be associated with an increased risk for repetitive injuries (48).

3.4.2 Motivational climate and injuries

In the current study we focused on the role of the ballet teacher or ballet master in the motivational climate. While they are not the only factors, which determine a motivational climate, they are significant others with a big influence on dancers.(49) Especially in the lives of professional dancers, they are the persons dancers spend most of their time with. Focusing on this important influence of the teacher the motivational climate has been identified as a key predictor for health, wellbeing as well as the athlete's or artist's performance, engagement, and adherence in sports- as well as in dance science (4-10). Self-efficacy (19) as well as self-worth (22, 50), enjoyment and perceived ability (20, 21, 28) can be fostered through EMC. Moreover, EMC can provide an environment for dancers in which they are allowed or even encouraged to report and cure their injuries and complaints without fear of sanctions or other ramifications.

In the contrary, teachers, who encourage ego-orientation or who exhibit controlling behavior create a DMC. In a previous study, female football coaches/trainers were shown to become a source of distress for the athletes through their choices and behaviors, which could be linked to overuse injuries (29). In another study on female youth football, the association between previous injuries and features of a DMC (i.e., ego-orientation as well as performance climates) was demonstrated (30).

Our study is the first to report that DMC can be positively related to musculoskeletal injuries in dancers, confirming Duda's model with respect to physiological correlates. The Empowering and Disempowering Motivational Climate-Questionnaire, which we adapted for dancers, investigates the behavior and motivational strategies of the ballet teacher or ballet master, which create a certain motivational climate. As our results indicate, already nuances of DMC can threaten the dancer's wellbeing by heightening the occurrence of injury. According to Duda's model, the DMC most likely impacts on injury occurrence by thwarting dancers' feelings of task-focused competence, autonomy- and relatedness, and making it more likely that the dancer has an ego-involvement and controlled motivation. Our results are consistent with previous studies, which have considered alternative psychological outcomes such as burnout, need dissatisfaction, reduced accomplishment, and overall ill-health in child, adolescent, and adult athletes of various team and individual sports (6, 25, 28, 51-53).

The relationship with overuse injuries, which constitute the majority of dancers' injuries, is of particular interest in our findings. Unfortunate handling of pain as well as injury has recurrently been described as a factor in the high number of overuse injuries in dancers (3, 16, 17), in which disempowering environments could play a role. The creation of a

DMC could lead to the perceived need in dancers to work through pain and injury in order to please teachers or avoid sanctions,(54-56). Moreover, a competitive atmosphere, as an integrating aspect of a disempowering environment, might force dancers to push themselves through pain, risk acute as well as overuse injuries in their goal to outperform others or keep contracts. The fear of mistakes, as another aspect of DMC, could lead to the need to overcome individual anatomical limitations in the search of dance technical excellency, which might contribute to injury risk by employing the need for compensatory strategies, ignoring the need to reduce workload or modify exercises to allow complaints and injuries to heal.(18)

Our findings show that DMC can be linked to injuries, while an EMC can positively support injury prevention and may thus support wellbeing, consistent with previous research on dancers (7, 8). However, a growing number of researchers stress the importance of considering the interaction between EMC and DMC rather than regarding EMC and DMC as mutually exclusive concepts (38, 57, 58). Lower-order empowering (i.e., autonomy- and social support as well as task-involving) and disempowering (i.e., ego-involving and controlling behavior) dimensions interact with each other (6). This suggests that in reality, the overall motivational climate for most dancers is not only positive or negative, i.e., the behavior of the ballet teacher or ballet mater towards the dancer is most likely empowering and disempowering. Our findings emphasize the importance of this interaction with respect to dancers' injuries. When both climate scores were taken into account in the regression analysis, the preventive effects of the EMC disappeared. Moreover, when the confounders were included, EMC did not moderate DMC on injuries. These findings build upon Appleton and Duda's, 2016, who showed that even strong perceptions of EMC

(mean scores between 4 and 4.5) might not be enough to prevent ill-health and suboptimal functioning (6). However, different aspects have to be discussed with regard to these findings: Dancers might perceive basically positive, task-involving approaches such as allowing and working on mistakes as troublesome and pressuring, thus as disempowering. On the contrary, a pushing or even pressuring behavior in a ballet teacher or ballet master could be interpreted as disciplined and thus regarded as task-involving aspect, although the questionnaire applied to investigate the motivational climate would regard such tendencies as disempowering. This would result in a different understanding and interpretation of questionnaire items in dancers and researchers. Such tendencies were also found in other studies investigating motivational climate in dancers. (27, 58) The EMC and DMC scores of our total sample were quite close, albeit more disempowering than empowering. Explorative factor analysis showed that dancers had a tendency to perceive disempowering features such as ego-involving and competitive environment in the questionnaire as more positive than expected, probably as accepted aspect of their lives.

Another aspect is that Appleton and Duda's findings might be especially relevant in dance with respect to the difference we found between amateur and professional dancers. The ballet dancers in our study perceived lower levels of EMC than DMC. Professional dancers in particular reported lower scores for EMC (2.8 ±1.02) and higher scores for DMC (3.6 ±1.03) than amateurs (EMC 3.8 ±.75; DMC 2.7 ±.89). Several factors could be responsible for these results: On the one hand, life, goals, environment as well as workload and consequently quality of motivation are different between professional and amateur ballet dancers. On the other hand, pressures and expectations from audience and

organizations, such as schools, theatres etc., on teachers to produce excellent dancers, together with a lack of knowledge in those teachers, who have transitioned from their own career into teaching/training dancers without any further special education, could result in them creating more of a DMC than EMC. However, since injury numbers in professional dancers are high (1), our findings have to be regarded as specifically important in the field of professional dance. Those teaching and training dancers have to be aware of their essential role in creating an empowering, (i.e., injury-preventive) climate but equally, refrain from creating or allowing any disempowering nuances in teaching and training environments in order to protect their dancers from injuries and ill-health. Moreover, stressing EMC and avoiding DMC altogether would make teachers more susceptive to the feedback and individual goals and needs of the dancer. The latter will also have a performance enhancing effect, as cited in the above, and additionally might reduce the high costs of absence, sick leave and related expenses such as re-casting, re-rehearsing etc. in companies (59, 60) because it has the potential to reduce injury numbers.

3.4.3 Strengths and limitations

This study is the first to investigate the association between the motivational climate created by ballet teachers or master and the presence of musculoskeletal injuries in ballet dancers. While our main findings are comparable to previous literature, some limitations exist in this cross-sectional and retrospective study. Recall bias has to be taken into consideration regarding our instructions that dancers may think of their primary teacher, the motivational climates created by them, and injuries of the previous two years. Also, we instructed the study participants to think of the teacher they spend most of their time with since dancers very often have more than one ballet teacher or ballet master. The

current design was chosen because a prospective research design with a subset of dancers was considered not feasible since professional dancers declared their fear of sanctions when speaking their minds freely. For that matter, the survey was executed completely anonymously. Moreover, this initial reaction of dancers supports our results reflected in the high DMC scores, especially in professional dancers. However, although the professional dancers of our sample reported lower mean scores for EMC and higher for DMC than the amateurs, our number of amateurs was too low to stratify our data. We grouped dancers into professional and pre-professional as opposed to amateurs by weekly hourly workload. As such we did not make a distinction between professional and pre-professional/vocational dancers. Finally, we do not know whether our study population is representable for the main stream dance population. However, our very large international study with a wide distribution as far as across 27 nations is the first to evaluate the association between motivational climates and musculoskeletal injuries as well as the interaction between EMC and DMC with regard to injuries.

3.4.4 Practical implications

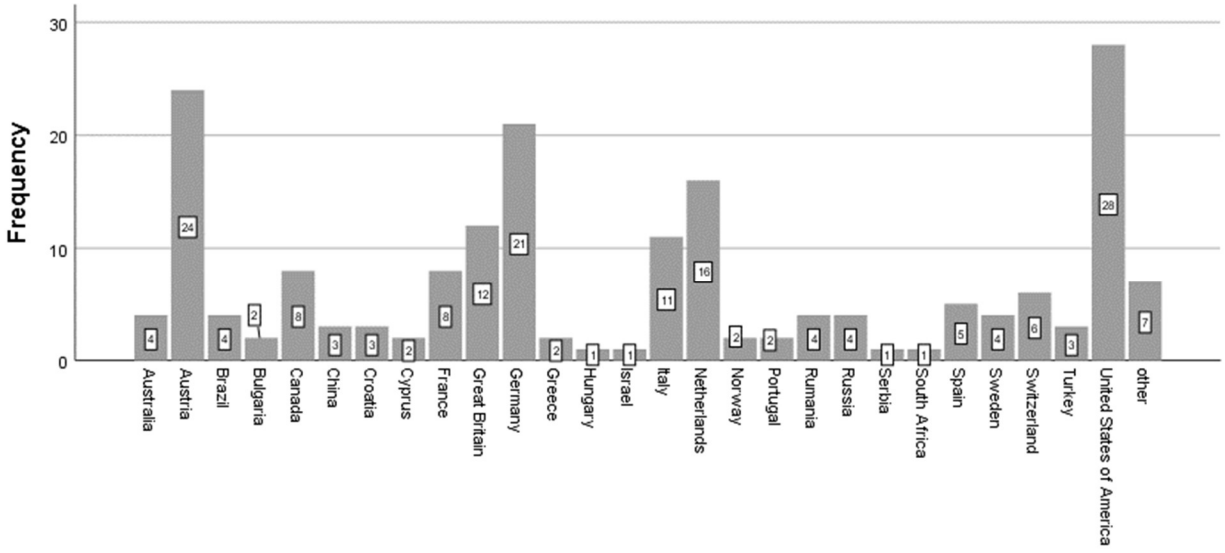
Our findings provide important practical implications for professional and amateur dancers, ballet teachers as well as health and administrative personnel working with dancers. As shown in various team and individual sports as well as in educational settings, the behavior of the teacher or coach, which creates a certain motivational climate, plays an essential role for the wellbeing of the performing artist, athlete or student (6, 7, 30, 61). EMC may not only prevent injuries, as we could confirm in our sample, but fosters intrinsic motivation by supporting commitment through enjoyment, task-focused goal orientation, and perceived competence, leading to performance enhancement (62). However, our

results stress that it may be even more important to strive to avoid any disempowering nuances emerging in training and work environment of ballet dancers, if injuries are to be prevented.

3.5 Conclusion

In order to avoid injuries in ballet dancers it is not enough to create an EMC in ballet education, training, and work environment, because the potentially preventive EMC seems to be diminished in the presence of a DMC. Ballet teachers or ballet masters should try to avoid DMC altogether to prevent injuries and ill-health in dancers and foster positive outcomes such as injury reduction, overall health, and performance enhancement.

Appendix 1: Number of dancers per nationality



Appendix 2: Overview of reported acute and overuse injuries
Legend:
FHL: Flexor hallucis longus muscle

Reported injuries	Reported injuries	Reported injuries
Lower back issues and pain	Ruptured ACL	Dancer's Tendonitis (FHL and tibialis)
Inflammation, bruises, burns	Ruptured hamstring	Sore muscles with (severe) pain
Concussion	Ruptured ligament	Osteoarthritis
Dislocated bones, (sub-)luxations	Ruptured muscle (not specified)	Overtraining, Stress
Fractured 2nd metatarsal	Ruptured rotator cuff	Tibial Stress Syndrome
Fractured 5th metatarsal	Ruptured tendon	Trigger toe (with FHL tendonitis)
Fractured tibia	Sprained ligament	Pain (unspecified)
Fractured rib, bruised rib	Sprained/twisted ankle	Breathing problems
Fractured toes	Sprained/twisted knee	Ankle pain/overuse (unspecified)
Fractured wrist	Sprained/twisted wrist	Calf pain/overuse (unspecified)
Fracture (not specified)	Muscle and other (repetitive) injury	Foot pain/overuse (unspecified)
Impingement ankle/foot	Supination trauma	Hip pain/overuse (unspecified)
Impingement femoroacetabular	Tendinopathy (Achilles)	Knee pain/overuse (unspecified)
Intervertebral disc issues/prolaps	Toenail and Skin lesions	Neck pain/overuse (unspecified)
Luxated/-ing patella	Chronic Respiratory Diseases	Shin pain/overuse (unspecified)
Luxated shoulder	Eating Disorders, Dehydration	Toe pain/overuse (unspecified)
Meniscus lesion	Dehydration	

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Chapter 4

Science of Training & Neuromuscular Warm-up

Neuromuscular warm-up is associated with fewer overuse injuries in ballet dancers compared to traditional ballet specific warm-up routines

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Abstract

Neuromuscular warm-up exercises (NMWU) have been shown to prevent injuries. In dance, research on warming-up is scarce. We investigated (1) warm-up habits among ballet dancers, and (2) the effects of NMWU and Traditional ballet specific warm-up (TBSWU) on injuries.

A cross-sectional survey-study among ballet dancers (>18 years) recorded acute and overuse injuries sustained in the previous two years. Warm-up behavior was assessed through 28 items. Dancers were grouped into NMWU or TBSWU. NMWU was based on neuromuscular warm-up programs in sports science and included exercises improving strength, power, proprioception, sensorimotor control, or cardiovascular stimulus. TBSWU consisted of stretching, dance-technical exercises, marking steps/running-through-choreographies, and stretching with tools. Separate linear regression analyses adjusted for confounding factors were performed for acute and overuse injuries.

192 dancers (26.7±7.82 years, 159 females, 132 professionals) reported 203 acute and 469 overuse injuries. 47.4% always warmed up (mean duration 20.7±13.2 minutes) based on stretching (63%), technical-exercises (58.9%), strength-training (54.7%), and the barre (53.6%). 9.4% never warmed up.

31 dancers (16.15%) classified for TBSWU, 16 dancers (8.3%) for NMWU. 145 dancers did combined exercises. NMWU was associated with fewer overuse injuries compared to TBSWU (β = -2.34; CI95% -3.54 to -1.14). No association was found with acute injuries.

As in athletes, NMWU might be protective against overuse injuries in dancers. Large-scale prospective cohort studies are needed to gain more insight into NMWU as a possible component of injury prevention in ballet.

4.1 Introduction

Injuries in classical ballet, especially overuse, have a multifactorial etiology.[1-6] All involved, including dancers, companies, theatres, and insurances, sustain ongoing losses through the high numbers of injuries and dancers' temporary absence from work. This can include costs such as insurances, Worker's Compensation, treatment, rehabilitation, re-casting and re-rehearsing, among others.[7,8] In addition to the physical complaints, pain, and high stress resulting from their injuries, the affected dancers even risk termination of their careers.

An important injury prevention measure could be an appropriate warm-up. In sports science neuromuscular (NM) sport specific warm-up has been shown to prevent injuries.[10-14] This warm-up targets the athlete's proprioceptive[9] and sensorimotor abilities, strength and power, without engaging in technical drills. Neuromuscular warm-up specifically enhances the joint position sense (proprioception) and balance as well as anticipatory and compensatory reflexes, relevant for protection of joints in dynamic stability.[15-23] Injury risk, [24,25] especially to the lower limbs, [26] was reduced, which is the most affected anatomical location in dancers.[5]

There is little consensus in dance, specifically in ballet, as to which activities can be categorized as warm-up.[27] Traditional approaches are based on stretching routines [28] commonly followed by skill drills. Sports science has shown that stretching as a warm-up has no injury preventive effects. [29-32] Prolonged stretching is even discussed as a limiting factor for performance, especially for jump height, through a decrease in power production and muscle activation. [33,34] However, it remains unclear which warm-up

routines are commonly used in ballet and studies investigating the association between warm-up procedures and injury risk in ballet dancers are lacking.

Hence, the aim of this study was twofold: (1) to clarify the warm-up habits and behaviors of ballet dancers, and (2) to compare the effects of NMWU and TBSWU on injuries.

4.2 Methods

4.2.1 Study design

A cross-sectional cohort study was performed, using an online survey. The METC-LDD (Medical-Ethic Committee Leiden│Den Haag│Delft) waived METC approval as it did not fall under the purview of the WMO, the Medical Research Involving Human Subjects Act (N19.082/RM/fIT1). Prior informed consent of the participants was obtained electronically.[35]

4.2.2 Participants

4.2.2.1 Inclusion & exclusion criteria

Professional, pre-professional, and amateur ballet dancers over 18 years of age, who had a regular classical ballet training experience of at least 3 years were eligible to participate. Surveys received with less than 75% of questions answered were excluded.

4.2.2.2 Recruitment method

The link to the survey was presented via social media (Facebook, Instagram). 188 ballet ensembles and 51 dance organizations from around the world were informed via email and through contact forms on their website.

The survey was accompanied by a short explanation, in which the dancers were asked to further distribute and share the information through their personal contacts, within theatres, ensembles, dance panels, blogs, and other contact options.

The survey was executed anonymously, as no identifying data was collected.

4.2.3 Assessments

4.2.3.1 Population

The following baseline demographics were assessed: sex, nationality, age at initiating ballet and workload of the previous two years. As recommended in dance science literature [36], workload was assessed weekly as dancer exposure, which equals a dancer's event (independent of the duration of the event), i.e. participation in a class, rehearsal, or performance. Furthermore, workload was recorded per athlete exposure hour, a duration of 60 minutes. Level of expertise (professional or amateur) was derived from the reported athlete exposure hours: professional dancers were defined as dancers with 16+ exposure hours per week, whereas amateurs had a maximum of 15 hours of dancing per week.[37,38]

4.2.3.2 Injuries

Primary outcome measures were the number of acute and overuse musculoskeletal injuries. Overuse injuries were defined as physical complaints, which "could not be linked to a clearly identifiable event"[39] (such as an accident), sustained within the previous two years[40] and from dance related activities (i.e., performance, rehearsal, or technique class). Self-reported overuse injuries were recorded through 17 possible injury locations, including 16 body parts and one injury location not listed on the survey but provided as a free-text item.

Acute injuries were defined as injuries, whose "onset could be linked to a specific injury event"[39] in the course of dance related activities (i.e., performance, rehearsal, or technique class) within the previous two years. Comparable to the assessment of overuse injuries, 17 items (16 body parts and 1 additional free-text item) assessed acute injuries.

4.2.3.3 Warm-up behavior

Warm-up habits and behaviors in ballet dancers within the previous two years were assessed through a total of 28 items specifically composed for the purpose of this study *(Table 1).* 6 questions were answered via 1-5 Likert Scale ('never' = 1 to 'always' = 5), 2 multiple response questions contained 6 and 15 items, respectively, and 1 question served to assess duration in minutes, based on free-text input.

4.2.4 Creation of survey questions and analysis of warm-up programs

Available NMWU programs for injury prevention in sports science were analyzed through extensive literature research. The questions of the survey *(Table 1)* and the grouping of the dancers for the evaluation of the two warm-up protocols (i.e. NMWU and TBSWU) were derived from that analysis. Thus, we developed a novel questionnaire that was based on previous warm-up programs and practical experience of experts which was not previously validated.

4.2.4.1 Neuromuscular warm-up

Three different injury-preventive neuromuscular warm-up programs served as models for the current study: The *'FIFA 11+* [11,13,41-45], the *'HarmoKnee'* [46,47], and the *'PEP'* (Prevent Injuries and Enhance Performance Program). [14,48,49] Those three programs share a common structure, duration, and content and are commonly used in multiple athletic populations.[11,13,41,43,45] These programs are based on a variety of exercises grouped into exercise sets, which target the overall aspects: (1) general warm-up through jogging or running for 5-10 minutes, and specific warm-up through (2) strength and core stabilization, (3) sensorimotor and proprioceptive abilities in statics and dynamics, and (4)

cardiovascular stimulus based on longer duration of exercises supported by non-stop designs.

Based on the described research, the survey questions for our purposes were composed with the aim to translate the NMWU protocols from sports science into practical dance settings. This resulted in seven exercise sets assessing the four overall aspects of NMWU. They were adapted to fit into dance settings by two of the authors of this study, who are internationally acknowledged experts in the field of dance medicine and dance pedagogy, designing and conducting training for dancers (JEK, JHS).

4.2.4.2 Traditional ballet specific warm-up

Since, to our knowledge, there is no documentation of warm-up habits in ballet dancers available, the design for the assessment of TBSWU was derived from practical experience of the experts and included practical descriptions from ballet teachers, ballet masters, and professional dancers in the preparatory phase of the study. The goal was to use a similar framework as was used for the NMWU assessment, to support the purpose of this study, i.e., the comparison between the groups. This led to a final number of 8 exercise sets assessing overall aspects of traditional ballet dancers' warm-up procedures: (1) General warm-up through stretching; (2) marking steps or dancing through choreographies/combinations; (3) dance technical exercises; and (4) various methods of stretching with and without tools.

4.2.4.3 Grouping of the dancers into the TBSWU and NMWU groups

Our two groups were stratified based on data analysis. Dancers, who performed more than 1 exercise set from both the TBSWU and NWU were excluded from the analyses.

Additionally, cutoff points were introduced to match the number of exercise sets to the warm-up programs cited in sports science literature.[11,13,14,41-48] Those programs were based on multiple exercises grouped into exercise sets, rather than one or a few isolated exercises. Based on these studies, we only placed dancers into one of the warm-up groups when they included at least half of the exercise sets into their warm-up routines. Because the NMWU protocol consisted of 7 exercises, a cutoff point of 4 was used. To be assigned to the TBSWU group, dancers had to perform at least 5 of the 8 exercises (cut-off point = 5).

4.2.5 Statistical analysis

SPSS 25 for Windows was used for statistical analysis. Data was screened for errors using descriptive statistics, explorative plots, and multicollinearity statistics. Differences in baseline demographics of the TBSWU and NMWU were tested using the Mann-Whitney U-test for continuous variables and Fisher's exact (Chi-square) tests for categorical variables. In addition, with the same statistical tests, the TBSWU and NMWU groups were compared to the other dancers. Multivariate linear regression models were used to examine whether warm-up procedures were associated with injury risk. The dependent variables were number of acute injuries and number of overuse injuries per person. For both dependent variables, two models were conducted: Model 1 included the dichotomous variable "warm-up procedure" (i.e. NMWU versus TBSWU). Model 2 included warm-up procedure and adjusted for the confounders age, sex, and level of expertise (i.e., amateur or pre-/professional dancer).

