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MUSCULOSKELETAL INJURIES AND GENERALIZED JOINT LAXITY IN BALLET DANCERS

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ABSTRACT

Aims To examine the incidence and type of musculoskeletal injuries in classical ballet dancers, to analyse these injuries in relation to absence from performance, and to identify dancers at risk of frequent injuries in a Swedish professional ballet company (*study I*). To analyse spinal sagittal mobility and joint laxity in young Swedish ballet dancers in comparison with controls (*study II*). To assess the incidence of musculoskeletal injuries, the site and type of injury, and the most common injury diagnoses in young ballet dancers at the Royal Swedish Ballet School in Stockholm, Sweden (*study III*). To investigate age- and gender-specific associations between joint hypermobility, generalized joint laxity and musculoskeletal injuries in young Swedish ballet dancers (*study IV*).
Methods In *study I*, 98 professional ballet dancers (48 men, 50 women, average age 28.3, range 17–47) at the Royal Swedish Ballet in Stockholm were studied in a combined retro-prospective way. All injuries for which the dancers sought medical care during Aug 1988–Jun 1993 at the in-house outpatient clinic were registered. Injury incidence rates per 1,000 activity hours were calculated and χ^2 test and unpaired t-test were used for statistical analyses. In *study II*, 23 dance students (11 boys, 12 girls) in 4th grade at the Royal Swedish Ballet School in Stockholm, and 36 controls at a public Swedish school were examined regarding spinal configuration in standing. The spinal sagittal mobility was measured by use of De Brunner's kyphometer and Myrin's inclinometer. Joint mobility was measured and registered by employing a modified form of the Contompasis method. For comparison between dancers and the controls, the student's t-test was used. In *Study III,* 476 students (297 girls and 179 boys) aged 10–21 at the Royal Swedish Ballet School in Stockholm made up the study group. A 7 year (August 1988 to June 1995) retrospective analysis of medical records in the school orthopaedic outpatient clinic was undertaken. Data on diagnosis, site of injury and type of injury were collected, and the injuries were classified as traumatic or due to overuse. Injury incidence rates per 1,000 activity hours were calculated. Statistical differences for the total injury incidence rates between genders, age groups, and for type of injury were calculated and t-test was used to test statistically significant differences between proportions. In *study IV*, 216 (130 girls, 86 boys) ballet students in 4th grade were examined while entering the Royal Swedish Ballet School between Aug 1988 and Jun 1995. Joint mobility was measured applying the modified Contompasis method and the results were subdivided into three groups based on the score obtained. Medical records were analysed and all injuries for the period were registered. Injury incidence rates per 1,000 activity hours were calculated. For statistics a conditional risk set model using Cox regression was employed.
Results In *study I*, 95% of the 98 dancers suffered an injury when employed for one year or more. The dancers incurred 390 injuries over the 5-year study period i.e., 0.6 inj/1,000 activity hours. Most injuries were due to overuse and located in the foot and ankle region. The injury profile differed significantly between the genders and between younger and older dancers. Female dancers more frequently suffered overuse injuries while male dancers more frequently suffered knee injuries. Ankle sprain was the most common diagnosis, mostly occurring among dancers <26 years. In *study II,* the ballet dancers were found to have a less prominent thoracic kyphosis, lumbar lordosis, and showed a higher incidence of joint mobility. In *Study III,* the injury incidence was 0.8/1,000 hours of activity and the injury incidence tended to increase with increasing age. The injury panorama in the younger dancers resembled those in professional adult dancers in study I. Most injuries occurred due to overuse, ankle sprain was the most common traumatic injury and tendinosis pedis the most common overuse injury. *Study IV* showed that more female dancers (32.3%) than male dancers (15.1%) had a manifest generalized joint laxity (GJL). A significantly increased injury risk was found among students with GJL (hazard ratio=1.62, 95% CI=1.09–2.39) Higher age implied an increased injury risk and interaction tests revealed a particularly increased injury risk among those >10 years with manifest GJL.
Conclusions Musculoskeletal injuries are common in both young and adult ballet dancers. The association between GJL and injury risk in young ballet dancers implies that there is a need for screening programmes regarding GJL and appliance of primary prevention in order to prevent musculoskeletal injuries in young ballet dancers.

CONTENTS

LIST OF PUBLICATIONS

This thesis is based on the following original articles, which will be referred to in the text by their Roman numbers.

I The injury panorama in a Swedish professional ballet company.
Nilsson C, Leanderson J, Wykman A, Strender LE.
Knee Surg Sports Traumatol Arthrosc. 2001 Jul;9(4):242–6.

II Spinal sagittal mobility and joint laxity in young ballet dancers: A comparative study between first-year students at the Swedish Ballet School and a control group.
Nilsson C, Wykman A, Leanderson J.
Knee Surg Sports Traumatol Arthrosc. 1993;1(3–4):206–8.

III Musculoskeletal injuries in young ballet dancers: A descriptive study of dancers at the Royal Swedish Ballet School.
Charlotte Leanderson, Johan Leanderson, Anders Wykman, Lars-Erik Strender, Sven-Erik Johansson, Kristina Sundquist
Knee Surg Sports Traumatol Arthrosc. 2011; 19 (1531–35).

IV Joint hypermobility, generalized joint laxity and musculoskeletal injuries in young Swedish ballet dancers: A prospective study.
Charlotte Leanderson, Anders Wykman, Johan Leanderson, Lars-Erik Strender, Sven-Erik Johansson, Kristina Sundquist
Manuscript.

ABBREVIATIONS

ACL	Anterior Cruciate Ligament
BJHS	Benign Joint Hypermobility Syndrome
CI	Confidence Interval
FHL	Flexor Hallucis Longus
FTA	Fibulo Talare Anterior
GJL	Generalized Joint Laxity
HR	Hazard Ratio
MRI	Magnetic Resonance Imaging
n	Sample size

INTRODUCTION

HISTORY

Classical ballet is an art form and, in a historical perspective, an almost ancient, most un-physiological way of practising physical activity. Ballet dancing dates back to the 15th century where it was an integral part of court entertainment in Italy. In France, the Italian-born Queen Catherine de Medici adopted ballet into the French court scene. The ballet culture in France developed further and flourished vigorously in 1661 when Louis XIV, himself a designated dancer, founded the Académie Royale de Danse, regarded worldwide as one of the first organized ballet schools. Through the contribution of Jean-Baptiste Lully, a French composer and artist, and Pierre Beauchamps, a dancer and director who also established the five positions in ballet, the court ballet also formed the French Opera Ballet, acknowledged as the world's oldest opera ballet company (Anderson, 1992, Lee, 2002).

In Sweden, King Gustav III, famous for his predilection for the fine arts, founded the Royal Swedish Ballet in 1773, the fourth oldest ballet company in the world. King Gustav III set the scene for the Swedish ballet culture, the tradition and development passing far beyond his own lifetime. Classical ballet also flourished in Denmark, where the famous choreographer August Bournonville created the Bournonville School at the Royal Danish Ballet during the 19th century, and in Russia (Terry, 1979). After the Russian Revolution in 1917, many Russian dancers fled to Paris to join the Ballets Russes (The Russian Ballets) in their exile. The Ballets Russes were directed by Sergei Diaghilev and the company performed in many countries worldwide, albeit mostly in Europe. The young choreographer George Balanchine worked in the Ballets Russes before he established himself in the United States, developing neoclassical ballet as well as founding the School of American Ballet and the New York City Ballet (Purvis, 2009). During the 20th century, Isadora Duncan, Martha Graham and Merce Cunningham were important examples in the development of modern dance. Modern dance broke the traditions of classical ballet and the dancers often performed in bare feet and non-traditional costumes (Mazo, 2000, Roseman, 2004). Contemporary ballet includes elements of both classical ballet and modern dance. One of the most famous representatives of contemporary ballet in Sweden is the Cullberg Ballet, founded by Birgit Cullberg in 1967.

THE DANCER

A ballet dancer combines athletic performance and aesthetic values in the dance. A first-rate professional dancer often bears a story of an introduction to dance at an early, sometimes preschool age, and is often, already at the age of 19–20 years, ready to seek employment in a ballet company, as a professional dancer. The career of the dancer lasts for about 15–25 years and when the dancer retires between 40 and 45 years of age, the influence on the musculoskeletal system has lasted for a considerable amount of time. Ballet dancing demands the physiological characteristics of an elite athlete in terms of VO_2 uptake, muscular strength, and endurance, while, during performance, the focus is solely on the artistic interpretation. Furthermore, the dancer should also, within the movement, deliver a delicate interpretation of emotions such as joy, love, astonishment, fear, hatred, loss, longing or whatever sense the dancer is supposed to interpret through the character given in the plot. The solo dancer is given a certain amount of artistic freedom within the choreographic frame for each ballet, while the dancers in the corps-de-ballet usually must be totally unison in their dance performance, and the demands for alignment leave very little space for individual differences regarding the appearance on stage.

The dance, in terms of physical activity, is an almost unparalleled physical activity where certain main characteristics differentiate ballet from other sports activities. This is particularly salient for classical ballet. First: the position of the lower extremity generated by the five positions in classical ballet aiming for a 180 degrees turnout. Second: the use of en-pointe shoes in female dancers, in which an excessive axial load is placed on the joints of the feet with repetitive microtraumas generated by repetitive maximum plantar flexion. Third: the controlled, well-balanced body movement often performed in non-physiological positions, which is the aim itself of the activity, requiring assiduous training to reach the desired performance and placing extensive strain on muscles, ligaments, and joints.

In order to perform the ballet movements correctly, the dancer must find equilibrium between the individually determined ranges of motion and the extreme movements, avoiding placing additional torsional force on the lumbar spine and the lower extremity. The extreme pressure on the musculoskeletal system in a ballet dancer implies an almost inevitable risk of injuries, both as a young dancer in training and as an adult professional dancer.

INJURIES

Injuries could be regarded as one of the most frequent medical problems in ballet dancers. In a study of dancers in three professional dance companies, 94% reported some kind of musculoskeletal problems during the preceding 12 months (Ramel and Moritz, 1994). The type of injuries in ballet dancers partly resemble those of traditional sport athletes (Garrick and Requa, 1993, Klemp and Learmonth, 1984, Rovere et al., 1983, Sammarco, 1984, Sohl and Bowling, 1990, Teitz, 1983, Wykman and Oxelbeck, 1991). However, the specific training and performance in ballet also render more dance-specific injuries such as certain overuse soft-tissue injuries to the lower extremity, stress fractures to the metatarsal bones and early onset arthrosis in the ankle, foot, knee, and hip joints of former ballet dancers (Andersson et al., 1989, van Dijk et al., 1995).

Previous research from the United States has suggested that pain in the lower leg is the most common problem among ballet dancers, followed by musculoskeletal problems associated with the ankle, foot, knee, and lower spine (Washington, 1978). A survey of injuries in professional dancers from the UK found that, of the 141 dancers, 47% had experienced a chronic injury and 42% an injury in the previous six months that had affected their dancing. About four fifths reported having had at least one injury at some time that had affected their dancing, and almost half were currently suffering from at least one chronic injury that gave them continuing problems. The back and ankle were the most common sites of injuries. For those dancers with chronic injuries, muscular injuries were most common, followed by fractures and dislocations. Soft-tissue injuries included sprains, strains, tears of muscles and ligaments and inflammation of muscles and other soft tissues (Bowling, 1989). A 19-week study among professional ballet dancers in the Norwegian National Ballet revealed that, of the 41 dancers, 31 experienced at least one injury. The majority of injuries involved the foot and ankle, 22% were acute injuries and 75% were soft-tissue injuries. Most injuries were of mild to moderate severity and 16% resulted in absence from work (Byhring and Bo, 2002). A systematic review published in 2008 evaluated 15 cohort studies, 13 cross-sectional studies, and 1 validation study performed since 1966. The authors of that review found a high prevalence of lower extremity and back injuries in dancers, with soft-tissue and overuse injuries predominating (Hincapie et al., 2008).

