From the department of Molecular Medicine and Surgery, Stockholm Sports Trauma Research Center, Karolinska Institutet, and the Swedish School of Sport and Health Sciences, Stockholm, Sweden

Swedish TeamGym –
Injury incidence, mechanism, diagnosis and postural control

Marita L Harringe

Stockholm 2007

Published by Karolinska Institutet.

ISBN 978-91-7357-415-0

Printed by
REPROPRINT AB
Stockholm 2007
www.reproprint.se
Gårdsvägen 4, 169 70 Solna

ABSTRACT

Teamgym is a fairly new and popular form of gymnastics originating in Scandinavia. Among the gymnastics disciplines teamgym attracts the highest number of gymnasts in Sweden. The discipline differs in several ways from the most known form of gymnastics, artistic gymnastics. It is therefore important to study injury incidence, mechanism and diagnosis in teamgym to be able to develop relevant injury prevention programs.

Aim: The main aim of the present thesis was to study injury incidence, injury mechanism, injury site and diagnosis in Swedish teamgym. A second aim was to evaluate if specific exercises for segmental muscle control of the lumbar spine can prevent or reduce low back pain in young female gymnasts. A third aim was to study if, and in that case how, low back pain or lower extremity injuries influence postural control, and also to evaluate the reliability of postural control measurements.

Material and method: This thesis included gymnasts during practice and competition. One hundred and eighty-eight gymnasts answered a questionnaire during a National Championship for male and female juniors as well as seniors (study I). Forty-two top level senior male and female gymnasts were followed during one season of training and competition and injuries were registered with respect to diagnosis and mechanism (study II). Fifty-one young top level female gymnasts reported low back pain during a period of 12 weeks. At inclusion they were divided in one intervention group and one control group. After four weeks of baseline an eight-week training program including specific exercises for segmental muscle control of the lumbar spine was introduced and evaluated (study III). Finally, fifty-seven female gymnasts were measured in upright standing on an AMTI force platform (study IV). They were measured standing on hard and foam surface with eyes open and eyes closed during 120 seconds, respectively. A test-retest was conducted to determine the reliability of these measurements.

Results: Teamgym gymnasts practice and compete in spite of symptoms from injuries. The injury incidence in top level teamgym was 2.2 / 1000 gymnastics hours, and there was no difference between male and female gymnasts. Most injuries were found in the lower extremity, with the ankle joint being most often injured. The second most injured site was the lower back, where muscle and ligament injuries were represented. The most frequent injury mechanisms were joint compression, joint rotation and hyperextension, and the landing phase of the gymnastics skill was most critical. Half of the injuries were reported at the end of the training session and often while the gymnasts were in a negative state of mood such as stressed or afraid. Gymnasts with low back pain did not experience pain every day. During a period of one month 24 out of 51 gymnasts reported low back pain between one and 28 days. After an eight-week training period with specific exercises for segmental muscle control of the lumbar spine, the intervention group was significantly improved with respect to less number of days with low back pain. A tendency towards the opposite was revealed in the control group. Gymnasts with low back pain showed a larger area of center of pressure, standing on foam surface with eyes closed, than gymnasts with lower extremity injuries. Only gymnasts with low back pain reported pain at the test occasions. Tests with eyes closed were more reliable than tests with eyes open and tests during 120 seconds were in most cases more reliable than tests during 60 seconds.

Conclusions: Top level teamgym gymnasts practice and compete in spite of symptoms from injuries. The ankle joint and the lower back are the most common sites for injuries. Gymnasts with low back pain show altered postural control compared to gymnasts with lower extremity injury. This may be due to pain. A specific muscle training program of the local lumbar muscles reduced the number of days with low back pain in young female gymnasts.

SVENSK SAMMANFATTNING (SWEDISH SUMMARY)

Bakgrund: Truppgymnastik är en ung tävlingsform med sitt första svenska mästerskap 1980. Det är en snabbt växande gymnastikform och idag finns både nordiska och europeiska mästerskap samt tävlingar på ungdomsnivå över hela världen. I Sverige är det den mest utövade formen av tävlingsgymnastik med 14 807 licensierade truppgymnaster (12.768 kvinnliga och 2.039 manliga gymnaster) jämfört med 1.388 individuella tävlingsgymnaster (1.002 kvinnliga och 386 manliga gymnaster), år 2007. Det bör dock nämnas att endast ett fåtal av dessa gymnaster tävlar på nationell och internationell nivå.

Truppgymnastik är en lagsport och avgörs i följande tre grenar: tumbling, trampett och fristående. På elitnivå (junior och senior) består laget av 6-12 gymnaster som utför övningarna som ”en enhet” och prestationen i varje gren poängbedöms med en siffra. På ungdomsnivå kan lagen bestå av upp till 16 gymnaster. Sporten är under ständig utveckling och i och med internationaliseringsprocessen har redskapen anpassats och standardiserats. Eftersom sporten är relativt ung och skiljer sig med avseende på redskap och tävlingsform från den mer klassiska tävlingsgymnastiken, artistisk gymnastik, är det av stor vikt att sporten följs och skador registreras. Detta kan i sin tur möjliggöra utveckling av skadeförebyggande åtgärder.

I studie I och II har skadebild, skadeincidens, de vanligaste diagnoserna samt skademekanismer inom truppgymnastik kartlagts. Dessa två studier ligger till grund för studie III och IV. Syftet med dessa studier var att undersöka om specifik stabiliserande segmentell träning av ländryggens muskler kan förebygga eller minska ländryggsbesvär samt om och i så fall hur ländryggsbesvär och skador i nedre extremitet påverkar postural kontroll hos truppgymnaster.

Studie I

Titel: Do team gymnasts compete in spite of symptoms from an injury?

Harringe ML, Lindblad S, Werner S. *Br J Sports Med 2004;38:398-401*

Syfte: Syftet med denna studie var att kartlägga skadebild samt undersöka om truppgymnaster tävlar trots att de har besvär från någon skada.

Material & metod: Etthundraåttioåtta gymnaster som deltog på Svenska cupen eller Juniorcupen 1996 besvarade en enkät bestående av frågor avseende skador och besvär på tävlingsdagen (Appendix A).

Resultat: Femtioåtta procent av gymnasterna (110 av 188) tävlade trots att de rapporterade besvär från en eller fler skador. Sextiofem procent (n=95) av skadorna återfanns i nedre extremitet, varav fot/fotled var den vanligaste skadelokalisationen (34%, n=37), och 22% (n=32) av skadorna återfanns i ryggen. Femtiofem procent (n=103) av gymnasterna uppgav att de hade haft upprepade besvär med någon skada någon gång under deras tid som gymnaster. Ryggen var det vanligaste området för upprepade besvär. Gymnaster som rapporterade upprepade besvär från knäleden hade en högre BMI än gymnaster som inte rapporterade upprepade besvär från knäleden.

Studie II

Titel: Injury incidence, mechanism and diagnosis in top level teamgym: a prospective study conducted over one season.

Harringe ML, Renström P, Werner S. *Scand J Med Sci Sports 2007;17:115-119*

Syfte: Syftet med denna studie var att studera skadebild, typ av skada och skademekanismer inom truppgymnastik på elitnivå.

Material & metod: En manlig och en kvinnlig gymnastiktrupp (n=42), med internationell erfarenhet, tillhörande de främsta inom svensk truppgymnastik deltog i studien. Gymnasterna följdes prospektivt under en tävlingssäsong. Samtliga gymnaster som ådrog sig skador under säsongen undersöktes och diagnosticerades av medicinsk personal och skadorna registrerades.

Resultat: Totalt inträffade 42 skador vilket motsvarade 2.2 skador / 1000 gymnastik-timmar. Incidensen skilde sig inte mellan manliga och kvinnliga gymnaster. Tjugosex skador var lokaliserade till nedre extremitet och fotledsdistorsion var den vanligaste skadan. Totalt ådrog sig gymnasterna tolv skador i ryggen. Åtta av dessa skador drabbade ländryggen av vilka muskel- och ligamentskador var vanligast. Gymnasterna ådrog sig fyra skador i övre extremitet. De flesta skadorna inträffade i nedslaget av en övning och de vanligaste skademekanismerna var kompression och / eller rotation i en led. Detta som en följd av över- eller underrotation i samband med nedslag. Hälften av skadorna inträffade eller rapporterades i slutet av träningen och gymnasterna uppgav ofta att de kände sig stressade och trötta i skadeögonblicket.

Studie III

Titel: Low back pain in young female gymnasts and the effect of specific segmental muscle control exercises of the lumbar spine: a prospective controlled intervention study.

Harringe ML, Nordgren JS, Arvidsson I, Werner S. *Knee Surg, Sports Traumatol, Arthrosc 2007;15:1264-1271*

Syfte: Syftet med denna studie var att utvärdera om stabiliserande segmentell muskelträning kan förebygga eller minska ländryggsbesvär hos unga elitaktiva kvinnliga truppgymnaster.

Material & metod: Femtioen unga kvinnliga truppgymnaster (11-16 år) från tre olika gymnastikföreningar i Stockholm deltog i studien. Trupperna tillhörde Sveriges bästa trupper på ungdomsnivå, och samtliga gymnaster i studien tränade för att deltaga på ungdoms- SM direkt efter studieperiodens slut. Två av de tre föreningarna utgjorde interventionsgrupp (n= 33), och den tredje kontrollgrupp (n=18). Studien pågick i 12 veckor. Under denna period svarade samtliga gymnaster, från såväl interventionsgruppen som kontrollgruppen dagligen på frågan: ”Har du haft ont i ryggen idag?” Om ”ja” ombads gymnasten att markera smärtlokalisationen med ett kryss på en smärtteckning samt beskriva intensiteten enligt Borg´s CR10-skala (Appendix F). Gymnasterna ombads även att beskriva vad som förvärrade och vad som lindrade besvären. Efter fyra veckors

”baseline” instruerades interventionsgruppen i specifik ländryggsstabiliserande muskelträning med progressiv stegring. Träningen genomfördes gemensamt för respektive trupp i samband med uppvärmningen och pågick i åtta veckor.