Table 1: Survey questions which assessed warm-up
Legend: BMTPT is the acronym for Ballet-Master, Teacher, Pedagogue, or Trainer/Coach

Please, think of the previous two years when you answer the following questions

In the previous 2 years I have been warming up prior to class/training. O O O O O never seldom sometimes very often always
In the previous 2 years I have been warming up prior to class/training for …… minutes.
When I don't warm up this is because O I don't need to O I use the barre as warm-up O There is no room, space, or time available for me in my schedules O I feel better without O I am stretching O My BMTPT doesn't like it when I do
I am structuring my warm-up into different blocks (general warm-up and specific warm- up) O O O O O never seldom sometimes very often always
I am generally warming up by stretching. O O O O O never seldom sometimes very often always
I am generally warming up by running, jogging, bouncing, or swinging for around 5 minutes. O O O O O never seldom sometimes very often always
I am/was specifically warming up by doing O Balance exercises on wobbly surfaces O Balance exercises with eyes closed O Stretching with weights, therabands, Deuserbands, foot stretchers, and other O Intense static stretching (staying in stretch positions for several minutes) O Dynamic stretching (moving through stretching positions without stops) O Marking steps O Dancing through choreographies O A barre O Selected technical exercises (i.e., tendus, jetés, ronds… and other) O Strength training (e.g., plank, side planks, air-plane, push-ups, sit-ups, and other) O Strength training using a theraband for resistance O A barre exercise with a nonstop design (= no breaks between exercises) O Slow motion alignment training (e.g., training of dynamic leg axes, and other) O Mentally going through steps O Waiting for class/rehearsal to begin, doing nothing much
Does your BMTPT insist that you execute a or the warm-up you described above? O O O O O never seldom sometimes very often always
I am feeling cold and "not ready" when I start dancing. O O O O O never seldom sometimes very often always

4.3. Results

4.3.1 Warm-up behavior

4.3.1.1 Population

192 ballet dancers (159 (82.6%) females), with a mean age of 26.7 ±7.8 years completed the questionnaire and were included in the analyses. *Table 2* displays the general demographics. Dancers represented 28 nations *(Figure 1),* and most dancers were professional dancers (70%). A total of 203 acute injuries and 469 overuse injuries were recorded. Of the 192 dancers, 119 had at least one acute injury, 164 dancers had at least one overuse injury, and 110 dancers had at least one of both injury mechanisms.

Table 2: General demographics.
Values are given as the mean ±SD or n(%) of the population; Dancer exposure (= per event, independent of the duration of the event, i.e., not necessarily 60 minutes); Athlete exposure (= per 60 minutes); Acute injuries: sudden onset caused by high-intensity forces, i.e., accidents resulting in sprains, strains, contusions, fractures etc.; Overuse injuries: result from repetitive micro-traumata of submaximal mechanical loading, also called "chronic injuries".

	All dancers (n=192)
Sex	
Female	159 (82.6%)
Male	33 (17.4%)
Age at participation *(years)*	26.7 ±7.82
Ballet experience *(years)*	14.5 ±7.00
Age at ballet initiation *(years)*	8.1 ±5.84
Athlete exposure *(workload in hours/week)*	26.8 ±15.30
missings	4
Dancer exposure *(workload in events/week)*	12.3 ±9.60
missings	5
Level of expertise	
Professionals	132 (68.8%)
(Athlete exposure/week)	35.6 ±8.20
Amateurs	56 (29.2%)
(Athlete exposure/week)	6.1 ±3.92
Acute injuries total	1.1 ±1.15
Overuse injuries total	2.4 ±1.86

4.3.1.2 Warm-up procedures

47.4% of the dancers always warmed up within the previous two years, with a mean duration of 20.7 ±13.2 minutes. *Table 3* displays the details on warm-up habits in our population. 7.8% always and 15.6% very often felt cold and not ready when they started dancing. When asked for reasons as to why they did not execute a warm-up, 57.3% of the dancers affected reported that there was no space/room or no time in their schedules to warm up. 69.3% of ballet teachers/masters never insisted that their dancers warm up and 4.2% of teachers/masters did not want their dancers to warm up.

63.0% used dynamical stretching, 58.9% selected ballet technique exercises, 54.7% used strength training and 53.6% used the traditional barre as warm-up. 16.7% always used stretching as general warm-up, while 5.2% used swinging, running, or bouncing to generally increase body core temperature. Only 9.4% structured their warm-up into general and specific warm-up exercises, while 31.8% never did.

4.3.2 Association between warm-up procedures and injuries

4.3.2.1 Population

Figure 2 shows the grouping of dancers into the two warm-up programs. *Table 4* presents the demographics of the two warm-up groups, TBSWU and NMWU. 31 dancers (16.2%) were assigned to the TBSWU group with a mean number of 5.71 ±1.15 exercise-sets per dancer. 16 dancers (8.3%) were assigned to the NMWU group and used a mean of 5.1±1.6 exercise-sets per dancer. *Table 5* shows the comparison of warm-up habits and exercises between the two groups: 83.9% of dancers in the TBSWU group always (51.6%) and very often (32.3%) generally warmed up by stretching, compared to the

NMWU group with 0.0%, respectively. In the NMWU group, 81.5% of dancers generally raised their body core temperature through jogging, swinging or bouncing (18.8% always and 62.5% very often), compared to 0.0%, respectively, in the TBSWU group. The NMWU group had a high focus on proprioceptive/sensorimotor control exercises: 81.3% performed balances on wobbly surfaces (0.0% in TBSWU), 75.0% trained balance exercises with eyes closed (0.0% in TBSWU), and 62.5% worked on slow motion alignment training (6.5% in the TBSWU group). Duration of warm-up also differed between the groups, with TBSWU reporting a mean warm-up duration of 18.39 ±8.7 minutes, compared to 29.4 ±14.3 minutes in the NMWU group.

4.3.2.2 Warm-up and injuries

Table 6 shows the results of the different linear regression models. NMWU was negatively associated with overuse injuries per participant. On average, in the NMWU group we found 2 overuse injuries fewer per participant compared to the TBSWU group (β -2.34, 95%CI -3.54 to -1.14; r^2 36.1). No effects were noted for acute injuries (β -0.09, 95%CI -0.96 to 0.78; r^2 0.59).

Table 3: Details on warm-up habits in ballet dancers.
n(%) of the study population or mean ±SD

Warm-up assessment	All dancers n=192
Warm-up in the previous two years before training	
Never	4 (2.1)
Seldom	21 (10.9)
Sometimes	24 (12.5)
Very often	52 (27.1)
Always	91 (47.4)
Duration of warm-up *(minutes, mean ±SD)*	20.7 ±13.2
When the dancer did not execute a warm-up it was because…	
…he/she did not need to	33 (17.2)
…the barre was the warm-up	89 (46.4)
…there was no room/space or time available in the schedules	110 (57.3)
…he/she felt better without warm-up	7 (3.6)
…stretching was the warm-up	35 (18.2)
…the teacher/master did not like it when they warm-up	8 (4.2)
Did the teacher/master insist on a/the described warm-up	
Never	133 (69.3)
Seldom	17 (8.9)
Sometimes	13 (6.8)
Very often	11 (5.7)
Always	18 (9.4)
Warm-up was structured into two blocks (general and specific warm-up)	
Never	61 (31.8)
Seldom	37 (19.3)
Sometimes	43 (22.4)
Very often	33 (17.2)
Always	18 (9.4)
General warm-up: stretching	
Never	28 (14.6)
Seldom	34 (17.7)
Sometimes	57 (29.7)
Very often	41 (21.4)
Always	32 (16.7)
General warm-up: jogging, bouncing, swinging or other for approx. 5 minutes	
Never	60 (31.3)
Seldom	55 (28.6)
Sometimes	40 (20.8)
Very often	27 (14.1)
Always	10 (5.2)
Specific warm-up:	
Dynamic stretching (moving through stretching positions without stops	121 (63.0)
Selected technical exercises (e.g., tendus, jétés, ronds, and other)	113 (58.9)
Strength Training (e.g., planks, air-plane, push-ups, and other)	105 (54.7)
The barre	103 (53.6)
Strength training using a theraband for resistance	69 (35.9)
Stretching with weights, therabands, Deuserbands, foot stretchers and other	64 (33.3)
Intense static stretching (staying in stretch positions for minutes)	53 (27.6)
Marking steps	45 (23.4)
Slow motion alignment training (e.g., training of dynamic leg axes, and other)	36 (18.8%)
Balance exercises on wobbly surfaces	34 (17.7%)
Balance exercises with eyes closed	26 (13.5%)
Dancing through choreographies	23 (12.0%)
A barre exercise with a non-stop design (i.e., no breaks between exercises)	15 (7.8%)

Table 3 (continued): Details on warm-up habits in ballet dancers.
n(%) of the study population or mean ±SD

Mental warm-up: e.g., mentally going through steps	44 (22.9)
Waiting for class/rehearsal, doing nothing	18 (9.4)
The dancer felt cold and not ready when the class/rehearsal started	
Never	34 (17.7)
Seldom	62 (32.3)
Sometimes	51 (26.6)
Very often	30 (15.6)
Always	15 (7.8)

Table 4: Demographics
of the traditional ballet specific warm-up group (TBSWU) and neuromuscular warm-up group (NMWU).
Mean ±SD or n(%) of the groups

	TBSWU n=31	NMWU n=16	P-value
Sex			0.21
Females	28 (90.3%)	12 (75.0%)	
Males	3 (9.7%)	4 (25.0%)	
Age *(years)*	21.6 ± 3.6	28.1 ± 5.9	0.00
Experience *(years)*	12.7 ± 3.6	15.3 ± 5.1	0.08
Age at Initiation *(years)*	6.1 ± 2.1	8.7 ± 5.3	0.04
Athlete exposure *(hours/week)*	32.5 ±9.6	33.4 ±12.8	0.95
Missings	1	0	
Dancer exposure *(events/week)*	18.5 ±6.3	14.0 ±8.2	0.07
Missings	0	1	
Professionals	28 (93.3)	14 (87.5)	0.60
Amateurs	2 (6.7)	2 (12.5)	
Acute injuries	1.3 ±0.7	1.1 ±1.6	0.07
Overuse injuries	3.3 ±1.8	1.3 ±1.1	0.00

Table 5: Details on habits and comparison of warm-up procedures in ballet dancers, who were assigned to traditional ballet specific (TBS) or neuromuscular (NM) warm-up (WU) n(%) of the groups or mean ±SD, NA: Not applicable.

	TBSWU group n=31	NMWU group n=16
Duration of warm-up (minutes)	18.39 ± 8.7	29.4 ±14.3
Traditional Ballet Specific Warm-up:		
General warm-up *(1 exercise set)*:		
Always generally warming up by stretching	16 (51.6)	NA
Very often generally warming up by stretching	10 (32.3)	NA
Specific warm-up *(7 exercise sets):*		
Marking steps	18 (58.1)	NA
Dancing through choreographies/exercises	11 (35.5)	NA
The barre	27 (87.1)	NA
Selected technical exercises (e.g., tendus, jétés, ronds, and other)	28 (90.3)	5 (31.3)
Dynamic stretching (moving through stretching positions without stops)	25 (80.6)	4 (25.0)
Intense static stretching (staying in stretch positions for minutes)	19 (61.3)	NA
Stretching with weights, therabands, Deuserbands, foot stretchers and other	23 (74.2)	1 (6.3)
Neuromuscular Warm-up:		
General Warm-up *(1 exercise set)*:		
Always generally warming up by jogging, bouncing, swinging for 5 min.	NA	3 (18.8)
Very often generally warming up by jogging, bouncing, swinging for 5 min.	NA	10 (62.5)
Specific Warm-up *(6 exercise sets):*		
Balance exercises on wobbly surfaces	NA	13 (81.3)
Balance exercises with eyes closed	NA	12 (75.0)
Slow motion alignment training (e.g., training of dynamic leg axes)	2 (6.5%)	10 (62.5)
Strength Training (e.g., planks, air-plane, push-ups, and other.)	5 (16.1%)	16 (100.0)
Strength training using a theraband for resistance	5 (16.1%)	13 (81.3)
A cardio barre with a nonstop design (no breaks between easy exercises)	NA	5 (31.3)

Table 6: Associations between traditional ballet specific or neuromuscular warm-up, and acute or overuse injuries
Reference category: TBSWU is coded with 0, NMWU is coded with 1
Model 1: unadjusted model
Model 2: adjusted for age, sex, and level of expertise (i.e., pre-/professional or amateur dancer)

Parameters acute injuries	β	*95% CI for β*		Parameters overuse injuries	β	*95% CI for β*	
		Lower	Upper			Lower	Upper
Model 1: unadjusted Warm-up	-0.23	-0.92	0.46	Model 1: unadjusted Warm-up	-2.01	-3.00	-1.02
Model 2: adjusted Warm-up	-0.09	-0.96	0.78	Model 2: adjusted Warm-up	-2.34	-3.54	-1.14

Table 7: Baseline comparison of dancers excluded (EX) from assessment of the association between warm-up and injuries and those, who performed one of our warm-up procedures, i.e., traditional ballet specific (TBS) or neuromuscular (NM) warm-up, respectively.
values or presented as N (%) or mean ±SD

	All EX N=145	All WU N=47	P-value
Females Males	119 (82.1) 26 (17.9)	40 (85.1) 7 (14.9)	0.82
Age *(years)*	27.6 ±8.3	23.8 ±5.4	0.00
Ballet experience *(years)*	14.8 ±7.6	13.6 ±4.3	0.48
Ballet initiation *(age, years)*	8.5 ±6.3	7.0 ±3.7	0.29
Athlete exposure *(workload in hours/week)*	142 24.8 ±16.1	46 32.8 ±10.7	0.01
Dancer exposure *(workload in events/week)*	141 10.8 ±9.8	46 17.0 ±7.2	0.00
Professionals Amateurs	90 (63.4) 52 (36.6)	42 (91.3) 4 (8.7)	0.00
Acute injuries total	1.0 ±1.2	1.2 ±1.1	0.11
Overuse injuries total	2.4 ±1.9	2.6 ±1.9	0.47

4.4 Discussion

The aim of this study was (1) to clarify the warm-up habits of ballet dancers and (2) to compare the effects of NMWU and TBSWU on injuries. In total, 192 dancers from 28 nations reported 203 acute and 469 overuse injuries. Results regarding warm-up behavior show dancers mainly engaged in stretching and technical dance exercises as a warm-up. Furthermore, warm-ups hardly ever followed injury preventive recommendations from sports science. However, half of our population did include strength training into their routines. NMWU was associated with fewer overuse injuries compared to TBSWU routines. No association was found between warm-up protocols and acute injuries.

There is little consensus in ballet on the design and execution of a warm-up. Warm-up routines as well as their association with ballet injuries have not yet been studied before. In sports science, the injury preventive effects of NMWU in individual and team sports of all genders, ages, and levels of expertise has been demonstrated.[10,11,13,14,42-44,46,48,50] In dance, only a few studies are dedicated to the topic of warming-up.[51,52] While classical ballet dancers are not always directly comparable to other athletes, many of the risk factors associated with dance injuries were tackled through NMWU in sports: insufficient dynamic joint stability, lower limb alignment and lumbopelvic control, as well as strength or general fitness deficits.[53-55]

In spite of the existing research stressing the importance of general warm-up, only 9.4% of our population always structured their warm-up into two blocks (i.e. general followed by specific warm-up), whereas 31.8% never did. As our findings show, traditional ballet-specific ways of warming-up focus on stretching and mainly anaerobic, repetitive technical drills, previously associated with overuse injuries.[56,57] In contrast, our NMWU group

showed a focus on general warm-up, resembling examples from sports science, where a graduate increase in exercise intensity from 50% up to 90% of HRmax [17] is essential to increase performance [58], while avoiding injury risk from stretching on cold body.[28,59] Moreover, NMWU protocols provide a different focus than the main technical training of the athlete, supplementing strength, power, and sensorimotor training, vital to prevent overuse injuries to the lower limbs. [11,26,41,44].

The duration of the NMWU routines in sports medicine we referred to was 20-30 minutes.[11-14,41-49] Our NMWU group reported a mean duration of 29.4 ±14.3 minutes, while our TBSWU group showed shorter mean time spent on their warm-up (18.39 ±8.7 minutes). The question may arise, whether duration matters more than content of warm-up. However, when only those NMWU and TBSWU dancers who warmed up for >20 minutes as well as those who warmed up specifically for 20-30 minutes were selected for linear regression, results did not differ from the regression presented in Table 6. Although the number of dancers was small in this testing of duration (n=24 and n=15, respectively), the results indicate that the content of the warm-up (i.e., the neuromuscular exercises) matters, not the duration.

While injury risk through stretching is particularly high and underestimated in dancers [60-63], our findings show many dancers use stretching as a warm-up. However, a focus on stretching as warm-up failed to prevent injuries.[29-32,64,65] Regular static stretching does increase long term flexibility[66,67] which is essential for classical ballet. However, stretching exceeding 30-60 seconds has shown to result in compression reducing blood supply for muscles, connective tissue, and nerves. [68] That, combined with a lack of stabilizing

strength, might result in the often reported reduced sensorimotor control [69] and decreased performance in athletes [33,34,70-73] as well as dancers. [74]

Literature reports a significant inverse correlation between the athletes' and coaches' knowledge, their compliance to injury-preventive programs, and injury rates.[12,16,42] Our findings show many dancers already engage in selected neuromuscular exercises. However, 69.3% of ballet teachers or ballet masters do not insist on their dancers' warming-up, and 4.2% of dancers reported their ballet teachers or ballet masters do not want them to warm-up. Moreover, when dancers could not execute a warm-up, the main reason reported (57.3%) was a lack of room or time available, indicating missing support from teachers, masters, and administrations. Research points out the importance of knowledge and education in coaches, resulting in higher compliance of coaches and athletes for the implementation of injury preventive measures, such as warming-up.[16,75]

Comparing our warm-up groups (*Table 7*), we could see a discrepancy between reported athlete exposure hours (i.e., 60 minutes), and dancer exposure (i.e., the duration of an event is unknown).[76] Our warm-up groups are comparable with regard to athlete exposure hours as their weekly workload. However, the TBSWU group showed higher means of dancer exposure events than the NMWU group. Ramifications are important, because although athlete exposure hours are comparable, dancer exposure events must have been shorter in duration but higher in frequency. Thus, dancers might not have enough time or do not engage in sufficient warm-up before training or after any break of >15 minutes. [17] Hence, our findings stress the importance of NMWU in injury prevention revealed by this discrepancy.

4.4.1 Strengths and limitations

This is the first study investigating ballet dancers' warm-up routines in order to provide an essential overview on their preparatory habits. Comparing warm-up routines, this study suggests a preventive relationship between NMWU and overuse injuries. A strength of the study is that an international survey was conducted and the questionnaire was distributed over many dance ensembles and dance organizations. However, some limitations should be addressed. A non-validated questionnaire was used, of which the retrospective design based on self-report might have introduced recall bias. Moreover, as always with a survey, the group that filled out the questionnaire might not be representative for the whole dance population. Another limitation is the small group size of especially the NMWU group. The warm-up groups showed differences in age, initiation-age, and dancer exposure, as discussed above, reducing their comparability. We attempted to correct these differences through confounder adjustment, although residual confounding cannot be ruled out. In older dancers, age and years of dancing could have led to more injuries, based on more time available for their development, or to fewer, due to more experience. Being more mature, and therefore perhaps more knowledgeable[77], the NMWU dancers may have already determined how essential NMWU is and identified it as a booster for performance and health, as suggested in previous literature.[78]

Being the first to study warm-up habits in ballet dancers as well as an association between warm-up programs and injuries, this study succeeded to show that (neuromuscular) warm-up is worth being investigated as a possible means of injury prevention in dancers, derived from sufficient evidence in sports medicine.

4.5 Conclusion

Our study gives an overview on the warm-up routines ballet dancers use prior to training, rehearsal or performance. Comparing traditional ballet specific warm-up habits with neuromuscular approaches we found that NMWU was negatively associated and TBSWU positively associated with injuries. In order to reduce the burden and risk of overuse injuries, dancers might consider introducing NMWU prior to activity. Prospective, longitudinal studies of warm-up routines as a means of injury prevention in ballet dancers are warranted, using trials from sports science as an example.