To sum up, injuries represent an important health problem among dancers, which calls for further research on specific risk factors for injuries and chronic pain. The present thesis focused on the injury panorama in young ballet dancers as well as in adult, professional ballet dancers. In addition, the potential influence of joint hypermobility and generalized joint laxity on the incidence of musculoskeletal injuries in young male and female ballet dancers was studied. The results may have clinical implications as a possible way to prevent injuries in both male and female ballet students as well as in adult professional dancers.

JOINT MOBILITY AND GENERALIZED JOINT LAXITY

Ligamentous laxity has been associated with several pathological syndromes, such as Marfan's syndrome, Ehlers-Dunlos disease, and osteogenesis imperfecta, but also with other clinical conditions such as subluxation of the shoulder and the patella, and injuries to the ligaments of the knee (Nicholas, 1970, Runow, 1983). Previous studies have shown that generalized joint laxity and joint hypermobility are more common in ballet dancers and other athletes than in the general population (Steinberg et al., 2006, McCormack et al., 2004, Nilsson et al., 1993, Bennell et al., 1999, Nicholas, 1970, Runow, 1983, McNerney and Johnston, 1979). For example, previous studies have examined the hip external rotation, an important asset in dancers in order to perform an adequate turnout of the hip (Hamilton et al., 1992, Khan et al., 1997). Dancers had a significantly greater total external rotation of the hip than the controls (Khan et al., 1997). Hamilton et al. (1992) found that ballet dancers were flexible but not hypermobile, and that they had a range of motion in the hip and ankle joints that was different from the general population.

Joint hypermobility has often been regarded as an asset in the endeavour to accomplish a full 180 degree turnout of the hip, knee, and ankle joints in order to become a first-rate dancer. Studies have nevertheless indicated that there is no association between joint hypermobility and dancing excellence (McCormack et al., 2004, Klemp and Chalton, 1989).

There are age-specific differences in joint mobility among ballet dancers. One study demonstrated a declining prevalence of joint hypermobility from student to professional ballet dancer and also within the ballet company from corps de ballet to principal dancer (McCormack et al., 2004). The authors also stated that benign joint hypermobility syndrome might have an important negative influence on the young dancer's chance of becoming a soloist or a principal dancer.

Joint hypermobility in the normal population is associated with gender, age, ethnicity, and nutritional status (Larsson et al., 1993, Seckin et al., 2005, Jansson et al., 2004, Seow et al., 1999, Hasija et al., 2008). A large study of randomly selected Swedish school children (aged 9, 12, and 15 years). (Jansson et al., 2004) found that the distribution of generalized joint laxity and the limits for hypermobility were age- and gender-specific. Boys presented significant decreases in the frequency of generalized joint laxity with increasing age, while in girls the highest frequency of generalized joint laxity was seen at the age of 15.

Joint hypermobility and generalized joint laxity may lead to an increased injury risk. There are studies that have indicated that joint hypermobility and generalized joint laxity are associated with injuries in ballet dancers (Hamilton et al., 1992, Negus et al., 2005, Reid et al., 1987, Briggs et al., 2009) The study by Hamilton et al. (1992) found that male dancers who had suffered four or more injuries had greater elbow extension and increased straight-leg raising ability than male dancers with fewer than four injuries. The same study demonstrated that female dancers with a limited hip turnout were more frequently injured. A study by Öhlen suggested that young female gymnasts with abnormal spinal mobility, increased lumbar lordosis, and generalized joint laxity represent a subset of axial hypermobility that may constitute a specific aetiology for low back pain (Öhlen et al., 1989).

It has also been suggested that generalized joint laxity is an aetiological factor in the development of early-onset arthrosis, a condition often seen in professional dancers (Andersson et al., 1989).

However, there are other studies that show no relationship between joint mobility and injury frequency (Klemp and Chalton, 1989, Klemp and Learmonth, 1984) which indicates a need for more studies on this topic.

AIMS

The overall aim of this study was to examine the incidence of musculoskeletal injuries, including site and type of injuries, in ballet dancers, and to investigate associations between joint hypermobility, generalized joint laxity and musculoskeletal injuries in young ballet dancers.

Specific aims

1. To examine the incidence and type of musculoskeletal injuries in professional classical ballet dancers at the Royal Swedish Ballet in Stockholm (study I).

2. To analyse these injuries in relation to absence from performance and to identify dancers at risk of frequent injuries (study I).

3. To analyse spinal sagittal mobility and joint laxity in a group of young ballet dancers in comparison with a control group (study II).

4. To assess the incidence of musculoskeletal injuries in young ballet dancers at the Royal Swedish Ballet School in Stockholm (study III).

5. To assess the injuries regarding site and type and the most common diagnoses (study III).

6. To investigate age- and gender-specific associations between joint hypermobility, generalized joint laxity and musculoskeletal injuries in young ballet dancers at the Royal Swedish Ballet School in Stockholm (study IV).

MATERIALS AND METHODS

The study populations in the present thesis were recruited from the Royal Swedish Ballet in Stockholm (study I, see below) and the Royal Swedish Ballet School (studies II—IV), which is a public school with a dance profile in Stockholm. The studies cover the compulsory Swedish school programme until 9th grade. Students are enrolled in the 4th grade (10 years of age) after performing various entrance examinations. After six years of compulsory schooling with an extended course in dance, regarded as a preparation for higher educational professional studies, students can apply to enrol for additional studies at upper secondary school level. At the time of studies II–IV these additional studies lasted for two years (they now include a study period of three years), also providing formal competence for further university studies. At the time of the studies about 20–25 children were accepted each year to the school in 4th grade and about 25–30 at the upper secondary school level. Occasionally, students were also enrolled in 7th grade after entrance tests. The students received 6 h/week of dance training during the first school year (4th grade), 10.5 h/week between the 5th and 7th grades, 11.5 h/week in the 8th grade, and 15 h/week in the 9th , 10th, and 11th grades.

Table A. Overview of the four studies.

	Study I	**Study II**	**Study III**	**Study IV**
Data source/ study population	Royal Swedish Ballet (RSB)	RSB school Vårbackaskolan, Vårby	RSB school	RSB school
Measurement methods	Injury protocol	Debrunner's kyphometer Myrin's inclinometer Contompasis method Goniometer	Injury protocol	Injury protocol Contompasis method Goniometer
Outcome	Injury panorama, injury incidence per 1,000 activity hours	Spinal sagittal mobility, joint laxity	Injury panorama, injury incidence per 1,000 activity hours	Musculoskeletal injuries Generalized joint laxity (GJL)
Number of subjects	98 (48 men 50 women)	23 dancers 36 controls	476 (179 boys, 297 girls)	216 (86 boys, 130 girls)
Age	17–47		10–21	10–21
Number of injuries	390	–	438	92
Study design	Open cohort combined retrospective prospective	Descriptive	Open cohort retrospective	Open cohort prospective
Statistical model	Chi 2 test, unpaired t-test	t-test	t-test	Conditional risk set model/Cox regression
Study period	Aug 1988– June 1993	1989	Aug 1988– June 1995	Aug 1988– June 1995

Injury protocol

An injury protocol was designed to include diagnosis, site of injury, type of injury, sick leave, radiographs, physical therapy treatment, and surgical treatment.

The protocols used at the Royal Swedish Ballet and the Royal Swedish Ballet School were similar, apart from the professional dancers' form also including information about the dancers' role in the company and whether the injury occurred during rehearsal or performance.

STUDY I

Subjects

The study was carried out over five ballet seasons of August to June, 1988–1993, at the Royal Swedish Opera House in Stockholm. The Royal Swedish Ballet is the official professional ballet company located in the Opera House in Stockholm. At the time of the study, the company had on average 78 members (range 72–80) in these performing years, 46 women (43–48) and 32 men (29–34). Most of the dancers were members of the corps de ballet, on average 57 (54–60). Twelve soloists (10–14), and 9 principal dancers (8–10) were also included. The average age during all 5 years was 28.3 years (17–47). The average period of dancing experience was 20 years (7–37). The training (class), rehearsal, and performance times totalled 48 h per week.

Methods

All injuries that occurred in the performing seasons 1988–1993 were recorded. An orthopaedic consultant was affiliated with the Royal Swedish Ballet and was located in the Opera House. A naprapath was employed by the Opera House on a full-time basis. The clinic was open daily and the orthopaedic consultant was present one day a week and was on call every day for emergency consultations.

Initially, a retrospective recording over two ballet seasons (1988–90) was made of all injuries from which the dancers had sought orthopaedic consultations. A form was designed in which the diagnosis, site of injury, injury mechanism, and type of injury were registered. The form also included information about the dancer's professional status. In the 3-year prospective part of the study (three seasons, 1990–1993) the same protocol was used. All injuries needing medical consultation were examined by the same orthopaedic consultant (AW).

Injury concept

The injuries were classified as either traumatic, i.e., the patient could define a specific sudden onset of pain with a defined trauma included, or as due to overuse.

Statistical analysis

We used the chi-squared test to compare injury incidence during both the retrospective and prospective periods of the study and to detect differences in injury frequency between the sexes or between right and left side. The unpaired t-test was used for comparison of ages in the dancers with and without stress fractures (Nilsson et al., 2001).

STUDY II

Subjects and methods

The study included all the first-year (4th grade) students (11 boys and 12 girls) at the Royal Swedish Ballet School. All were 10 years old. Informed consent was obtained from their parents. Their practice time was 10 h per week. The Swedish Ballet School works closely with the Royal Swedish Ballet. Members of the school often take part in performances given by the Royal Swedish Ballet, and many of the present members of the Ballet were recruited from the school.

Thirty-six children in the fourth grade at a Swedish state school made up the control group (11 boys and 25 girls). All were 10 years old. Informed consent was obtained from their parents. None of the controls took ballet classes or participated in organized gymnastic training during their leisure time. Each child was examined clinically to detect any evidence of scoliosis.

The neutral spine configuration in standing position was registered and sagittal spine mobility was measured with Debrunner's kyphometer. This instrument comprises a protractor with a 1° scale at the junction of two double parallel arms connected to blocks large enough to span two spinous processes. The angles of kyphosis and lordosis are read directly from the scale of the kyphometer. The kyphosis was measured between spinous processes C7–T1 and T11–12. The lordosis was measured between T11–12 and S1–S2.

The neutral spine configuration was defined as the spinal posture in the relaxed erect standing position. The child was asked to look straight ahead and stand relaxed with arms hanging. Sagittal ranges of motion were studied in the thoracic and lumbar spine. Total backward bending in the lumbar spine could not be measured using Debrunner's kyphometer because many of the children bent beyond its range; instead, for this we used Myrin's inclinometer (Mellin, 1986).

Generalized joint laxity was measured by one observer employing a modified form of the Contompasis method as described by McNerney et al. (McNerney and Johnston, 1979).

It comprises six different tests:

1. Passive opposition of the thumb to the flexor aspect of the forearm
2. Passive dorsiflexion of the fifth metacarpophalangeal joint
3. Passive hyperextension of the elbow
4. Passive hyperextension of the knee
5. Calcaneal stance position
6. Hyperflexibility of the spinal column

For the first five tests, a numerical value for each side was determined. For test 6, one value was obtained. Generalized joint laxity was defined as present if the total score was 40 points or more. Values for each side should be equal; a difference in symmetry suggests an acquired type of laxity in the joint concerned. For statistical treatments of results, student's t-test was used (Nilsson et al., 1993).

STUDY III

Subjects and methods

The present study covers the period between August 1988 and June 1995 (ordinary semesters) at the Royal Swedish Ballet School, a public school in Stockholm. All students who attended the school for at least one year during the study period were included. In total 476 students (297 girls and 179 boys) attended the ballet school during the study period.