Resultat: Tjugofyra av gymnasterna (47%) rapporterade besvär från ländryggen under de första fyra veckorna. Gymnasterna hade ej dagliga besvär. Nio gymnaster exkluderades från den fortsatta analysen då de ej hade svarat regelbundet på frågorna. Efter träningsperioden hade ryggbesvären hos gymnasterna i interventionsgruppen signifikant förbättrats genom färre dagar med smärta. I kontrollgruppen kunde ingen förändring påvisas, men en tendens till försämring med avseende på antalet dagar med smärta förelåg (p=0.06). Åtta (av 15) gymnaster i interventionsgruppen var helt besvärsfria efter studieperiodens slut och 14 (av 15) gymnaster i interventionsgruppen utan besvär vid studiens start ådrog sig inga besvär under studiens gång. Tre (av 8) gymnaster i kontrollgruppen ådrog sig besvär under studiens gång och en (av 4) gymnaster blev besvärsfri. Då förändring över tid jämfördes mellan grupperna förelåg en skillnad både avseende antalet dagar med smärta och den maximalt skattade smärtintensiteten.

Studie IV

Titel: Postural control measured as center of pressure excursion in young female gymnasts with low back pain or lower extremity injury.

Harringe ML, Halvorsen K, Renström P, Werner S. *Accepterad för publikation i Gait & Posture 2007*

Syfte: Syftet med denna studie var att undersöka om och i så fall på vilket sätt ländryggsbesvär och nedre extremitetsskador påverkar postural kontroll. Dessutom var syftet att studera reliabiliteten vid mätning av postural kontroll samt hur tiden vid försöket påverkar mätningen.

Material & metod: Femtiosju kvinnliga truppgymnaster (12-21 år) från tre gymnastikföreningar i Stockholm deltog i studien. Gymnasterna delades in, i förhållande till skadelokalisation i följande fyra grupper: besvärsfria gymnaster (NI, n=18), gymnaster med ländryggsbesvär (LBP, n=11), gymnaster med skada i nedre extremitet (LEI, n=17) och gymnaster med både ländryggsbesvär och skada i nedre extremitet (MI,

n=11). Postural kontroll mättes med en AMTI kraftplatta (Accusway, Massachusett ins, USA) och rådata bearbetades med hjälp av Matlab®, Natick, USA. Insamlingsfrekvensen var 50 Hz. Gymnasterna stod barfota, på båda fötterna, med armarna längs sidorna. Mätningarna genomfördes på hårt underlag, med öppna och slutna ögon, och på mjukt underlag, med öppna och slutna ögon. Vidare genomfördes en test-retest av mätningarna med en veckas mellanrum. I denna reliabilitetsstudie ingick 35 av gymnasterna: gymnaster utan besvär (NI, n=9), gymnaster med ländryggsbesvär (LBP, n=7), gymnaster med skada i nedre extremitet (LEI, n=8) och gymnaster med både ländryggsbesvär och skada i nedre extremitet (MI, n=9). Två gymnaster exkluderades då de ådrog sig ytterligare skador mellan de två testtillfällena.

Resultat: Vid mätning av postural kontroll på mjukt underlag och med slutna ögon förelåg ett större svaj, mätt som ”center of pressure” (COP) area, hos gymnaster med ländryggsbesvär jämfört med gymnaster med skada i nedre extremitet. Bäst reliabilitet förelåg vid mätning på mjukt underlag med slutna ögon under 120 sekunder.

TABLE OF CONTENTS

LIST OF ORIGINAL PAPERS

This thesis is based on the following original papers. Each paper will be referred to by its Roman numeral (Study I-IV). In addition, some hitherto unpublished results are presented.

I **Do team gymnasts compete in spite of symptoms from an injury?**
Marita L Harringe, Staffan Lindblad, Suzanne Werner.
Br J Sports Med 2004;38:398-401.

II **Injury incidence, mechanism and diagnosis in top level teamgym: a prospective study conducted over one season.**
Marita L Harringe, Per Renström, Suzanne Werner.
Scand J Med Sci Sports 2007;17:115-119.

III **Low back pain in young female gymnasts and the effect of specific segmental muscle control exercises of the lumbar spine: a prospective controlled intervention study.**
Marita L Harringe, Jeanette S Nordgren, Inga Arvidsson, Suzanne Werner.
Knee Surg, Sports Traumatol, Arthrosc, 2007;15:1264-1271.

IV **Postural control measured as center of pressure excursion in young female gymnasts with low back pain or lower extremity injury.**
Marita L Harringe, Kjartan Halvorsen, Per Renström, Suzanne Werner.
Accepted for publication in Gait & Posture 2007

ABBREVIATIONS

Abbreviations as used in the present thesis.

AG	Artistic Gymnastics
ANOVA	Analysis of Variance
Ant-post	Anterior-Posterior
BMI	Body Mass Index
COM	Center of Mass
COP	Center of Pressure
CNS	Central Nervous System
CV	Coefficient of Variance
IASP	International Association for the Study of Pain
ICC	Intraclass Correlation Coefficient
LBP	Low Back Pain
LEI	Lower Extremity Injury
MI	Multiple Injuries
MDC	Minimally Detectable Change
Med-lat	Medial-Lateral
NAIRS	National Athletic Injury Registration System
NI	Non-Injured
RMS	Root Mean Square
SEM	Standard Error of Measurement
SD	Standard Deviation
TG	TeamGym

DEFINITIONS

Definitions as used in the present thesis.

Abdominal hollowing: is a drawing-in action of the abdominal wall, especially the lower abdominal area, aiming to achieve an isometric co-contraction of the local muscles of the lumbar spine, the transversus abdominis and multifidus muscles, in particular (Richardson & Jull, 1995).

COM: is the location in three-dimensional space of the weighted average of the COM of each body segment. It is the point through which the gravity can be said to act (hence sometimes also referred to as center of gravity). (Winter, 2005)

COP: is the point of application of the ground reaction force, measured by a force platform. CNS controls the COP through muscle activation, in order to maintain balance. (Winter, 2005)

Ellipse area: is the COP excursion enclosed inside the 95% ellipse, measured in cm^2, calculated from the force platform measurements.

Hyperextension: is defined as a joint exceeding its normal range of motion. This can, for example, be the result of an un-controlled take-off from the trampette. In this thesis this mechanism resulted in cases of muscle injury to the lower back.

Injury: is defined as ‘any physical complaint’; in study II the definition was: injury, i.e. any physical complaint, leading to modified practice or absence from practice during one week or more

Joint compression: is defined as a force compressing two or more bones of a joint. This can, for example, be the result of a back somersault not completed at landing, a so called under-rotation. In this thesis this mechanism resulted in cases of internal ankle joint injury.

Joint rotation: is defined as one part of a joint being fixed, while the other rotates. This can, for example, be the result of a twist, which is not completed at landing. The rotation continues while the foot is stuck to the landing mat. In this thesis this mechanism resulted in cases of ligament injury to the ankle joint.

Low back pain: is defined as pain in the area between the level of the 12th rib and the gluteal folds (Biering Sörensen, 1983; Papageorgiou, 1995; Watson, 2002)

Overuse: is defined as an injury or a symptom that has been gradually developed over a period of time. This can, for example, be the result of performing landings and take-offs on various types of surfaces. In this thesis this mechanism resulted in cases of medial tibial syndrome.

Pain: is defined as 'an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage' (IASP) (Merskey, 1986, 1994)

Re-injury: in the present thesis re–injury is defined as 'a repeated injury to the same site (study I) or same anatomic structure (study II), regardless of time between injury occasions'

Symptoms: is defined as 'remaining problems (i.e. physical complaints), of any kind, such as pain, swelling or instability, from a previous injury, irrespective of severity'

INTRODUCTION

Gymnastics – the state of the art

Gymnastics is performed in a "million" ways all over the world. It is performed as general exercises or as more pre-decided exercises as in competitive or military gymnastics. In 1813 Per Henrik Ling (1776-1839) founded the Swedish School of Sports and Health Sciences. The Swedish gymnastics educated at the school was founded by Ling and was together with "Turnen" from Germany and "Sports" from England the most performed forms of gymnastics until the middle of the 20th century. Gymnastics in all forms includes a large portion of body control and top level gymnasts use their bodies to perfection.

Teamgym

Picture 1. Floor programme performed by GT Vikingarna, Stockholm, Sweden.
Reprinted with permission from Peter Lindholm ©.

Teamgym is a new and popular form of gymnastics originating in Scandinavia. Among the disciplines of gymnastics, teamgym attracts the highest number of gymnasts in Sweden. Today, in 2007, 14.807 gymnasts (12.768 females, 2.039 males) are licensed for teamgym, compared to 1.388 gymnasts (1.002 females, 386 males) licensed for artistic gymnastics (personal communication; Swedish Gymnastics Federation). Of the gymnasts licensed for competition only a few percent compete at the highest level of competition for each age level. There are youth, junior and senior competitions and the age intervals in Sweden are; youth level of competition 11-15 years of age, junior level of competition, female gymnasts 13-18 years of age and male gymnasts 13-20 years of age, and senior level of competition from the age of 16 years old. Internationally the junior age is 13-18 years old irrespective of gender. The age intervals are integrated, as described above, and it is possible for skilled gymnasts to compete at more than one level. The sport is spreading around the world and there are competitions at youth level in Europe, USA and Australia. The 1st European Championship for seniors took place in Finland in 1996 and teamgym is an official discipline within the European Union of Gymnastics.

Picture 2. Tumbling performed by Sofiaflickorna, Stockholm, Sweden.

Picture 3. Trampette performed by Brommagymnasterna, Stockholm, Sweden. Reprinted with permission from Peter Lindholm ©.

The sport differs in several ways from the most known form of gymnastics, artistic gymnastics. Artistic gymnastics is an individual sport, while teamgym is a team sport. At youth level of performance a male team consists of 6-16 members and a female or mixed team consists of 8-16 members. At junior and senior level a male, female or mixed team consists of 6-12 members. The events in teamgym include: tumbling (Picture 2), trampette (Picture 3) and floor programme (Picture 1). These events are the same for males and females in contrast to artistic gymnastics, where some of the events for male and female gymnasts differ from each other. Teamgym also includes a mixed discipline, where the team consists of both male and female gymnasts. Each event in teamgym is performed by the team members simultaneously. The floor programme is performed during approximately three minutes by the entire team. It is the most aerobic event, and a perfectly synchronized team is important. Tumbling and trampette are explosive events.