Figure 1: Nationalities of the population

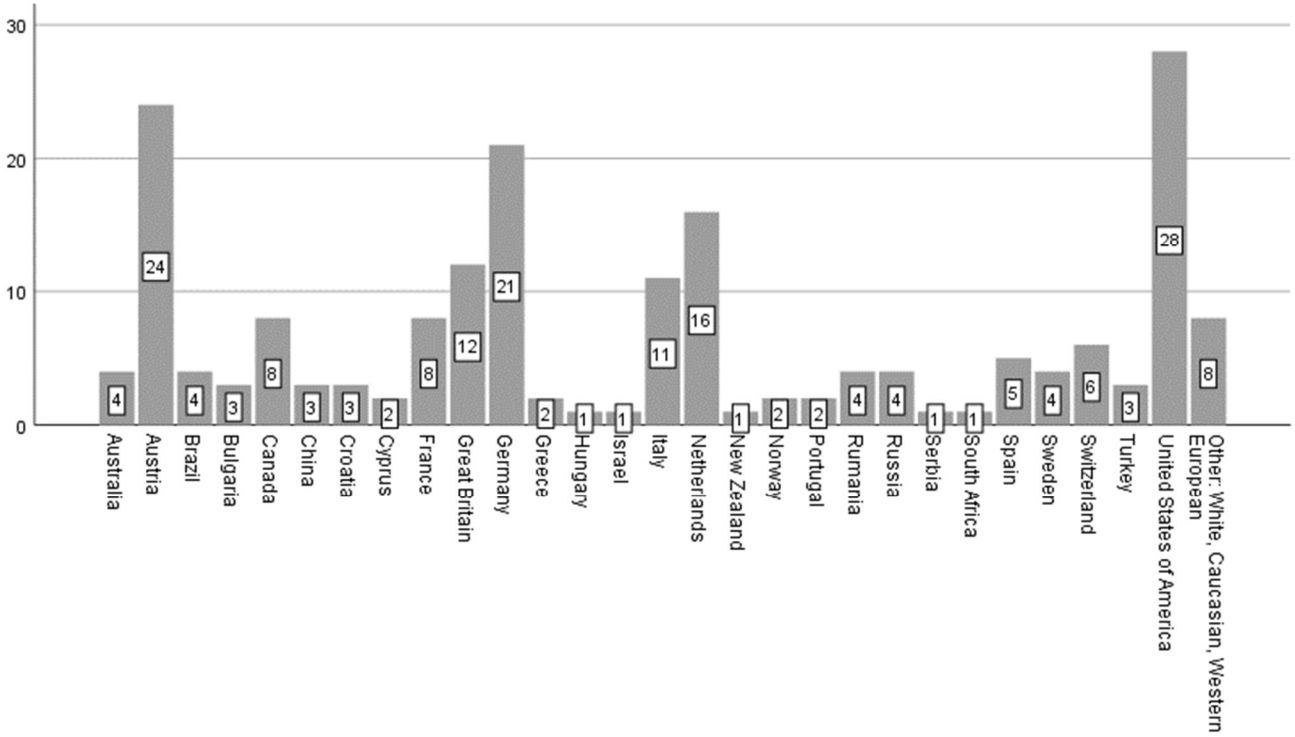
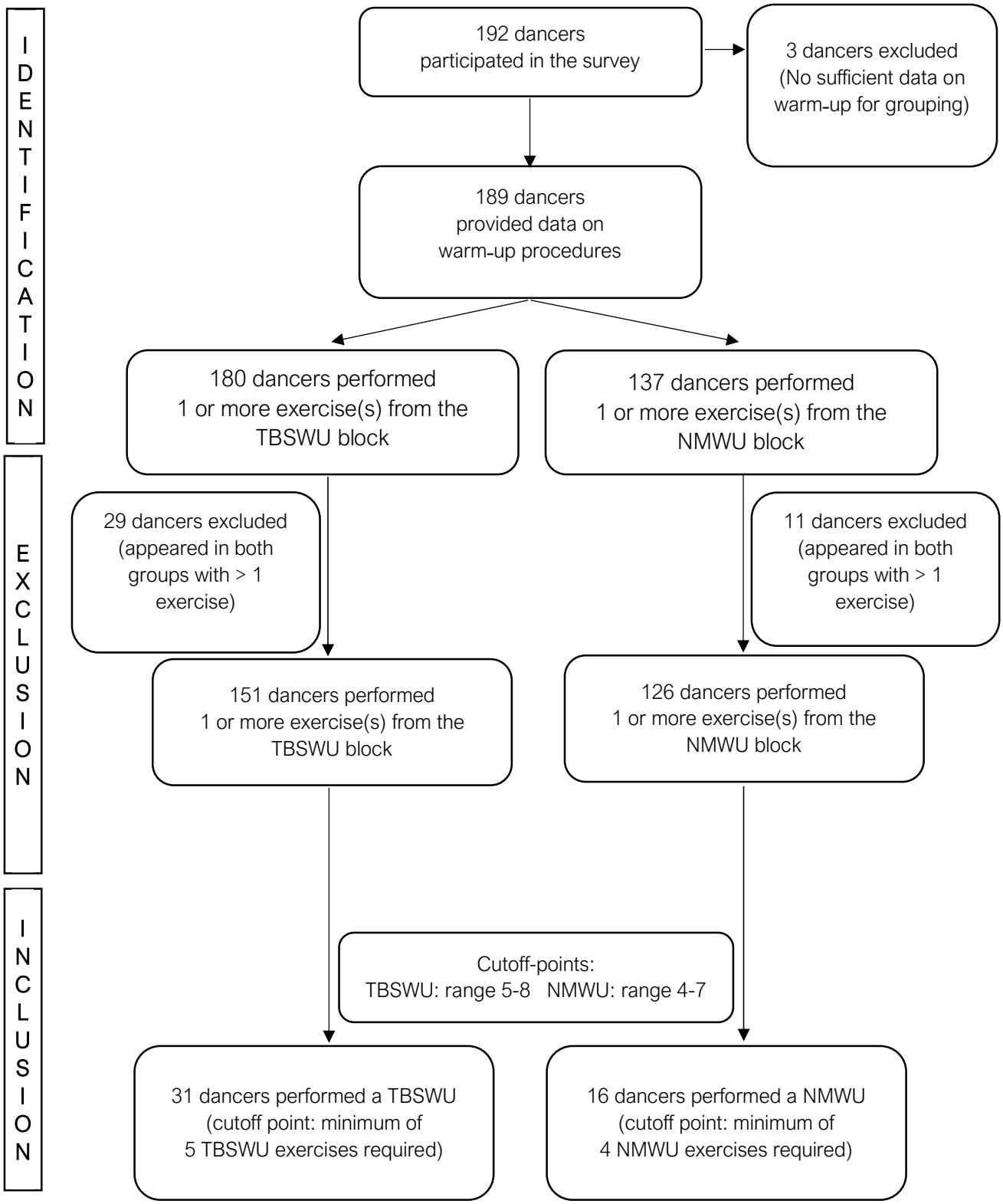


Figure 2: Identification and grouping of dancers according to warm-up procedures
traditional ballet specific warm-up: TBSWU
neuromuscular warm-up: NMWU



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Chapter 5

Preventive Dance Medicine & Causes of Injuries

The perspective of ballet dancers on causes of dance injuries and implementation of preventive dance medicine by their ballet teachers and masters

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Submitted

Abstract

Ballet dancers have a high injury risk. We aimed to gain insight in the causes for acute and overuse injuries and the level of implementation of preventive dance medicine by ballet teachers/masters as perceived by dancers.

An international cross-sectional online-survey was based on the Fit-to-Dance-Questionnaire and literature. Adult amateur, pre-professional, and professional ballet dancers reported the perceived causes of their injuries sustained in the previous two years. Multiple answers per injury were possible. Additionally, the dancers rated the level of implementation of preventive dance medicine by their ballet teachers and ballet masters based on 21 items using a 5-point-Likert-scale. Causes were analyzed per-injury as well as per-dancer.

188 ballet ensembles and 51 dance organizations were contacted, 192 ballet dancers (mean age 27 ±7.8 years, 83% females) responded. 119 dancers (62%) reported 203 acute and 164 (85%) reported 469 overuse injuries. Fatigue was the most frequently perceived cause for acute injuries in the per-injury (43.8%) and per-dancer analysis (32.8%). For overuse injuries, pressure from the teacher/master was most frequently perceived as cause in the per-injury analysis (51.2%), specifically in pre-/professional dancers (61.3%). In the per-dancer analysis, fatigue/overtraining scored highest for overuse injuries (n=107; 55.7%). Other causes were previous/repetitive injuries (acute-per-injury: 26.1%, acute-per-dancer: 22.4%, overuse-per-injury: 46.3%, overuse-per-dancer: 53.1%) or erroneous dance technique (acute-per-injury: 24.6%, acute-per-dancer: 21.9%, overuse-per-injury: 47.8%, overuse-per-dancer: 45.3%). With regard to perceived level of implementation of dance medicine by ballet teachers/masters to

prevent musculoskeletal injuries, 2 items received high ratings, 12 moderate ratings and 6 low ratings.

Fatigue and pressure accounted for the majority of causes for injuries. Perceived support by ballet teachers/masters regarding injury prevention and dance medicine was moderate to low. Future research should focus on the awareness, attitudes and the important role of ballet teachers/masters for injury prevention in dancers.

5.1 Introduction

Ballet dancers have a high injury risk. In amateur ballet dancers an incidence rate of 0.97 injuries per 1.000 hours of dance exposure has been reported.(3) In professionals these numbers are higher, Allen et al reported an injury incidence rate of 4.4 injuries per 1000 hours of dance exposure with a mean of 6.8 injuries per dancer in one year(2). while the risk for pre-professionals to sustain an injury per year was 76%, with a yearly incidence of 1.42 injuries and a rate of injury of 1.38 per 1000 hours of dance.(1)

Risk factors for these musculoskeletal injuries have been investigated, however, the relationships between those risk factors and injuries are not clear yet.(4, 5) Injuries can place a high burden on the physical and psychological health of dancers. In addition they can have large financial consequences for the dancers themselves, their companies, and insurances.(1, 6, 7) Therefore, gaining insight in the causes of dance injuries in ballet is of utmost importance.

Literature has shown that there is a broad spectrum of risk factors and possible causes, which vary from suboptimal scheduling of training, leading to fatigue(8, 9), overtraining(10, 11), as well as injuries as a result of too little recovery time and adaptation of tissues after injuries (8, 12-15). Also factors such as repetitive movements, as well as erroneous dance technique which disrespects the individuality of the dancer(5) have been pointed out as causes of injuries. Knowledge on the prevention of eating disorders(16, 17) is as important as the differentiation between injury and pain as well as the handling of pain, injury, and repetitive injuries. Moreover, the likelihood a dancer would report and discuss injuries without fear of repercussions is low, specifically in disempowering motivational climates(18), while an optimal rehabilitation and transition back into normal

training are essential for full recovery. Even more these are vital aspects of injury prevention, while identification and elimination of risk factors for sustained injuries need to be handled accurately.(19-21)

Despite this growing body of research, injury rates and risks have not declined during the last decades(22) in pre-professional(1, 23), professional(2, 24) and amateur dancers.(25, 26) A few studies, for instance the Fit for Dance Surveys (27-29) have evaluated causes for injuries as perceived by dancers however the two injury mechanisms, acute and overuse, were not evaluated separately. Information on dancers' perceptions is essential to develop tailor-made injury prevention programs for the different types of ballet injuries. Therefore, the first aim of this study is to investigate the causes ballet dancers perceive for their acute and overuse injuries. Successful injury prevention could be supported by involving dancers directly. Giving dancers a voice will allow to base future measures of injury prevention on dancers' opinions, facilitating their essential compliance upon practical implementation, at best in collaboration with their teaching personnel.(30) The latter is supported by evidence from sports injury research showing that coaches are the most influential individuals for injury prevention in sports settings.(31, 32) They have the authority to promote prevention behaviors and are in charge of injury management.(33) Research has shown that the sports coach's attitude towards injury prevention programs is the major determinant of whether interventions reach their athletes.(34, 35) In ballet, the role of the ballet teacher or ballet master regarding injury prevention has not yet been investigated, although repeatedly addressed, discussed, and criticized.(29, 36-40) Therefore, the second aim is to gain insight how ballet dancers perceive and rate the implementation of preventive dance medical measures taken by their ballet teachers or ballet masters. As such, preventive dance medicine, derived from the construct

“preventive medicine“(41), includes all aspects of dance medicine which particularly aim for primary injury prevention. Since injury mechanisms as well as the need for preventive dance medical implementation has to be handled differently for amateur and pre- and professional settings, we reported our findings for both levels of expertise separately.

5.2 Methods

5.2.1 Study design

This study was part of a large scale international cross-sectional cohort study on ballet dance injuries.(18) The link to the online survey was presented via social media (Facebook, Instagram). A total of 188 ballet ensembles and 51 dance organizations from around the world were informed and asked to share the survey through their contacts and blogs. The survey was executed anonymously. The Medical-Ethic Committee Leiden│Den Haag│Delft approved the study as not falling under the rules of WMO, the Medical Research Involving Human Subjects Act (N19.082/RM/fIT1). Informed consent of the participants was obtained electronically.(18)

5.2.2 Participants

5.2.2.1 Inclusion & exclusion criteria

Eligible participants were adult (>18 years of age) professional, pre-professional, and amateur ballet dancers who had had a regular classical ballet training and experience for at least 3 years prior to participation. Excluded were dancers who answered less than 75% of the survey questions for this paper.

5.2.3 Assessments

5.2.3.1 Demographics

Sex, nationality, age when they started to dance ballet, years of ballet experience, and the workload of the previous two years were recorded based on self-report to assess baseline demographics. Weekly dancer exposure concerning participation in dance activity as well

as exposure time concerning activity duration were used to calculate weekly workloads. Dance exposure equals an event with unknown duration, e.g., participation in a class, rehearsal, or performance. Time exposure has a clear duration of 60 minutes per unit (hour). The level of expertise (i.e., pre-professional and professional, or amateur dancer) was derived from the reported time exposure hours based on previous research reporting work hours in dancers(42-45): Pre-professional and professional dancers were defined as dancers with 16+ time exposure hours per week, whereas amateurs had a maximum of 15 hours per week.

5.2.3.2 Injury

Acute injuries were defined as being related to an identifiable event and a precise onset(46) in the course of dance related activities such as performance, rehearsal, or technique class within the previous two years. Overuse injuries were defined as musculoskeletal complaints or injuries which could not be linked to a clearly identifiable event(46) but sustained within the previous two years(19) from dance related activities. Both injury types were recorded through 17 items, respectively. Sixteen pre-defined body parts were listed and one additional free-text item could be used to report other injuries than those associated with the predefined body parts. More details on injuries were published in a previous paper.(18)

5.2.3.3 Perceived causes for injuries

For each reported injury, dancers were asked to assess the causes they perceived. The Fit to Dance UK-Questionnaire(28, 47) served as an example for their assessment, allowing for multiple answers per injury. The list of 11 causes in the 1996-version and 16 causes in the 2005-version was extended for the purpose of this study, based on literature

research assisted by a librarian *(Appendix 2).* Titles and abstracts of the search results (n=224) were screened for keywords and eligible articles were read (n=120), resulting in 31 articles of the search included as references. Causes as well as risk factors investigated or discussed in at least one of the retrieved papers were added to the list of our survey, resulting in 34 predefined causes to be investigated, 17 for each injury type, respectively (*Appendix 1*). As in the Fit to Dance UK-questionnaires, an additional free-text option allowed to report any additionally perceived cause which was not in the list. Based on the literature research, our changes included: (1) a differentiation between reasons for acute and overuse injuries due to the different underlying mechanisms of injury etiology, and thus more listed possibilities for both types of injuries. (2) rewording of items to clarify meaning or allow for differentiation, e.g., '*repetitive movements in rehearsal*' became '*repetitive movement in rehearsal or training*'; '*insufficient warm up*' became '*insufficient warm up or cool/warm down*'; '*psychological (eg depression)*' was divided up into several aspects such as '*anxiety*', '*depression*', or '*insecurity (e.g., new or difficult choreography or technique that made you feel "unready")*'. (3) adding items such as '*Insufficient recovery time*', or '*Pressure from the ballet teacher or ballet master*'.

After the survey, two additional causes were added to our predefined list of causes based on the dancers' results: "Ballet teacher, ballet master (behavior, teaching/working methods)" was added as additional cause for acute injuries and "Forced turnout" was added to overuse injuries.

Causes were analyzed using two different approaches: per-injury and per-dancer. In the "per-injury" approach all causes of all injuries were included. Thus, all causes for each single injury were taken into account irrespective of the dancer who reported these

injuries. In the “per-dancer” approach we analyzed the different causes given by each dancer who sustained an injury. As such, each cause reported by an individual dancer was included only once, irrespective of whether a dancer reported the same cause multiple times in case of multiple injuries. We conducted these two different approaches to meet the problem of interdependency and overestimation of causes. For instance, a dancer with five overuse injuries who reported the cause ”repetitive or previous injury” for each of the five injuries, would in case of the per-injury analysis result in five times the cause “repetitive or previous injury”. In the per-dancer analysis, this would result in one time the cause “repetitive or previous injury”.

5.2.3.4 Implementation of preventive dance medicine into dance practice

Through 21 items, dancers were asked to rate their teachers’/masters’ efforts regarding the implementation of aspects of preventive dance medicine into practice. Recurrently, dancers were instructed to think about the previous two years and their primary ballet teacher or ballet master when answering. The phrasing and content of the questions were based on the „Empowering and Disempowering Motivational Climate Questionnaire” allowing to put a focus on the teacher/master.(48)

20 items addressed three selected umbrella aspects, which have received a lot of attention in dance science and have previously shown to be related to dancers' health and wellbeing: First, handling of pain and injury(20, 49) (e.g., dancing through pain, supporting reporting of pain, respecting medical orders) was asked in five items (e.g., *“My Ballet Master|Teacher|Pedagogue|Trainer tells me to work through pain because it is part of dancing.”*). Second, science of training(5, 8, 15, 45, 50, 51) (e.g., scheduling, rest-work-ratio and fatigue, warm-up, attitude towards and implementation of strength and

proprioceptive training, or acknowledgement of anatomical individuality) was documented using 10 items (e.g., *"My schedules include enough rest for me to feel fully recovered after training, rehearsal, performance."*). Third, sociopsychological support(18, 52), used five items (e.g., *"My Ballet Master|Teacher|Pedagogue|Trainer encourages dancers to speak out, e.g., addressing problems, wishes."*). One question with an additional free-text option served as opening question (i.e., *"My Ballet Master|Teacher|Pedagogue|Trainer talks about dance medicine"*).

All 21 items were based on a 1-5-Likert-scale (never=1 to always=5) with "sometimes" as median. In order to allow for an interpretation of results, cutoff points graded the Likert-mean-value into three equal categories, e.g., low level, moderate level and high level of implementation. That was accomplished by subtracting the lowest possible mean score from the highest (5-1=4) and dividing the results by three (5-1=4 : 3) resulting in even intervals of 1.33 for all three categories (1.00 + 1.33 = 2.33; 2.34 + 1.33 = 3.67; 3.68 + 1.33 = 5).(53) For supporting statements with regard to implementation of preventive dance medicine (e.g., *"My BMTPT wants me to report pain immediately…"*) the categories were 1.00-2.33 low, 2.34-3.66 moderate, and 3.67-5.00 for high level of preventive implementation. For non/supporting\ statements (e.g., *"My BMTPT tells me to dance through pain because it is part of dancing."*) the categories were reversed, resulting in 1.00-2.33 as high, 2.34-3.66 as moderate, and 3.67-5.00 as low.

5.2.4 Statistical analysis

Statistical analysis was based on SPSS 25 for Windows using descriptive statistics and explorative plots, normality was checked using histograms and QQ-Plots. Results were presented as mean values and percentages of the questions' Likert-scales. All analysis

were conducted for the whole study population and stratified for pre-/professional and amateur dancers.

Data on perceived causes for both types of injury (acute and overuse) were analyzed per injury, and per dancer in order to meet the issue of dependency. Cronbach's α was applied to test the internal reliability of the items investigating implementation of dance medicine, and explorative factor analysis (EFA) was used to identify the underlying structure of the scale (Extraction method: Maximum Likelihood; Rotation method: Equamax with Kaiser Normalization; Kaiser-Meyer-Olkin Measure of Sampling Adequacy and Bartlett Test). This analysis tested the answers the dancers gave on a clear pattern and thus an internal reliability, e.g., whether the dancers understood the questions, whether negative statements were understood negatively and positive understood positively.

5.3. Results

5.3.1 Population

Of the 192 dancers who completed the questionnaire, 70% were pre-professional or professional dancers, 30% were amateurs, coming from 28 different nations.(50) The dancers had a mean age of 26.7 ±7.8 years, most dancers were female (82.8%). 119 dancers reported 203 acute injuries, with a range of one to six injuries per dancer. 164 dancers were affected by 469 overuse injuries, ranging from one to nine injuries per dancer *(Table 1).*

5.3.2 Perceived causes for injuries

For acute injuries, the mean number of causes per injury was 3.9 ±2.81. For overuse injuries the mean number of causes per injury was 10.8 ±9.84. For acute injuries, the most often reported cause was fatigue with 43.8% in the per-injury and 32.8% per-dancer analysis. With respect to overuse injuries, in the per-injury analysis pressure from the ballet teacher or ballet master was most frequently perceived as cause (n=240; 51.2%), predominantly in pre-professional and professional dancers (n=233; 61.3%). In the per-dancer analysis, “Fatigue, overtraining and overwork” was most the frequently perceived cause (n=107; 55.7%). Further causes were errors in the dance technique (acute-per-injury: 24.6%, acute-per-dancer: 21.9%, overuse-per-injury: 47.8%, overuse-per-dancer: 45.3%), or previous/repetitive injuries (acute-per-injury: 26.1%, acute-per-dancer: 22.4%, overuse-per-injury: 46.3%, overuse-per-dancer: 53.1%). Details can be found in *Table 2*.

5.3.3 Perceived implementation of dance medicine

Cronbach's α suggested good internal reliability between items which assessed the practical implementation of preventive dance medicine as supported or not supported (support α 0.909; no-support α 0.886). Explorative factor analysis (KMO 0.915; Bartlett Test p = 0.00) showed clear loading onto 2 factors, which was additionally verified in a Scree Plot.

Table 3 presents the results for how dancers perceive the support by their ballet teachers and masters with regard to the implementation of dance medicine into practice. The table is structured according to our categories, presented in the methods section: 1) handling of pain and injury, 2) science of training, and 3) sociopsychological support.

With regard to the perceived implementation of dance medicine, in pre-/professional dancers, 1 of the 21 items received high ratings, 9 aspects were reported to be moderately implemented and 11 received low support. In amateurs, 8 were highly incorporated, 7 moderately, and for 6 the implementation was low (*Table 3*).

Table 1: General demographics.
Values are given as the mean ±SD (range) or n(%) of the population
Time exposure (= per 60 minutes)
Dancer exposure (= per event, independent of the duration of the event, i.e., not necessarily 60 minutes)
Acute injuries were related to an identifiable event and a precise onset in the course of dance related activities such as performance, rehearsal, or technique class.
Overuse injuries were physical complaints or injuries which could not be linked to a clearly identifiable event but sustained from dance related activities such as performance, rehearsal, or technique class.

	All dancers 192	Pre-/Professionals 132 (68.8)	Amateurs 56 (29.2)
Sex			
Female	159 (82.8)	102 (77.3)	53 (94.6)
Male	33 (17.2)	30 (22.7)	3 (5.4)
Age *(years)*	26.7 ±7.82 (41)	24.7 ±5.5 (25)	31.0 ±10.35 (41)
Ballet experience *(years)*	14.5 ±7.00 (49)	14.43 ±5.2 (30)	14.5 ±10.05 (49)
Age at ballet initiation *(years)*	8.1 ±5.84 (43)	7.37 ±3.02 (15)	9.8 ±9.46 (42)
Time exposure *(workload in hours/week)* *missings*	26.8 ±15.30 (59) 4	35.6 ±8.20 (44) 4	6.1 ±3.92 (14) 0
Dancer exposure *(workload in events/week)* *missings*	12.3 ±9.60 (65) 5	16.1 ±9.28 (65) 4	4.25 ±2.80 (14) 1
Acute injuries			
total number of acute injuries in the population	203 (in 119 dancers)	156 (in 87 dancers)	43 (in 29 dancers)
acute injuries per dancer	(6)	(6)	(3)
0	73 (38.0)	45 (34.1)	27 (48.2)
1	65 (33.9)	45 (34.1)	18 (21.1)
2	36 (18.8)	27 (20.5)	8 (14.3)
3 and more injuries	18 (9.6)	15 (11.36)	3 (5.4)
Overuse injuries			
total number of overuse injuries in the population	469 (in 164 dancers)	380 (in 117 dancers)	83 (in 44 dancers)
overuse injuries per dancer	(9)	(9)	(5)
0	28 (14.6)	15 (11.4)	12 (21.4)
1	42 (21.9)	20 (15.2)	20 (35.7)
2	33 (17.2)	20 (15.2)	13 (23.2)
3 and more injuries	89 (38.1)	77 (58.3)	11 (19.4)

Table 2: Causes dancers perceived for their acute and overuse injuries.
Causes are reported per injury n(%), and per dancer n(%) in which each reported cause was only included once for each dancer.