The present study had an open-cohort design in which all students were followed from baseline until they graduated from the school. In addition, the open cohort also included the new students that started each year. During the study period, 1–5 students dropped out each year. The students received 6 h/week of dance training during the first school year (4th grade), 10.5 h/week between the 5th and 7th grades, 11.5 h/week in the 8th grade, and 15 h/week in the 9th, 10th, and 11th grades. Exposure time (number of hours of dancing) was used in the estimated incidence rate calculations and was determined from data from the school board regarding daily registered attendance at dance training.

All Swedish schools offer free access to health care. At the time of the study, the school health care unit at the Royal Swedish Ballet School employed a naprapath, who worked on a daily basis. In addition, an orthopaedic consultant held a weekly outpatient clinic. On other days of the week, students with acute injuries were able to receive emergency medical care from the same orthopaedic consultant at the orthopaedic department at Karolinska University Hospital. The orthopaedic consultant is a co-author of this paper (AW). He served as the school orthopaedic consultant during the study period and examined all students with dance-related medical problems.

All injuries for which students received orthopaedic care (from AW) between 1988 and 1995 were recorded and included in the present analysis. The injury records were evaluated between 2006 and 2007. The research protocol was designed to include diagnosis, site of injury, type of injury, sick leave, radiographs, physical therapy, and surgical treatment. No students were excluded from the study (i.e. no exclusion criteria were applied).

Injury concept

Injuries were classified as traumatic in cases in which the student's pain arose as the result of a defined trauma. All other injuries were deemed to be caused by overuse.

Statistical analysis

Injury incidence rates per 1,000 activity hours were calculated for both female and male students. Statistical differences for the total injury incidence rates were calculated between girls and boys and between age groups (Table 1). Test of difference was also performed for type of injury (trauma vs. overuse) for each age group ($\leq$10 years, 11–14 years, and 15–21 years) and by sex (Table 2). *P*-values for differences between incidence rates were calculated based on the binomial distribution (Rothman, 1986) and t-test was used to identify statistically significant differences between proportions. A two-sided *P*-value <0.05 was considered to be statistically significant. All analyses were performed using STATA software (STATA 2005, Leanderson et al., 2011).

STUDY IV

Subjects and methods

The present study was carried out between August 1988 and June 1995, i.e. during ordinary semesters, at the Royal Swedish Ballet School in Stockholm. All first-year students (4th grade, 10 years old) were examined for joint mobility. All examined students who had attended the school for at least one year during the study period were included. Twenty-eight students were examined for joint mobility, while seeking medical care for an injury. These students had either entered the school before the time of the study or entered the school at a higher age. In total, 216 dancers participated in the study.

The injuries were classified as traumatic with a specific onset of pain or as due to overuse. At the time of the study, the school healthcare unit at the Royal Swedish Ballet School also cooperated with a naprapath working on a daily basis. In addition, an orthopaedic consultant maintained an outpatient clinic on a weekly basis. On the remaining days of the week all students with an acute injury could receive emergency medical care from the same orthopaedic consultant at the orthopaedic department at the Karolinska University Hospital. The orthopaedic consultant is a co-author of this paper (AW) and he served as the school orthopaedic consultant during the years included in the present study and examined all students with dance-related medical problems. All injuries for which the examined students had sought medical care from AW during 1988–1995 were recorded and included in the present analysis.

Joint hypermobility was measured by two of the authors of the present study (AW, CL) employing a modified version of the Contompasis method as described by McNerney et al. (McNerney and Johnston, 1979).

No warm-up was conducted before the measurements were performed. Six separate tests were included:

1. Passive opposition of the thumb to the flexor aspect of the forearm.
2. Passive dorsiflexion of the fifth metacarpophalangeal joint.
3. Passive hyperextension of the elbow.
4. Passive hyperextension of the knee.
5. Calcaneal stance position.
6. Hyperflexibility of the spinal column.

For the first five tests, measurements were performed on both the left and the right side. Based on the given number of points, the students were divided into the following three categories:

1. No joint hypermobility/laxity (18–25 points)
2. Joint hypermobility (26–39 points)
3. Generalized joint laxity (40 or more points)

We chose 26 points as a cut-off for the presence of joint hypermobility, which is in agreement with previous research on joint mobility in ballet dancers (McCormack et al., 2004).

Statistical analysis

Differences in the distribution of laxity between boys and girls were tested by a chi-squared test. Injury incidence rates were calculated per 1,000 activity hours for both male and female students. The data were analysed by a conditional risk set model (time from previous event) using Cox regression to calculate hazard ratios (HRs) with 95% confidence intervals (CIs). This model assumes that a subject is not at risk of a second event until the first event has occurred (Prentice et al., 1981).

Three models were calculated (crude, sex-adjusted, and sex- and age-adjusted). Interaction tests were performed between sex, age, and joint laxity. All analyses were performed using the STATA software (2005).

RESULTS

STUDY I

The injury patterns in the retrospective and prospective parts of the study were similar. There were 390 injuries to 98 dancers (mean 3.8±3.33 injuries/dancer, range 0–16; 48 men, and 50 women; Table 1). The average age of the injured dancers was 26.6 years. 95% sought medical consultations during the 5-year period. The 5% who did not suffer an injury during this period did not differ in age, sex, or dance status from the injured dancers.

Table 1. Type and location of 390 injuries to 98 dancers: percentages (*T/O* proportion of traumatic/overuse injuries).

	Female (*n*=50; 208 injuries)		Male (*n*=49; 182 injuries)		Total (*n*=98; 390 injuries)	
	%	T/O	%	T/O	%	T/O
Ankle, foot	62.0	36/64	46.2	45/55	54.0	37/63
Lower leg	4.3	49/51	1.1	100/0	2.8	58/42
Knee	5.8	26/47	18.7	34/66	11.0	32/68
Thigh, groin	3.4	21/79	4.4	60/40	3.8	40/60
Lower back, gluteal region	16.8	30/70	19.2	60/40	17.9	44/56
Upper extremity	4.8	100/0	9.9	45/55	7.2	60/40
Miscellaneous	2.9	76/24	0.5	100/0	1.9	80/20
Total	100.0	–	100/0	–	100/0	–

Injuries

There were 0.62 injuries per 1,000 h of activity (women 0.56, men 0.70). The injury was traumatic in 43% of cases, and in the others no trauma was noted, i.e., the injuries were due to overuse. In 75% of the cases the injury was located in the lower limbs (Table 1). Men suffered 79% of the traumatic knee injuries, particularly male soloists. Women suffered more frequently from overuse injuries. No difference was found in injury frequency between men and women, with the exception of the season of 1991–1992, when injuries to the male dancers were significantly more common (P<0.05; Fig. 1). More than ten injuries each were suffered by nine dancers (four men, five women; mean age 27.7 years, range 19–40), each of whom had been employed for at least four years. Most of the injuries in these more frequently injured dancers were minor and were spread over at least four seasons.

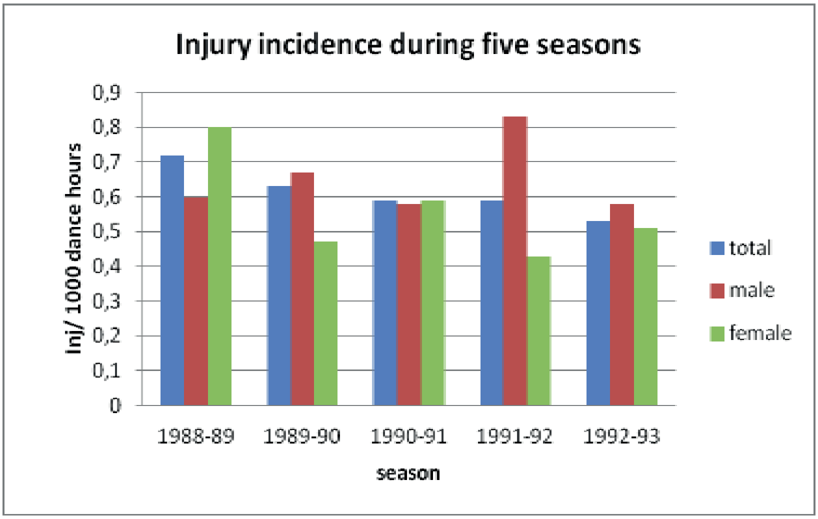

Fig. 1. Total number of injuries in male and female dancers during the five seasons of the study.

Sick leave

The median period of full sick leave was 2.3 weeks per injury (range 1–100 weeks). Two dancers, one suffering from a partial rupture of the Achilles tendon and one from tibialis posterior tendinitis, retired from dancing because of these injuries during the period of the study. A knee injury causing recurrent symptoms in a male dancer required 78 weeks of sick leave. Other injuries causing a prolonged period of sick leave included posterior impingement of the ankle joint (6 weeks, woman), knee injuries and achillodynia (10–12 weeks, both sexes), and ankle sprains (6–8 weeks, both sexes). Injuries causing more than 6 weeks of absence on a 50% basis were achillodynia, lumbago, and knee injury. Some injuries required absence from dancing, initially on a full-time basis and thereafter on a 50% basis. In 71% of cases the injury required sick leave for one week or less.

Foot and ankle injuries

Ankle sprain was the most common diagnosis, with 53 injuries to 29 dancers, for an average of 11 injuries per year (range 7–19). There was a higher incidence of ankle sprains in the right ankle than in the left ($P<0.05$). The majority of ankle sprains (75%) occurred in dancers who were 26 years of age or younger. The incidence of ankle sprain was about four times higher in the youngest dancers than in those aged 30 years or over ($P<0.05$; Fig. 2).

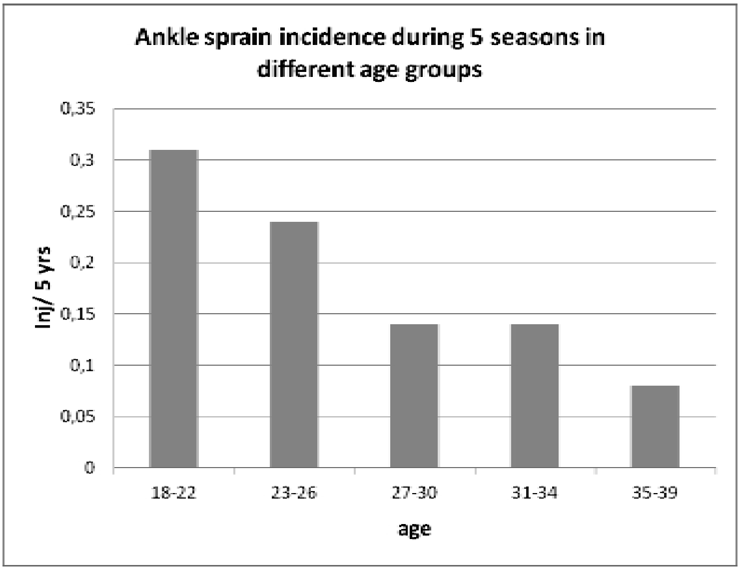

Fig. 2. Incidence of ankle sprain in different age groups.

Twelve fractures in the foot and ankle region were recorded. Eight of these were found in female dancers and included two cases of so-called dancer's fracture and four of stress fractures. One stress fracture was recorded among the male dancers. All stress fractures were located in the metatarsals of the foot. The dancers affected by stress fractures were younger (mean age 20.7 years, 18–25) than the average company age (28.3 years; $P<0.05$).

The foot and ankle region was the location of 46% of the injuries in men and 62% of those in women ($P<0.05$; Table 2). In men 40% of injuries were traumatic, such as distortions; in women 35% were traumatic and 65% were from overuse, with a subacute onset. Tendon problems in the ankle region caused symptoms in 32% of the foot injuries to female dancers. The most common location was the flexor hallucis tendon, followed by the peronei tendons and the Achilles tendon. Forefoot pain (metatarsalgia) was more common in the women (10% of foot injuries in women).

Knee injuries

Of all the knee injuries 74% were incurred by men. Both traumatic and overuse injuries were more common than in women ($P<0.0001$). Apicitis patellae (jumper's knee) was the most common diagnosis. The traumatic knee injuries included cases of distortions and ruptures of the medial or lateral menisci.