At least six members of the team perform three series of tumbles and three different vaults, in a row one by one, and the team receives a total score for each event. Gymnasts at the highest level of teamgym perform difficult skills, comparable to artistic gymnasts. Double somersaults and double twists are not uncommon, exercises most likely to put high impact to the body. Compared to artistic gymnasts the senior top-level teamgym gymnasts are usually older and taller and practice fewer hours per week (Bak et al, 1994). However, since the level of performance continuously improves, the number of hours in training increases. It is not unusual that teamgym gymnasts at the age of 12 years practice 10-15 hours per week. It is likely to believe that this amount of training and early specialization may lead to an increased risk of injury (Kujala et al, 1996).

Injuries in gymnastics

Gymnastics-related injuries are relatively frequent and some of them are serious leading to life long handicap. Therefore, it is important to find reliable and successful methods for injury prevention in gymnastics. This requires a good knowledge about incidence, diagnosis and severity of injuries as well as injury mechanisms (Meeuwisse 1991; Van Mechelen et al 1992; Kujala et al 1995; Parkkari et al 2001). In artistic gymnastics injuries as well as mechanisms have been studied for the last two decades (Caine et al 1989; Lindner & Caine 1990; Wadley & Albright 1993; Dixon & Fricker 1993; Sands et al 1993; Bak et al 1994; Kolt & Kirkby 1999). The lower extremity is most often injured in female artistic gymnastics with the ankle joint being the most common site for injuries (Lindner & Caine, 1990; Dixon & Fricker, 1993; Kolt & Kirkby, 1999). Upper extremity injuries occur more often in male gymnasts than female gymnasts (Dixon & Fricker, 1993; Bak et al 1994). The reason for this is most likely due to the fact that the apparatus differs between male and female artistic gymnasts and thereby also the impact to different body sites. The injuries occur largely due to an increased impact (Sands, 2000). The impact of the gymnast is exacerbated by striking apparatuses or surfaces that are not intended for such impacts (Sands, 2000). Teamgym can in many ways be compared to artistic gymnastics. However, it is a team sport and the apparatus as well as the rules and regulations differ between the two gymnastics disciplines. Therefore, it is important to study injury incidence, mechanism and diagnosis in teamgym.

Intrinsic and extrinsic injury risk factors

In order to develop appropriate sports specific injury prevention programs it is necessary to identify intrinsic risk factors such as body composition, muscle strength, muscle flexibility and previous injury, and extrinsic risk factors such as level of performance, surfaces, apparatus and competition situations (van Mechelen et al 1992; Parkkari et al, 2001). Since teamgym is a fairly new form of gymnastics, the extrinsic factors continuously change. During the last decade springboard has been eliminated and exchanged with trampette, and the tumbling surface has been changed several times. It was only recently that the apparatus were standardized in Europe. New apparatus leads to new demands on the gymnasts and influence intrinsic factors such as muscle strength and flexibility. The level of performance improves and consequently the rules and regulations are continuously undergoing revision. Outside Europe teamgym is just starting to spread and at youth level the regulations differ from country to country depending on level of performance and popularity of the sport. A world Championship would be helpful in order to establish guidelines for teamgym as an international sport.

Low back pain

Low back pain is a well known health problem in the Western society with a life-time prevalence of approximately 70 to 80% (Biering Sörensen, 1983). It is common among physically active as well as inactive adolescents and a prevalence of 24 to 57% has been reported (Homer & Macintosh, 1992; Wadley & Albright, 1993; Burton et al, 1996; Kujala et al, 1996; Harreby et al, 1999; Hutchinson, 1999; Sjolie, 2004). Injuries to the back is common in gymnastics, and the diagnostic spectrum includes severe injuries such as endplate damages, fractures and disc-degeneration as well as muscle strains, ligament sprains and non-specific low back pain (Caine et al, 1989; Swärd et al, 1990; Swärd et al, 1991; Homer & Mackintosh, 1992; Katz & Scerpella, 2003;Bennett et al, 2006). Depending on the variation in study design the prevalence of low back pain in gymnastics alone can only be estimated, but is probably somewhere between 30 and 85% (Caine et al, 1989; Swärd et al, 1990; Swärd et al, 1991; Homer & Mackintosh, 1992). It should be recognized that low back pain is a symptom and the underlying tissue damage is in most cases unknown or difficult to verify (Jarvik et al, 2002; Deyo, 2002; Bono, 2004). The intervertebral disc and the growth zone are especially vulnerable (Swärd et al 1989; Lundin et al 1998; Karlsson et al 1998; Lundin et al 2000; Baranto et al 2004). Swärd et al (1991) reported early disc degeneration in male elite gymnasts between the age of 19 and 29 years. However, these findings were not evident in another study on adolescent male gymnasts in Finland (Tertti et al, 1990). Magnetic resonance imaging (MRI) and computed tomography (CT) have been recommended for evaluating low back pain (Swärd et al, 1991; Thornbury et al, 1993; Jarvik et al, 2002). This may not always reveal the injury present. In a porcine model, Baranto et al (2004) had to perform histological examinations in some cases to verify tissue damage after a combination of compression and rotation of lumbar segments.

Muscle control of the lumbar spine

The spine is inherently unstable and the control of the spine relies on well coordinated muscles (Panjabi, 1992). The muscles can be divided into global and local muscles (Bergmark, 1989). The global muscles are the large torque producing muscles providing general trunk stability. The local muscles are attached to the spine and are responsible for segmental stability (Bergmark, 1989). Muscles such as the transversus abdominis, obliquus internus, diaphragm, iliocostalis, multifidus and quadratus lumborum have been suggested to be active in protecting and stabilizing the lumbar spine (McGill, 1991; Andersson et al 1996; Richardson & Jull, 1995; Wilke et al, 1995; Quint et al, 1998; Hodges, 2003). Of the local muscles the transversus abdominis and the lumbar multifidus have been suggested to especially contribute to lumbar stability (McGill, 1991; Richardson & Jull, 1995; Wilke et al, 1995; Quint et al, 1998).

The transversus abdominis is a sheet-like muscle arising from the inguinal ligament, iliac crest, thoracolumbar fascia and the lower six ribs. Its fibers run transversely into the apponeurosis of the abdominal wall and participates via its aponeurosis in the linea alba (Platzer, 1986). Transversus abdominis is the abdominal muscle most closely associated with the control of intra abdominal pressure (Cresswell 1992, 1994). It also influences stiffness and intersegmental motion of the lumbar spine through its connection to the thoracolumbar fascia (Hodges & Richardson, 1997b). Furthermore, this muscle preactivates, during a movement of the upper or lower extremity, even before the primary movers of the actual extremity (Hodges & Richardson, 1996, 1998). This pre-activation is delayed in patients with low back pain (Hodges & Richardson, 1998). The muscle may fuse completely in its lower region with the obliquus internus muscle and sometimes it is completely replaced by obliquus internus (Platzer, 1986). Obliquus internus has a similar course and structure as the transversus abdominis and arises from the inguinal ligament, the thoracolumbar fascia and the iliac crest. There are three main parts for insertion. The cranial part inserts into the last three ribs, the middle part divides in two, an anterior and a posterior layer, and continues medially into the apponeurosis. They form a frame around the rectus abdominis and reunite in the linea alba (Platzer, 1986).

The multifidus muscle consists of a number of small fasciculi which extend from the sacrum to the 2nd cervical vertebra. The multifidus is best developed in the lumbar region. Below the lumbar portion of multifidus is described. The muscle bundles arises from the mamillary processes of the lumbar vertebrae, cross two to four vertebrae and are inserted in the spinosus processes of the appropriate higher vertebrae (Platzer, 1986). The lumbar multifidus muscles have been demonstrated to contribute to the lumbar stiffness (Wilke et al, 1995; Kaigle et al, 1995). By stimulating the intervertebral discs of the lumbar spine an activation of the paraspinal muscles were demonstrated in a porcine model (Indahl et al, 1995). Furthermore, a segmental activation was demonstrated when stimulating the facet joints of the lumbar spine (Indahl et al, 1997). In order to provide good stability the multifidus muscles have to function properly and therefore it is essential to know that the recovery of the multifidus muscles is not automatic after resolution of acute, first-episode low back pain (Hides et al, 1996). A number of authors have also found that the multifidus muscles are impaired in patients with low back pain (Hides et al, 1994; Rantanen et al, 1993; Biederman et al, 1991). Rantanen et al (1993) demonstrated ‘moth eaten’ type I muscle fibers in the multifidus muscle of patients with chronic back pain.

Specific training – pain control

In 1995 Richardson & Jull presented specific muscle exercises to control the lumbar spine. The specific exercises were suggested to re-activate the local muscles of the lumbar spine and to control pain in patients with low back pain. The base for this training is the drawing-in action (Richardson & Jull, 1995), in this thesis called the abdominal hollowing (Figure 1). It is an isometric muscle contraction shown to activate the transversus abdominis and/or obliquus internus (Beith et al, 2001; Hides et al, 2006) but also believed to enhance co-activation with the lumbar multifidus muscles (Richardson & Jull, 1995, Hides et al, 1996; Vera-Garcia et al, 2006). The abdominal hollowing is performed by gently drawing in the abdominal wall, especially of the lower abdominal area. It is an isometric contraction and the time length for which the exercise is held is important (Figure 1) (Richardson & Jull, 1995).

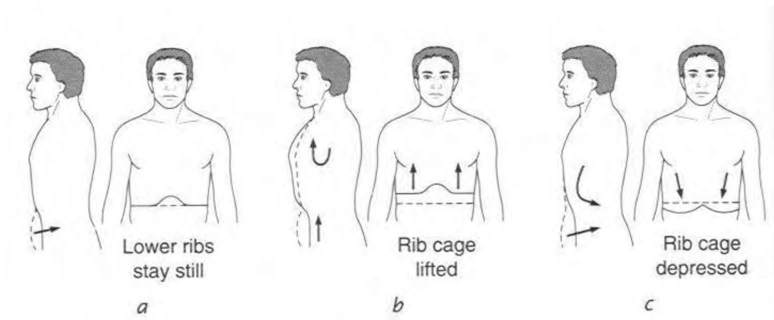


Figure 1. Abdominal hollowing

From C.M. Norris, 2000, Back Stability, page 88, figure 4.3 © 2000 by Christopher M. Norris. Reprinted with permission from Human Kinetics (Champain, IL).