	ACUTE INJURIES					
	Reported causes per injury			Reported causes per dancer		
Reported causes	Acute injuries in all Dancers n=203	Acute injuries in Pre-/Professionals n=156	Acute injuries in Amateurs n=43	All dancers n=192	Pre-/Professionals n=132	Amateurs n=56
Fatigue (being exhausted; overly tired)	89 (43.8)	65 (41.7)	21 (48.8)	63 (32.8)	46 (34.8)	16 (28.6)
Previous or repetitive pain, complaint or injury	53 (26.1)	36 (23.1)	15 (34.9)	43 (22.4)	29 (22.0)	13 (23.2)
Technical errors in the dance technique	50 (24.6)	43 (27.6)	6 (14.0)	42 (21.9	35 (26.5)	6 (10.7)
Insufficient warm up or warm down	40 (19.7)	25 (16.0)	12 (28.0)	31 (16.1)	20 (15.2)	9 (16.1)
Floor	34 (16.7)	29 (18.6)	5 (11.6)	24 (12.5)	19 (14.4)	5 (8.9)
Insecurity (with a new choreography/technique making you feel “unready”)	30 (14.8)	25 (16.0)	5 (11.6)	22 (11.5)	18 (13.6)	4 (7.1)
Unfamiliar movements	29 (14.3)	22 (14.1)	6 (14.0)	22 (11.5)	16 (12.1)	5 (8.9)
Insufficient training status (e.g., strength, endurance, early specialization)	27 (13.3)	18 (11.5)	9 (20.9)	22 (11.5)	15 (11.4)	7 (12.5)
Ballet teacher, ballet master (behavior, teaching/working methods)	21 (10.3)	19 (12.2)	2 (4.7)	19 (9.9)	17 (12.9)	2 (3.6)
Partner, Pas de Deux, lifts	20 (9.9)	19 (12.2)	0 (0.0)	17 (8.9)	16 (12.1)	0 (0.0)
Insufficient preparation or preparation time (before performance etc.)	18 (8.9)	15 (9.6)	3 (7.0)	17 (8.9)	14 (10.6)	3 (5.4)
Poor diet, hunger and related fatigue, weakness or failure to concentrate	17 (8.4)	12 (7.7)	5 (11.6)	16 (8.3)	11 (8.3)	5 (8.9)
Different teachers, masters, chorographers and varying demands	16 (7.9)	12 (7.7)	4 (9.3)	14 (7.3)	10 (7.6)	4 (7.1)
Costumes, footwear	7 (3.4)	5 (3.2)	2 (4.7)	5 (2.6)	3 (2.3)	2 (3.6)
Props	5 (2.5)	5 (3.2)	0 (0.0)	4 (2.1)	4 (3.0)	0 (0.0)
Stage (curtains, sets, pictures, monuments, cables, or other)	5 (2.5)	4 (2.6)	1 (2.3)	5 (2.6)	4 (3.0)	1 (1.8)
Backstage	2 (1.0)	2 (1.3)	0 (0.0)	2 (1.0)	2 (1.5)	0 (0.0)
Lights, spotlights	1 (0.5)	1 (0.6)	0 (0.0)	1 (0.5)	1 (0.8)	0 (0.0)
Other reasons	13 (6.4)	9 (5.8)	4 (9.3)	13 (6.8)	9 (6.8)	4 (7.1)

Table 2 (continued): Causes dancers perceived for their acute and overuse injuries.
Causes are reported per injury n(%), and per dancer n(%) in which each reported cause was only included once for each dancer.

	OVERUSE INJURIES					
	Reported causes per injury			Reported causes per dancer		
Reported causes	Overuse injuries in all Dancers n=469	Overuse injuries in Pre-/Professionals n=380	Overuse injuries in Amateurs n=83	All dancers n=192	Pre-/Professionals n=132	Amateurs n=56
Pressure from the ballet teacher, ballet master	240 (51.2)	233 (61.3)	7 (8.4)	76 (39.6)	70 (53.0)	6 (10.7)
High repetition of the same movements	225 (48.0)	198 (52.1)	23 (27.7)	104 (54.2)	88 (66.7)	15 (26.8)
Technical errors in the dance technique	224 (47.8)	203 (53.4)	20 (24.1)	87 (45.3)	73 (55.3)	13 (23.2)
Fatigue, overtraining, overwork	222 (47.3)	176 (46.3)	41 (49.4)	107 (55.7)	80 (60.6)	25 (44.6)
Previous or repetitive pain, complaint or injury	217 (46.3)	188 (49.5)	28 (33.7)	102 (53.1)	81 (61.4)	20 (35.7)
Insufficient resting or recovery time	178 (38.0)	156 (41.1)	18 (21.7)	86 (44.8)	72 (54.5)	13 (23.2)
Insufficient warm up or warm down	83 (17.7)	57 (15.0)	25 (30.1)	48 (25.0)	29 (22.0)	18 (32.1)
Schedules (too tight, too demanding, unbalanced)	79 (16.8)	69 (18.2)	8 (9.6)	48 (25.0)	40 (30.3)	7 (12.5)
Floor	56 (11.9)	48 (12.6)	8 (9.6)	32 (16.7)	27 (20.5)	5 (8.9)
Insufficient training status (e.g., strength, endurance, early specialization)	53 (11.3)	35 (9.2)	17 (20.5)	34 (17.7)	22 (16.7)	11 (19.6)
Forcing turnout rotation (En Dehors)	49 (10.4)	46 (12.1)	3 (3.6)	29 (15.1)	27 (20.5)	2 (3.6)
Financial pressure, existential fear	46 (9.8)	44 (11.6)	2 (2.4)	27 (14.1)	26 (19.7)	1 (1.8)
Anxiety	40 (8.5)	35 (9.2)	5 (6.0)	27 (14.1)	22 (16.7)	5 (8.9)
Poor diet and related hunger, fatigue, or health consequences	38 (8.1)	27 (7.1)	11 (13.3)	28 (14.6)	19 (14.4)	9 (16.1)
Pressure from colleagues and peers	28 (6.0)	21 (5.5)	7 (8.4)	20 (10.4)	13 (9.8)	7 (12.5)
Different teachers, masters, choreographers and varying demands	21 (4.5)	18 (4.7)	3 (3.6)	16 (8.3)	13 (9.8)	3 (5.4)
Insufficient preparation or preparation time (before performance, etc.)	17 (3.6)	15 (4.0)	2 (2.4)	12 (6.3)	10 (7.8)	2 (3.6)
Depression	10 (2.1)	7 (1.8)	3 (3.6)	10 (5.2)	7 (5.3)	3 (5.4)
Partner, Pas de deux, lifts	6 (1.3)	6 (1.6)	0 (0.0)	5 (2.6)	5 (3.8)	0 (0.0)
Other reasons	26 (5.5)	21 (5.5)	5 (6.0)	23 (12.0)	18 (13.6)	5 (8.9)

Table 3: Questions to evaluate the perceived level of implementation of aspects of dance medicine and science into practice.
The values are displayed as Likert-1-5-point-scale mean values ±standard deviation in line with the respective question. Dancers' ratings are displayed an n(%)
BMTPT: Ballet Master, Ballet Teacher, Pedagogue, Trainer
Rating of the Likert-scale mean values in 1.33 intervals as a reference for the level of implementation:

Level of rating	High levels of implementation	*Moderate levels of implementation*	Low levels of implementation
Supporting statements	3.67-5.00	*2.34-3.66*	1.00-2.33
Non-supporting statements	1.00-2.33	*2.34-3.66*	3.67-5.00

Opening question	All dancers (n=192)	Pre-/Professional (n=132)	Amateur (n=56)
My BMTPT talks about dance medicine.	1.7 ±1.2	1.7 ±1.2	1.8 ±1.2
Never	130 (67.7)	93 (70.5)	36 (64.3)
Seldom	19 (9.9)	13 (9.8)	6 (10.7)
Sometimes	20 (19.4)	11 (8.3)	7 (12.5)
Very often	12 (6.3)	6 (4.5)	5 (8.9)
Always	11 (5.7)	9 (6.8)	2 (3.6)
Handling of pain and injury			
My BMTPT wants me to report pain immediately that he/she can adjust or cancel training etc.	*2.7 ±1.6*	*2.4 ±1.6*	*3.3 ±1.5*
Never	70 (36.5)	58 (42.9)	11 (19.6)
Seldom	29 (15.1)	21 (15.9)	8 (14.3)
Sometimes	24 (12.5)	13 (9.8)	11 (19.6)
Very often	27 (14.1)	18 (13.6)	8 (14.3)
Always	42 (21.9)	22 (16.7)	18 (32.1)
My BMTPT wants me to be checked by a medical professional with any complaint/pain/injury.	*3.0 ±1.5*	*2.9 ±1.5*	*3.4 ±1.4*
Never	40 (20.8)	31 (23.5)	9 (16.1)
Seldom	38 (19.8)	35 (26.5)	2 (3.6)
Sometimes	31 (16.1)	13 (9.8)	18 (3.1)
Very often	40 (20.8)	27 (20.5)	12 (21.4)
Always	43 (22.4)	26 (19.7)	15 (26.8)
My BMTPT tells me to work through pain because it is part of dancing.	*2.9 ±1.5*	*3.2 ±1.5*	2.1 ±1.2
Never	51 (26.6)	25 (18.9)	25 (44.6)
Seldom	33 (17.2)	23 (17.4)	9 (16.1)
Sometimes	35 (18.2)	21 (15.9)	13 (23.2)
Very often	34 (17.7)	25 (18.9)	8 (14.3)
Always	39 (20.3)	38 (28.8)	1 (1.8)
My BMTPT sticks to the medical professional's orders (e.g., rest, sick leave, modified training) that I can fully recover or heal injuries.	*3.2 ±1.5*	*2.8 ±1.5*	4.0 ±1.2
Never	39 (20.3)	36 (27.3)	3 (5.4)
Seldom	35 (18.2)	30 (22.7)	4 (7.1)
Sometimes	24 (12.5)	16 (12.1)	8 (14.3)
Very often	41 (21.4)	26 (19.7)	14 (25.0)
Always	53 (27.6)	24 (18.2)	27 (48.2)

Table 3 (continued): Questions to evaluate the perceived level of implementation of aspects of dance medicine and science into practice. The values are displayed as Likert-1-5-point-scale mean values ±standard deviation; n(%)

My BMTPT analyses my technique after I reported pain or injury to avoid further harm or repetitive injury.	*2.4 ±1.5*	**2.0 ±1.3**	*3.2 ±1.5*
Never	82 (42.7)	71 (53.8)	11 (19.6)
Seldom	33 (17.2)	23 (17.4)	9 (16.1)
Sometimes	23 (12.0)	12 (9.1)	10 (17.9)
Very often	26 (13.5)	16 (12.1)	10 (17.9)
Always	28 (14.6)	10 (7.6)	16 (28.6)
Science of training and acknowledgment of individuality			
My schedules include enough rest for me to feel fully recovered after training, rehearsal, performance.	*2.6 ±1.2*	**2.3 ±1.1**	*3.2 ±1.2*
Never	37 (19.3)	32 (24.2)	5 (8.9)
Seldom	60 (31.3)	46 (34.8)	13 (23.2)
Sometimes	44 (22.9)	35 (26.5)	9 (16.1)
Very often	40 (20.8)	15 (11.4)	23 (41.1)
Always	11 (5.7)	4 (3.0)	6 (10.7)
My schedules and training are adjusted to make sure that I am never overly fatigued.	**1.8 ±1.2**	**1.5 ±1.0**	*2.4 ±1.4*
Never	113 (58.9)	90 (68.2)	21 (37.5)
Seldom	38 (19.8)	27 (20.5)	11 (19.6)
Sometimes	20 (10.4)	7 (5.3)	12 (21.4)
Very often	11 (5.7)	4 (3.0)	6 (10.7)
Always	10 (5.2)	4 (3.0)	6 (10.7)
My BMTPT shortens/cancels breaks to make me train/rehearse longer.	*2.6 ±1.4*	*3.0 ±1.3*	1.8 ±1.1
Never	62 (32.3)	26 (19.7)	33 (58.9)
Seldom	33 (17.2)	21 (15.9)	11 (19.6)
Sometimes	36 (18.8)	30 (22.7)	6 (10.7)
Very often	43 (22.4)	38 (28.8)	5 (8.9)
Always	18 (9.4)	17 (12.9)	1 (1.8)
My BMTPT insists that I warm up.	**1.8 ±1.3**	**1.6 ±1.3**	**2.1 ±1.4**
Never	133 (69.3)	101 (76.5)	31 (55.4)
Seldom	17 (8.9)	9 (6.8)	6 (10.7)
Sometimes	13 (6.8)	3 (2.3)	10 (17.9)
Very often	11 (5.7)	8 (6.1)	3 (5.4)
Always	18 (9.4)	11 (8.3)	6 (10.7)
My BMTPT tells me that strength training is bad for my aesthetic line.	1.9 ±1.3	2.2 ±1.4	1.3 ±0.8
Never	122 (63.5)	71 (53.8)	47 (83.9)
Seldom	12 (6.3)	9 (6.8)	3 (5.4)
Sometimes	26 (13.5)	23 (17.4)	3 (5.4)
Very often	19 (9.9)	16 (12.1)	3 (5.4)
Always	13 (6.8)	13 (9.8)	0 (0.0)

Table 3 (continued): Questions to evaluate the perceived level of implementation of aspects of dance medicine and science into practice. The values are displayed as Likert-1-5-point-scale mean values ±standard deviation; n(%)

My BMTPT wants me to close eyes in balances or shorter combinations.	1.6 ±1.0	1.4 ±1.0	1.8 ±1.0
Never	135 (70.3)	106 (80.3)	28 (50.0)
Seldom	25 (13.0)	10 (7.6)	13 (23.2)
Sometimes	19 (9.9)	6 (4.5)	12 (21.4)
Very often	9 (4.7)	6 (4.5)	3 (5.4)
Always	4 (2.1)	4 (3.0)	0 (0.0)
My BMTPT wants me to train without mirrors.	*2.6 ±1.0*	*2.6 ±1.0*	*2.7 ±1.0*
Never	28 (14.6)	20 (15.2)	7 (12.5)
Seldom	58 (30.2)	39 (29.5)	17 (30.4)
Sometimes	77 (40.1)	55 (41.7)	21 (37.5)
Very often	23 (12.0)	13 (98)	10 (17.9)
Always	6 (3.1)	5 (3.8)	1 (1.8)
My BMTPT wants me to train without barre.	1.8 ±1.1	1.7 ±1.0	2.2 ±1.1
Never	104 (54.2)	79 (59.8)	21 (37.5)
Seldom	44 (22.9)	30 (22.7)	14 (25.0)
Sometimes	27 (14.1)	13 (9.8)	14 (25.0)
Very often	11 (5.7)	6 (4.5)	5 (8.9)
Always	6 (3.1)	4 (3.0)	2 (3.6)
My BMTPT wants me to turn the feet out further than I think I can.	*2.9 ±1.6*	*3.3 ±1.6*	2.0 ±1.3
Never	64 (33.3)	33 (25.0)	28 (50.0)
Seldom	25 (13.0)	13 (9.8)	11 (19.6)
Sometimes	19 (9.9)	13 (9.8)	6 (10.7)
Very often	40 (20.8)	32 (24.2)	8 (14.3)
Always	44 (22.9)	41 (31.1)	3 (5.4)
My BMTPT prevents me from turning out too much that I can maintain my correct leg axis.	*2.5 ±1.6*	2.0 ±1.4	*3.5 ±1.5*
Never	88 (45.8)	76 (57.6)	11 (19.6)
Seldom	20 (10.4)	15 (11.4)	4 (7.1)
Sometimes	25 (13.0)	17 (12.9)	8 (14.3)
Very often	24 (12.5)	10 (7.6)	14 (25.0)
Always	35 (18.2)	14 (10.6)	19 (33.9)
Psychological support			
My BMTPT encouraged dancers to speak out (e.g., addressing problems, wishes).	1.0 ±1.07	0.8±1.02	1.27±1.05
Never	89 (46.4)	70 (53.0)	19 (33.9)
Seldom	41 (21.4)	31 (23.5)	9 (16.1)
Sometimes	44 (22.9)	21 (15.9)	22 (39.3)
Very often	15 (7.8)	8 (6.1)	6 (10.7)
Always	3 (1.6)	2 (1.5)	0 (0.0)
My BMTPT did not appreciate questions or opinions.	2.1 ±1.36	*2.5±1.28*	1.1±1.0
Never	32 (16.7)	12 (9.1)	19 (33.9)
Seldom	38 (19.8)	18 (13.6)	18 (32.1)
Sometimes	43 (22.4)	28 (21.2)	15 (26.8)
Very often	42 (21.9)	38 (28.8)	3 (5.4)
Always	37 (19.3)	36 (27.3	1 (1.8)

Table 3 (continued): Questions to evaluate the perceived level of implementation of aspects of dance medicine and science into practice. The values are displayed as Likert-1-5-point-scale mean values ±standard deviation; n(%)

My BMTPT commented on my weight.	*2.4 ±1.5*	*2.7 ±1.6*	1.7 ±1.0
Never	89 (46.4)	52 (39.4)	34 (60.7)
Seldom	26 (13.5)	13 (9.8)	12 (21.4)
Sometimes	23 (12.0)	17 (12.9)	6 (10.7)
Very often	24 (12.5)	22 (16.7)	2 (3.6)
Always	30 (15.6)	28 (21.2)	2 (3.6)
My BMTPT made sure that things to do were within my range of capabilities that I can feel secure and self-confident.	*2.8 ±1.3*	**2.3 ±1.3**	3.8 ±0.9
Never	49 (25.5)	48 (36.4)	0 (0.0)
Seldom	31 (16.1)	28 (21.2)	3 (5.4)
Sometimes	51 (26.6)	31 (23.5)	18 (32.1)
Very often	39 (20.3)	16 (12.1)	22 (39.3)
Always	22 (11.5)	9 (6.8)	13 (23.2)
My BMTPT encouraged me to think about the end of my dancing career and make plans for the future or consult a career transition specialist.	**1.6 ±1.1**	**1.6 ±1.1**	**1.6 ±1.1**
Never	139 (72.4)	95 (72.0)	40 (71.4)
Seldom	22 (11.5)	17 (12.9)	5 (8.9)
Sometimes	15 (7.8)	8 (6.1)	7 (12.5)
Very often	7 (3.6)	5 (3.8)	2 (3.6)
Always	9 (4.7)	7 (5.3)	2 (3.6)

5.4 Discussion

First, this study aimed to investigate the causes ballet dancers perceived regarding their sustained acute and overuse injuries in the previous two years. Secondly, dancers were asked to rate their perceived teachers'/masters' level of implementation of three selected aspects of preventive dance medicine (science of training, handling of pain and injury, psychological support). When taking all individual injuries and their individual causes into account we found that fatigue was the most frequently perceived cause for acute injuries. For overuse injuries, pressure by teachers and masters was the cause most often reported, predominantly in pre-professional and professional dancers. When looking at the causes reported per dancer, we found that fatigue, overtraining and overwork also scored highest for overuse injuries, followed by high repetitions of the same movements and previous/repetitive injury. The causes dancers perceived of their injuries were mirrored in the level of support they perceived regarding implementation of preventive dance medicine. In pre-/professional settings, practical implementation of preventive dance medicine received low to moderate support by ballet teachers and masters. In amateur dancers, support was perceived as moderate to high.

5.4.1 Overuse injuries as complex multifactorial issue

Our analyses of perceived causes were conducted separately, "per-injury" and "per-dancer", to meet the issue of interdependency of causes for multiple injuries in single dancers. Additionally, we investigated causes for acute and overuse injuries separately. As our findings show, for acute injuries little differences were present between "per injury" or "per dancer", showing that dancers contributed equally to the perceived causes. Moreover, for acute injuries, the mean number of causes dancers reported per injury was

3.9. Although causes of acute injuries, as we showed, are often multifactorial, the causes are most often known, facilitating diagnosis but also treatment as well as documentation for later evaluation.(46) With an average of 10.8 causes per injury, however, dancers reported more causes for each of their overuse injuries than for the acute injuries, indicating they could not as clearly decide for a cause as with acute injuries. This supports the issue of complexity of overuse injuries which might be more difficult to handle. They develop over a longer period of time, consequently multiple factors will contribute to their development. For that matter, our dancers reported several causes stressing the complex multifactorial nature of overuse injuries compared to acute injuries. Our findings support previous publications on the difficulty of defining, recording, handling as well as preventing overuse injuries(54) and highlight their multifactorial causality.(55) The interaction and interdependency of causes has to be taken into account in order to prevent underreporting or simplification of the complex issue of overuse injuries. Future research might benefit from such an approach in order to investigate the complexity of overuse injuries.

5.4.2 Perceived causes and implementation of preventive dance medicine

In line with our findings, fatigue, exhaustion and overwork have already been reported as causes for injuries in dancers.(28, 56). Previous research investigating the demands of ballet dancers' work days(45) showed that 90% of the ballet professionals spent less than 60 consecutive minutes resting at any one time during their work day, 33.3% even less than 20 minutes. Moreover, overtraining due to imbalances in work-to-rest ratio (16, 56) has also been associated with a decline in performance, long-term health issues, injuries (especially overuse) and burnout.(10, 57) As such, time exposure and related fatigue from

duration and intensity of workload can be linked to injury risk. Possible training asymmetries which disrespect the necessary balance between load and loadability of injured or overused tissue can further prolong fatigue through abnormal training responses. That again could prolong recovery time while increasing (re-)injury risk and declining performance outcomes. In our population, fatigue was perceived as cause for 44% of all acute and 56% of all overuse injuries, while only 26% of the dancers reported that their schedules included enough rest to feel fully recovered.

The importance of correct handling of pain and injury, the recognition of a dancer's individuality as well as the installation of an empowering motivational climate are stressed to reduce the risk of (repetitive) injuries.(5, 18, 58) As researched in sports science, the coach is the first and foremost institution when it comes to injury prevention in athletes(31, 32, 34, 35), which can also be confirmed by our results in ballet dancers. In our population, the top five causes for overuse injuries in both analyses are, at least partially a direct responsibility of the teacher or master.(29) Those causes, such as planning of training, dance technique, or fatigue and overtraining, scored high as perceived causes while support of teacher/master for those aspects was perceived as moderate to low.