Back injuries

The spine was the location of 17% of injuries. Low back pain, including 13 cases of sciatica, was the most common diagnosis (n=60, 15%), and was found in both sexes and in all age groups. During the period of the study three patients underwent surgery because of lumbar disc herniation.

Injuries to the upper limbs were more common in men than in women ($P<0.05$). The most frequent injuries were distortions and dislocations in the fingers, and rotator cuff problems in the shoulder (Nilsson et al., 2001).

Table 2. Injuries to the foot and ankle region by diagnosis: percentages of all injuries recorded in female and male dancers during 5 years (1988–1993)

	Female (%)	Male (%)
Traumatic		
Fracture foot	2.9	1.1
Fracture ankle	0	0.5
Foot sprain	3.8	4.4
Ankle sprain	14.9	12.1
Overuse		
Stress fracture	1.9	0.5
Tendinitis/vaginitis	13.9	12.0
Peroneus	4.3	1.6
Flexor hallucis longus	8.6	6.6
Tib. post	1.0	3.8
Achillodynia	6.2	4.4
Dorsal impingement	2.4	1.1
Ant. impingement	1.0	1.1
Recrocalc. bursitis	1.4	3.3
Metatarsalgia	6.2	2.7
Miscellaneous	6.4	3.0
Total	62.0	46.2

STUDY II

Spinal configuration

Mean thoracic kyphosis was 11.8° (4°–23°) in the ballet group and 29.4° (16°–44°) in the control group ($P<0.01$). Mean lumbar lordosis was 22.1° (6°–35°) in the ballet group, and 30.7° (15°–53°) in the controls ($P<0.01$). No differences were found between boys and girls.

Range of motion

The mean sagittal range of motion in the thoracic spine was 71.1° (25°–101°) in the ballet group and 55.0° (20°–103°) in the controls ($P<0.01$). In the lumbar spine, the mean sagittal range of motion was 95.6° (56°–123°) in the ballet group and 94° (56°–116°) in the control group. No differences were found between boys and girls.

Joint hypermobility

The mean laxity score was 34.3° (22°–55°) in the ballet group and 29.1° (22°–42°) in the control group (P<0.01). Five of the 23 children in the ballet group, as against only 2 of the 36 controls, scored over 40 points. No differences were found between boys and girls (Nilsson et al., 1993).

STUDY III

Injury incidence

Table 3 shows the total injury incidence/ 1,000 activity hours for female and male dancers by age. Increasing age seemed to be associated with an increased injury incidence rate and some of the differences between age groups were statistically significant (Table 3).

Table 3. Injury incidence per 1,000 activity hours in girls and boys of different ages. Girls and boys were analysed separately.

	Incidence		*P*-value
	Girls	Boys	Girls vs. boys
Overall (all ages)	0.8	0.8	
Age group			
≤10 yrs	0.3	0.5	ns
11–14 yrs	0.7	0.6	ns
15–21 yrs	0.9	1.1	ns
Between-age group comparison	*P*-value		
	Girls	Boys	
≤10 vs. 11–14 yrs	0.04	ns	–
≤10 vs. 15–21 yrs	0.005	0.03	–
11–14 vs. 15–21 yrs	ns	0.0006	–

Distribution of injuries

Table 4 shows the distribution of injuries by site, age, gender, and type (trauma/overuse). Overuse injuries were more common than traumatic injuries in the 11–14 and 15–21 years age groups.

Table 4. Distribution of injuries by site, age, sex and type of injury (trauma/overuse). Test of difference (*p-value)* between type of injury for each age group and by sex.

	Age						
	≤ 10 yrs		*11–14 yrs*		*15–21 yrs*		*All ages*
	Number of injuries (trauma/overuse)						
	Girls	Boys	Girls	Boys	Girls	Boys	Total
Site of injury							
Foot/lower leg	0/4	1/3	14/30	7/24	28/65	17/33	67/159
Knee	1/2	0/1	2/31	3/12	2/20	1/17	9/83
Thigh/hip	0/0	0/0	1/16	1/2	0/14	1/11	3/43
Back	0/0	0/1	3/8	0/8	4/14	3/16	10/47
Upper extremity/misc.	0/0	0/0	4/2	3/0	3/1	2/2	12/5
Total	1/6	1/5	24/87	14/46	37/114	24/79	101/337
P-value (trauma vs. overuse)	ns	ns	0.00001	0.00001	0.00001	0.00001	0.00001

Table 5. The most common diagnoses. Numbers of injuries and percentages of all injuries recorded in female and male dancers between August 1988 and June 1995 are shown.

	Number of injuries (%)	
	Girls	Boys
Traumatic injuries		
Ankle sprain	31 (7.1)	19 (4.4)
Distorsion dig pedis	15 (3.4)	4 (0.9)
Overuse injuries		
Foot		
Tendinosis pedis	37 (8.5)	19 (4.4)
Calcaneodynia	16 (3.7)	11 (2.5)
Plantar fasciitis	10 (2.3)	9 (2.1)
Knee		
Jumper's knee	13 (3.0)	18 (4.1)
Tendonitis genu	19 (4.4)	6 (1.4)
Chondromalacia patellae	19 (4.4)	6 (1.4)
Hip/thigh		
Tendinosis groin	28 (6.4)	13 (3.0)
Back		
Low back pain	23 (5.3)	22 (5.1)

In total, 210 female and male dancers (44% of the 476 dancers) suffered injuries, of which 101 were traumatic and 337 due to overuse. Mean age at the time of injury was 14.5 years. The most common site of injury was the foot/lower leg ($P<0.05$, data not shown in tables), except in girls aged 11–14 years, in whom injuries to the foot/lower leg and knee were of similar incidence. Injuries to students aged ≤10 years were not tested for significance due to the low number of cases in this age group. No statistically significant differences between boys and girls were found for either traumatic or overuse injuries in the different age groups. This was also the case when site of injury was included in the statistical comparisons, with the exception of overuse injuries to the thigh/hip, which were more common in female dancers than in males (P=0.01) (data not shown in tables).

Diagnoses

Ankle sprain was the most common traumatic diagnosis. The most common overuse diagnosis was tendinosis pedis (Table 5). Twelve fractures were registered, of which eight were metatarsal fractures. The most frequently affected soft tissues in the ankle were the peroneal tendons and the flexor hallucis longus (FHL) tendon (data not shown in tables) (Leanderson et al., 2011).

STUDY IV

Distribution of joint mobility

Table 6 shows the percentage distribution of joint hypermobility/laxity among the dancers, indicating a significant difference between boys and girls (P=0.004, chi-squared test). A higher percentage of the female students (32.3%) had manifest general joint laxity compared to the male students (15.1%) whereas the opposite pattern was observed for the category no joint hypermobility/laxity; more than half of the male students and about one third of the female students had no joint hypermobility/laxity.

Table 6. Distribution of joint hypermobility/laxity among the dancers, by sex. Numbers and percentages (in parentheses).

	Boys n (%)	Girls n (%)	Total n (%)
No joint hypermobility[1]	44 (51.2)	41 (31.5)	85 (39.4)
Joint hypermobility[2]	29 (33.7)	47 (36.2)	76 (35.2)
Generalized joint laxity[3]	13 (15.1)	42 (32.3)	55 (25.4)
Total	86 (100.0)	130 (100.0)	216 (100.0)

[1] 18–25 points (Contompasis method as described by McNerney et al.)

[2] 26–39 points

[3] 40 or more points

Test of distribution; p=0.004, chi^2 test

Number of injuries

Table 7 shows the number and percentages of musculoskeletal injuries in relation to the subgroups of joint mobility. For all categories, most of the students suffered no injury. In total, 92 of the 216 students (42.6%) suffered at least one injury during the follow up. The highest percentage (67.1%) of students suffering no injury was found in the category joint hypermobility. Among the students that were assessed to have GJL, 43.6% suffered no injury. Among the students with GJL, almost 15% suffered from four or more injuries.

Table 7. Distribution of number of injuries and percentages (in parenthesis) by joint hypermobility/laxity.

	Number of injuries					Total
	0	1	2	3	≥4	
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
No joint hypermobility[1]	49 (57.7)	15 (17.7)	11 (12.9)	7 (8.2)	3 (3.5)	85 (100)
Joint hypermobility[2]	51 (67.1)	5 (6.6)	13 (17.0)	3 (4.0)	4 (5.3)	76 (100)
Generalized joint laxity[3]	24 (43.6)	12 (21.8)	9 (16.4)	2 (3.6)	8 (14.6)	55 (100)
Total	124 (57.4)	32 (14.8)	33 (15.3)	12 (5.6)	15 (6.9)	216 (100)

[1] 18–25 points (Contompasis method as described by McNerney et al.)

[2] 26–39 points

[3] 40 or more points

n represents the number of individuals in each cell.

Statistical models

Table 8 shows the hazard ratios (HR) with 95% confidence interval in students by subgroups of joint mobility. Those with no joint hypermobility/laxity are used as reference. An increased HR was seen in students with GJL (crude model: HR=1.44, 95% CI=1.01–2.06). This risk remained significant also after adjustment for age and gender. Students with joint hypermobility had a slightly lower, although non-significant, risk of suffering an injury. Higher age implied an increased risk of suffering an injury.

Interaction age/joint laxity

Table 9 shows the interaction between age and joint laxity. Young dancers (≤10 yrs) with joint hypermobility were used as reference. All subgroups had an increased risk of suffering an injury compared to the reference group, although some of the increased risks were non-significant. A particularly increased risk (HR=4.85, 95% CI=2.02–11.64) of suffering an injury was found in older (>10 yrs) dancers with manifest GJL.

Table 8. Hazard ratios (HR) with 95% confidence intervals (CI) in three models for the association between joint hypermobility/laxity and injury rates. Data analysed by a conditional risk set model (time from previous event) using Cox regression.

Variables	Crude model	Sex-adjusted model	Sex- and age-adjusted model
	HR (CI)	HR (CI)	HR (CI)
No joint hypermobility[1]	1 (ref)	1 (ref)	1 (ref)
Joint hypermobility[2]	0.87 (0.56–1.35)	0.88 (0.57–1.57)	0.88 (0.57–1.39)
Generalized joint laxity[3]	1.44 (1.01–2.06)	1.48 (1.02–2.16)	1.62 (1.09– 2.39)
Boys		1.10 (0.79–1.56)	1.03 (0.73–1.45)
Girls		1 (ref)	
Age			
≤10			1 (ref)
>10			1.69 (1.16–2.48)

[1] 18–25 points (Contompasis method as described by McNerney et al.)

[2] 26–39 points

[3] 40 or more points

Table 9. The interaction between age and joint hypermobility/laxity (hazard ratios with 95% confidence interval), adjusted for sex.

	Hazard ratios	95% CI
Age/Laxity		
≤10 years/ no joint hypermobility[1]	1.83	(0.79–4.27)
≤10 years/ joint hypermobility[2]	1 (ref)	
≤10 years/ generalized joint laxity[3]	1.98	(0.88–4.46)
>10 years/ no joint hypermobility[1]	1.74	(0.75–3.99)
>10 years/ joint hypermobility[2]	2.55	(1.08–6.05)
>10 years/ generalized joint laxity[3]	4.85	(2.02–11.64)

[1] 18–25 points (Contompasis method as described by McNerney et al.)

[2] 26–39 points

[3] 40 or more points

DISCUSSION

MAIN FINDINGS

Study I

In adult dancers, the injury incidence rate was 0.6/1,000 dance hours. Most injuries were due to overuse. The median sick leave was 2.3 weeks per injury. Male adult dancers suffered more frequently from acute injuries to the knee joint. Traumatic injuries were seen most frequently in male soloists. Female adult dancers more often suffered overuse injuries, especially to the foot and ankle region. The young professional dancers more often suffered traumatic injuries, for example, ankle sprain, and also stress fractures.