The exercise is difficult to learn, especially for those with low back pain, and the key to correct performance is to continue with a normal breathing (Richardson & Jull, 1995; O'Sullivan et al, 1997). To control for correct muscle contraction a pressure bio-feedback unit (Figure 2) (Chattanooga group, Inc USA) (Jull et al, 1993; Richardson & Jull, 1995; Hagins et al, 1999; Storheim et al, 2002) can be used. The device is helpful, in particular during the learning phase, for guidance of performing the muscle contraction correctly (Storheim et al, 2002).

Figure 2. The pressure bio-feedback unit. The unit is inflated to 70 mmHg pressure and placed under the lower abdomen while the subject is lying in prone position. When the correct contraction is performed, pressure decreases by approximately 6-8 mmHg (Richardson & Jull, 1995).

Earlier investigations using these types of exercises have led to reduced pain intensity and functional disability levels, decreased rate of re-occurrence as well as recovery of the segmental multifidus muscles to pre-injury size (Richardson & Jull, 1995; O'Sullivan et al, 1997; Hides et al, 2001). To our knowledge these types of exercises have not been investigated in an adolescent athletic population.

The co-contraction of local agonistic and antagonistic muscles of the lumbar spine should be performed with long duration of training and low forces. Around 25% of maximal voluntary contraction has been suggested for this type of training (Richardson & Jull, 1995). The specific training is commenced in the four point kneeling and prone positions (Richardson & Jull, 1995). The abdominal hollowing in these positions always activates obliquus internus and rarely activates rectus abdominis (Beith et al, 2001) and therefore the appropriate muscles for the hollowing maneuver are more easily reached. Progressive training is always important and once the patient knows how to perform the exercise the duration and number of repetitions should be increased (Richardson & Jull, 1995). Thereafter body position should be changed, for instance from a prone position to a standing position and following that, the isometric contraction should be held during dynamic functional movements of the trunk. Finally, an integration of the local and global muscle systems should be enhanced (Richardson & Jull, 1995).

Pain rating

The definition of pain recommended by the International Association for the Study of Pain (IASP) is ’an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage’ (Merskey, 1986, 1994). The description of pain may be sensory, affective or evaluative, but usually it is primarily sensory (Merskey, 1994). Pain is subjective, and consequently it is not possible to compare pain intensity between individuals (Merskey, 1994). There are different scales and disability questionnaires used to assess low back pain (Fairbank et al, 1980; Roland & Morris, 1983; Salén et al, 1994), but none especially developed for an athletic population. The Visual Analogue Scale (VAS) (Carlsson, 1983; Price et al, 1983) and the Borg’s category-ratio scale (Figure 3) (Borg et al, 1991; Borg, 1998) are often used combined with questions regarding daily activity.

0	Nothing at all	"No P"
0.3		
0.5	Extremely weak	Just noticeable
1	Very weak	
1.5		
2	Weak	Light
2.5		
3	Moderate	
4		
5	Strong	Heavy
6		
7	Very Strong	
8		
9		
10	Extremely Strong	"Max P"
11		
•	Absolute maximum	Highest possible

Borg's CR10 scale
© Gunnar Borg 1981,1982,1998

Figure 3. Borg’s CR 10 Scale (P=perception).

Postural control

Postural control can be defined as the ability to maintain control over posture, i.e. to keep the center of mass (COM) within the limits of stability (Horak & McPherson, 1996). It is influenced by the vestibular, visual and the proprioceptive systems coordinated by the central nervous system (CNS) (Maisson, 1992; Horak & McPherson, 1996). Afferent signals from receptors in e.g. joints, muscles and ligaments continuously communicate and strategies for postural control are developed (Dietz, 1992). Postural control is the base for performance of movements (Horak & McPherson, 1996). This control must be considered especially important in gymnastics, where each and every skill needs to be performed with a high level of precision and timing. Pain, from injury, or pain provocation, has been suggested to change strategies for postural control (Hodges 2001; Hodges et al, 2004). This could be a delicate problem in sports with high technical demands such as gymnastics. Each and every skill has to be performed with exactly the same precision every time repeated. An altered postural control could disturb this performance and thereby result in an increased risk for injury.

Stabilometry

In order to assess postural control in upright standing different types of force platforms are often used. These platforms register the ground reaction force from which the excursion of the center of pressure (COP) is calculated. Parameters such as the force, the area, displacement and velocity of COP excursion can be calculated and evaluated. These parameters have been used in several studies to compare patients with low back pain and healthy controls. Those with low back pain seem to produce a different COP trajectory than the healthy controls (Nies & Sinnott, 1991; Alexander & LaPier, 1998; Mientjes & Frank, 1999; della Volpe, 2006). Furthermore, postural sway is reported to be increased in functionally unstable ankle joints and therefore postural control measurements have been used as outcome after rehabilitation (Tropp et al, 1985; Evans et al, 2004; Fu & Hui-Chan, 2005). The reliability of force platform data is assumed to be acceptable (Goldie et al, 1989; Geurts et al, 1993; Fu & Hui-Chan, 2005; Stevens et al, 2006). However, it is important to test the reliability of measurements in the specific population at study. In the case of young gymnasts it is not known whether COP excursion in upright standing is a reliable measurement and whether it changes with different injury locations.

AIMS OF THESIS

The main aim of the present thesis was to study injury incidence, injury mechanism, injury site and diagnosis in Swedish teamgym. A second aim was to evaluate if specific exercises for segmental muscle control of the lumbar spine can prevent or reduce low back pain in young female gymnasts. A third aim was to study if, and in that case how, low back pain or lower extremity injury influence postural control, and also to evaluate the reliability of postural control measurements.

Specific aims:

Study I**:** The primary aim of this investigation was to study whether teamgym gymnasts participate in national competitions in spite of symptoms from an injury. A secondary aim was to describe sites and occurrence of these symptoms.

Study II**:** The aim of this investigation was to prospectively follow and study injury incidence, injury mechanism and injury diagnosis in top level teamgym gymnasts.

Study III**:** The aim of this investigation was to evaluate a specific muscle training program of the local lumbar muscles, implemented in the regular training, in order to prevent or reduce low back pain among young female teamgym gymnasts.

Study IV**:** The primary aim of this investigation was to study how center of pressure is influenced by low back pain and lower extremity injury in top level female gymnasts. A secondary aim was to evaluate the reliability of these measurements using a test-retest design, and how this depends on the duration of the test.

SUBJECTS

This thesis is a study on injuries in Swedish teamgym and all gymnasts included in the studies were competing at the highest level (for each age group) of teamgym. Furthermore, all included gymnasts in study II had international experience, meaning that they had represented Sweden in a Nordic or European Championships. Unpublished material regarding injuries at three Swedish National Championships for senior gymnasts is also included in this thesis. The age intervals for the different levels of competition: youth, juniors and seniors, have been changed over the years. Therefore, there are some differences between the studies within the thesis and between the thesis and the “Rules and Regulations of 2007”. Today the age intervals in Sweden are as follows, youth level: 11-15 years old for both male and female gymnasts, junior level: female gymnasts 13-18 years of age and male gymnasts 13-20 years of age, senior level: from the age of 16 years old. Internationally the junior age is 13-18 years old irrespective of gender. The age intervals are integrated, as described above, and it is possible for skilled gymnasts to compete at more than one level. Anthropometrics and training data for the gymnasts included in study II-IV are presented in Table I. The gymnasts are presented at the level of competition, at which they were competing when included in study II-IV, respectively. The Body Mass Index (BMI) is calculated as weight / height^2. The gymnasts are presented according to competition level at the time for inclusion.

Table I Anthropometrics and training data by level of competition for the gymnasts included in study II-IV (n=133).

	Youth female gymnasts (n= 55)	**Junior female gymnasts (n=31)**	**Senior female gymnasts (n=30)**	**Senior male gymnasts (n=16)**
Age (years)	13 (11-16)	15 (13-18)	18 (14-23)	22 (17-25)
Height (m)	1.56 (1.32-1.74)	1.65 (1.48-1.72)	1.63 (1.47-1.74)	1.78 (1.73-1.86)
Weight (kg)	45 (28-63)	52 (38-67)	55 (41-65)	73.5 (70-99)
Body mass index (kg/m^2)	17.9 (15.1-23.1)	19.2 (16.2-24.2)	21.1 (17.6-23.8)	23.6 (20.1-31.6)
Gymnastics experience (yrs)	7 (4-11)	10 (7-14)	13 (7-19)	16 (7-19)
Training sessions/week	4 (3-4)	4 (3-4)	4 (3-5)	4 (3-5)
Training hours/week	9 (6-12)	12 (8-12)	11 (8-14)	12 (7.5–15)

Values are expressed in median (range)

Due to the design of study I, with defined time periods for some of the questions regarding training, it is not possible to construct median and range values comparable to those in study II-IV, and therefore these gymnasts are not included in Table I.

In study I the age groups were as follows: juniors 12-18 years and seniors 14 years and older. For those gymnasts aged 14 to 18 years old the level of skill was mainly the cause for whether the gymnast competed as a junior or senior gymnast. If they competed at both Championships they were only included once in study I. In study I, 188 gymnasts competing at the Swedish Cup (seniors) and the Junior Cup (juniors) were included and questions about symptoms from injuries on the day of competition were asked. These competitions are National Championships and moreover the qualification competitions for the Nordic Championships for juniors and seniors. Three times as many female as male competitors participated in these competitions.

In study II, 42 senior gymnasts, 16 male and 26 female gymnasts representing two of the top-level teams in Sweden were followed during one season (August – May) of training and competition. The male gymnasts were between 17 and 25 years old and the female gymnasts were between 14 and 23 years old.

In study III, 51 female gymnasts, aged 11-16 years, from three gymnastics teams in Stockholm participated in the study. Written consent was collected from the gymnasts and their guardians before the start of the study. The teams were, at the time for study III, practicing for the youth National Championship in teamgym. Two teams were included in an intervention group (n= 33) and one team formed a control group (n=18). The medical status of the included gymnasts in each team was unknown to the investigators at the time of inclusion. Nine gymnasts were excluded during the study period and the final analyses are therefore based on 42 gymnasts, 30 in the intervention group and 12 in the control group.