Ballet teachers and ballet masters' hold an important and influential role as significant others in direct contact with the dancer. How they talk to and treat dancers can directly contributes to the etiology of dancers' injuries.(18) In our population, nearly 50% of the dancers documented that teachers or masters never commented on their weight. Although with 50% moderate, this might be a first step towards the prevention of eating disorders, since a high focus on low weight can contribute to injuries.(37) However, in other respects, our population documented teacher/master behavior of dangerously low levels of support. With a mean of 0.8 of 5 available points on the Likert-scale in pre-

/professionals, perceived support to speak out in case of problems or wishes received the lowest rating of all available items. Distress in dancers increases if the climate of reporting an injury, speaking out on shortcomings, or becoming injured altogether is answered with sanctions or disempowering teacher behavior.(30, 59) Even more, such distress was found to be associated with a prolonged recovery time as well as increased (re-)injury risk.(60, 61) For that matter, negative engagement between teacher and dancer does not support the implementation of injury-preventive dance medical approaches for which empowering motivational climates are as essential as early identification and correct handling of pain and injury.(18, 20)

While often regarded as historical cliché(40), such aspects of controlling behavior by authorities(18, 38) must not be underestimated.(62) Our analysis showed that those dancers who perceived pressure from their teachers/masters and who reported teacher/master related aspects as causes for their injuries also reported the highest number of injuries. As stated in the methods section, dancers used the "other causes" option for acute injuries so often to report behavioral extremes in their ballet teachers/masters that we included those as additional cause into our analysis. The teacher/master is by far not the only factor contributing to the etiology of dance injuries. However, as described in sports science(34, 35), they are in a key position(18, 29, 52) with regard to injury prevention. The latter is supported by our results. While teachers and masters themselves are under pressure to „produce perfect dancers", however, in times of available scientific approaches to education and performance enhancement, they would also have evidence-based support to fulfill their key role in dancers injury prevention efficiently.(39, 63)

Based on our analysis, different injury preventive measures should be developed and implemented for dancers' acute and overuse injuries. Dance medical interventions focusing on fitness and conditioning have shown injury-preventive results by first and foremost acknowledging the needs and individuality of dancers in practice.(12) Our results indicate that more aspects might need a focus on the dancer's individuality. For instance individual perceptions of fatigue, insufficient preparation time before a premiere and necessary adaptation of schedules, a focus on the individual's abilities and anatomy with respect to dance technique, screening after injury to avoid further harm, the need to match individual skill levels with choreographic demands, or individual corrections of insufficient training status should be taken into account. Those were further aspects perceived as causes for injuries in our population while simultaneously reported to receive little support from ballet teachers/master with respect to implementation of preventive dance medicine.

Erroneous dance technique has already been described as risk factor(64, 65) perceived in 25% of acute and 48% of overuse injuries in our population. Furthermore, 49 dancers (per-injury: 10.4%, per-dancer: 15.1%) specified forcing turnout as the most frequently perceived dance technical error leading to their injuries in the "other causes"-item, making us include it as an individual cause. While the association between erroneous turnout and injuries needs further scientific clarification(5), our results show that in practice dancers t perceive the neglect of their individuality in the historical striving for „ideal turnout" of 180° as a cause for injuries.

Targeted integration of conditioning (e.g., strength and proprioception training) as well as appropriate warm-up are to be considered essential aspects of evidence-based teaching, training and injury prevention.(12, 50) The answers of our study population indicate that

two thirds of teaching personnel do not regard strength training as a threat to the dancer's aesthetics(66), while a lack of conditioning was only perceived as cause for 9% of all acute and 11% of all reported overuse injuries. This is an essential step towards the acknowledgment of athleticism in dance and away from related historical approaches. However, only a small number of teachers focus on warm-up(50) and exercises for proprioception training(67, 68) as well as related aspects such as the targeted use of mirrors(37, 69, 70) or barres.(71, 72)

A further aspect also highly depends on proactive inclusion of preventive dance medicine and does not appear to receive sufficient implementation. Psychological and social support with regard to transitioning from active career into second career path or retirement has been discussed in previous research.(73) A focus on positive, conscious and professionally guided preparation for that transition in order to reduce stress, prevent denial and fight risk of psychological and physiological ill-health has been recommended.(73) Our population reported very low levels of support, which, however, should already be part of vocational education.

The differences between pre-/professional and amateur dancers show that injury preventive approaches need to be different in various levels of expertise. While injury preventive dance medicine seems to be better supported in amateur settings on the first impression, results should not be used for comparison. Lives, work load, pressure, as well as goals are different between professional and leisure-oriented dance environments. Therefore, we recommend to develop preventive strategies at a more personalized, individual basis and not a one-size-fits-all approach. Amateur dance settings are supposed to have a focus on enjoyment and thus will differ with respect to injury-related outcomes. However, literature has shown that amateurs have to cope with unreasonable

levels of pain and numbers of injuries as well(3, 43), confirmed by our results. The fact that amateurs reported fatigue as the highest perceived cause for both types of injuries might also show the need to monitor aspects such as planning of training in amateur settings. Teachers might be trying to compensate for lower training frequency by increasing training intensity. Any resulting overload could be a reason for the answers of our amateur-population although our number of amateurs was too low to discuss conclusions.

5.4.3 Strengths and limitations

Some limitations of our study have to be acknowledged. First, as with all surveys based on self-report, recall bias will be present for all reported data. Moreover, we don't know whether dancers recalled all of their injuries because minor ones might be easier forgotten than severe or recurring ones which might have been counted less when they occurred several times. Secondly, for our population our results are not presented in the context of workload/1000-hours of dance as we did not assess hours of dance per week over time. Thirdly, we also do not know whether our population is representable for the dancers' population, although we were able to include a very representable number of different nationalities and thus backgrounds. However, our study is the first study using a dual analysis of perceived causes, the per-dancer and per-injury analysis, providing essential insight into acute and overuse injuries which were additionally assessed separately. Moreover, it is a first approach through two different perspectives, namely the perceived causes and the perceived support for injury prevention with a clear focus on the ballet teacher/master. Therefore, we believe that our results may contribute to dance injury prevention. The anonymous design which was not restricted to one school or company

was deliberately chosen to support dancers to speak out and comply, which has been a previous and recurrent issue.(18, 30)

5.5 Conclusion

Fatigue and pressure accounted for the majority of causes for injuries. Perceived support by ballet teachers/masters regarding injury prevention and dance medicine was moderate to low. Our results could show that the individuality of dancers should be regarded as an important aspect in injury prevention. By documenting dancers' perceptions as well as the support for the implementation of dance medical research into dance practice dancers receive, we could stress the importance of implementing dance medical research into practice. Such support, among other measures, might be essential to reduce injuries in ballet dancers. Our results also contributed by highlighting the important role of the teacher/master as a major factor in practical implementation of dance medicine. Future research should also analyze, which causes teachers/masters perceive for their dancers' acute and overuse injuries and evaluate teachers'/masters' scientific knowledge and their awareness of the importance of their role in injury prevention through the practical implementation of dance medical research into dance practice. High levels of education in teachers and masters are of utmost importance, because many perceived causes and low levels of practical implementation are related to them and their scientific/practical expertise.

Appendix 1: Multiple response questions to evaluate the reasons, which dancers perceive for their acute or overuse injuries accompanying the injury assessment of each body part.
Acute injuries were related to an identifiable event and a precise onset in the course of dance related activities such as performance, rehearsal, or technique class.
Overuse injuries were physical complaints or injuries which could not be linked to a clearly identifiable event but sustained from dance related activities such as performance, rehearsal, or technique class.

What do you think was the cause of this acute injury?

1) Fatigue (i.e., being exhausted, overly tired)
2) Floor
3) Insufficient warm up or warm down
4) Insecurity (e.g., with a new or difficult choreography or technique making you feel "unready")
5) Different teachers, masters, chorographers, repertory, or varying demands
6) Unfamiliar movements
7) Poor or inadequate diet, hunger, and related fatigue, weakness, or failure to concentrate
8) Partner, partnering work, lifts
9) Props
10) Environment, stage (temperature, curtains, sets, pictures, monuments, cables, etc.)
11) Backstage (stairs, steps, cables, or other)
12) Lights, spotlights
13) Costumes, footwear
14) Previous or repetitive pain, complaint or injury, ignoring early warning signs
15) Technical errors in the dance technique
16) Insufficient training status (e.g., strength, endurance, early specialization)
17) Insufficient preparation or preparation time (before performance etc.)
18) Other: …….. *(open text question)*

What do you think was the cause of this overuse injury/complaint?

1) Fatigue, overtraining, overwork
2) Floor
3) Insufficient warm up or warm down
4) Different teachers, masters, choreographers and varying demands
5) High repetition of the same movements
6) Poor or inadequate diet and related hunger, fatigue or health consequences
7) Pressure from the ballet teacher, ballet master
8) Pressure from colleagues and peers
9) Previous or repetitive pain, complaint or injury, ignoring early warning signs
10) Technical errors in the dance technique
11) Schedules (e.g., too tight, too demanding, unbalanced)
12) Anxiety
13) Depression
14) Financial pressure, existential fear
15) Insufficient resting or recovery time
16) Insufficient training status (e.g., strength, endurance, early specialization)
17) Insufficient preparation or preparation time (before performance, etc.
18) Other: …….. *(open text question)*

Appendix 2: Search strategy

(("Dancing"[mesh] OR "dancer"[tw] OR "dancers"[tw] OR "dancing"[tw] OR "dance"[tw] OR "dances"[tw] OR "danc*"[tw] OR "classical ballet"[tw] OR "ballet"[tw] OR "ballet*"[tw] OR "ballerina"[tw] OR "ballerina*"[tw] OR "aesthetic sports"[tw] OR "aesthetic sport"[tw] OR "esthetic sports"[tw] OR "aesthetic sports"[tw]) AND ("overuse injury"[tw] OR "overuse injuries"[tw] OR "overuse injur*"[tw] OR "over use injury"[tw] OR "over use injuries"[tw] OR "over use injur*"[tw] OR "overuse trauma"[tw] OR "overuse trauma*"[tw] OR "overuse foot injuries"[tw] OR "overuse ankle injuries"[tw] OR "overuse foot injur*"[tw] OR "overuse ankle injur*"[tw] OR "overuse knee injur*"[tw] OR "overuse knee injur*"[tw] OR "overuse lower extremity injuries"[tw] OR "overuse lower extremity injur*"[tw] OR "overuse lower limb injuries"[tw] OR "overuse lower limb injur*"[tw] OR "overuse musculoskeletal injuries"[tw] OR "overuse musculoskeletal injur*"[tw] OR "overuse related injuries"[tw] OR "overuse tendon injuries"[tw] OR "overuse tendon injur*"[tw] OR "overuse type injuries"[tw] OR "overuse type injur*"[tw] OR (("overuse"[tw] OR "over use"[tw] OR "overus*"[tw] OR "over us*"[tw]) AND ("Wounds and Injuries"[Mesh] OR "injury"[tw] OR "injuries"[tw] OR "injured"[tw] OR "injur*"[tw] OR "injuries"[Subheading] OR "fracture"[tw] OR "fractures"[tw] OR "fractured"[tw] OR "fractur*"[tw] OR "trauma"[tw] OR "trauma*"[tw] OR "nontraum*"[tw] OR "rupture"[tw] OR "ruptured"[tw] OR "ruptur*"[tw] OR "tear"[tw] OR "tear*"[tw])) OR "acute injury"[tw] OR "acute injuries"[tw] OR "acute injur*"[tw] OR "acute trauma"[tw] OR "acute trauma*"[tw] OR "acute foot injuries"[tw] OR "acute ankle injuries"[tw] OR "acute foot injur*"[tw] OR "acute ankle injur*"[tw] OR "acute knee injur*"[tw] OR "acute knee injur*"[tw] OR "acute lower extremity injuries"[tw] OR "acute lower extremity injur*"[tw] OR "acute lower limb injuries"[tw] OR "acute lower limb injur*"[tw] OR "acute musculoskeletal injuries"[tw] OR "acute musculoskeletal 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fault"[tw] OR "insufficient warm up"[tw] OR "warm up"[tw] OR "warming up"[tw] OR "Insecurity"[tw] OR "insecure"[tw] OR "new choreography"[tw] OR "new technique"[tw] OR "new techniques"[tw] OR "insufficient training status"[tw] OR "insufficient strength"[tw] OR "insufficient endurance"[tw] OR "Insufficient preparation time"[tw] OR "Insufficient time"[tw] OR "preparation time"[tw] OR "Poor diet"[tw] OR " hunger"[tw] OR "Different teachers"[tw] OR "different choreographers"[tw] OR "Backstage"[tw] OR "backstage"[tw] OR "stage lights"[tw] OR "stage light"[tw] OR "stage lighting"[tw] OR "stagelights"[tw] OR "stagelight"[tw] OR "stagelighting"[tw] OR "Insufficient recovery time"[tw] OR "recovery time"[tw] OR "Unsuitable floors"[tw] OR "Unsuitable floor"[tw] OR "Schedule"[tw] OR "Schedules"[tw] OR "Financial pressure"[tw] OR "Financial pressures"[tw] OR "Financial Stress"[tw] OR "Insufficient trainin"[tw] OR "Insufficient preparation time"[tw] OR "preparation time sleep"[tw] OR "rest"[tw] OR "overtraining"[tw] OR "overtrain*"[tw] OR "performance"[ti] OR "perform*"[ti] OR "supercompensation"[tw] OR "supercompensat*"[tw] OR "burnout"[tw] OR "Eating disorders"[tw] OR "OR Eating disorder"[tw] OR "bone mineral density"[tw] OR "Bone Density"[tw] OR "insufficient nutrition"[tw] OR " BMI"[tw] OR "Body Mass Index"[tw] OR "energy"[tw] OR "energy intake"[tw] OR "energy level"[tw] OR "energy depletion"[tw] OR "Shoes"[mesh] OR "Anxiety"[mesh] OR "Depression"[mesh] OR "Fear"[mesh] OR "Stress, Psychological"[Mesh] OR "Psychological Distress"[Mesh] OR "Peer Influence"[Mesh] OR "Motivation"[Mesh] OR "Frustration"[mesh] OR "Behavior"[mesh] OR "Fatigue"[mesh] OR "Warm-Up Exercise"[Mesh] OR "Hunger"[mesh] OR "Financial Stress"[Mesh] OR "Burnout, Psychological"[Mesh] OR "Sleep"[Mesh] OR "Sleep Wake Disorders"[Mesh] OR "Rest"[mesh] OR "Athletic Performance"[Mesh] OR "Performance Anxiety"[Mesh] OR "Physical Functional Performance"[Mesh] OR "Work Performance"[Mesh] OR "Feeding and Eating Disorders"[Mesh] OR "Bone Density"[Mesh] OR "Malnutrition"[mesh] OR "Body Mass Index"[Mesh] OR "Energy Intake"[Mesh] OR (("pressure"[tw] OR "competence"[tw] OR "knowledge"[tw] OR "education"[tw] OR "pressur*"[tw] OR "competenc*"[tw] OR "knowledg*"[tw] OR "education*"[tw]) AND ("trainer"[tw] OR "trainers"[tw] OR "coach"[tw] OR "coaches"[tw] OR "teacher"[tw] OR "teachers"[tw] OR "master"[tw] OR "masters"[tw] OR "colleague"[tw] OR "colleagues"[tw] OR "peers"[tw]))))

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Chapter 6

Injury, Stress & Injury Prevention

Injury as a stressor in 67 first year contemporary dance students: A longitudinal cohort study

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Submitted

Abstract

In athletes, injuries lead to increased stress but athletes cope better with consecutive than with first-time-injury. In dancers such information is lacking. Thus we investigated whether injuries are associated with increased stress-levels, and if consecutive injuries are related to higher stress levels than first injury. Bachelor dance students were prospectively followed during five academic years (2016-2022). During the first month of the year, respectively, baseline characteristics were recorded using the "Performing artist and Athlete Health Monitor" (PAHM) including the VAS pain scale, the VAS stress scale, and the "Oslo Sport Trauma Research Center Questionnaire on Health Problems" (OSTRC). Throughout the year, stress, injuries and injury severity were reported monthly. The first-month assessment served as baseline in which dancers had to be injury free to be included in this analysis. Paired t-tests were conducted. 67 dancers (age 18.8 ±.8 years, 58.2% female) sustained at least one injury, of those 33 at least one consecutive injury. OSTRC severity scores ranged from a mean of 28.7 ±17.5 for first injuries to 31.4 ±17.1 for consecutive injuries. The mean baseline stress level for injuries was 24.3 ±17.2. Stress levels during first and consecutive injuries were elevated compared to the baseline stress levels, 34.8 ± 18.7 and 35.1 ±23.0, respectively. There were no differences between stress levels during first and consecutive injuries. Injuries are associated with increased stress levels in dancers, but stress levels were equally high after first and consecutive injury. We emphasize the importance of a holistic approach to injury rehabilitation, thus not only focusing on the physiological injury as such, but also include the dancers' psychological recovery and a focus on stress management for both enhanced recovery as well as prevention of future injuries.

1. Introduction

It is well known that mental stress has negative effects on health. For instance, chronic mental stress has been linked to several diseases, including mental disorders[1-5]. According to Andersen and Williams' stress-injury model, mental stress increases the risk of injury by inducing neurophysiological changes which can lead to a loss of neuromuscular control and flexibility, increased muscular tension, restriction of peripheral vision, or attentional deficits.[6]

In studies on ballet dancers the association between general as well as dance-related stress and injuries was confirmed.[7-9] Recently, research has demonstrated that this association could also be found in contemporary dancers.[10] Moreover, Noh and colleagues showed that being free from worry and being self-confident reduced the number of injuries, whilst dancers who had negative dance stress (i.e. presence of worries) had to face longer duration of injuries.[8]

Based on these studies[8-11], it can be concluded that stress increases the risk of injury. However, the injury as such might be regarded as a stressor as well. Several models attempted to describe stress responses to injury. Brewer's response model suggests that injury is first appraised cognitively, influenced by personal and situational factors, followed by an emotional and behavioral stress response.[12] Mainwaring's model highlights a more complex, multidimensional, person-to-situation interaction between factors related to the affected individual and their environment rather than a linear process of events.[11] Therein, the individual's psychological, physical, behavioral and social responses act as moderators, affecting and being affected by intrinsic determinants (e.g., demographics, traits, coping behavior, identity, nutritional aspects, knowledge, other stressors), as well

as extrinsic factors (e.g., dance environment, financial situation, social support, dance culture and identity, treatment).[13] As such, Mainwaring's model stresses the importance of a more holistic approach to the individual who sustained an injury. The latter is important since it will affect not only the physical rehabilitation of the injured but also address the individual athlete's psychological recovery which requires strong social support.[11, 14]

In sports science it has been described that athletes cope better with consecutive injuries than with a first-time-injury, having shown to be less anxious and more accepting with consecutive injury.[15] In dancers, however, such information is lacking. A very common approach in traditional dance settings is to perform and train despite the injury and in presence of pain.[16-18] The latter has also been described in other athletes[19]. Such an approach after a sustained injury may intensify dancers' fear of more severe and/or consecutive injuries [17, 20], which might increase stress levels after consecutive injuries. Therefore, we hypothesize that dancers' stress levels upon second- or further injuries are increased instead of decreased.

For that matter, the purpose of this study was to investigate whether 1) injuries are associated with increased stress levels, and 2) if consecutive injuries are associated with higher perceived stress levels than first injury in first-year contemporary dance students.

2. Methods

2.1 Participants

From the study year 2016-2017 until 2021-2022, five cohorts of first-year contemporary dance students (N=145) of Codarts University of the Arts, the Netherlands, were prospectively followed during one academic year (September to June). Results from the study year 2019-2020 were excluded from the analysis due to Covid-19 restrictions which prevented students from following regular classes.

The participants were enrolled in a four-year Bachelor Dance program, which focus on acquiring a wide range of modern dance techniques and competencies in various modern and contemporary styles as well as (modern) jazz, ballet, and 'floorwork'. Furthermore, the first-year of the Bachelor Dance's curriculum focuses on performance creative skills (i.e., improvisation, composition, and drama) as well as on basic knowledge on health (i.e., nutrition, anatomy, and (sport)psychology). First year dance students were included in this study if they were injury free in the first month of the academic year (to obtain a baseline stress level) and had sustained at least one injury in the rest of the academic year. An intake assessment as well as a baseline stress measurement had to be available.

2.2 Procedures

Data were collected at regular intervals for management and educational purposes and data collection was additionally embedded in the curriculum. In accordance with the Declaration of Helsinki, all students were informed prior to the procedure and provided written consent. The Medical Ethics Committee Erasmus MC of Rotterdam, the Netherlands, granted ethical approval for the study (MEC-2019-0163).

During the first month of each academic year, baseline characteristics were recorded, e.g., age (years), sex (male/female) and one-year history of injury (yes/no). Injuries in the past year before students entered the educational program at Codarts Rotterdam were registered. This one-year injury history was defined as “any physical complaint resulting in a fulltime loss of dance activities (e.g., participation in class, rehearsal, performance) for at least one week beyond the day of onset in the past year” [21]. Throughout the academic year, the students were asked to complete monthly questionnaires on their physical and mental health through the "Performing artist and Athlete Health Monitor" (PAHM). PAHM was developed by Codarts Rotterdam and is used to monitor physical and mental health in pre-professional and professional performing artists and athletes [22-24]. This online monitoring tool consists of several questionnaires and items, e.g., the visual analogue scale (VAS) pain scale, the VAS stress scale, the "Oslo Sport Trauma Research Center Questionnaire on Health Problems (OSTRC)", and items on injury characteristics, sleep quality, feelings, emotions, satisfaction with rehearsals and satisfaction with performances.

2.3 Assesment of Injury

The "Oslo Sport Trauma Research Center (OSTRC) Questionnaire on Health Problems" was assessed during the monthly questionnaire and consists of four key questions on the consequences of health problems on dance participation, training volume, performance and the degree to which students perceive any symptoms.[25] Possible answers ranged from 0 (no problem, no reduction, no effect, or no symptoms) to 25 (cannot participate at all or severe symptoms).[26] Questions 1 and 4 were scored on a four-point scale (0, 8, 17, and 25), while questions 2 and 3 were scored on a five-point scale (0, 6, 13, 19, and 25). The OSTRC Questionnaire has a high internal consistency, with a Cronbach’s alpha

of 0.96, good face validity [25, 26], and has previously been used within the performing arts.[10, 21, 22, 24, 27-31]

The severity of a health problem was calculated using the sum score of the four questions (scale 0-100) according to the method proposed by Clarsen et al., 2013.[26] If the severity score was higher than zero, a health problem was registered and the student was asked whether the health problem was an injury, mental complaint, or other problem. An all-complaint injury (i.e., substantial or non-substantial injury) was defined as "any physical complaint sustained by a dancer resulting in a severity score higher than zero (i.e., leading to consequences on participation, training volume, and/or performance), irrespective of the need for medical attention or time-loss from dance activities".[24] Substantial injuries were defined as problems leading to moderate or severe reductions in training volume (value ≥13 on question 2 of the OSTRC Questionnaire) or moderate, severe, or complete reductions in performance (value ≥13 on question 3 of the OSTRC Questionnaire).[25] Non-substantial injuries were defined as problems requiring no or little reduction in training volume (value <13 on question 2 of the OSTRC Questionnaire) or no or little reduction in performance (value <13 on question 3 of the OSTRC Questionnaire).[25] For the current study we selected the first and consecutive injury irrespective of their severity.