Study II

Compared with the controls, the dance students showed a higher incidence of joint hypermobility, greater mobility of the thoracic spine, a less prominent lordosis of the lumbar spine and a less prominent kyphosis in the thoracic spine in the neutral standing position. For all variables except total range of motion in the lumbar spine, statistically significant differences were found between the two groups. No differences were found between boys and girls regarding the variables measured.

Study III

The most important findings in ballet students were that: (1) the total injury incidence rate was 0.8 per 1,000 dance hours in both female and male dancers; (2) with increasing age in the students, the injury incidence tended to increase; (3) most injuries occurred as the result of overuse; (4) 76% of injuries affected the lower extremities; and (5) ankle sprain was the most common traumatic diagnosis, while the most common overuse diagnosis was tendinosis pedis. In addition, a few differences between boys and girls were noted.

Study IV

There were significant gender differences in the percentage distribution of joint hypermobility/laxity: more female dancers than male dancers had a manifest GJL, whereas the opposite pattern was observed for the category no joint hypermobility/laxity. A significantly increased injury risk was found among ballet students with GJL, whereas those with joint hypermobility had a slightly lower risk, but not to a statistically significant extent. Higher age implied an increased injury risk, and interaction tests revealed a particularly increased injury risk among older dancers with manifest GJL (HR=4.85).

Injuries and comparison with previous studies

The injury incidence rates and injury patterns described in the present studies of adult professional dancers as well as young ballet students are largely similar to those described in previous studies of dancers (Albisetti et al., 2009, Arendt and Kerschbaumer, 2003, Askling et al., 2002, Bronner et al., 2003, Byhring and Bo, 2002, Denton, 1997, Dore and Guerra, 2005, Gamboa et al., 2008, Garrick and Requa, 1993, Hodgkins et al., 2008, Khan et al., 1995, Liederbach et al., 2008, Luke et al., 2002, Marshall, 1989, Nunes et al., 2002, O'Kane and Kadel, 2008, O'Malley et al., 1996, Petrucci, 1993, Prisk et al., 2008, Quirk, 1994, Ramel and Moritz, 1994, Sohl and Bowling, 1990, Stretanski and Weber, 2002, Wykman and Oxelbeck, 1991). A previous study by Gamboa et al. (2008) screened 204 dancers aged 9–20 years during a 5-year period and found an injury incidence of 0.8 per 1,000 dance hours, a figure that is identical to that calculated in study 3, i.e., among ballet students. In study I, involving adult professional ballet dancers (Nilsson et al., 2001) the total injury incidence was 0.6 per 1,000 dance hours, slightly lower than that in the ballet students in study III. In study I of adult dancers, 74% of recorded knee injuries were sustained by male dancers (Nilsson et al., 2001) A similar gender difference was not, however, observed in study III, i.e., among ballet students.

As in previous studies, the majority of injuries in the present studies were located in the lower limbs, especially overuse injuries in the foot and ankle region (Garrick and Requa, 1993, Klemp and Learmonth, 1984, Rovere et al., 1983, Sammarco, 1984, Sohl and Bowling, 1990, Teitz, 1983, Wykman and Oxelbeck, 1991) For example, the findings that the majority of injuries were due to overuse are consistent with the results of previous research (Bowling, 1989, Bronner et al., 2003, Byhring and Bo, 2002, Gamboa et al., 2008, Garrick and Requa, 1993).

Several previous studies have also shown, in accordance with the results of the present studies, that the most common site of injury is the foot and ankle region (Byhring and Bo, 2002, Gamboa et al., 2008, Garrick and Requa, 1993, Ritter and Moore, 2008, Russell et al.). In contrast, some previous studies based on self-report found the spine to be the most common site of injury in ballet dancers (Arendt and Kerschbaumer, 2003, Bowling, 1989, Ramel and Moritz, 1994). A systematic review published in 2008 evaluated 15 cohort studies, 13 cross-sectional studies, and 1 validation study performed since 1966. The authors of that review found a high prevalence of lower extremity and back injuries in dancers, with soft-tissue and overuse injuries predominating (Hincapie et al., 2008).

Overuse injuries in ballet dancers can result in long periods of sick leave. Most of the injuries in the present studies were, however, minor and did not require long absence from dancing during recovery. Most were due to overuse and permitted dancing in spite of pain, for a short period and in a restricted manner, often combined with physical therapy. The results of the study by Ramel et al. (Ramel and Moritz, 1994) showed that many dancers had musculoskeletal problems that did not affect their daily work, and did not require orthopaedic consultation. However, in study I of adult dancers, a majority of the dancers sought medical consultations because of injuries during the ballet season: 95% of the dancers employed for more than one season sought medical consultations at some time during the 5-year period.

Comparison with other youth sport activities

Although the present studies did not include comparisons with the injury rates in other youth sports activities, several previous studies of children and adolescents in other sports activities are worth mentioning. For example, data from the Swiss organization “Youth and Sports”, which engages young people aged 14–20 years in 30 different sports, showed that the highest injury incidence in boys was found in ice hockey, handball and soccer; the injury incidence rates per 1,000 activity hours were 0.86, 0.72, and 0.66, respectively (de Loes, 1995). For Swiss girls, handball, soccer and basketball had the highest injury incidence; the injury incidence rates per 1,000 activity hours were 0.76, 0.67, and 0.49, respectively (de Loes, 1995). However, the data from the Swiss study were based on visits to the emergency department and they are, therefore, not directly comparable with the data of the present study. Other studies including both overuse and traumatic injuries have found a higher injury incidence in soccer, which is one of the most common sports worldwide (Timpka et al., 2008). A Swedish survey included 1,800 soccer-playing boys aged 13–16 years from three municipalities (Timpka et al., 2008) and found that the injury incidence varied between 2.4 and 6.8 per 1,000 activity hours. For young female elite soccer players the injury incidence varied between 2.7 and 13.9 per 1,000 activity hours (Jacobson and Tegner, 2007). Game time was associated with a higher injury incidence than during practice. Previous studies have shown that young female athletes have an increased risk of suffering a traumatic injury to the knee region (Devan et al., 2004), e.g. an injury to the anterior cruciate ligament (Hewett et al., 2006, Arendt and Dick, 1995).

Söderman et al. (2001) found an increased incidence of knee injuries in female soccer players aged 16 years and younger. In study 3, we noted only 5 traumatic knee injuries among the 297 female dancers during a period of 7 years. No statistically significant gender difference was found.

Potential mechanisms behind the increased injury risk

To achieve the qualities of a professional ballet dancer, much is demanded of ballet students (Andersson et al., 1989, Micheli et al., 1984). Repetitive movements at full turnout of the hips and the lower extremities, excessive forward bending of the lumbar spine and, for girls, dancing en pointe, introduced at the age of 11–12, are examples of activities requiring a large range of motion, correct technique and adequate strength.

Three important aspects that differentiate classical ballet from other sporting activities that put the dancer at risk of suffering an injury are: (a) the female dance work en-pointe, (b) the five classical positions, with the feet in 180° turnout of the lower limbs for 4/5 positions, (c) the dance movement itself, being the goal of training resulting in repetitive movements.

The turnout ability of the hip joint in the individual dancer, determined by anatomy, also primarily sets the conditions regarding the working position for the knee and ankle joints. When full turnout is not possible in the hip joints, compensatory turnout is required in the knee and/or ankle joint (Coplan 2002). This is acquired by e.g. the dancer flectating the knee joint, positioning the feet in 180 degrees turnout before extending the knee joint with the feet position locked. This puts excessive strain on the medial aspect of the knee. To further increase the turnout ability the dancer forces the foot in pronation rendering further load to the medial aspect of the knee and the medial/ posteriomedial, and plantar aspect of the foot. Tilting the pelvis in anterior direction also facilitates the external rotation of the hip joint. The repetitive compensatory movements of the pelvis and the knee and ankle joints result in an increased torsional force and a greater risk of injury. The flexibility training of the hip joint also puts additional force on the joint and may cause injuries to the hamstring insertion on the tuber ischii.

Various anatomical and physiological factors have also been suggested as causing the increased injury risk, i.e., the level of conditioning, the lower extremity alignment and anatomy, and generalized joint laxity (Arendt and Dick, 1995, Ekstrand, 1982, Klemp and Learmonth, 1984, Schon et al., 1994).

Ankle sprain was the most common traumatic diagnosis in both genders, the majority occurring in the right ankle. A previous Swedish study (Leanderson et al., 1996) found a greater mean postural sway on the right foot during single limb stance in ballet dancers, indicating a potentially higher risk of injury (Tropp et al., 1984)

Ankle sprains are of particular concern among gymnasts as well. Like ballet dancing, gymnastics involves repetitive, extreme movements and important artistic elements. Previous studies of gymnasts have shown that the sites at which injuries typically occur are similar to those in dancers, namely the lower limbs and back (Cupisti et al., 2007, Keller, 2009). In addition, advanced-level female gymnasts commonly suffer from overuse injuries and non-specific pain in the ankle and lower back (Caine and Nassar, 2005).

Prophylactial programmes may be useful for the prevention of injuries. However, in many aspects the world of classical ballet is conservative. It is not mandatory that dancers perform a physiological warm-up programme within the daily dance routine included in the working hour schedule. This was the case in the ballet company studied in the present thesis and is likely still so in many other classical ballet companies. In contrast, in a previous study of soccer players, a prophylactic programme including strengthening exercises and a physiological warm-up reduced muscle-tendon injuries by 75% (Ekstrand, 1982). However, it is difficult to establish whether the injury risk in classical ballet dancers is actually a result of a conservative regimen towards training and/or attitudes in teachers, choreographers and ballet dancers in terms of artistic expression.

In an analysis of the risk factors for injuries in soccer, shoe wear and playing surface were judged to cause most injuries. The present ballet shoe is of very old design. The floors of many major stages slope in order to present as much as possible of the performance to the audience. This may cause additional stress to the ligaments and joints of the dancers. Thus, a newly developed shoe with shock-absorbing sole and floors that absorb shocks may prevent many injuries. A recent study from the UK explored the relationship between dance shoe type and foot pressure characteristics. The authors tested whether use of demi-pointe shoes reduces the injury risk. Demi-pointe shoes provide an intermediate pressure condition that may help the dancer to adapt more gradually to the pressure demands of pointe shoes. The authors hypothesized that, in order to "condition" the feet for advanced dance where pointe shoes are used, it may be advisable to start with the utilization of demi-pointe shoes. The results showed that dancers who wore demi-pointe shoes before starting with pointe shoes were less likely to have a ballet-related injury or a lower leg, ankle, or foot injury (22% compared to 30% in those who had not worn demi-pointe shoes). The dancers in this demi-pointe shoe group were also older when they first sustained an injury (Pearson and Whitaker, 2012). A study of ballet dancers in the USA compared stiffness of bilateral lower extremities in ballet dancers performing sauté on a low-stiffness, shock-absorbing, "sprung floor" to that during the same movement on a high-stiffness floor (wood on concrete). The stiffness of bilateral lower extremities at the point of maximum compression was significantly higher on the low-stiffness floor compared to a high-stiffness floor. The finding of increased stiffness of the lower extremities in the sprung floor condition suggests that some of the force of landing the jump was absorbed by the surface, and was therefore not absorbed by the participants' lower extremities. The authors concluded that this may imply that a sprung dance floor may help to prevent dance-related injuries (Hackney et al., 2011).

Prevention studies of injuries in other sports are also scarce. A recently published review article characterised the nature of the sport injury prevention literature by reviewing published articles that evaluated specific clinical interventions designed to reduce sport injury risks (McBain et al., 2012). Only 139 of 2525 articles retrieved met the inclusion criteria. Of these, the majority investigated equipment or training interventions whereas only 4% focused on changes to the rules and regulations that govern sport. The focus of intervention research was on acute injuries in collision and contact sports, whereas only 20% of the studies focused on non-contact sports. However, none of these articles included injury prevention programmes regarding dance sports.