In study IV postural control was measured in 57 female gymnasts, aged 12-21, from three teamgym gymnastics clubs in Stockholm. Written consent was collected from the gymnasts and, when appropriate, their guardians before the start of the study. The gymnasts were divided according to injury location in four subgroups: gymnasts without injury (NI, n=18), gymnasts with low back pain (LBP, n=11), gymnasts with lower extremity injury (LEI, n=17) and gymnasts with both low back pain and lower extremity injury, hereafter called the multiple injury group (MI, n=11). Furthermore, thirty-five of the gymnasts were measured at two occasions within one week. One gymnast sustained an acute ankle sprain and one gymnast sustained back pain between the two test occasions and was excluded from the analysis. The four subgroups analyzed were non-injured (NI, n=9), lower extremity injury (LEI, n=8), low back pain (LBP, n=7) and multiple injury group (MI, n=9).

METHODS

In study I, II and IV the subjects answered questions regarding injuries and whether they were suffering from possible symptoms from injuries. In study I the questionnaire (Appendix A) was handed out at the day of competition, while in study II and IV the questions were asked at the start of each study. A specific baseline form (Appendix B) was developed for this purpose in study II and IV. The questionnaire in study I was divided in two parts: the first part consisted of anthropometrics and training data and the second part of possible symptoms from injuries at the day of competition. Page three and four of the questionnaire was not included in study I (Appendix A). A one week test-retest of the questionnaire was conducted and good reliability was found. The first part of the questionnaire (Appendix A, page one) was evaluated with Spearman rank correlation coefficient (Spearman *R*) and showed correlation between 0.92 and 1.0 for all questions except for strength training, showing 0.72. The second part (Appendix A, page two and five) of the questionnaire showed a 100% correlation for all questions except for the questions regarding event when the injury occurred (92%), how long they had practiced the skill (92%) and the re-injury rate (83%). The questionnaires were handed out consecutively at the competition hall prior to competition. The answering rate was 63% (n=188) and the drop-outs did not differ with respect to gender or age when compared to those who answered the questionnaire.

In study II and during the Swedish National Championships (unpublished data) all injuries were registered at the time of injury. In study II injuries leading to a modified participation or absence from gymnastics during one week or more were included. Regarding the unpublished data presented in the result section all injuries that occurred during the Swedish National Championships 2001, 2002 and 2006 are presented. All injured gymnasts in study II (and the majority of the injured gymnasts at the Championships) were examined by the same sports physiotherapist (MH) with experience of teamgym. Each injury was registered with respect to injury mechanism and diagnosis. A specific injury form was used in study II (Appendix C) and during the National Championships (Appendix D). Injuries that needed further evaluation were referred to, and examined by, a sports orthopaedic surgeon. If necessary the orthopaedic surgeon referred the patient to a radiological examination, magnetic resonance imaging or an arthroscopy. Only recurrent injuries to the exact anatomic structures were considered to be re-injuries. Questions regarding skill, time of injury and mood at the time of injury were asked. Injuries that occurred outside gymnastics were not included in any of the studies in this thesis. The exposure of teamgym was registered both by an individual training dairy which was summarized on a weekly basis (Appendix E) and the ordinary attendance charts of the coach.

Study III was focused on low back pain among young female gymnasts. The study comprised 12 weeks, four weeks of baseline (week 1-4) and eight weeks of intervention (week 5-12). Every day, the gymnasts answered questions regarding low back pain (Appendix F). Low back pain was defined as pain in the area between the level of the 12th rib and the gluteal folds (Biering Sörensen,1983; Papageorgiou et al, 1995; Watson et al, 2002). Due to the fact that pain can diminish although the multifidus muscles of the lumbar spine have not completely recovered (Hides et al, 1996), one day of pain was enough to be included in the study as "gymnast with low back pain". The results from this daily rating of low back pain were not revealed until after the intervention period was completed. After four weeks of baseline the intervention group was instructed, by a physiotherapist, how to perform the training program. The training program was based on the drawing-in action, in this thesis called abdominal hollowing, presented by Richardson

& Jull (1995). It is an action aiming to an isometric co-contraction of the local muscles of the lumbar spine, the transversus abdominis and lumbar multifidus muscles, in particular. The gymnasts were instructed to gently draw in the abdominal wall, especially of the lower abdominal area, while keeping a normal breathing. The training program was performed every training session (3-4 times / week) and became part of the warm-up. At the start of the investigation a Stabilizer, bio-feedback pressure unit (Chattanooga group, Inc USA) (Jull et al, 1993; Richardson & Jull, 1995; Hagins et al, 1999; Storheim et al, 2002) was used to control for correct muscle contraction. In order to give all gymnasts attention, the control group was visited by a physiotherapist the same amount of times as the intervention group. The gymnasts were given time for questions regarding injuries and advice and regimen was provided to them.

In study IV postural control was evaluated in gymnasts with low back pain, lower extremity injury and non-injured gymnasts. Center of pressure (COP) was measured in upright standing with an AMTI® force platform (Figure 4) (model OR6-7-1000, Advanced Mechanical Technology, Inc., Watertown, MA, USA). The gymnasts stood barefooted in a two-legged stance with eyes open and eyes closed, on hard and foam surface during 120 seconds, respectively (Mientjes & Frank, 1999). The foam surface consisted of an Airex® Balance-pad (Figure 5)(© Carmen-M.Rock M.A, Dr. Brügger-Institut Zürich, Switzerland) placed in the center of the platform. The gymnasts were standing in an upright position focusing on a target placed at eye level at a distance of two meters in front of them. They were instructed to stand comfortable, normal posture, with the feet close together in the center of the platform and the arms hanging along the side of the body. The instructions were the same for each test and once they had taken the position on the platform they were asked to close their eyes in the eyes closed condition. The tests were performed in identical order for all of the gymnasts: 1. Hard surface – eyes open, 2. Hard surface – eyes closed, 3. Foam surface – eyes open, and 4. Foam surface – eyes closed. Before performing the tests, the gymnast was asked if she had pain, and if her answer was ‘yes’ the pain was evaluated with Borg’s category-ratio pain scale (Figure 3) (Borg et al, 1991, Borg, 1998).

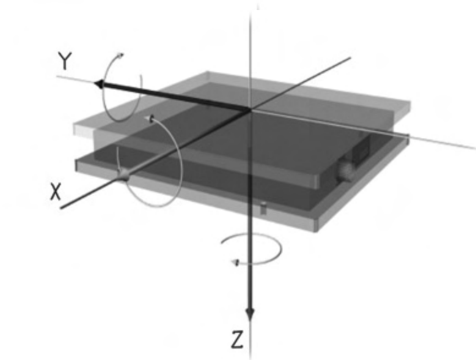


Figure 4. An AMTI force platform illustrating the three force and moment components.

Figure 5. The foam surface provided by an Airex® Balance-pad placed in the center of the force platform.

Ground reaction force data was sampled at 50 Hz and the AMTI MSA-6 Amplifier System was used together with a personal computer and an analogue data acquisition system (A/D converted at 16-bit resolution). The force platform measured the three force components, Fx, Fy and Fz, and the three moment components, Mx, My and Mz (x, y and z are the medial-lateral, anterior-posterior, and vertical directions, respectively) (Figure 4). A Butterworth low pass filter with cut-off frequency of 10 Hz was applied to the sampled data. For calculation of COP measurements custom software written in MATLAB® (The MathWorks, Inc. Natick, MA, USA) was used and the 120 seconds registration period was divided and analyzed in periods of 4x30 seconds, 2x60 seconds and 1x120 seconds. The COP parameters considered were: The 95% ellipse area (cm^2), Standard Deviation (SD) anterior-posterior (ant-post) and medial-lateral (med-lat) direction (cm), path length (cm), root mean square (RMS) velocity ant-post, med-lat and total (cm/s) and mean frequency ant-post and med-lat directions (Hz) (Appendix G).

A one-week test-retest study of the AMTI force platform measurements was conducted. Thirty-five of the gymnasts were measured at two occasions. Intraclass correlation coefficient (ICC2,1), coefficient of variance (CV) and minimal detectable change (MDC) was calculated for each of the COP parameters (Beckerman et al, 2001; Weir JP, 2005; de Vet et al, 2006). These measurements were calculated for each subgroup, respectively.

The ICC considers both the variability between individuals and between test-retest occasions and the CV shows consistency between the test-retest. The CV is a complement to the ICC, and is calculated with the standard error of measurement (SEM), equivalent to %SEM. In a homogenous group, with a small variability between individuals, the ICC could show a false low value. That is if the variability between individuals is smaller than the variability between tests (Weir, 2005). A high ICC and a low CV could be interpreted as a reliable measurement. The recommended interpretation of the ICC is: 0.8-1.0 = excellent, 0.6-0.8 = good and <0.6 = poor (Bartko, 1966). The CV values have to be interpreted from one study to another, but no larger than 0.33 should be accepted (Johnson & Welch, 1939).

STATISTICAL METHODS

Statistica, Statosoft®, Scandinavia AB, was used for the statistical analysis in all the studies except for the logistic regression modeling in study I, where SAS®, version 8.0, was used. The quantitative data are presented as means (standard deviation) (Study I,II,IV) and medians (range) (study I-III) and categorical data are presented as proportions and percentages (study I-III). A p-level ≤ 0.05 was considered statistically significant in all the studies. The specific statistics used for each and one of the included studies are presented hereunder.

Study I: Logistic regression modeling of the dependent variables - the day of the competition and re-injury - were done and presented with a multivariate model. All variables that were significant in an univariat model were included in the multivariate model. Odds ratios and corresponding 95% confidence intervals are presented for all the variables included in the model.

Study II: Injury incidence was calculated as injuries per 1000 gymnastics hours and a 95% confidence interval was estimated. Gymnastics hours include hours in training, competition and exhibition as one unit. Cross tabulations and Chi^2-test were used to detect possible relationships between injury and injury mechanisms.

Study III: Differences regarding anthropometrics and training data as well as low back pain between the intervention group and the control group and between gymnasts with and without low back pain were analyzed with Mann-Whitney U test. The last four weeks of the study period (called completion) were compared to the first four weeks (called baseline) with respect to days with low back pain and intensity of pain. The maximal as well as the median estimated intensity of pain was analyzed. This change over time was compared between the intervention group and the control group using Mann-Whitney U test. Within each group the Sign test was used regarding estimated intensity of pain and the Wilcoxon matched pairs test was used analyzing days with pain.