We categorized dancers as "dancers with substantial injuries" if they were injury-free in the month of baseline assessment (September) and sustained a substantial injury in the period between October and June. Dancers were categorized as "dancers with all-complaint injuries" if they were injury-free in the month of baseline assessment (September) and sustained a non-substantial or substantial injury in the period between October and June.

Consecutive injuries were considered consecutive if they were new injuries sustained after the first injury, or if they were sustained months apart from the first injury. For the latter, injury data had to be available prior to the injury and the dancers had to be injury-free before the month of the consecutive injury.

2.4 Assessment of Stress

On a monthly basis, students were asked to indicate their stress levels. Perceived general stress scores were measured using a visual analogue scale (VAS) ranging from 0 (no stress) to 100 (extreme amount of stress). The VAS is frequently used in stress assessment which also has been used to measure stress in dancers [10], and several validity studies have highlighted its psychometric properties. The VAS is at least as sensitive as other stress scales (i.e., 14-items Perceived Stress Scale) [32], is significantly correlated with objective stress measurements such as cardiovascular parameters (e.g., heart rate, blood pressure)[33], and shows satisfactory reliability[34] and inter-judge reliability [35]. No minimal clinically important difference has been determined.[36]

The stress level assessed in the first month of the academic year (September) was used as the baseline stress level. Stress levels measured within the month in which a first or consecutive injury occurred were used as accompanying injury stress levels. In addition, we subtracted the baseline stress levels from the stress levels that were reported during the month in which the first injury occurred as well as from the stress levels accompanying the consecutive injury to calculate changes in stress levels.

2.5 Statistical Analysis

SPSS Version 25 (IBM Corp., Armonk, USA) was used for all statistical analyses. Descriptive statistics were applied to describe baseline characteristics and stress scores using medians, interquartile ranges, frequencies and proportions (%). Normality was tested for parametric procedures using the Shapiro-Wilk test as well as explorative descriptive statistics, histograms, and Q-Q-plots. The analysis were conducted for the whole group, i.e., all-complaint injuries, as well as stratified for dancers with substantial injuries and dancers who sustained non-substantial injuries, respectively.

The differences between baseline stress levels and stress levels during injury were calculated with a paired students t-test. Additionally, we compared the changes in stress levels during the first and consecutive injury with a paired students t-test. For the t-tests we performed a complete case analysis (i.e. including those participants for which we have no missing data regarding stress scores).

To assess if there was a seasonal effect on stress levels we also calculated the monthly stress levels of the dancers who were injury free throughout the whole year. In addition we compared their baseline stress level to another month we randomly selected in such a way that the proportion of stress levels in a particular month was similar to that of the first all-complaint injuries.

3. Results

3.1 Participants

145 first-year students from 5 cohorts of first-year bachelor dance students participated in this study and gave their informed consent. In total, 67 students were injury-free at baseline assessment, sustained at least one injury during the academic year, and were therefore included in our analysis (*Figure 1*). The included dancers had a mean age of 18.8 ± 0.8 years, and 39 (58%) of the 67 dancers were female. The numbers of participants varied slightly between the different cohorts throughout the five years. Demographics can be found in *Table 1*.

3.2 Injuries

Throughout all cohorts, all dancers reported at least one all-complaint injury (substantial or non-substantial). Of these 67 dancers, 33 had at least one consecutive injury. OSTRC severity scores for first all-complaint injuries showed a mean of 28.7 ± 17.5 (minimum 6 to maximum 74). For consecutive all-complaint injuries OSTRC scores were 29.8 ± 16.3, with a minimum of 6 and a maximum of 67. The number of all-complaint injuries per dancer ranged from 1 to 7. In our population, 29 dancers (43%) sustained at least one substantial injury, of whom 8 also had a consecutive substantial injury. The number of substantial injuries per dancer ranged from 1 to 4 (*Table 1*). 38 dancers reported at least one non-substantial injury, of whom 14 had a consecutive non-substantial injury *(Figure 1)*.

3.3 Stress Levels

Mean baseline stress levels of the different groups are depicted in *Table 2 and Table 3*. The mean stress level for all included dancers was 26.9 ±19.8. In the whole group as well in the stratified analysis for substantial injuries and non-substantial injuries, we found that the stress levels during both the first injury and the consecutive injuries were significantly

elevated compared to the baseline stress levels (*Table 2*). The differences ranged from a 8 point increase in the non-substantial injury group during first injury to 27 points in the substantial injury group during both their first and consecutive injury. No differences were found between stress levels during first injuries and consecutive injuries. No statistically significant difference for a seasonal effect was found in the injury free dancers (mean difference -6.0 ±23.6; CI95% -14.6 to 2.3).

Table 1: Demographics: Dancers with at least one substantial or all-complaint injury
The values are given as the mean ±standard deviation, n (%) of the population

	N = 67
Age at baseline (years)	18.8 ± .80
Female	39 (58.2)
Cohort (year of study)	
2016-2017	12 (17.9)
2017-2018	14 (20.9)
2018-2019	13 (19.4)
2020-2021	14 (20.9)
2021-2022	14 (20.9)
Number of substantial injuries per dancer	N = 29
1 substantial injury	18 (62.1)
2 substantial injuries	8 (27.6)
3 substantial injuries	1 (3.5)
4 substantial injuries	2 (6.9)
Number of all-complaint injuries	N = 67
1 all-complaint injuries	21 (31.3)
2 all-complaint injuries	20 (29.9)
3 all-complaint injuries	13 (19.4)
4 all-complaint injuries	5 (7.5)
5 all-complaint injuries	6 (9.0)
6 all-complaint injuries	1 (1.5)
7 all-complaint injuries	1 (1.5)

4. Discussion

In first year contemporary dance students, we prospectively investigated whether injuries are associated with increased stress levels, and if consecutive injury periods are associated to higher perceived stress levels than first injury periods. Our results showed that stress levels increased during a period when an injury was sustained. However, the stress levels during consecutive injury periods and the stress levels perceived during the period of the first injury seemed similar.

Research has shown that the perception of stress is subjective, depending on factors such as the personality and coping behavior of the injured person, the motivational climate or perceived social support.[9, 13, 29, 37] As previously shown, stress responses as well as a history of stressors such as previous injury were strongly associated with injury rates in dancers [10] and other athletes [6, 38]. We, however, showed the reverse association and that the injury as such should be regarded as a stressor for the dancer since the aftermath of an injury results in heightened stress levels and thus can lead to less optimal or reduced ability to perform or, in a worst case scenario, the need to quit training and performing until fully recovered. For that matter, injuries come with emotional, physiological, cognitive, and social ramifications, which potentially increase stress reactions in the injured.[7, 12, 39-41] Injuries leave a person with pain as well as a variety of interchanging emotions. These emotions range from shock to anxiety, confusion, worry, frustration up to optimism and are depending on the severity of the injury and external influences[11] as well as prospect and success of rehabilitation.[13] Our results showed that our dancers can be compared to other athletes, because both target groups show increases of stress during injury periods.[42]

However, differences between dancers and other athletes seem apparent. Research in sports medicine has shown that first time injured athletes experienced the rehabilitation period as more stressful, they were less self-confident and exhibited a lower overall mood compared to consecutively injured athletes.[15] In contrast, consecutively injured athletes, however, coped better with second or third injury than with first time injuries. They were more accepting of consecutive injuries, were more socially secure and less anxious and thus likely less stressed.[15] This is not in agreement with our findings in dancers. We found that stress levels after consecutive injuries did not differ from stress levels after first injuries. Two aspects, namely the handling of injury in traditional dance settings as well as the resulting negative outcomes and thus negative experience of first injury might explain this difference and are discussed in the following.

Sports science has documented the so-called athletic identity which describes the tendency in athletes to continue training despite injury and pain, specifically in those athletes whose identification with their sport and dedicated discipline, i.e., athletic identity, was very high.[19] In dance, the same tendency was found which can be detrimental to dancers' health.[17, 43, 44] Comparable to other sports[11], injury is regarded as a threat to dancers' and institutions' existence, and dancers live in fear of injury and pain.[17] Simultaneously, however, they also have to learn to accept injuries as a part of their dance careers and work through them to avoid sanctions or missing out on opportunities.[17, 23, 29]. While many dancers perceive the confusion resulting from this counter-intuitive approach[17], they try to accept it as part of their identity and attempt to regard injury as a positive sign of vocation, dedication and discipline in order to cope.[17, 45] However, there is a fine line between working through and accepting injury[18, 42] versus failing to show self-responsible health seeking behavior which includes seeking assistance, getting

diagnosis and treatment and rehabilitating injury to avoid further consequences such as overuse or consecutive injury.[46] This ill-advised hardiness as coping strategy after an injury could contribute to the increased stress response our dancers also and especially perceived after consecutive injury. Furthermore, and comparable to other sports professionals[47], dancers exhibited higher pain and pain tolerance thresholds[20] than non-athletic controls. A variety of biological as well as psychological factors introduced through rigorous professional athletic training are considered to be responsible.[47] However, in contrast to other athletes, dancers were also found to be more acutely sensitive to pain.[20] Although this appears to be a paradox on first thought, the study tried to explain it through dancers' high experience of pain and injury as well as their fear of it.[20] Those results and our results underscore the importance of adequate handling of the first injury, since inadequate handling could result in problematic stress responses as well as negative outcomes of injury which both can negatively affect healing and prolong recovery.[8, 40, 41, 48, 49] As such, dancers' specifically high stress levels after consecutive injury might result from such acute sensitivity as a consequence of their fear of negative experiences after their first injury.

4.1 Practical implementations & future research

Our results showed that dancers perceive elevated stress levels during first and consecutive injury periods. Above all, implementing primary injury prevention measures in order to spare dancers such stress experiences cannot be overstressed. Furthermore, adequate handling of pain and injury in dance settings have been stressed in literature before.[16, 18, 20] The importance of such an approach is substantiated by our results, which show the need to help dancers to cope with their stress during injury periods, but also actively reduce stress levels in the first place. Various reasons might contribute to the

elevated stress response levels which need to be investigated in order to be able to assist dancers in finding ways of reducing and handling those stress responses. Among them are adequate coping skills of the dancer [31], but also active compliance to primary injury prevention as well as health seeking behavior in case of injury. The latter includes reporting injuries[23] which needs to be fostered through empowering motivational climates[29], emotional and social support[37] as well as the importance of and compliance to holistic injury rehabilitation taking not only the injury but also psychosocial aspects into account [11].

Diagnosis, treatment and rehabilitation of injuries implies coming to terms with the injury and its sequelae, including the application of coping skills and thus building resilience. While moving through multidimensional phases of injury appraisal through targeted rehabilitation[11], emotions in athletes have shown to be changing from predominantly negative at first to becoming more positive, particularly after diagnosis.[50] Reasons are that the knowledge somebody gains through diagnosis will decrease injury-related stress levels and thus coping behavior.[7] Going through rehabilitation allows to reflect on the lessons learned through injury occurrence.[50] As such, they increase resilience and are essential for future coping behavior but also secondary injury prevention. If dancers, for whatever reason, deny and continue training at the pre-injury level they might remain engulfed in negative emotions by missing out on those beneficial effects of diagnosis and rehabilitation. Further research is needed to investigate whether this might increase stress levels and make them prone to a consecutive injury.

4.2 Strengths, limitations & recommendations

To our knowledge this is the first study to investigate injury as a stressor in dancers. A major strength of this study is the longitudinal prospective design. Nonetheless, some

limitations have to be addressed. The self-reported injuries and stress scores led to limited diagnostic details available for analysis. Future research could combine objective with subjective documentation of injuries and stress perception, including medical diagnosis of injuries as well as stress measurement based on physical parameters such as amylase and cortisol sampling.[51, 52] Furthermore, we assessed stress on a monthly basis, and therefore, short periods of stress peaks [53] as well as likely daily fluctuations [54] might be overlooked. Moreover, part of the effect we found could be due to seasonal fluctuations of stress levels, for instance due to exams. Using higher sampling frequencies, for instance weekly, will provide more accurate data, although compliance might be lower.[55] Future studies should prospectively assess injury as a stressor in various dance populations as well as in bigger sample sizes, since we ended up with small sample sizes due to stratification, in order to be able to conclude for different age groups, dance styles, dance levels and years of dance experience.

4.4 Conclusion

Our results indicate that injury in itself can be regarded as a stressor in dancers. Hence, our results suggest that injury rehabilitation and prevention programs as well as the education of dancers should include coping skills and the handling of stress in dancers' lives in order to facilitate dancers' handling of stress following an injury .

Figure 1: Flowchart documentation of the inclusion criteria for analysis

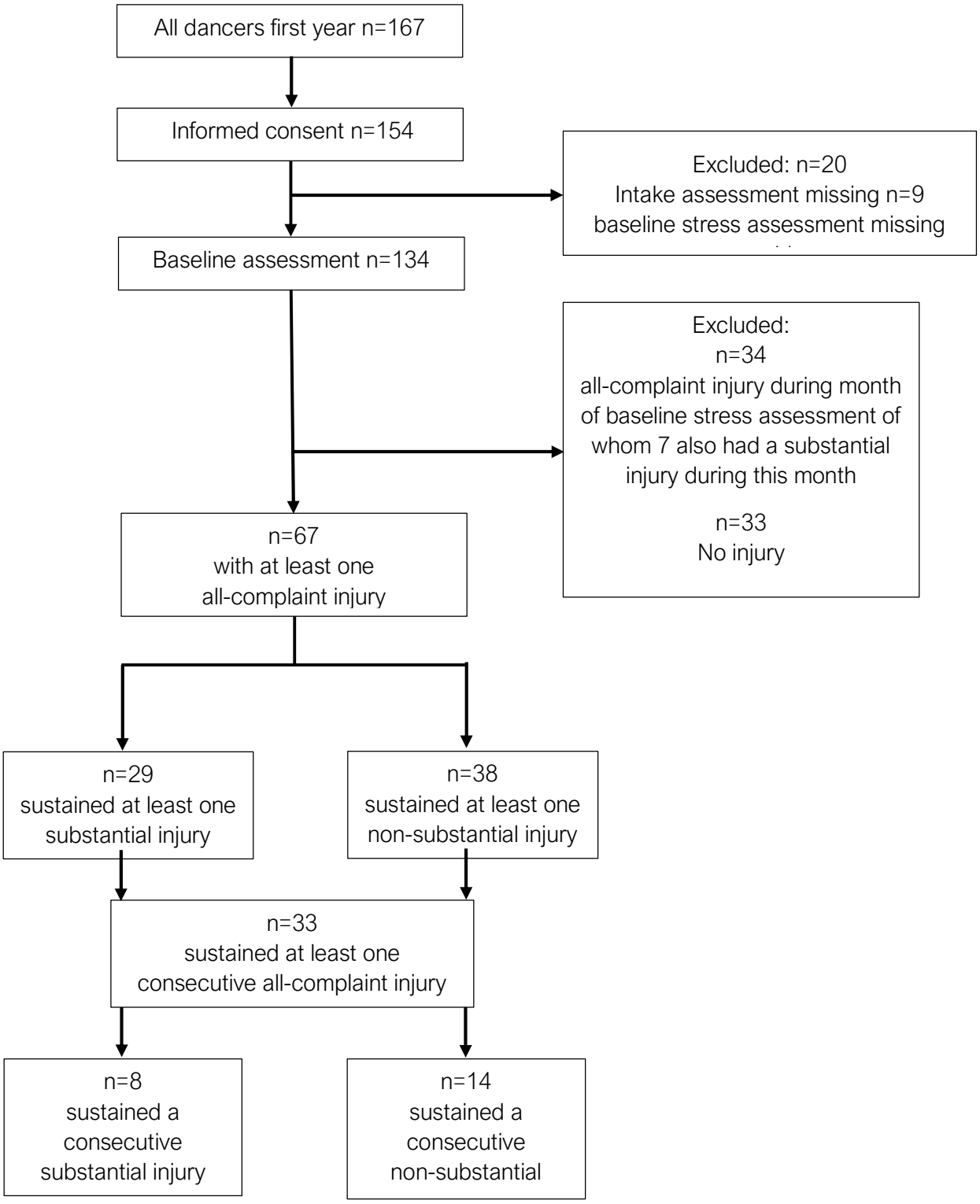

Table 2: Comparison stress levels at baseline to stress levels in the month of an injury occurence (paired t-tests)
The values are given as the mean ±standard deviation (SD), n (%) of the population; CI: Confidence interval, 95%

	Baseline Stress levels	First injury Stress levels	Mean difference between baseline & first injury	Consecutive Injury Stress levels	Mean difference between baseline & consecutive injury	Mean change difference between first & consecutive injury
	Mean (SD)	Mean (SD)	Mean (SD) (95%CI)	Mean (SD)	Mean (SD) (95%CI)	Mean (SD) (95%CI)
All-complaint Injuries N=67	26.9 ±19.8	35.5 ±19.7	-8.6 ±23.4 (-14.3 to -2.9)	NA	NA	NA
All-complaint Injuries N=33	24.3 ±17.2	34.8 ± 18.7	NA	35.1 ±23.0	-10.8 ±26.4 (-20.1 to -1.4)	-3.3 ±18.3 (-9.8 to 3.2)
Substantial injuries N=29	28.7 ±21.4	39.4 ±22.1	-10.7 ±23.9 (-19.8 to -1.6)	NA	NA	NA
Substantial Injuries N=8	28.0 ±16.5	49.8±13.1	NA	54.8 ±25.1	-26.8 ±24.5 (-47.2 to -6.3)	-5.0 ±26.0 (-26.8 to 16.8)
Non-substantial Injuries N=38	25.5 ±18.7	33.7 ±21.0	-8.2 ± 23.6 (-15.9 to -0.4)	NA	NA	NA
Non-substantial Injuries N=14	22.1 ±13.7	28.1 ±18.5	NA	29.8 ±17.2	-7.7 ±22.1 (-20.5 to 5.1)	-1.61 ±19.9 (-13.1 to 9.9)

Table 3: Stress levels of injury-free and injured dancers, including injury frequencies per month
Values are given as N of the injury-free and all-injury population, mean ±standard deviation (SD)

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
N injury-free	33	31	29	28	23	24	23	22	24
Stress level Mean ±SD	26.9 ±20.7	34.7 ±24.3	33.1 ±20.3	27.8 ±20.5	30.7 ±24.0	23.1 ±22.8	30.0 ±21.1	39.8 ±26.4	42.5 ±26.4
N injured	67	63	61	53	57	56	56	53	50
Stress level Mean ±SD	26.9 ±19.8	28.8 ±18.2	32.7 ±18.5	30.3 ±20.6	31.4 ±19.2	33.7 ±21.5	38.6 ±22.5	41.8 ±24.6	47.3 ±23.8
Injuries n (%)									
First all-complaint injury	NA	16 (23.9)	21 (31.3)	4 (6.0)	8 (11.9)	7 (10.4)	7 (10.4)	4 (6.0)	-
Consecutive all-complaint injury	NA	-	7 (10.4)	11 (16.4)	8 (11.9)	6 (9.0)	7 (10.4)	4 (6.0)	3 (4.5)

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Chapter 7

General Discussion

This thesis was dedicated to investigating aspects which advocate the synergy between dance medicine and dance pedagogy with the aim to prevent injuries in classical ballet dancers. As such we investigated crucial aspects in dance medicine and their association with the etiology and prevention of ballet dancers' musculoskeletal injuries. Specifically, this thesis looked into aspects which have not yet been studied before, such as warm-up or motivational climate in order to provide the basis for future research. Also we evaluated effects of erroneous dance technique, the causes that dancers perceived for their injuries and their perceived implementation of dance medicine into dance practice by their ballet master or ballet teacher. Three of our aims, chapters 3, 4 and 5, were investigated on the basis of an online survey study.

6.1 Chapter 2: Dance Technique & Turnout

Turnout is the most essential aspect of ballet technique, and the association between erroneous or biomechanically misaligned turnout and injuries is commonly claimed.[1] In Chapter 2, we studied this association by conducting a systematic literature review. Our review could not provide a scientific conclusion on the association due to the heterogeneity and low methodological quality of the available studies.

Turnout is the external rotation of the leg as a complex dance technical issue depending on the overall neuromuscular control of the individual dancer. Total turnout involves the whole body of a dancer with specific impact on the lumbar spine and its lumbosacral inclination.[2] The leg alignment is dominated by the dancer's active monitoring of the hip joint, as the strongest aspect of total turnout. However, natural and highly individual anatomical below-hip contributors also have significant influence on the dancer's total

turnout. Among them are the obligatory end rotation of the knee, the extend of the tibia torsion and the flexibility of the talocrural as well as Lisfranc and Chopart joint complexes.

Based on PRISMA Guidelines, our systematic literature search was supported by a librarian and involved seven databases (PubMed, Embase, Emcare, Web of Science, Cochrane Library, Academic Search Premier, ScienceDirect). Studies investigating the relationship between compensated or forced turnout and musculoskeletal injuries in all genders, all ages, and levels of expertise in dancers were included, provided that details on misaligned turnout measurements and injuries were stated. Of the 7 reviewed studies in chapter 2, all authors came to the conclusion that forced or compensated turnout was associated with injuries. However, neither “forced” nor “compensated turnout” has yet been uniformly defined, and several studies showed severe misinterpretation of the determinant. The studies investigating the lower extremities presented a hip-focus only while the non-hip contributors were reduced to being the compensation or forcing of turnout and thus responsible for injuries. As such, like some reviewed studies concluded, all dancers compensated turnout. Such misinterpretation of natural anatomical variations limit the understanding of injury mechanisms underlying misaligned turnout and prevent a scientific interpretation of the association between exposure and outcome.