Potential mechanisms behind specific injury types

The most common injuries in our studies were, as in other ballet studies, overuse injuries to the foot and ankle region. The foot and ankle region is vulnerable in classical ballet dancers. A study from the Departments of Radiology and Orthopaedics at Chelsea and Westminster Hospital in London examined MRI features of foot and ankle injuries in ballet dancers. The authors found that the causes of foot and ankle pain can be divided into four different categories: the impingement syndromes; tendon abnormalities; osseous pathology; and ligament abnormalities. They concluded that, although clinical examination mostly is sufficient, imaging is often necessary to confirm the diagnosis and ensure appropriate management (Hillier et al., 2004).

The FHL tendon is one of the most affected tendons in ballet dancers. The FHL tendon has a stabilizing function in the medial part of the ankle during demi-pointe and en-pointe positions and is frequently exposed during dance (Bowling, 1989, Byhring and Bo, 2002, Wykman and Oxelbeck, 1991). Crepitations posterior to the medial malleol due to tendinosis/tendovaginitis stenosans are frequently found in ballet dancers. The repetitive demi-pointe and en-pointe positions cause an enlargement of the FHL muscle generating an entrapment in the tarsal tunnel that causes pain during dorsal flexion of the ankle and MTP I joints. Recurrent pain may require surgery and sick leave for several weeks. Stress fractures to the metatarsals are common in ballet dancers. The most common site is a fracture to the proximal part/neck of the second (and third) metatarsals where excessive force is applied working en-pointe and demi-pointe. These metatarsals have a more fixed position than the other metatarsals, and in anatomical variations with a long second toe, the force during dance is additional. The classical "Dancer's fracture" affects the distal part of the fifth metatarsal and is often due to a supination trauma while landing (Goulart et al., 2008).

Ankle sprain was the most common injury in both the ballet students and the professional ballet dancers in the present studies. The diagnosis was most common in younger professional dancers (mean age 26.3 yrs) with a medical history of supination trauma while landing, chiefly affecting the lateral aspect of the ankle and the FTA ligament. The equilibristic movements required with increasing level of difficulty in ballet call for excellent balance, technique, and adequate proprioception of the ankle joint. In a study of the influence of ankle sprain regarding postural sway in ballet dancers by Leanderson et al. (1996), impaired proprioception in the injured ankle was registered, which was interpreted to be associated with a development of functional instability of the ankle joint. One possible mechanism is peroneal muscle weakness, leading to hyperpronation and calcaneovalgus position, leading to a medial strain to the ankle and knee joint.

Classical ballet is often performed with dancing in semi-pointe or full pointe. These two positions are unstable positions of the ankle joint that require full activity of the muscles acting around the joint. If a dancer has suffered an injury followed by muscle weakness, it may be more difficult than expected to regain full muscle function. A similar mechanism of overuse injury is seen in individuals with atrophy of the vastus medialis muscle after knee injury, leading to a lack of hyperextension of the knee, gait disorder and valgus strain. In ballet dancers, excessive force is placed on the knee joint in order to accomplish the adequate ballet positions. Achieving this position of the feet often requires a pronation of the ankle joint, also adding an inversion trauma to the ankle joint. The diminishing frequency of ankle sprains seen in the older professional dancers in the study of professional dancers (Nilsson et al., 2001) may represent acquired dancing skills and adequate strength, giving fewer sprains.

Other frequently registered injuries in our studies of ballet dancers are also seen in traditional sports. These include overuse injuries to the knee, such as Jumper's knee, Mb Osgood-Schlatter, and Apicitis patellae. Medial knee pain due to the dance specific positions with 180° turnout is also frequently seen in ballet dancers, along with patellofemoral pain often originating from poor knee control.

Back problems are common in ballet dancers (Arendt and Kerschbaumer, 2003, Bowling, 1989, Ramel and Moritz, 1994, Gamboa et al., 2008) and the aetiology and long-term effects of these injuries are not fully understood. In a radiological study of athletes, including gymnasts, Swärd et al. (1990) found a correlation between back pain and the presence of reduced disc height, Schmorl's nodes and an altered vertebra body configuration. A study by Bennett et al. examined Olympic female gymnasts physically and with MRI and found anterior ring apophyseal injuries and degenerative disk disease to be common in these athletes. An association was also seen between spondylolysis, spondylolisthesis, and one case of bilateral oedema of the L3 pedicle in gymnasts with current low back pain (Bennett et al., 2006). However, another MRI study of young competitive gymnasts concluded that in spite of the excessive axial force on the spine and the large range of motion required for practising gymnastics, damage to the intervertebral disc was uncommon in young gymnasts (Tertti et al., 1990). In an MRI study of female ballet dancers (n=20) and flamenco dancers (n=20), aged 18–31, no differences regarding the frequency of degenerative discopathy were found when compared to a control group (Capel et al., 2009). A study by Tsai et al. (Tsai and Wredmark, 1993) of former female elite gymnasts did not report a higher incidence of current back problems in comparison to matched controls. This was also reported by Piazza et al. (2009) in a study of a cohort of former elite rhythmic gymnasts.

The dance-technical differences, with male dancers carrying their female partners, reflect the origin of many injuries, but the impact of anatomical variations and radiological findings found in gymnasts and other sport athletes are not fully clarified. An incongruent muscle mass due to dominant left/right hand and previous, not adequately recovered injuries, rendering poor core muscle control, are also contributing factors in the origin of back pain. Some cases of lumbar disc herniation were found in the present studies and also some cases of stress fractures. Among the diagnoses found in the injury panorama in young and professional ballet dancers in the present studies (Leanderson et al., 2011, Nilsson et al., 2001) there is probably an overlap in the origin of back problems, where discoligamental affection in some cases is likely to be interpreted and diagnosed as being of muscular origin.

Another location, relatively frequently affected with pain, was the heel and Achilles region. In the younger dancers pain of apophycitis calcanea nature, where the insertion of the Achilles tendon is affected due to the rapid growth period, was frequently noted. In addition, symptoms of retrocalcaneal bursitis due to repetitive demi-pointe and en-pointe dancing was also seen. A symptom-causing os trigonum was also found among the diagnoses. Os trigonum is an accessory bone at the posterior aspect of the talus, most often asymptomatic, that is found in 3–15% of the population (Wykman and Oxelbeck, 1991). It may occasionally cause impingement symptoms due to repetitive extreme plantar flexion in ballet dancers. Anterior impingement is also seen in dancers, caused by an interaction in the space between the anterior face of tibia and the dorsal portion of the talar neck, which in e.g. the demi-plie position narrows and can cause entrapment of soft tissue, often as a result of osteophytes from recurrent ankle sprains (O'Kane and Kadel, 2008).

Potential mechanisms, gender differences

There were differences in injury frequency and location between the genders in study I of adult dancers. Of the traumatic knee injuries, 79% were registered in men. These findings may reflect the difference in dance technique between men and women in classical ballet. For example, male dancers perform equilibristic movements and high jumps, and this may explain why traumatic ankle and knee injuries and jumper's knee are more common in male than in female dancers, Also, male dancers are susceptible to injuries in the upper limbs since they lift their female partners during dancing. However, female dancers, whose movements are more aesthetic in character and often performed en-pointe or demi-pointe, leading to a higher load and strain on the ankle region, may suffer more injuries to the foot and ankle, especially of overuse nature.

Potential mechanisms, age differences

In the adult dancers, the risk of suffering an ankle sprain was greatest among the younger performers; 75% were found in dancers aged 26 years or younger. This is in accordance with a previous study of basketball players (Leanderson et al., 1993). A possible explanation behind this finding may be that the performing level in dancing and many other sports may improve with the number of years of training, bringing with it a better technique, increased strength, and endurance. The present finding in ballet students that a higher age implied an increased risk of suffering a musculoskeletal injury is most likely a result of more difficult movements, more time of exposure to dance and a higher degree of difficulty with increasing age.

Moreover, the injury incidence rate was higher in the ballet students than in the professional dancers. The injury panorama did somewhat alter during the school years. In the study of ballet students, injuries to the hip and groin region increased with age and training, and the incidence in the 14-year-old group was higher than in the professional dancers. Also, the incidence of foot and ankle injuries in female dancers in the same age group was more frequent than in professional dancers. This may be a result of the increasing focus on hip turnout and toe dancing. All ballet students start at the age of 10, and puberty is associated with a rapid growth period and a change of body composition, which could influence the injury incidence. During puberty, the dance training becomes harder, with increased forces on the musculoskeletal system. Additionally, the rapid growth period also results in an increased sensitivity in the growth plate of the tibial tuberosity and the apex of patella, which could lead to an increased injury incidence located to the knee region and preferably of overuse nature. Such an increased sensitivity in the os calcaneii could also lead to various degrees of apophysitis calcaneii and achillodynia, which was one of the most common diagnoses in the lower extremity. Injuries to the knee and ankle region are also determined by the turnout ability of the hip joint. When full turnout is not possible in the hip joint, an increased torsional force is put upon the knee and ankle region in the endeavour to achieve a full turnout position in the feet. This mechanism is also most frequently present among adult dancers. Four of five of the positions in ballet include 180° hip turnout. The increased stress on the joints in the lower extremities is not fully understood, and the consequences of limited joint mobility may influence injury incidence, injury location, and severity. Studies have shown that in order to acquire a full 180° turnout of the hips, the mobility training must be initiated at an early age. In a study of dance students who start dance training at 16–18 years of age, the improvement of the range of motion of the hip joint was only marginal.

Stress fractures

Fractures to the metatarsal bones are common in ballet dancers (Albisetti et al., 2010, O'Malley et al., 1996, Wykman and Oxelbeck, 1991).

There were five stress fractures in the adult dancers in study I, four of them in women. Professional dancers with stress fractures were younger (20 years) than average. In the ballet students, there were eight cases of fractures to the metatarsal bones, which could be explained by the force applied to the metatarsal region due to vigorous dance techniques and dancing en pointe. A previous study has also noted an increased frequency of stress fractures in female ballet dancers with eating disorders (Frusztajer et al., 1990).

Previous studies have shown that ballet dancers have increased bone mineral density in weight-bearing regions (Matthews et al., 2006, Kadel et al., 1992, Karlsson et al., 1993, van Marken Lichtenbelt et al., 1995, Young et al., 1994). It is possible that the increased bone mineral density occurs in experienced dancers and that it is less pronounced in younger dancers. Stress fractures at an early stage in the dancing career may have been the result of a sudden increase in hard training at a young age on hard surfaces without shock-absorbing soles.

Long-term consequences of ballet dancing on the joints

One of the previously described long-term consequences of ballet dancing on the joints is arthrosis. Previous studies have shown increased rates of arthrosis in the ankle, foot, knee, and hip joints of former ballet dancers (Andersson et al., 1989, van Dijk et al., 1995). For example, a study from the Netherlands showed that former female dancers aged 50–70 years had a significant increase in the prevalence of arthrosis in the ankle and subtalar and first metatarsophalangeal joints in comparison to controls (van Dijk et al., 1995).

Joint hypermobility and GJL

Various measures have been used to assess joint hypermobility/laxity in dancers. For example, a study of 149 dance students found that the Beighton score, Contompasis score and the 5th metatarsal dorsiflexion angle were significantly higher for dancers than controls (McCormack et al., 2004).

There are several methods and different criteria for establishing GJL in an individual. Most common is the Beighton scale which includes five different tests with the different outcome of + or –. Four out of five should be evaluated as + and the tests are: thumb opposition, digiti minimi hyperextension, elbow hyperextension, knee hyperextension and spinal hyperflexion. The tests should be performed symmetrically. However, our experience is that joint hypermobility is a continuancy parameter, following a normal distribution of joint mobility. For this reason, a lot of information may be lost by using the binominal method associated with the Beighton score. Also, in a cross-sectional British study of a population-based birth-cohort of GJL in 14-year-old children (Clinch et al., 2011), using the Beighton scale, the authors suggested that the cut-off of ≥4 was too low and not suitable for individuals with a musculoskeletal system under development, including 27.5% of the girls and 10.6% of the boys as having GJL.