Study IV: Differences between subgroups regarding anthropometrics and training data were analyzed with one-way ANOVA. Repeated measure ANOVA, mixed design, with one between group factor "Group" (NI, LBP, LEI and MI) and with two within group factors "Condition" (eyes open and eyes closed) and "Surface" (hard and foam surface) was used to compare the COP parameters. Planned comparison was performed to detect differences between subgroups for each test situation with correction according to Bonferroni. In order to investigate the four test situations with respect to degree of challenge to the postural control a two-way repeated measure ANOVA was used. The ICC and the CV was calculated for the four subgroups in the test-retest study. Furthermore repeated measure ANOVA, as described above, was used to study differences between groups in order to find possible explanations to low ICC and CV values.

ETHICAL APPROVALS

All studies were approved by the ethical committee at the Karolinska University Hospital, Stockholm, Sweden.

Dnr: 01-365 (study I and unpublished material)

Dnr: 99-039 (study II)

Dnr: 01-179 (study III and IV)

RESULTS

Injury site and diagnosis

Teamgym gymnasts compete despite having symptoms from injuries. In study II only eighteen out of 42 gymnasts entered the study without any symptoms from earlier injuries. Fifty-eight percent (110 out of 188) of the gymnasts in study I reported symptoms from a total of 147 injuries on the day of competition. A significantly higher number of seniors compared to juniors competed in spite of symptoms from an injury. The most common injury location in teamgym was the lower extremity with 65% of the self reported injuries (study I) and 62% of the prospectively registered injuries (study II). Of injuries to the lower extremity, the ankle joint was the most injury prone joint (study I & II). The second most common injury location was the back with 22% of the symptoms in study I and 19 % of the registered injuries in study II. In study III 24 out of 51 young female gymnasts reported low back pain over a 4-week period. The reported pain varied from 1 to 28 days and the intensity was reported between 0.3 and 10 on Borg's pain scale (Figure 3). Injury diagnoses in study II are presented in paper II, and injury diagnoses from the Swedish National Championships (unpublished data) are presented in Table II (p. 40). Four injuries to the lower extremity in study II required surgery.

Comparing injury sites (study I) between male and female gymnasts and between junior and senior gymnasts, male senior gymnasts reported proportionally (although not statistically significant) a higher number of ankle/foot, back and wrist/hand problems. Female junior and senior gymnasts reported a higher number of knee and lower leg problems than male gymnasts. Male junior gymnasts did not report any symptoms from the back.

Injury incidence

The injury incidence reported in study II was 2.2 injuries per 1000 gymnastics hours for males (95% confidence interval 1.1 to 3.4) as well as for females (95% confidence interval 1.4 to 3.0). The overall incidence rate was 2.2 injuries per 1000 gymnastics hours with a 95% confidence interval equivalent to 1.6 to 2.9.

Re-injuries

Fifty-five percent (n=103) of the 188 gymnasts in study I reported that they had suffered a re-injury during their career as gymnasts. A total of 137 re-injuries were reported in study I. Fifty-five percent (n=75) of those 137 re-injuries involved the lower extremities with 28% (n=38) to the ankle joint. Back problems accounted for 31% (n=42). In study II the definition of re-injury was 'a repeated injury to the exact anatomic structure as a former injury'. In this study only 19% (n=8) of the injuries were considered re-injuries. Estimating potential risk factors using logistic regression modeling in study I, gymnasts who reported re-injuries to the knees had a significantly higher BMI than those with no re-injuries to the knees ($p = 0.049$).

Injury mechanisms

Fifty-two percent (n=22) of the injuries in study II occurred during the "landing phase", 21.5% (n=9) during "take-off" and 5% (n=2) during the "run-up" for tumbling and vaulting. Another 21.5% (n=9) of the injuries occurred in different parts of the "specific skill". While analysing the injury charts in study II, four different injury mechanisms could be observed. These were the following: joint rotation, joint compression, hyperextension and overuse. When combinations of these mechanisms were reported the main mechanism was registered. Main mechanism in this thesis was defined as the mechanism that was believed to have the most influence on the injury. When a "tsukahara" (a gymnastics skill) is under-rotated at landing the main mechanism was evaluated to be a joint compression, although there was a joint rotation, as well. The joint compression was determined to be the main mechanism. Dividing the injuries into these mechanisms 38% (n=16) of the injuries in study II were due to joint compression, 24% (n=10) to joint rotation, 17% (n=7) to hyperextension and 21% (n=9) were due to overuse. No correlations were found between injury mechanism and diagnosis in study II.

Injury occasion

Most injuries were sustained during practice, 81% in study I and 71% in study II, followed by competition (12%, study I; 10%, study II). In the prospective investigation (study II) 19% of the injuries occurred at exhibition, but only 3% of the injuries in study I were reported to have occurred during exhibition. Gymnasts in study I reported that 35% of the injuries had occurred during tumbling and in study II these figures were 52%. In study I, 23% of the injuries was sustained in trampette and 11% in springboard training, thus, representing 34 % in vaulting. At the start of study II the event springboard had been eliminated from the senior level of competition. In study II 28.9% of the injuries occurred in the event trampette. Nine percent in study I and 9.5% in study II of the injuries were sustained during floor programme. Twenty-six percent of the injuries in study II occurred at the beginning of the session and 24% at mid-session. Furthermore, 33% of the injuries occurred at the end of the session and another 17% of the injuries were reported to have a gradual increase towards the end of the session.

Forty-five percent of the injuries in study I had occurred in a skill that the gymnasts had known for ≥ two years and in study II the gymnasts reported that they knew the skill "very well" in 47% of the injury cases. Eight of the skills in study II were considered new to the gymnasts and in six of those skills the gymnasts reported that they were under high stress at the time of injury. Regarding state of mood, which was registered in study II, at the time for injury, the answers were grouped as "positive", "negative" and "as usual". Answers such as happy, alert and concentrated were regarded as "positive feelings", while tired, stressed, afraid, not concentrated and/or out of focus were regarded as "negative feelings". Answers such as; there was nothing different from other occasions, OK and as usual were regarded as "as usual". All together 53% of the injuries in study II (registered with this question) occurred while the gymnasts were in a negative state of mood. In 32% of the injury cases the gymnasts felt "as usual" and in 12% they were in a positive state of mood. In one injury case the gymnast was playing around.

Prevention or reduction of low back pain

Gymnasts who performed the specific training program (study III) based on the abdominal hollowing were significantly improved with respect to less number of days with low back pain after the intervention. A tendency towards the opposite (p=0.06) was revealed in the control group. Eight (out of 15) gymnasts became pain free and 14 (out of 15) stayed symptom free in the intervention group. Three gymnasts (out of 8) in the control group sustained low back pain and one (out of 4) became pain free during the study period. The gymnasts in both groups reported pain during a variety of activities such as sitting, walking, running, jumping, laying down, carrying heavy items, extension, flexion and rotation of the spine as well as touching and stretching the spine and specific gymnastics exercises. They reported pain relief from resting, heat, manipulation and flexion of the spine, laying down on the back, massage and "nothing particular".

Influence of injury on postural control

The center of pressure (COP) excursion was influenced by injury location (study IV). There was a significant difference between the subgroups "low back pain" and "lower extremity injury" regarding the COP area with eyes closed standing on foam surface, both in ant-post and med-lat direction, during the 120 seconds measurement. The "low back pain" group showed a larger area compared to the "lower extremity injury" group. The "low back pain" group also showed a larger path length, area and velocity than the other subgroups in all test situations during 120 seconds, although the differences were not statistically significant. Comparing each subgroup between the test situations the COP excursion increased significantly with the degree of challenge to the postural control. Hard surface with eyes open (test 1) being the least challenging test and thereafter hard surface with eyes closed (test 2), foam surface with eyes open (test 3) and finally foam surface with eyes closed (test 4) being the most challenging test. Studying the COP parameters in the first 30 and 60 seconds of the tests, the same pattern could be detected as during the 120 seconds test, although the differences were not significant.

Reliability of center of pressure measurements

Considering ICC values over 0.6 in combination with CV values below 0.2 as acceptable, tests on foam surface were more reliable than tests on hard surface. Furthermore, tests with eyes closed were more reliable than tests with eyes open and tests during 120 seconds were in most cases more reliable than tests during 60 seconds. However, the reliability in the injured subgroups showed a larger variability than the non-injured group and when standing on foam surface with eyes closed the reliability values dropped going from 60 to 120 seconds (Table IV in paper IV). The reliability of the 30 seconds tests was not acceptable. In the "low back pain" group five (out of 7) gymnasts estimated higher intensity of pain at the first test compared to the second test. In the "multiple injury" group five (out of 9) gymnasts estimated higher intensity of low back pain at the first test compared to the second test, but with a smaller range than the "low back pain" group. None of the gymnasts in the "non-injured" and "lower extremity injury" group complained of pain at either time of the tests.

Unpublished data

Injuries occurring at the Swedish National Championships in teamgym 2001, 2002 and 2006 have been recorded (Table II, III). The medical team at each competition, consisting of at least one sports physiotherapist (MH) and one physician specialized in sports medicine, examined all the gymnasts and filled out a form including sex, age, time for injury, event, mechanism and diagnosis or injured tissue (Appendix D). The form also included a question regarding whether the injury was a 'new' injury, i.e. occurring for the first time at the competition, or was an 'old' injury having occurred a first time prior to the competition.

Two-hundred and thirty-five female and 92 male gymnasts participated in 2001, 156 female and 92 male gymnasts in 2002 and 162 female and 60 male gymnasts in 2006. A total of 797 gymnasts sustained 51 injuries during the three competitions. Injury, diagnosis, injury mechanism and skill in which the gymnasts were injured are presented in Table II and III. Eighteen of the injuries occurred in 2001 (6%), 20 injuries in 2002 (8%) and 13 injuries in 2006 (6%). Ten of the injuries occurred in male gymnasts, which corresponds to 5% of the male gymnasts and 41 injuries occurred in female gymnasts corresponding to 7% of the female gymnasts. Of all reported injuries, 32 injuries were a first episode injury ('new' injury) and 19 injuries had occurred prior to the competition ('old' injury). Of those previous injuries six had occurred within two weeks prior to competition, four injuries within two months and nine injuries had occurred for more than three months prior to the competition. One gymnast had rested for two weeks prior to competition due to the injury. The other 18 gymnasts had proceeded with their training despite injury.