Several papers have been published on turnout assessment or definition as well as related aspects of turnout.[3-5] The first publications date back to the 1980s/90s, and the relationship of erroneous turnout and injuries has ever since been claimed and investigated. [6, 7] However, our review could show that first and foremost a lack of standardized definitions and assessments of the determinant led to low methodological qualities of the reviewed publications and prohibit a scholarly conclusion on the relationship between misaligned turnout and injuries.

Although we were not able to draw a conclusion on the effect of erroneous or biomechanically misaligned turnout on injuries, several lessons can be learned from it. First, we found and could explain the described misconception of the turnout. Second, our review proposes the first medical clarification of "compensating" and "forcing" turnout based on the individuality of the dancer's body, which can prevent such misinterpretation and loss of resources in future studies. Third, we reason why total turnout of a dancer's leg including the motion of the lumbar spine is dependent on complex motion cycles rather than generalised (hip) joint dominance only. Fourth, we noted the importance of future study designs – and specifically recruitment methods of subjects – which rule out reverse causality. Hence reverse causality could have been an issue in almost all reviewed studies as dancers who were already injured were subjected to turnout measurements As such, forced or compensated turnout could have been the cause of their injuries or it could have been the other way round and their injuries had made them default to compensatory strategies in order to fulfil the demands of turnout. Fifth, our explanations offer methods of turnout assessment to facilitate as well as standardize future research. Preferably, such methods should be based on 3-D kinematic analysis in combination with physical examination, allowing for objective dual assessment of maximum passive joint range of motion to account for anatomical variations, locate sites prone to (overuse)injury, and investigate underlying injury mechanisms.

6.2 The Online Survey

In chapter 3, 4 and 5 we present three publications based on an online survey for which we contacted 188 ballet ensembles and 51 dance organizations. Adult ballet dancers were asked to participate. The first part of the survey used the Oslo Sports Trauma Center

Overuse Injuries Questionnaire[8] and additional items to assess overuse and acute injuries of the previous two years. In the second part, we used the Empowering and Disempowering Climate Questionnaire[9] to evaluate the motivational environment of the participants. The third part of our survey was dedicated to questions assessing aspects of science of training in dancers, such as warm-up. Another part asked dancers how they perceive their ballet teachers' and ballet masters' handling of different aspects related to their injury prevention.

The survey was executed anonymously, because pre-professional and professional dancers declared their fear of sanctions when they answered our questions about their teachers and masters. Such situations had been described in previous research[10] and were confirmed by our results presented in chapter 3 and 5. Since our survey study was based on self-report, recall bias might have occurred. Further limitations might be that we do not know whether our sample is representative for all dancers, although we included 29 nations. However, our design has shown to be important to encourage dancers to answer our questions in the first place. The wish of our sample to conduct the study anonymously has stressed the importance of our approach. By incorporating validated questionnaires for the majority of our survey we meant to ensure an appropriate level of scientific approach.

In total 192 ballet dancers answered more than 75% of the survey's items and were included in the studies. They had a mean age of 27 ±7.8 years and 83% were females. 203 acute injuries were reported by 119 dancers (62%) and 469 overuse injuries were documented in 164 dancers (85%).

6.3 Chapter 3: Motivational Climate & the Ballet Teacher / Master

In chapter 3 we investigated the association between motivational climate and musculoskeletal injuries. A motivational climate is the atmosphere which, amongst others, leaders, such as teachers, create for their learners or workers through their behavior. Two different climates are distinguished a (more) empowering or a (more) disempowering motivational climate. While the first supports autonomy, perceived competence, and relatedness and is associated with wellbeing, the latter thwarts those aspects and has been related to ill-being and reduced levels of performance.[11, 12] Sports science identified the motivational climate created by the coach in the etiology of athletes' injuries.[13, 14] In dance, and specifically in ballet, no studies have yet investigated such an association. Therefore, the association between an empowering (EMC) or disempowering (DMC) motivational-climate and musculoskeletal injuries in ballet was investigated.

The motivational climate was assessed with the Empowering-and-Disempowering-Motivational-Climate-Questionnaire[9] based on a 1-5-point Likert scale, while the Oslo-Sports-Trauma-Research-Centre-Overuse-Injury-Questionnaire[8] assessed overuse injuries within the last two years. Linear regression investigated the association between exposure and outcome, adjusting for the confounders age, sex, level of expertise (i.e., amateur, pre-professional or professional ballet dancer), years of experience, and the dancer's age at starting to dance ballet.

In general, no atmosphere or climate in the setting of ballet or dance, or any teacher/master is only good or only bad. Thus, in real-life as well as in the setting of ballet and dance, EMCs and DMCs co-exist[15, 16]. Therefore, we also studied the interaction

or effect moderation between the two sub-domains of motivational climate. We aimed to find out if EMC moderates the association between DMC and injuries and thus if EMC has a preventive effect on. For that reason, an interaction term between EMC and DMC assessed the effect modification based on the Johnston-Neyman-Score which identifies points in the range of the moderator (EMC) in which the interaction effect of X (DMC) on Y (injuries) becomes statistically significant.[15, 17]

The total mean score of EMC was 3.1 ±1.07, which was lower in pre-professional and professional dancers with a mean of 2.8 ±1.03. The DMC of the total population was 3.3 ±1.08. With 3.6 ±1.03 it was higher in pre-/professional dancers than in amateurs (2.7 ±0.89). Our results showed that EMC was associated with fewer acute (β=-0.22; 95%CI -0.40 to -0.04) and fewer overuse injuries (β=-0.74; 95%CI -0.99 to -0.50), while DMC was associated with more injuries (acute: β=0.30; 95%CI 0.13 to 0.47; overuse: β=0.74; 95%CI 0.50 to 0.98). When tested together and adjusted for confounders, EMC lost its protective effect while DMC was positively associated with injuries throughout all settings. Testing the interaction, EMC showed no moderating effects on DMC in the adjusted models of our regression analysis.

Our results contribute to future research and injury prevention in ballet environments. First, we could provide some initial indications that disempowering climates are related to musculoskeletal injuries in ballet dancers. Second, through the analysis of effect moderation we could show that the initially preventive effect of empowering climates disappeared with any nuances of disempowering climates being present. For dance practice these implications are of high significance. Since injury prevalence and risks in ballet are very high, it is paramount to find and install measures to prevent dancers' injuries. Our study was the first to show that the person of the ballet teacher (or ballet

master in professional environments) holds a key role regarding injury prevention in dancers. Before we conducted our study, the danger of disempowering, authoritative teacher/master behavior had been anecdotally claimed to be related to dancers' illbeing and their high injury risk. However, while literature documented and condemned narcistic, inappropriate teacher/master behavior[18, 19], no evidence existed to make this more than one of the many historical clichés told about classical ballet.

Many of the perceived and used values and norms ruling contemporary ballet environments date back to the first ballet academy founded by Louis XIV, the Acadèmie Royale de Danse in 1661.[20] Structures of ballet classes and training approaches have been following the same basic routines for decades and centuries.[21] However, demands imposed on dancers are constantly rising, the dancer has become a high performing athlete[22] rather than an artist only. Thus, some traditional notions of teaching and training dancers will have to adjust. One of them is the behavior of ballet teachers and masters. In our study population, this behavior relatively often created a disempowering climate, as DMC scores were high. Also, chapter 5 confirms the necessity of such a change towards empowering climates, if dancers' injuries want to be prevented, because dancers themselves have identified the person of the ballet teacher or ballet master as one of the most important perceived causes for their overuse injuries.

6.4 Chapter 4: Science of Training & Neuromuscular Warm-up

Neuromuscular warm-up programs (NMWU) have been shown to prevent injuries in sports science, investigating thousands of athletes from various fields, such as soccer or basketball.[23-27] In dance, research on warm-up is scarce, while the association between (neuromuscular) warm-up and injuries has not yet been studied at all.

Our aims in Chapter 4 were twofold: We used an online survey to ask ballet dancers from 18 years of age onwards to report their warm-up habits with the aim to provide documentation of warm-up routines among ballet dancers. Furthermore, we studied the association between neuromuscular warm-up and traditional ballet specific warm-up habits (TBSWU) and dancers' musculoskeletal injuries, respectively. Acute and overuse injuries sustained in the previous two years were recorded while warm-up behavior was assessed through 28 items specifically composed for the purpose of our study.

The documentation of the dancers' warm-up routines showed that 47.4% always warmed up with a mean duration of 20.7±13.2 minutes, while 9.4% of our population, including professionals, reported that they never warmed up. Furthermore, our results also verified ballet warm-up procedures which previously had only been anecdotally claimed: 63% based their warm-up on stretching, which has not shown to have injury-preventive effects on athletes[28, 29] but was, in the contrary, associated with injury in sports and dance science.[30-34] 58.9% of our dancers used dance technical-exercises and 53.6% used the barre. Both might add to injury risk through an increase of the already high numbers of repetitive movements in ballet, as also discussed in Chapter 5. However, 54.7% of ballet dancers already included strength-training into their warm-up routines, a component of injury-preventive neuromuscular warm-up.

For the analysis of a possible association between warm-up habits (neuromuscular versus traditional-stretching-based routines), dancers were grouped into NMWU or TBSWU groups based on the warm-up habits they reported. Previous analysis of neuromuscular warm-up programs used in sports science served as a model to identify the dancers for our NMWU group. Dancers qualifying for NMWU were warming up with exercises improving strength, power, proprioception, sensorimotor control, additionally providing

basic cardiovascular stimulus. The dancers identified for our TBSWU group used stretching, dance-technical exercises, marking steps or running-through-choreographies, and stretching with tools as their warm-up routines.

31 dancers (16.15%) classified for TBSWU, 16 dancers (8.3%) for NMWU. 145 dancers did combined exercises and were thus not included into either of the two groups. Separate linear regression analyses adjusted for confounding factors were performed for acute and overuse injuries. Our results confirmed previous investigations in sports science, showing that NMWU was associated with fewer overuse injuries compared to TBSWU (β = -2.34; CI95% -3.54 to -1.14). In our analysis, no association was found with acute injuries, which were less often observed than overuse injuries as the majority of dancers' injuries were overuse in nature. Bigger samples and prospective, randomized controlled studies are needed to test this association.

6.5 Chapter 5: Preventive Dance Medicine & Causes of Injuries

In Chapter 5 we asked dancers to report the causes they perceived for their injuries. Additionally, we asked them to rate the level of support they perceived from their ballet teachers and ballet masters through practical implementation of dance medical injury-preventive measures. We used an international cross-sectional online-survey with items based on the Fit-to-Dance-Questionnaire[35-37] and literature research assisted by a librarian. Adult amateur, pre-professional, and professional ballet dancers reported the perceived causes of their injuries which they sustained in the previous two years. Multiple answers per injury were possible, and reported causes were analyzed per-injury as well as per-dancer to meet the problem of interdependency and overestimation of causes: In the “per-injury” approach all causes of all injuries were included. In the “per-dancer”

approach we analyzed the different causes given by each dancer who sustained an injury. As such, each cause reported by an individual dancer was included only once, irrespective of whether a dancer reported the same cause multiple times in case of multiple injuries. The rating of the perceived level of support through implementation of preventive dance medicine by the dancers' ballet teachers and ballet masters was based on 21 items using a 5-point-Likert-scale.

Confirming results of previous studies, we also found that fatigue was the most frequently perceived cause for acute injuries (52.9%) in the per-injury and per-dancer analysis.[36] With 51.2%, pressure from the ballet teacher or ballet master was most frequently perceived as cause for overuse injuries in the per-injury analysis (specifically in pre-/professional dancers with 61.3%). In the per-dancer analysis, fatigue and overtraining scored highest for overuse injuries (n=107; 65.2%). Other causes dancers perceived as causes for their injuries were previous and repetitive injuries or erroneous dance technique, predominantly forcing of turnout. Perceived support of dancers' injury prevention from teachers and masters through practical implementation of dance medicine was perceived to be moderate to low, specifically in pre-professional and professional ballet dancers.

Our research not only provides another focus on the essential role of the ballet teacher and ballet master for injury prevention through practical inclusion of dance medicine into dancers' practice. It also allowed us to put the dancer into the spotlight by addressing them directly through our survey and putting the focus on their perception and opinion. Such an approach can be seen as an important contribution to future interventions in dance environments for three reasons. First, giving dancers a voice allows to gain deeper

insight into their world, their needs and how they perceive the development of their own injuries. This facilitates precise tailoring of future injury-preventive interventions. Second, asking dancers for their opinions and perceptions makes them feel listened to and heard. Hence, their active compliance for such interventions will be encouraged, because they feel empowered and actively involved.

Third, over centuries, the role of the dancer as a silent artist who is willing to suffer for their art form has manifested.[38, 39] This has resulted in paradox approaches in the attempt to accept and justify pain and injury as integrating aspect of ballet and dance [40, 41], numbing the natural instinct of a person to avoid and prevent them, or seek help with it. This necessity to develop such a ballet dancer's identity has shown to be different from the identities that link dancers of other dance styles, for instance hip hop.[42, 43] Such an identity is promoted by disempowering climates and leads to poor handling of pain and injury while it is detrimental to injury prevention, as we could show in Chapter 3. High tendencies towards eating- and body dysmorphic disorders, negative forms of perfectionism [44-46] as well as the detrimental notion that dancing comes with pain and injuries have become an integrating part of that identity[41], thwarting injury prevention in ballet. Our approach to directly address previously unresearched issues might contribute to change such shortcomings and support dancers' autonomy and self-determination in future.

6.6 Chapter 6: Injury as Stressor & Handling and Rehabilitation of Injury

Many prospective studies have shown the high prevalence and incidence of dancers' injuries.[47-50] Injuries and their sequelae might be regarded as a burden if they lead to increased psychological stress for those affected. While stress has shown to be one of the

risk factors for injury in dancers[51], however, no study has yet investigated this reverse association, i.e., whether injuries in dancers lead to heightened stress levels. Moreover, sports science has shown that athletes cope better with consecutive than with first-time-injury[52], another information which is missing in the field of dance medicine and science. For that matter, in Chapter 6 we investigated the stress levels dancers perceived for their first-time injury as well as their consecutive injuries and assessed whether first injuries have different stress levels than consecutive injuries.

145 Contemporary and Modern Dance Bachelor dance students were prospectively followed during five academic years (2016-2022). During the first month of each of the five cohort's academic year, respectively, dancers' baseline characteristics were recorded. The "Performing artist and Athlete Health Monitor" (PAHM)[10, 51, 53] served as the assessment tool. This monitoring system includes the VAS pain scale, the VAS stress scale, and the "Oslo Sport Trauma Research Center Questionnaire on Health Problems" (OSTRC)[8, 54]. Throughout the respective academic years, stress, injuries and injury severity were recorded monthly. The first-month assessment in September served as baseline assessment for stress level analysis in which dancers had to be injury free to be included in our study. Paired t-tests were conducted to compare dancers' baseline stress levels to their stress levels after first as well as consecutive injuries.

The OSTRC severity scores[8] served as reference for our definition of injuries. An "all-complaint injury" (i.e., substantial or non-substantial injury) was defined as "any physical complaint sustained by a dancer resulting in a severity score higher than zero (i.e., leading to consequences on participation, training volume, and/or performance), irrespective of the need for medical attention or time-loss from dance activities".[50] Substantial injuries

were health problems leading to moderate or severe reductions in training volume with a value of ≥13 on question 2 of the OSTRC Questionnaire or moderate, severe, or complete reductions in performance, reflected in a value of ≥13 on question 3 of the OSTRC Questionnaire.[8, 54] Non-substantial injuries were defined as problems requiring no or little reduction in training volume, shown as a recorded value lower than 13 on question 2 of the OSTRC Questionnaire or no or little reduction in performance, derived from a value lower than 13 on question 3 of the OSTRC Questionnaire.[8, 54] We categorized dancers as "dancers with substantial injuries" if they were injury-free in the month of baseline assessment (September) and sustained a substantial injury in the period between October and June. If they were injury-free in the month of baseline assessment (September) and sustained a non-substantial or substantial injury in the period between October and June, dancers were categorized as "dancers with all-complaint injuries". Perceived general stress scores were measured monthly, based on a visual analogue scale (VAS) ranging from 0 (no stress) to 100 (extreme amount of stress).

67 dancers, of which 58.2% were female, with a mean age of 18.8 ±.80 years sustained at least one injury. 33 of them reported at least one consecutive injury. For those "all-complaint injuries", OSTRC severity scores ranged from a mean of 28.7 ±17.5 for first to 31.4 ±17.1 for consecutive "all-complaint injuries". The mean baseline stress level for these "all-complaint injuries" was 24.3 ±17.2. All stress levels during first and consecutive "all-complaint injuries" were elevated compared to the baseline stress levels, 34.8 ± 18.7 and 35.1 ±23.0, respectively. There were no differences between stress levels during first and consecutive injuries for all-complaint as well as substantial injuries.

Our results could show that injuries in dancers are associated with increased stress levels and injury must therefore be regarded as a stressor in itself. However, while other athletes

have shown to cope better with consecutive injuries [52], dancers' stress levels were equally high after first injury and consecutive injuries, indicating that they do not. One reason might be that dancers learn early to regard injury as a sign for discipline and dedication[41, 55], attempting to turn injury and pain into a positive motivational factor as part of their unfortunate way of coping. However, many dancers are aware of the resulting internal controversy and vicious circle resulting from working through pain and injury while increasingly fearing their injuries' aggravation and thus their negative impact on their lives and performance abilities.[10, 41, 56] This aggravation we could show through our OSTRC severity scores which increased from first through consecutive injuries. The increasing stress levels we found could thus be due to dancers' increasing fear to become injured as well as dancers' anxiety upon sustaining an injury they commonly know they have to cope with by working through. Since injuries become more severe, stress levels thus will aggravate as well. Such increased stress levels [51] might facilitate consecutive or repetitive injuries which could contribute to the high number of overuse injuries and overtraining dancers have to face.

Our study is the first to highlight how much of a burden injury is for dancers, reflected in their increased stress levels from first-time through consecutive injury. With our analysis we want to highlight the importance of a self-responsible handling of pain and injury[56] in dance. Furthermore, we emphasize the importance of a holistic approach to injury rehabilitation.[57] Such an approach has to include a focus on dancers' psychological recovery as well as the generation of knowledge in dancers, teachers and administrating personnel regarding stress and injury management in order to avoid consecutive or repetitive harm. Such harm not only includes injuries derived from high stress levels[51]

but also possible ill-health through permanently increased psychological stress levels, e.g., decreased immune system, depression, or anxiety disorders.[58-60]

6.7 Conclusion & Outlook

In this thesis, several aspects of dance medicine and their association with dancers' musculoskeletal injuries were investigated. One of the aims was to provide preliminary evidence on topics which have not been investigated before. Another was to directly address shortcomings in dance environments, such as disempowering climates, low levels of support for injury prevention through superiors or the importance of correct handling of pain and injury as well as a holistic approach to injury rehabilitation. As such, our studies are meant to contribute to necessary changes within dancers' world which have to be introduced into dancers' environments with the aim to prevent the high numbers of musculoskeletal injuries in these dancers.

Although the person of teacher and master has remained unaddressed for so long, our investigations show how important the role of teaching and training personnel can be in the prevention of injuries. Our data give circumferential evidence that teachers / masters and trainers of dancers hold a key role in the prevention of dancers' injuries by early recognition of overuse and providing a healthy work environment. Even more, they have a major influence on and can co-create an empowering climate, which can prevent injuries of dancers. Since they spend many hours of training time with dancers, their role in the active implementation of research into practice is important, if done in an open discussion with dancers. Our research highlighted how dancers perceive the important association between their well- or ill-being and the role of their teachers/masters. As such we

confirmed previous research which has indirectly documented the deficiencies related to the role of the teacher. [19, 39-41, 55, 61]

Therefore, a focus on injury preventive measures, holistic injury rehabilitation, as well as the importance of follow-ups has to be stressed. As reasoned, first, is important that future research focuses on the person of the ballet teacher and ballet master, as a key person in injury prevention. Research should focus on the ballet teacher's and ballet master's awareness, attitudes, education and knowledge on musculoskeletal injuries and science of training as well as their motivational and educational skills. Second, future research should also actively include those it aims for, the dancers, to ensure their participation and facilitate any further cooperation, through which the dancers themselves can benefit from previously researched evidence. Dancers themselves are a key factor in their own injury prevention as well as rehabilitation. Their own knowledge of the correct handling of pain and injury is crucial in order to prevent an aggravation of their injuries as well as their stress levels. However, as our results from several studies showed, for dancers to be able to be self-responsible, it does not only need dancers' compliance, it also needs the environment provided by their superiors which empowers such responsibility. This already has to start in early education of dancers, as we could show in Chapter 6. In an open and close interaction between masters / teachers and dancers prevention of musculoskeletal injuries can be recognized early, and even better prevented in future by specific advices tailored to the individual dancer with his or her individual (anatomic / biomechanical) demands. Third, dancers as well as teaching and administrating personnel have to learn and apply evidence-based handling of pain and injury in order to prevent injuries as well as negative psychological stress in dancers' lives which has been attributed to (further)

injury[51] as well as mental illnesses such as depression and anxiety disorders and other effects on overall health.[58-60, 62, 63]

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Appendices

Summary

Summary

In Chapter 2, a systematic review aimed to investigate if compensating or forcing turnout (TO) leads to musculoskeletal injuries. Injury prevalence in dancers is high, and misaligned TO is claimed to bear injury risk.

The systematic literature review was conducted according to the PRISMA Guidelines using the databases of PubMed, Embase, Emcare, Web of Science, Cochrane Library, Academic Search Premier, and ScienceDirect. Studies investigating the relationship between compensated or forced TO and injuries in both genders, all ages, and levels of dancers were included. Details on misaligned TO measurements and injuries had to be provided. Screening was performed by two researchers, data extraction and methodological quality assessment executed by one researcher and checked by another.

7 studies with 1293 dancers were included. Methodological quality was low due to study designs and a general lack of standardised definition of pathology and methods of assessment of misaligned TO. The studies investigating the lower extremities showed a hip-focus only. Non-hip contributors as well as their natural anatomical variations were not accounted for, limiting the understanding of injury mechanisms underlying misaligned TO. As such no definite conclusions on the effect of compensating or forcing TO on musculoskeletal injuries could be made.

Total TO is dependent on complex motion cycles rather than generalised (hip) joint dominance only. Objective dual assessment of maximum passive joint range of motion through 3D kinematic analysis in combination with physical examination is needed to account for anatomical variations, locate sites prone to (overuse)injury, and investigate underlying injury mechanisms.