Therefore, we looked for a slightly differentiated scoring system regarding joint mobility. We found the Contompasis method which used a slightly different evaluation method and gave us the opportunity of employing a method previously used and studied, and also modifying the score by adding a group which we describe as having increased joint mobility but not generalized joint laxity. In the present studies, II and IV, the modified Contompasis method was used. It comprises six different tests; five from Beighton and additionally the calcaneovalgus test. The Contompasis method allowed us, in study IV, to differentiate the magnitude of joint mobility in order to compare individuals with manifest GJL with those with low joint mobility. With this method, a result of 26–39 points represented joint hypermobility. This group suffered the least risk of injury during the follow-up period. These findings could provide ideas for future researchers on how to evaluate mobility training sessions.

Hamilton et al. (1992) have suggested that increased flexibility is an asset in the selection process for ballet dancers. It is unclear, however, whether joint hypermobility is an asset or a liability in ballet dancers. For example, Klemp et al. demonstrated that ballet dancers' capacity for forward flexion of the lumbar spine with no finger-floor distance is independent of the degree of joint hypermobility (Klemp and Chalton, 1989). The study by Hamilton et al. (1992) also suggested that hypermobility may contribute to an increased incidence of injuries in male dancers. Previous studies have indicated that some degree of hypermobility is necessary in order to pursue a professional dancing career, although it is possible that joint hypermobility is a liability in order to become a first-rate dancer (Grahame and Jenkins, 1972). In addition, the prevalence of generalized joint laxity among professional dancers is relatively low (Klemp and Chalton, 1989, Klemp and Learmonth, 1984).

Decreased joint mobility may also be associated with increased injury risk. Previous studies have found that decreased joint mobility may contribute to dance-related injuries. A study of pre-professional ballet students found an association between non-traumatic injuries and decreased joint mobility, defined as reduced functional control of turnout of the lower extremity (Negus et al., 2005). Another study found an association between decreased joint mobility (measured as lower extremity flexibility pattern) and lateral hip and knee injuries in dancers (Reid et al., 1987).

Our findings that the ballet students with manifest GJL more frequently suffered musculoskeletal injuries while the ballet students with increased joint mobility were less prone to suffer an injury (although not to a statistically significant extent) could indicate that a mild form of joint hypermobility is an asset in order to become a first-rate dancer, whereas manifest GJL may be a liability.

It has been discussed whether it is possible to achieve a greater range of motion in a joint by performing repetitive movements and working in endpoint positions. It has also been argued that ligamentous laxity may be acquired from overuse of the joint (Grahame and Jenkins, 1972, Nicholas, 1970). An increasing hip and total lower limb turnout after intense ballet training has been demonstrated in young ballet dancers (8–11 yrs), while in older students (16–18 yrs) (Bennell et al., 2001, Khan et al., 2000) only a few were able to improve their total range of motion. In the present study the assessment of joint hypermobility was performed at the age of 10 years. Therefore, we believe that the high prevalence of joint hypermobility found in our dancers was most likely not a result of excessive ballet training. It is rather a result of a selection process where young girls and boys with the prerequisites to become a ballet dancer are more likely to be chosen in the admission tests and/or choose ballet before other sports. In study II of first-year students (4th grade) at the Royal Swedish Ballet School, it was found that GJL was present in 22% of the dancers and in 5% of the controls of corresponding age and sex. However, a majority of the ballet students did not fulfil the criteria for generalized joint laxity. The controls showed a different pattern, with a majority of the group having normal joint mobility and with very few hypermobile individuals. In the controls, there was no gender difference in joint mobility. In the larger study IV, however, a gender difference in joint hypermobility was found; the girls had a higher score than the boys.

Impaired proprioception might be a possible mediator between joint hypermobility and injuries. Swedish professional ballet dancers had an impaired proprioception of the ankle joint after an ankle sprain (Leanderson et al., 1996). Likewise, a clinical study found that patients with joint hypermobility had impaired proprioception of the knee joint (Sahin et al., 2008).

Lack of motivation for adequate physical preparation might also explain the increased injury risk among young dancers with GJL. For example, a young dancer with great joint mobility could have a stronger focus on the artistic performance and a lower motivation for strengthening and coordination exercises, which may lead to insufficient muscular strength and insufficient neuromuscular proprioception.

The gender differences observed in study IV, i.e., more female than male ballet students had manifest GJL, are in accordance with previous research on children, adolescents and adults in various settings (Larsson et al., 1993, Seckin et al., 2005, Jansson et al., 2004, Seow et al., 1999). In a study of joint mobility in normally active Swedish children and adolescents (Jansson et al., 2004) girls had a higher frequency of joint laxity than boys. A study by Quatman et al. (2008) found that, after onset of puberty, girls had a higher prevalence of GJL. In a Brazilian study of preschool children, the girls had greater joint mobility (Lamari et al., 2005). A possible mechanism behind these findings is that the body composition of girls and boys changes after puberty. However, almost none of the students had entered puberty when joint hypermobility was registered, mainly at 10 years of age.

Joint hypermobility and ligamentous laxity may be associated with increased injury risk in other types of sports too. For example, in female athletes it is believed that joint laxity is a factor predisposing for the development of knee injuries. In a study of female high-school and collegiate soccer and basketball players, increased knee laxity implied an increased risk of suffering an ACL injury (Myer et al., 2008).

These findings are in accordance with another American study of 33 physically active females (age 21 +-2.1) where GJL was identified as one of the variables most significantly related to ACL injury (Kramer et al., 2007). That study also found a significant association between ACL injury risk and previous ankle injury. In a study of Australian junior netball players (6–16 years) hypermobility was significantly associated with an increased injury incidence (Smith et al., 2005).

It has also been suggested that hypermobility predisposes to the various clinical conditions used as major or minor criteria for benign joint hypermobility syndrome (BJHS), e.g., arthralgia, low back and pelvic pain, joint luxation, soft-tissue rheumatism, abnormal cutis or genitourinary prolapse, varicose veins and hernia (McCormack et al., 2004).

A previous study from Denmark examined adults with generalized joint hypermobility. These individuals may experience symptoms such as pain and joint instability, which is likely to influence their gait pattern. The purpose of the Danish study was to perform a biomechanical gait analysis on a group of patients with generalized joint hypermobility and compare them to a group of healthy subjects. The subjects were filmed while walking on force platforms and net joint moments were calculated. The findings that adults with generalized joint hypermobility displayed higher joint moments during walking in both the frontal and the sagittal planes and increased knee joint loadings led the authors to conclude that this may explain the pain symptoms in this patient group (Simonsen et al., 2012).

Eating disorders in ballet dancers and injuries

Although eating disorders were not assessed in the present thesis, it has been shown that ballet dancers have a higher risk of developing eating disorders. A study from the USA examined whether disordered eating is associated with musculoskeletal injuries among 239 adolescent female ballet students. The dance students reported a variety of lifetime disordered eating behaviours including fasting (29.3%), vomiting (9.6%), and laxative use (4.2%). More than half (52.3%) reported a lifetime history of injury (stress fracture, broken bone, and/or medically treated tendonitis). A greater number of lifetime disordered eating behaviours was associated with a greater number of lifetime injuries (P=0.01). Moreover, vomiting history was associated with greater likelihood of injury (P=0.004) and increased time to recover from injury (median difference=22.8 days, P=0.006) (Thomas et al., 2011).

Ballet dancing emphasizes low body weight for optimal performance, which sometimes may predispose for the female athlete triad (FT). FT is characterized by disordered eating, menstrual irregularity, and low bone mass (Nichols et al., 2006). A study from Virginia compared the physical and behavioural characteristics of female elite ballet dancers to sedentary, recreationally active non-dancing controls. Six of the 15 dancers met the criteria for the FT (including low bone mineral density, menstrual irregularities, and eating disorders). The authors concluded that interventions aimed at preventing eating disorders in elite female ballet dancers may be needed to promote optimal health status (Doyle-Lucas et al., 2010)

Differences between classical ballet and modern dance

Researchers from the UK used time motion and video analysis of classical ballet and contemporary dance performance to examine possible performance differences. In total 93 dance performances (48 ballet and 45 contemporary) were examined for exercise intensity, changes in direction and specific discrete skills (e.g. jumps, lifts). Results revealed significant differences between classical ballet and contemporary dance for exercise intensity, changes in direction, and discrete skills. Ballet was characterised by longer periods at rest and high to very high exercise intensities, whilst contemporary dance was characterised by more continuous moderate exercise intensities. The authors concluded that these differences may have implications for the energy systems utilised during performance with ballet, potentially stressing the anaerobic system more than contemporary dance, and that the observed high rates in the discrete skills in ballet (5 jumps/min; 2 lifts/min) may cause local muscular damage, e.g. in relatively weaker individuals. To sum up, classical ballet and contemporary dance performances seem to be as significantly different in the underlying physical demands placed on their performers as the artistic aspects of the performance (Wyon et al., 2011).

A study from the USA examined the effect of comprehensive management (case management and intervention) on injury incidence, time loss, and patterns of musculoskeletal injury in a modern dance organization (Bronner et al., 2003). The comprehensive management included early and effective management of overuse problems before they became serious. Injury data were analysed in 42 dancers over a 5-year period, 2 years without intervention and 3 years with intervention. The number of dance days missed and workers' compensation cases because of injury were also compared across the 5-year period. The results showed that the intervention significantly decreased the number of days lost from work by 60% and reduced the annual number of new workers' compensation cases from a high of 81% to a low of 17%. Most new injuries occurred in younger dancers before the implementation of this programme. The results also showed that most injuries involved overuse of the lower extremity, similar to injuries reported in ballet companies. The similar types of injuries in the modern dance company suggests that comprehensive management with early and effective management of overuse problems before they become serious may be beneficial for classical ballet dancers as well.

Prevention measures

In a recently prepublished US study (Roberts et al., 2012) of 113,084 children, aged 3–19, seeking treatment in an emergency department for dance-related injuries, the lower extremity was the most common site of injury, with sprains and strains being the most common injuries. Forty percent of the injuries were found in dancers 15–19 years of age. The authors stated that further research is required regarding the design of age-specific preventive measures. The incidence of acute injuries has also been examined in a German study by Wanke et al. (2012) in which the findings are in agreement with the American article quoted above. A recently prepublished British study of professional dancers (Allen et al., 2012) has demonstrated an injury incidence of 4.4 injuries/1,000 hours of activity (females 4.1, males 4.8, $P<0.05$) with a mean of 6.8 injuries/dancer in

52 professional dancers over a study period of 1 year, indicating a great need for preventive measures.

The injury panorama found in young and professional dancers, as published in the studies included in this thesis, where ankle sprain represents the most common injury, indicates that a focus on preventive actions against primary, as well as recurrent sprains, should have high priority when injury prevention programmes are designed, and that a history of a previous ankle sprain should be obtained and taken ad notam. Early and mandatory strengthening exercises, including training with emphasis on balance and coordination, widely used in the rehabilitation process following an ankle injury, could perhaps be applied as a primary preventive measure in order to reduce the frequency of ankle sprains. This treatment facilitates the proprioceptive development that might account for a decrease in the incidence of ankle sprains found in the studies in this thesis.

In a review of hypermobility and musculoskeletal pain in children (McCluskey et al., 2012) four large databases were searched and 13 studies were included. Surveys performed in specific groups, e.g. dance, were excluded. No association was found between joint pain and hypermobility in Europeans, while differences were registered for Afro-Asian children. However, a previous study by El-Metwally et al. (2005) evaluated the influence of lower limb pain in 1,756 children between 3rd and 5th grade, and found that non-traumatic pain in pre-adolescent children was most often recurrent. Furthermore, joint hypermobility (Beighton score >5) was the only factor in pre-adolescent children, indicating a 3-fold increased risk of recurrent pain during adolescence.