Table II. Injury location, mechanism and diagnosis in male and female gymnasts sustained during the Swedish Championships in teamgym 2001, 2002 and 2006 (n=51).

Injury location	Male gymnasts	Female gymnasts	Mechanism*	Diagnosis	Additional examination
Lower Extremity					
foot	2		*2, 3*	heel pad bilat and unilat	X-ray
		1	*27*	ligament tear DIP MTP V	
		1	*18*	ligament injury MTP I - navicular	
ankle joint		4	*22,24,25,26*	anterior talo-fibular ligament tear	
		2	*39,47*	achilles tendon injury	
		1	*6*	anterior talo-fibular ligament and deltoideum ligament injury	
	2	9	*4, 7, 8, 9, 12, 13, 14, 15, 16, 17, 19*	internal joint and ligament injury	
lower leg		1	*46*	gastrocnemius strain (lateral part)	
knee joint		1	*21*	meniscus tear	MRI
	1	3	*29, 31, 41, 38*	coll ligament sprain (medial or lateral)	
		3	*23, 30*	ACL rupture	MRI
			1	ACL rupture, medial meniscus tear and fracture	arthroscopy
		1	*35*	pes anserinus strain	
	1		*36*	patellar tendon sprain	
		2	*48, 51*	quadriceps strain towards patellae	
thigh	2		*49, 50*	hamstrings strain	
Spine					
lumbar spine	1	2	*11, 34, 45*	muscle and ligament strains, "low back pain"	
thoracis spine	1	2	*37, 42, 43*	ligament sprain and muscle strain	X-ray
cervical spine		1	*44*	whiplash	CT
Upper Extremity					
shoulder joint		1	*5*	acromio-clavicular joint and muscle strain	
elbow joint		2	*28, 33*	medial coll ligament sprain	X-ray
hand		3	*20, 32, 40*	coll ligament MCP I, III tear, muscle strain	X-ray
		1	*10*	fractures at three locations in the hand	X-ray

* The numbers (in italic) refers to Table III. // ACL = anterior cruciate ligament, MTP = metatarso-phalangeal joint, DIP=distal phalangeal joint, MCP= metacarpo-phalangeal joint, MRI= Magnetic Resonance Imaging, CT = computed tomography

Table III. Four categories of mechanisms: including the gymnastics skill and the event in which the gymnasts were injured. The numbers (in italic) refer to the diagnoses in Table II. (n=51)

Joint compression (n=19)		**Joint rotation** (n=12)		**Hyperextension** (n=15)		**Overuse** (n=5)	
tsukahara straight /Tr	*1*	back handspring/Tu	*20*	take-off tsukahara/ Tr	*32*	various training/ Tr, Tu	*47*
double twist/ Tu	*2*	front handspring twist/Tu	*21*	back handspring/ Tu	*33*	after pre-training/Tr,Tu,Fl	*48*
double in 1 ½ out/ Tr	*3*	barani back somersault/Tu	*22*	warm-up	34	running-up / Tr	*49*
double back somersault/ Tu	*4*	tsukahara straight / Tr	*23*	double back somersault/ Tu	*35*	running-up / Tr	*50*
fall during running-up / Tr	*5*	back somersault x2 / Tu	*24*	front somersault-handspring/Tu	*36*	running-up/ Tu	*51*
back somersault x2/ Tu	*6*	take-off back somersault/Tu	*25*	double straight half out/Tr	*37*		
front somersault ½ / Tu	7	runnig-up /Tu	*26*	double straight half out/Tr	*38*		
back somersault 1/1 / Tu	*8*	piruette / Fl	*27*	back somersault 1/1/Tu	*39*		
tsukahara/ Tr	*9*	front somersault/ Tu	*28*	take-off tsukahara/ Tr	*40*		
fall (in a tumble)/ Tu	*10*	tsukahara 1/1 / Tr	*29*	tsukahara/ Tr	*41*		
double back somersault/ Tu	*11*	tsukahara straight / Tr	*30*	double half out/ Tr	*42*		
front handspring 1½ / Tr	*12*	tsukahara 1/1 / Tr	*31*	tsukahara/ Tr	*43*		
tsukahara/ Tr	*13*			overrotation – wiplash/ Tr	*44*		
double back somersault 1/1/Tu	*14*			double back somersault pike/Tu	*45*		
double back somersault/ Tu	*15*			full in half out/ Tr	*46*		
double straight/ Tr	*16*						
double somersault pike / Tu	*17*						
double somersault, straight/Tu	*18*						
full in half out/ Tr	*19*						

Tr = trampette, Tu = tumbling, Fl= floor programme

DISCUSSION

The present thesis provides information about injuries in teamgym and supports the fact that gymnasts compete and practice regardless of symptoms from injuries. More than half of the gymnasts at the highest level of competition reported symptoms from previous injuries on the day of a National Championship. Moreover, 24 (out of 42) top level gymnasts included in study II reported remaining symptoms from previous injuries at the start of the new season. This is in line with artistic gymnastics and dance, where similar results have been found (Bowling, 1989; Sands et al, 1993). However, in several sports such as football (soccer) and handball, a previous injury has been shown to be the most common risk factor for yet another injury (Ekstrand & Gillquist, 1983; Emery, 2005; Hägglund et al, 2006).

Injuries in teamgym – general aspects

The demand on perfect body control and technique is obvious in gymnastics. Each and every skill is repeated hundreds of times and motor control programs are created. Learning a new skill takes time and some, very complicated skills, might never reach the level of complete automatic motor control programs (Galley & Forster, 1987). Therefore it is important that the gymnasts are in good balance both physically and mentally while performing difficult skills. This is important in terms of training as well as competition. Furthermore, the impact from stress and extra pressure during competition has to be accounted for. One way of coping with this is to prepare well by training in a competitive environment. That is with all moments of disturbance that could appear in competition. (Galley & Forster, 1987)

Most injuries occurred during practice, at the end of the training session (study II), and in skills the gymnasts knew well (study I&II). Moreover, injured gymnasts reported stress and out of focus at the time for injury (study II). These findings imply that it is important to keep focus and concentration on a high level throughout the full training session. It may be possible to loose focus when a well known skill is performed. This is unfortunate since it might lead to injury. A study by Lindner & Caine (1990) showed that injuries in artistic gymnastics occur after a long time of practice on the same apparatus, and often in skills that the gymnast already knows well. Gymnastics practice sessions tend to be extended over long periods of time. In teamgym the average training session lasts for three hours (Table I) and if not prepared accordingly, that is physically (including energy intake) and mentally, there may be a risk to loose concentration at the end of the sessions. Maybe an increased number of training sessions and shorter duration of time, or a break in the middle of the training sessions could be solutions to limit the injury risk.

Apparatus and injury occasion

At the time for study I, 'vaulting' (now the event 'trampette') included skills performed on springboard as well as trampette. In study II, springboard had been excluded. This course of development in teamgym makes it difficult to compare injury occasion between study I and study II, with respect to events. The technical construction of the springboard and the tumbling mat may be similar and possibly produce about the same amount of impact on the gymnasts. However, no such study has been performed and therefore there is no evidence to support this speculation. In study I, tumbling accounted for 35% and springboard for 11% of the injuries and in study II, tumbling accounted for 52% of the injuries. Furthermore, trampette accounted for approximately 29% of the injuries in study II and 23% in study I. The development of equipment may be regarded as an advantage, but in some cases it may also be a disadvantage to a sport. To standardize the apparatus in teamgym may provide the sport with optimal conditions for increasing the level of performance. Whether this leads to a reduction of the injury rate still remains to be investigated. Contrary there is a possibility that this may lead to even more spectacular skills and possibly a higher number of severe injuries. During the National Championships the injuries were equally distributed between tumbling and trampette.

Pain and postural control

Pain, no matter the cause, has been shown to result in altered postural control (Hodges, 2001; Hodges et al, 2003; Smith et al, 2005; Moseley & Hodges, 2005). This could disturb the motor control programs, which may lead to injury. In the present thesis around two thirds of the gymnasts complained of symptoms from different injury locations. Mechanoreceptors in e.g. ligaments, joints and muscles provide the central nervous system continuously with information (Dietz, 1992). If these receptors are impaired due to tissue damage the afferent flow will be disturbed (Johansson et al, 1999). Gymnasts with low back pain in study IV, showed a larger area of the center of pressure (COP) than gymnasts with lower extremity injury. This altered postural control seemed to be influenced by pain. Gymnasts with lower extremity injury did not report pain at the test occasions in contrast to gymnasts with low back pain. The level of estimated pain varied between the test-retest occasions and the measurements for this group were the least reliable. If fluctuation in pain levels leads to disturbed sensory input and altered postural control, and since gymnastics depends on perfect timing and body control, pain could be a risk for a new injury to occur. This may prove to be valuable information and should further be investigated, since gymnasts tend to practice despite low back pain (study III).

Lower extremity injury

The ankle joint is one of the most frequently injured locations in sports (e.g. Garrick, 1977; Garrick & Requa; 1989; Omey & Micheli; 1999). This thesis provides similar information from teamgym. The ankle joint was the most common location for injury both in study I and II and also in unpublished observations during competition. The three events in teamgym are all characterized by impact to the lower extremity possibly explaining the site for injury. Most injuries occurred in the landing phase of the skills. In the tumbling event three or more tumbles follow in a row and the last tumble is often the most difficult and demanding one. Just a small mistake somewhere along the tumbles could affect the ankle or knee joint in the landing phase. In the trampette event the gymnasts rotate around both the horizontal and vertical axis of movement and a perfect landing is depending on timing and technique. Under or over rotation of somersaults and twists were common injury mechanisms (study II and unpublished data). These mechanisms most probably increase the impact to the joints and eventually lead to an injury (Sands, 2000). In addition, gymnasts reporting recurrent symptoms from the knees in study I had a significantly higher BMI. A high BMI or a poor landing may be a possible explanation to the high frequency of injuries to the lower extremity in teamgym. In order to reduce the amount of lower extremity injuries a special focus should be put on the landing phase. A correct technique in the skill is essential in order to perform a perfect landing. The programming of motor skills is time consuming (Galley & Forster, 1987). The fact that reaching perfection takes time may be overseen in the aim of performing more and more difficult skills. However, it is of utmost importance to provide the gymnasts with enough time while learning a new skill. Time is essential in order to reach correct technique and perfect landings (Galley & Forster, 1987).