Sports science identified the trainer-athlete-relationship in the etiology of injuries. In Chapter 3, we aimed to investigate 1. the association between empowering (EMC) and disempowering (DMC) motivational-climate (MC) and musculoskeletal injuries in ballet, 2. if EMC moderates the association between DMC and injuries.

A cross-sectional cohort survey-study was conducted among ballet dancers (>18 years) reporting acute and overuse injuries of the previous two years. MC was assessed with the Empowering-and-Disempowering-Motivational-Climate-Questionnaire (1-5-Likert). The Oslo-Sports-Trauma-Research-Centre-Overuse-Injury-Questionnaire assessed severity of overuse injuries. Linear regression was performed adjusted for the confounders age, sex, expertise, experience, and initiation-age with an interaction term between EMC and DMC to assess effect modification.

189 dancers (26.7±7.9 years; 130 professionals, 27 nations) reported 197 acute and 465 overuse injuries (previous two years). Mean EMC was 3.1±1.07, DMC 3.3±1.08. EMC was associated with less acute (β=-0.22; 95%CI -0.40 to -0.04) and overuse injuries (β=-0.74; 95%CI -0.99 to -0.50), while DMC was associated with more injuries (acute: β=0.30; 95%CI 0.13 to 0.47; overuse: β=0.74; 95%CI 0.50 to 0.98). When tested together and adjusted for confounders, EMC lost its protective effect (acute: β=-0.15; 95%CI -0.19 to 0.49; overuse: β=-0.34; 95%CI -0.81 to 0.12). DMC was positively associated with injuries throughout all settings (acute: β=0.43; 95%CI 0.10 to 0.76; overuse: β=0.46; 95%CI 0.00 to 0.91). EMC showed no moderating effects on DMC in the adjusted models.

It can be concluded that it is not enough to create an EMC in order to avoid injuries in dancers, which is but contra-effected in the presence of a DMC. Ballet-teachers/masters should avoid DMC altogether to prevent injuries in dancers.

In sports science, neuromuscular warm-up exercises (NM-WU) have shown to prevent injuries. In dance, research on WU is scarce. Hence, in Chapter 4, we investigated WU habits among ballet dancers, and evaluated if NM-WU is associated with less overuse or acute injuries compared to traditional-ballet-specific-WU (TBS-WU).

In a cross-sectional survey study among ballet dancers (>18 years) acute and overuse injuries sustained in the previous two years were reported per body part. WU behavior was assessed through 28 items. Dancers were grouped into NM-WU or TBS-WU. NM-WU was based on NW-WU programs in sports science and included exercises improving strength, power, proprioception, sensorimotor control, or cardiovascular endurance. TBS-WU consisted of exercises such as stretching. dance-technical exercises, marking steps/running-through-choreographies, and stretching with weights or tools. Separate linear regression analysis adjusted for confounding were performed for acute and overuse injuries.

192 dancers (26.7±7.82 years, 159 females, 132 professionals) reported 203 acute and 469 overuse injuries during the past two years. 47.4% of the dancers always warmed-up (mean duration 20.7±13.2 minutes); 9.4% never warmed-up. Stretching (63%), technical-exercises (58.9%), strength-training (54.7%), and the barre (53.6%) were most often mentioned.

145 dancers did combined exercises. 31 dancers (16.15%) classified for TBS-WU, 16 dancers (8.3%) for NM-WU. NM-WU was associated with less overuse injuries compared to TBS-WU (β=-2.34;CI95% -3.54/-1.14). No association was found between the different warm-up protocols and acute injuries.

As in athletes, NM-WU might be protective against overuse injuries in dancers. Large-scale prospective cohort studies are needed to gain more insight into NM-WU as possible means of injury prevention in ballet.

As previous research as well as our investigations have shown, ballet dancers have a high injury risk. In Chapter 5, we aimed to gain insight in the causes for acute and overuse injuries and the level of implementation of preventive dance medicine by ballet teachers/masters as perceived by dancers.

An international cross-sectional online-survey was based on the Fit-to-Dance-Questionnaire and literature. Adult amateur, pre-professional, and professional ballet dancers reported the perceived causes of their injuries sustained in the previous two years. Multiple answers per injury were possible. Additionally, the dancers rated the level of implementation of preventive dance medicine by their ballet teachers and ballet masters based on 21 items using a 5-point-Likert-scale. Causes were analyzed per-injury as well as per-dancer.

188 ballet ensembles and 51 dance organizations were contacted, 192 ballet dancers (mean age 27 ±7.8 years, 83% females) responded. 119 dancers (62%) reported 203 acute and 164 (85%) reported 469 overuse injuries. Fatigue was the most frequently perceived cause for acute injuries (52.9%) in the per-injury and per-dancer analysis. For overuse injuries, pressure from the teacher/master was most frequently perceived as cause in the per-injury analysis (51.2%), specifically in pre-/professional dancers (61.3%). In the per-dancer analysis, fatigue/overtraining scored highest for overuse injuries (n=107; 65.2%). Other causes were previous/repetitive injuries (acute-per-dancer: 35.3%, acute-per-injury: 36.1%, overuse-per-injury: 46.3%, overuse-per-dancer: 62.2%) or erroneous

dance technique (acute-per-dancer: 23.6%, acute-per-injury: 35.3%, overuse-per-injury: 47.8%, overuse-per-dancer: 53.0%). With regard to perceived level of implementation of dance medicine by ballet teachers/masters to prevent musculoskeletal injuries, 2 items received high ratings, 12 moderate ratings and 6 low ratings.

Fatigue and pressure accounted for the majority of causes for injuries. Perceived support by ballet teachers/masters regarding injury prevention and dance medicine was moderate to low. Future research should focus on the awareness, attitudes and the important role of ballet teachers/masters for injury prevention in dancers.

In a longitudinal cohort study presented in Chapter 6, we prospectively investigated the stress levels dancers perceive after injury and whether those stress levels are different for first-time injury and consecutive injuries.

From 2016 through 2022, five cohorts involving 145 Bachelor dance students were prospectively followed during their respective first academic year. Baseline characteristics were recorded during their first month of year, respectively. The "Performing artist and Athlete Health Monitor" (PAHM) which includes the VAS pain scale, the VAS stress scale, and the "Oslo Sport Trauma Research Center Questionnaire on Health Problems" (OSTRC) served as assessment tool. Stress levels, injuries and injury severity were reported monthly and recorded throughout the academic year. For stress analysis, the first-month stress assessment in September served as baseline in which dancers had to be injury free to be included in this analysis. Paired t-tests were conducted to investigate the difference between baseline and first as well as consecutive injuries, respectively.

67 dancers with a mean age of 18.8 ±.80 years (58.2% female) sustained at least one injury. 46 of them sustained at least one consecutive injury. OSTRC severity scores

ranged from a mean of 28.7 ±17.5 for first injuries to 31.4 ±17.1 for consecutive injuries. The mean baseline stress level for injuries was 25.3 ±17.7. Dancers' stress levels during first and consecutive injuries were elevated compared to the baseline stress levels, 34.0 ± 18.1 and 34.2 ±21.6, respectively. There were no differences between stress levels during first and consecutive injuries. We therefore conclude that injuries are associated with increased stress levels in dancers, but stress levels were equally high after first and consecutive injury in contrary to previously found results in other athletes. We emphasize the importance of a holistic approach to injury rehabilitation, including dancers' psychological recovery and a focus on stress management.

Nederlandse samenvatting

Nederlandse samenvatting

Bij dansers komen blessures veel voor, en men denkt dat het compenseren of forceren bij de turnout (TO) het blessurerisico verhoogd. In hoofdstuk 2 werd in een systematische review onderzocht of het compenseren of forceren bij de (TO) leidt tot blessures aan het bewegingsapparaat.

De systematische literatuurstudie werd uitgevoerd volgens de PRISMA-richtlijnen. Voor de zoekstrategie werden de volgende databases gebruikt: PubMed, Embase, Emcare, Web of Science, Cochrane Library, Academic Search Premier en ScienceDirect. Studies die het verband onderzochten tussen gecompenseerde of geforceerde TO en blessures bij mannelijke en/of vrouwelijke dansers werden geïncludeerd. Alle leeftijden en alle niveaus van dans werden geïncludeerd. Details over TO-metingen en blessures moesten beschikbaar zijn. De screening van de abstracts en artikelen werd uitgevoerd door twee onderzoekers, gegevensextractie en methodologische kwaliteitsbeoordeling werden uitgevoerd door één onderzoeker en gecontroleerd door een tweede onderzoeker.

Er werden 7 studies met in totaal 1293 dansers geïncludeerd. De methodologische kwaliteit was laag. Dit kwam voornamelijk vanwege de opzet van de studies en gebrek aan een gestandaardiseerde definitie van pathologie en methoden voor de beoordeling van TO. De studies die de onderste extremiteiten onderzochten, waren alleen gericht op de heup. Er werd geen rekening gehouden met andere factoren dan de heup en haar natuurlijke anatomische variaties, waardoor het inzicht in de letselmechanismen die ten grondslag liggen aan gecompenseerde TO werd beperkt. Als zodanig konden geen definitieve conclusies worden getrokken over het effect van het compenseren of forceren bij TO op letsels aan het bewegingsapparaat.

Totale TO is afhankelijk van complexe bewegingscycli in plaats van alleen algemene (heup)gewrichtsdominantie. Objectieve dubbele beoordeling van het maximale passieve bewegingsbereik van de gewrichten door middel van 3D-kinematische analyse in combinatie met lichamelijk onderzoek is nodig om rekening te houden met anatomische variaties, om plaatsen te lokaliseren die gevoelig zijn voor (overmatig) letsel, en om onderliggende letselmechanismen te onderzoeken.

In de sportwetenschap is de relatie gelegd met de wisselwerking tussen de trainer en atleet in de etiologie van blessures . In hoofdstuk 3 onderzochten we 1. de associatie tussen een “empowering” (EMC) en een “disempowering (DMC) motivationeel klimaat (MC) en musculoskeletale blessures bij ballet, 2. of EMC de associatie tussen DMC en blessures modereert.

Een cross-sectionele cohortstudie werd uitgevoerd onder balletdansers (>18 jaar) die gevraagd werden om via een elektronische vragenlijst hun acute en overbelastingsblessures van de afgelopen twee jaar te rapporteerden. MC werd beoordeeld met de Empowering-and-Disempowering-Motivational-Climate-Questionnaire (1-5-Likert schaal). Met de Oslo-Sports-Trauma-Research-Centre-Overuse-Injury-Questionnaire werd de ernst van de overbelasting blessures vastgesteld. Lineaire regressie werd uitgevoerd, gecorrigeerd voor de confounders leeftijd, geslacht, expertise (professioneel danser of amateur), aantal jaren ballet ervaring en aanvangsleeftijd, met een interactieterm tussen EMC en DMC om de effectmodificatie te beoordelen.

189 dansers (27±8 jaar; 130 professionals, 27 landen) rapporteerden 197 acute en 465 overbelasting blessures in de voorgaande twee jaar. De gemiddelde EMC was 3,1±1,07 en de gemiddelde DMC 3,3±1,08. EMC was geassocieerd met minder acute

blessures(β=-0,22; 95%CI -0,40 tot -0,04) evenals met minder overbelasting blessures (β=-0,74; 95%CI -0,99 tot -0,50), terwijl DMC geassocieerd was met meer blessures (acuut: β=0,30; 95%CI 0,13 tot 0,47; overbelasting: β=0,74; 95%CI 0,50 tot 0,98). Wanneer beiden samen in een model gevoegd werden, waarbij er gecorrigeerd werd voor confounders, verloor EMC zijn beschermende effect (acuut: β=-0,15; 95%CI -0,19 tot 0,49; overbelasting: β=-0,34; 95%CI -0,81 tot 0,12). DMC bleef echter positief geassocieerd met blessures (acuut: β=0,43; 95%CI 0,10 tot 0,76; overbelasting: β=0,46; 95%CI 0,00 tot 0,91). EMC bleek geen modererend effect op DMC te hebben.

Het lijkt er op dat het niet voldoende is om een EMC te creëren om blessures bij dansers te voorkomen. Het negatieve effect van een DMC lijkt groter, en balletdocenten/masters zouden een DMC moeten proberen te vermijden om blessures bij dansers te voorkomen.

In de sportwetenschap is aangetoond dat neuromusculaire opwarmingsoefeningen (NM-WU) blessures kunnen voorkomen. In de dans is onderzoek naar warming up (WU) schaars. Daarom onderzochten we in hoofdstuk 4 WU-gewoonten bij balletdansers, en evalueerden we of NM-WU geassocieerd is met minder overbelasting of acute blessures in vergelijking met traditioneel-ballet-specifiek-WU (TBS-WU).

In een cross-sectioneel onderzoek onder balletdansers (>18 jaar) werden zij via een elektronische vragenlijst gevraagd om acute en overbelasting blessures van de afgelopen twee jaar per lichaamsdeel te rapporteren. Hun WU-gedrag werd beoordeeld aan de hand van 28 items. Dansers werden ingedeeld in NM-WU of TBS-WU. NM-WU werd afgeleid uit diverse NW-WU programma's uit de sportwetenschappen en omvatte oefeningen ter verbetering van kracht, vermogen, proprioceptie, sensomotorische controle, of cardiovasculair uithoudingsvermogen. TBS-WU bestond uit oefeningen zoals stretchen.

danstechnische oefeningen, markeren van stappen/doorlopen-choreografieën, en stretchen met gewichten of hulpmiddelen. Lineaire regressieanalyses, gecorrigeerd voor confounding, werden apart uitgevoerd voor acute en overbelastings lessures.

192 dansers (26,7±7,82 jaar, 159 vrouwen, 132 professionals) rapporteerden 203 acute en 469 overbelasting blessures in de afgelopen twee jaar. 47% van de dansers deed altijd een warming-up (gemiddelde duur 21±13 minuten); 9,4% deed nooit een warming-up. Stretching (63%), technische oefeningen (59%), krachttraining (55%) en de barre (54%) werden het vaakst genoemd.

145 dansers deden gecombineerde oefeningen. 31 dansers (16,15%) werden in de TBS-WU groep geclassificeerd en 16 dansers (8,3%) in de NM-WU groep. NM-WU was geassocieerd met minder overbelasting blessures in vergelijking met TBS-WU (β=-2,34; CI95% -3,54/-1,14). Er werd geen associatie gevonden tussen beide groepen en acute blessures.

Net als bij atleten zou NM-WU bij dansers beschermend kunnen werken tegen overbelasting blessures. Grootschalige prospectieve cohortstudies zijn nodig om meer inzicht te krijgen in NM-WU als mogelijk middel voor blessurepreventie bij ballet.

Zoals uit zowel ons onderzoek als eerder onderzoek is gebleken, hebben balletdansers een hoog blessurerisico. In hoofdstuk 5 hebben we onderzoek gedaan naar de oorzaken van acute en overbelasting blessures en de mate van implementatie van preventieve dansgeneeskunde door balletdocenten/masters zoals gepercipieerd door dansers.

Een internationale cross-sectionele online-survey was gebaseerd op de Fit-to-Dance-Questionnaire en literatuur. Volwassen amateur-, pre-professionele en professionele balletdansers rapporteerden de waargenomen oorzaken van hun blessures in de

afgelopen twee jaar. Meerdere antwoorden per blessure waren mogelijk. Daarnaast beoordeelden de dansers het niveau van implementatie van preventive dance medicine door hun balletdocenten op 21 items met behulp van een 5-punts-Likertschaal. Oorzaken werden zowel per blessure als per danser geanalyseerd.

Er werden 188 balletensembles en 51 dansorganisaties gecontacteerd, 192 balletdansers (gemiddelde leeftijd 27 ±7,8 jaar, 83% vrouwen) reageerden. 119 dansers (62%) meldden 203 acute en 164 (85%) 469 overbelasting blessures. Vermoeidheid was de meest waargenomen oorzaak voor acute blessures (52,9%) in zowel de analyse per blessure als de analyse per danser. Voor overbelasting blessures werd druk van de docent het vaakst als oorzaak gezien in de analyse per blessure (51,2%), met name bij pre-/professionele dansers (61,3%). In de analyse per danser scoorde vermoeidheid/overtraining het hoogst voor overbelasting blessures (n=107; 65,2%). Andere oorzaken waren eerdere/herhalingsblessures (acuut-per-danser: 35,3%, acuut-per-blessure: 36,1%, overbelasting-per-blessure: 46,3%, overbelasting-per-danser: 62,2%) of een verkeerde danstechniek (acuut-per-danser: 23,6%, acuut-per-blessure: 35,3%, overbelasting-per-blessure: 47,8%, overbelasting per danser: 53,0%). Met betrekking tot het gepercipieerde niveau van implementatie van dansgeneeskunde door balletdocenten om blessures aan het bewegingsapparaat te voorkomen, kregen 2 items hoge waarderingen, 12 matige waarderingen en 6 lage waarderingen.

De meeste oorzaken van blessures waren vermoeidheid en druk. De ervaren ondersteuning door balletdocenten/masters met betrekking tot blessurepreventie en dansgeneeskunde was matig tot laag. Toekomstig onderzoek moet zich richten op het bewustzijn, de attitudes en de belangrijke rol van balletdocenten voor blessurepreventie bij dansers.

In een longitudinaal cohortonderzoek, dat in hoofdstuk 6 wordt gepresenteerd, hebben wij prospectief onderzocht of dansers meer stress ervarenna een blessure en of deze ervaren stress verschillt tussen een eerste blessure en een opeenvolgende blessures.

Van 2016 tot 2022 werden vijf cohorten met 145 bachelor dansstudenten prospectief gevolgd tijdens hun eerste academische jaar. Baseline kenmerken werden geregistreerd in de eerste maand van het academische jaar. De "Performing artist and Athlete Health Monitor" (PAHM) die de VAS-pijnschaal, de VAS-stressschaal en de "Oslo Sport Trauma Research Center Questionnaire on Health Problems" (OSTRC) omvat, diende als beoordelingsinstrument. Stressniveaus, blessures en blessure-ernst werden maandelijks gerapporteerd en gedurende het hele academische jaar geregistreerd. Voor de stressanalyse werd de stressbeoordeling van de eerste maand in september als baseline genomen, waarbij de dansers blessurevrij moesten zijn om in deze analyse te worden opgenomen. Gepaarde t-tests werden uitgevoerd om het verschil tussen de baseline en de eerste respectievelijk opeenvolgende blessures te onderzoeken.

67 dansers met een gemiddelde leeftijd van 18,8 ±.80 jaar (58,2% vrouwen) liepen ten minste één blessure op. 33 van hen rapporteerden daarna nog minstens één opeenvolgende blessure. De OSTRC ernstscores varieerden van een gemiddelde van 28,7 ±17,5 voor de eerste blessure tot 31,4 ±17,1 voor de opeenvolgende blessure. Het gemiddelde stressniveau bij blessures was 24.3±17.2 De gemiddelde stressniveaus van dansers tijdens de eerste en opeenvolgende blessures waren verhoogd in vergelijking met het gemiddelde stressniveau op de basislijn, respectievelijk 34,8 ± 18,7 en 35,1 ±23,0. Wij vonden geen verschillen tussen de stressniveaus tijdens de eerste en opeenvolgende blessures. Blessures lijken dus geassocieerd zijn met verhoogde stressniveaus bij dansers, maar er de stressniveaus na de eerste en opeenvolgende blessures lijken van

gelijke grootte , in tegenstelling tot eerder gevonden resultaten bij andere sporters. Wij willen het belang van een holistische benadering van blessure-revalidatie benadrukken, inclusief het psychologisch herstel van dansers en aandacht voor stressmanagement.

Publications Contributing to this Thesis

Kaufmann, J. E., Nelissen, R., Exner-Grave, E., & Gademan, M. (2021). Does forced or compensated turnout lead to musculoskeletal injuries in dancers? A systematic review on the complexity of causes. *Journal of biomechanics*, *114*, 110084. https://doi.org/10.1016/j.jbiomech.2020.110084

Kaufmann, J. E., Nelissen, R. G., Appleton, P. R., & Gademan, M. G. (2021). Perceptions of Motivational Climate and Association with Musculoskeletal Injuries in Ballet Dancers. *Medical problems of performing artists*, *36*(3), 187–198. https://doi.org/10.21091/mppa.2021.3021

Kaufmann, J. E., Nelissen, R., Stubbe, J.H., & Gademan, M. (2022). Neuromuscular warm-up is associated with fewer overuse injuries in ballet dancers compared to traditional ballet specific warm-up routines. *Journal of Dance Medicine & Science*. ePub date: September 15, 2022 https://doi.org/10.12678/1089-313X.121522e.

Kaufmann, J. E., Stubbe, J.H., Nelissen, R., & Gademan, M. (2022). The perspective of ballet dancers on causes of dance injuries and implementation of preventive dance medicine by their ballet teachers and masters. *Submitted 2022. In revision*

Kaufmann, J. E., Stubbe, J.H., van Rijn, R. M., Nelissen, R., & Gademan, M. (2023). Injury as a stressor in 67 first year contemporary dance students: A longitudinal cohort study. Submitted.

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This work is dedicated to my parents, who always believed in me. who never said that I can't, never doubted I could and loved me regardless of the outcome. I am blessed to have been born into your arms.

Curriculum Vitae

Judith-Elisa Kaufmann was born in Austria. She performed her first role as a soloist dancer with the age of 15 and receiving her first awards as soloist and as chief choreographer aged 16 and 17. After graduating from high-school aged 17 she started to work as dancer, choreographer and ballet master. After injuries and chronic illness had terminated her own active career too early, she focused on teaching and (dance) medical studies. Author of several books and publications on dance pedagogy and dance medicine, she became a university lecturer by the age of 25 and has been teaching dancers, teachers and clinicians internationally ever since.

In 1998 she founded a School for Ballet and Performing Arts in which she stressed the active inclusion and implementation of dance medicine and dance science as basis of all training and teaching. The lack of sufficiently educated teaching personnel for her school led her to found the meanwhile renowned Academy for Dance Pedagogy & Dance Medicine, Austria in 2005 (with an unofficial start in 2000). Her concept of Preventive Dance Medical Dance Pedagogy© is an internationally unique curriculum aiming to train teachers, ballet masters, and dancers in the active implementation of dance medicine and science into dance practice.

In 2018 she found her way to LUMC and from 2019 onwards received the support from a wonderful team to execute those studies which she always wanted to read and would have needed herself for teaching dance medicine. She is looking forward to many years of this empowering collaboration to come.

Grateful for her skill of being able to inspire and empower people, Judith-Elisa Kaufmann's intrinsic motivation for dance medicine and pedagogy allows her to juggle her jobs as a mother (which is the best of all), head of the academy, (university) lecturer, author, choreographer, and researcher.