In the study by McCormack et al. (2004) the authors concluded that the presence of BJHS was clearly not contradictive to a ballet-dancer career, and that the findings of BJHS being common among ballet dancers should not require a selection procedure for admission to professional ballet schools; it was, on the other hand, likely to identify individuals with BJHS in order to prevent future injuries. A 5-year follow-up of the same students (Briggs et al., 2009) using a self-reporting questionnaire with a response rate of 69%, was also performed where the frequency and type of injuries and sick leave >6 weeks was noted. There were significant differences in both male and female dancers regarding tendon injuries and sick leave >6 weeks. These results confirmed the authors' impression that joint hypermobility in dancers indicates vulnerability and susceptibility to prolonged healing following injury, and it was concluded that preventive actions in terms of early recognition and intervention are important. The findings in this thesis regarding GJL and injuries in ballet dancers confirm the results of previous studies indicating that GJL should be regarded as a risk factor in the development of musculoskeletal injuries in ballet dancers.

In the fields of rehabilitation and physical therapy, scientific knowledge and experience regarding sports injuries has greatly expanded in recent decades. Evidence-based medicine is being implemented within the everyday work routine of physical therapists, naprapaths and dance instructors working in the field of ballet. However, dance is an art form, and competition amongst ballet dancers is hard. Dancing despite injuries is common among ballet dancers because there is always another dancer evidently ready to replace the injured dancer. Therefore, education of young ballet dancers, imparting knowledge about anatomy, age-specific injury mechanisms, and preventive training, ought to be mandatory.

In order to improve the education and optimize the preparation of students in the Swedish ballet schools (grade 4–9) for additional studies at the upper secondary school level, and meeting the standards of a professional dancer, a new admission regime has recently been applied, conducted by the National Agency for Education. Subject-specific goals and standards for grading systems are included. Mandatory training regimes, e.g., core, strength, and endurance training, taken from evidence-based knowledge, could explicitly be considered for appliance within the official document of learning activities for young ballet dancers in Sweden. In the present study of the injury panorama in Swedish professional ballet dancers (Nilsson et al., 2001), a period of change in the repertoire brought about an increase in the injury frequency. This might indicate the need for individual, production-specific preventive intervention measures, allowing the dancer to be prepared to meet the specific demands of the individual difficulties in each ballet.

In the same study, traumatic knee injuries were more common in male dancers. Hypermobility of the knee joint has been associated with anterior cruciate ligament (ACL) injuries (Myer et al., 2008), and it has also been noticed that the post-operative outcome after an ACL reconstruction in patients with GJL is more often unsatisfactory (Kim et al., 2010). In a study by Ramesh et al. (2005) 169 patients undergoing ACL reconstruction were studied regarding injury mechanisms and joint laxity. Statistically significant associations were registered in terms of joint laxity (42.6% of injured patients) and hyperextension of the knee (78.7% of injured patients).

In a stratified cluster randomised controlled trial in order to evaluate the effect of a 15-minute neuromuscular warm-up programme in adolescent Swedish female soccer players (Walden et al., 2012), the overall rate of ACL injury was reduced by 64%. In total, 4,565 players (aged 12–17) in 230 Swedish football clubs participated in the study. The warm-up programme was to be practised twice a week and included training features regarding core stability, balance and proper knee alignment. Adapting knowledge from traditional sports, such as those mentioned above, could help reduce the injury frequency in ballet, and provide a breeding ground for a reduction of the persistent incidence of musculoskeletal injuries in ballet dancers.

LIMITATIONS AND STRENGTHS

One possible limitation of the study of adult dancers is that some cases may be lost as the orthopaedic consultant (AW) was present in the Opera House only once a week. However, both professional and young ballet students were seen, whenever necessary, by the same orthopaedic consultant (AW) at Karolinska University Hospital on the remaining days of the week. Although all dancers with musculoskeletal injuries requiring sick leave during the period of the study were examined by the orthopaedic consultant, injuries causing no or only 1–2 days of absence from dancing may have been lost in a study such as this. Further, the members of the Royal Swedish Ballet are not obliged to seek naprapathic or orthopaedic medical care within the Opera House. This is only a service offered to the dancers within the company. However, we believe that the majority of all injured dancers sought medical care within the Opera House. In addition, the naprapathic service was given daily and the devices for training and physical therapy were utilized by all injured dancers. The naprapath also worked in close collaboration with the orthopaedic consultant. A similar limitation of the studies of the ballet students exists as the students may have sought treatment at medical institutions other than the school health care unit for injuries that occurred during emergency hours. However, in order to document all injuries sustained, all students and parents were asked, on a voluntary basis, to report any institutional and non-institutional care that the students received outside the school health care unit (including paramedic care). However, the "true" injury incidence may have been slightly underestimated, although injuries not included in our data are likely to be few and/or minor. In addition, similar to the adult dancers, the rehabilitation and training regimens following injuries were recorded by the orthopaedic consultant and the school naprapath, working in collaboration. The naprapathic service was available daily and devices for training and physical therapy were utilized by all injured ballet students in the school. This increases the possibility of capturing a large proportion of all injuries. Moreover, the long study period should ensure that the injury patterns described are fairly representative. Another limitation of the data used in the present studies is that they were based on relatively old medical records. However, the results are still valid as they concur with those of more recent studies; the results showed that the magnitude of the injury rates was in accordance with studies based on more recent data. Moreover, dance training has most likely not changed significantly in the years since the period covered by the study. The definition of GJL was assessed by the modified Contompasis method (as described by McNearney). Although the Beighton scale is commonly used, we found it favourable to visualize not only the presence of GJL but also various degrees of joint hypermobility. We registered all laxity scores only at 10 years of age, which could be considered a limitation. However, the joint laxity score changed only slightly between ten and 15 years of age, and the gender ratio remained consistent according to a previous Swedish study (Jansson et al., 2004).

Finally, many soft-tissue injuries are, by their nature, difficult to classify clinically. Therefore, it is likely that some overlap exists between different types of diagnoses. A key strength of study IV is its prospective nature. It is, if not the first, one of the first prospective studies that has investigated the longitudinal association between joint mobility and injury risk in young dancers. Another strength is that the drop-out from the Royal Swedish Ballet School is low; only a few per cent of the students entering fourth grade dropped out.

CONCLUSIONS

The findings of the studies included in the present thesis are that there is a need to apply primary injury prevention in young and adult ballet dancers. The findings also indicate that GJL is likely to be a liability for the dancer and an important factor in the risk of suffering musculoskeletal injuries. This means that young ballet dancers with GJL need special attention in order to prevent injuries. Future studies could aim to further identify injury risk factors and to evaluate the effectiveness of different injury prevention programmes at reducing injury rates in ballet dancers. Future studies should also investigate what type of training could protect young ballet dancers with GJL from injuries.

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SVENSK SAMMANFATTNING/SWEDISH SUMMARY

SYFTE

Att kartlägga förekomst och typ av muskuloskelettala besvär hos klassiska balett-dansare, att analysera dessa skador i förhållande till sjukfrånvaro, samt att försöka identifiera riskfaktorer hos dansare med frekventa skador vid Operabaletten, Stockholm (*Studie I*).

Att analysera spinal sagittal rörlighet och överrörlighet i leder hos unga balettdansare vid Kungliga Svenska Balettskolan, Stockholm, i jämförelse med en kontrollgrupp (*Studie II*).

Att studera förekomsten av muskuloskelettala besvär, lokalisation och typ av skada, samt de vanligaste diagnoserna, hos unga balettelever vid Kungliga Svenska Balettskolan i Stockholm (*Studie III*).

Att undersöka ålders- och könsspecifika samband mellan ledrörlighet, generaliserad överrörlighet i leder och muskuloskelettala besvär, hos unga balettelever vid Kungliga Svenska Balettskolan, Stockholm (*Studie IV*).

METOD

I *studie I* har 98 professionella balettdansare (48 män, 50 kvinnor, medelålder 28,3 (17–47)) vid Operabaletten i Stockholm studerats i en kombinerad retro-prospektiv studie. Alla skador, för vilka dansarna sökte Operans läkarmottagning under perioden aug 1988 – jun 1993, registrerades. Skadeincidens per 1000 aktivitetstimmar beräknades och χ^2 test och oparat t-test användes för statistisk analys. I *studie II* undersöktes 23 danselever (11 pojkar, 12 flickor) i årskurs 4 vid Kungliga Svenska Balettskolan i Stockholm avseende spinal konfiguration och sagittal rörlighet med hjälp av De Brunners kyphometer och Myrins inklinometer. Ledrörlighet registrerades genom användande av en modifierad form av Contompasis-metoden. Resultaten jämfördes mellan dansarna samt med 36 ålders- och könsmatchade kontroller i årskurs 4, vid en kommunal skola. Student's t-test användes för statistisk analys. I *studie III* studerades 476 studenter (297 flickor och 179 pojkar) i åldern 10–21 år vid Kungliga Svenska Balettskolan i Stockholm i en retrospektiv journalstudie. De skador för vilka eleverna sökt skolans läkarmottagning registrerades i separata formulär. Uppgifter om diagnos, skadelokalisation, samt typ av skada kartlades. Skadeincidens per 1000 aktivitets-timmar beräknades. Statistiska skillnader avseende skadeincidens mellan könen, åldersgrupper och för typ av skada beräknades och t-test användes för att testa statistiskt signifikanta skillnader. I *studie IV* undersöktes 216 (130 flickor, 86 pojkar) balettelever (aug 1988 – juni 1995) avseende ledrörlighet genom användande av den modifierade Contompasis-metoden. Resultaten indelades i tre grupper för differentiering av ledrörligheten. Skadejournaler analyserades och samtliga skador under den aktuella perioden hos dessa elever registrerades. Skadeincidens per 1000 aktivitetstimmar beräknades. För statistisk analys användes en riskmodell med tillämpning av Cox-regression.

RESULTAT

I *studie I* drabbades 95 % av de 98 dansarna av en skada under en anställningstid på minst ett år. Dansarna erfor sammanlagt 390 skador under studieperioden på 5 år: 0,6 skador/1000 aktivitetstimmar. De flesta skadorna var av överbelastningskaraktär och var lokaliserade till fot- och ankelregionen. Signifikanta köns- och åldersskillnader förelåg avseende skadepanoramat. Kvinnliga dansare drabbades oftare av överbelastningsskador emedan manliga dansare oftare uppvisade knäskador. Fotledsdistorsion var den vanligaste diagnosen och var mest förekommande bland dansare <26 år. Balettdansarna i *studie II* hade mindre framträdande thorakal kyfos och lumbal lordos samt visade en högre incidens av generell ledrörlighet, i jämförelse med kontrollgruppen. I *studie III* beräknades skadeincidensen till 0,8/1000 aktivitetstimmar. Skadefrekvensen tenderade att öka med stigande ålder. De unga dansarna uppvisade ett skadepanorama liknande det hos de professionella vuxna dansarna i studie I. De flesta skadorna var av överbelastningskaraktär, mest frekvent tendiniter/tendinoser kring fotleden. Fotledsdistorsion var den vanligaste akuta skadan. *Studie IV* visade att fler kvinnliga dansare (32,3 %) än manliga dansare (15,1 %) företedde generaliserad överrörlighet i lederna (GJL). En väsentligt ökad skaderisk återfanns bland studenter med GJL (hazard ratio=1,62, 95 % CI=1,09–2,39). Högre ålder medförde en ökad skaderisk och interaktionstest visade en särskilt ökad skaderisk bland dem >10 år med en manifest GJL.

SLUTSATS

Muskuloskelettala besvär är vanliga hos både unga och vuxna balettdansare. Sambandet mellan GJL och en ökad skaderisk hos de unga balettdansarna utgör indikation för ett behov av screeningprogram avseende GJL samt utveckling och tillämpning av primärpreventiva åtgärder för att förebygga belastningsskador hos unga balettdansare.

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