Low back pain

The lower back was the second most common site for injury in the present thesis and in study II muscle strains and ligament injuries represented the majority of the diagnoses. Low back pain is a common problem among highly active adolescents (Homer & Macintosh, 1992; Wadley & Albright, 1993; Kujala et al, 1996; Hutchinson, 1999) and in study III, 24 out of 51 young gymnasts reported low back pain during a one-month period. Furthermore, the back was the most re-injured site reported in study I. The spine is inherently unstable and therefore well functioning muscles are needed (Panjabi, 1992). When an injury occur an inhibition, secondary to pain, of the damaged tissue is a fact (Arvidsson et al, 1986). Studies have shown that the recovery of the lumbar multifidus muscles is not automatic after a first-episode of low back pain (Hides et al, 1996). Specific training aiming to activate the injured muscles is needed (Richardson & Jull, 1995; O'Sullivan et al, 1997; Hides et al, 2001). Gymnasts are in general rather strong, and could probably initially compensate for this dysfunction, leading to decreased pain despite not fully recovered. At times of high repetitive load to the spine this compensation might not be enough and a more severe injury could occur. In 1991, Swärd et al. showed that male artistic gymnasts have a higher degree of early disc degeneration than non-athletes.

In study III, a specific training program was implemented in the warm-up session with the aim to prevent or reduce low back pain among youth female gymnasts. The training program was based on the abdominal hollowing exercise (Richardson & Jull, 1995) aiming to co-contract the local muscles of the lumbar spine. The result of this study indicates that it may be possible to reduce the amount of low back pain in this group of individuals. Whether this training also may play a role in the prevention of low back pain can not be concluded from this investigation. Three gymnasts (out of 8) in the control group and one gymnast (out of 15) in the intervention group sustained low back pain during the study period. This may indicate a possible preventive effect of the training, although not statistically proven. Since gymnastics is a sport with high demands on the spine (Swärd et al, 1991), this type of training may prove to play a special role in the prevention of these injuries.

Methodological considerations

Epidemiology

The sequence of injury prevention research has been described by van Mechelen et al (1992) as follows: 1) establishing the extent of the sports injury problem (incidence, severity), 2) establishing etiology and mechanisms of sports injuries, 3) introducing a preventive strategy, and 4) assessing its effectiveness by repeating step one. The magnitude of the problem should be identified and described in each sport (Meeuwisse 1991; van Mechelen et al 1992; Kujala et al 1995; Parkkari et al 2001). However, with regard to differences between sports, the magnitude of the problem can not always be described in the same way.

Injury definition

An injury definition has to be determined in order to compare results between different investigations. There are different ways of defining injuries within sports, e.g. time loss from athletic participation or altered athletic performance, tissue damage or medical attention injury (Noyes et al, 1988; Fuller et al, 2006). The time loss and altered athletic performance definition is probably the most common. However, an ankle sprain that limits dorsiflexion with for instance 10 degrees would be disabling for a gymnast, but the same injury may not be of any consequence to a figure skater. Moreover, an ankle sprain sustained by a football player would be reported as an injury but would not be reported by a bicyclist if it did not limit his/her participation. (Noyes et al, 1988) Defining injury by time lost from athletic participation also raises the issue of subjectivity, since one injured athlete will continue to practice sports while another athlete with the same injury feels too impaired to perform sports (Noyes et al, 1988). This inconsistency between sports and subjective responses from different athletes significantly affect how an injury is defined and how injury data are recorded and used. The time loss definition is difficult to apply in gymnastics, since gymnasts seldom stay out of gymnastics due to injury (Lindner & Caine, 1989; Sands et al, 1993; Harringe et al, 2004). The tissue injury definition requiring medical attention is probably the most objective method leading to the diagnosis of the injury. This may be a more appropriate definition in gymnastics but unfortunately not possible to fulfill completely, since advanced diagnostic methods such as for instance magnetic resonance images, radiological examination and ultrasound could be needed. This type of data collection by precise objective criteria is a “sensitive” way of injury definition and reproducible by more than one investigator (Noyes et al, 1988).

In gymnastics there is no consensus regarding the definition of injury. The following injury definitions have been used in the field of gymnastics: ‘the inability to perform an activity requiring the use of a specific body part for longer than one day due to a physical complaint related to gymnastics’ (Lindner & Caine, 1990), ‘any gymnastics related physical damage that cause the gymnast to miss or modify one or more training sessions, competitions or both’(Kolt & Kirkby, 1999), ‘ any damaged body part that would interfere with training’ (Sands et al, 1993) and checking hospital injury charts (Dixon & Fricker, 1993). To our knowledge there is only one study, besides the present thesis, where injuries in teamgym are reported (Bak et al, 1994). The injury definition used in the study by Bak et el (1994) was ‘any damage leading to pain or restriction in activity’.

The first study in this thesis was based on a questionnaire handed out at a competition. This questionnaire consisted of questions about possible injuries or symptoms from injuries at the day of competition. The symptoms could be of any type such as pain, swelling or instability for instance. Thus, the purpose of this study was to find out whether teamgym gymnasts participate in competition in spite of symptoms from previous injuries. They were also asked to define the site and describe their injuries according to the ‘Report on sports injuries from the Folksam Insurance Company’ (Folksam, 1994).

In study II, the injury definition was injuries leading to modified participation or absence from gymnastics during one week or more. The time limit one week was used to be able to compare between gymnasts in teamgym. Top level teamgym gymnasts do not practice every day (Harringe et al 2004, 2006). However, the total numbers of hours in training per week are in most cases comparable between the gymnasts. In artistic gymnastics, where the injury definition ‘modified training at one session or more’ has been used, the average time for modified training period per injury has been reported to last between 1.8 weeks for sub-elite gymnasts and 2.4 weeks for elite gymnasts (Kolt & Kirkby, 1999). Only a few injuries influence the training for less than one week in artistic gymnastics (Lindner & Caine, 1989). Injuries leading to modified participation were included in study II since gymnasts seldom stay out of practice due to symptoms from an injury. This is evident in artistic gymnastics (Lindner & Caine, 1989; Sands et al, 1993), but also in teamgym, which has been confirmed in the present thesis.

Re-injury

In study I, the gymnasts were asked if they had suffered an injury more than once at the same site during their carrier as gymnasts. This was defined as a re-injury. A similar definition has been used in artistic gymnastics (Caine et al, 1993). This definition only gives an estimation of the re-injury rate, as we neither know the time period between the injuries nor whether the symptoms were due to an identical injury or two different injuries to the same site. In study II, we analyzed the re-injuries more carefully with respect to injury diagnosis and exact location of tissue damage. Still, we did not define the time period between the original injury and the re-injury, which has been done by Hägglund et al (2007), according to the Union of European Football Associations (UEFA). The UEFA definition of a re-injury is ’an injury of the same type and location of a previous injury that occurred within two months of the final rehabilitation day of the previous injury’. In sports medicine it is often suggested, although no consensus exists, that re-injuries are associated with incomplete rehabilitation. Whether it is correct to set a time limit in order to distinguish a re-injury from a new injury can therefore be discussed.

In football Arnason et al (1996) mean that ’the player is defined as injured until he is able to play a match or comply fully with all instructions given by the coach’. According to the UEFA model the player should be able to take part in 100% of the team’s training program to be recorded as participating in that session (Hägglund et al, 2007). If this definition should be used in gymnastics the majority of the gymnasts (Sands et al, 1993; Kolt & Kirkby, 1999; Harringe et al, 2004), would be classified as injured and subsequently not be recorded as participating in that session. This depends on the fact that gymnasts practice in spite of symptoms from injuries. The type of skills performed during practice is highly individual, and modified training is rather a rule than an exception in teamgym.

Injury incidence

The incidence is usually reported as the number of injuries / 1000 activity hours (e.g. Dick et al, 2007). This means that the time of exposure needs to be collected for each gymnast. The exposure time is usually revealed based on training diaries. The exposure time for different activities should also be registered (Hägglund et al, 2005). In study II, the exposure was registered using an individual training diary as well as the coach’s attendance chart. The incidence was reported as number of injuries / 1000 gymnastics hours, which was defined as time spent in training, competition and exhibition as one unit. It would have been interesting to calculate injury incidence at competition as well as exhibition and practice, respectively. In order to do so, time spent at competition and exhibition should be registered separately. This is not as easily accomplished in teamgym as it may be in other team sports such as football (soccer) and handball, for instance, where the match time is specified. In this aspect teamgym should rather be compared to individual sports such as track and field, which have a similar problem with a lot of practice hours but very short time of exposure during competition. The top level competitions in teamgym are few and usually scheduled over a week end. However, the exposure time during the three events at a teamgym competition does not last for more than nine minutes all together (Rules and regulations, 2007). In the present thesis the majority of gymnasts reported injuries during practice. This is in line with previous reports (Lindner & Caine, 1989; Bak et al, 1994). The relative risk to sustain an injury during competition or exhibition may be higher than during practice but difficult to confirm. With another methodology, reporting exposure time during competition and exhibition, it may be possible to calculate the injury incidence during these activities. However, the methodology needed would be time consuming reaching over several years.

Injury mechanisms

The mechanisms of injury are sports specific. This means, for instance, that the inciting event for an ankle sprain in football is not the same as in gymnastics. Therefore it is very important to study the injury mechanism including inciting event in different sports (Meeuwisse 1991; Van Mechelen et al 1992; Kujala et al 1995; Parkkari et al 2001; Bahr & Krosshaug, 2005). Study II and the registration at the National Championships have provided information on how injuries occur in teamgym. The events leading to an injury situation are important as well as to include a description of the whole body and joint biomechanics leading to injury (Bahr & Krosshaug, 2005). This information should be considered in a model that also includes internal and external risk factors (van Mechelen et al; 1992; Bahr & Krosshaug, 2005). In this thesis the gymnastics skill leading to injury as well as the joint biomechanics at the time of injury was determined by observations and interviews (study II and registration at the National Championships). The exact magnitude and direction of force and thereby injury mechanism from field observations can not be completely determined. Therefore, besides observations, the injured gymnasts were interviewed, following an injury protocol (Appendix C, D), by the test leader, a sports physical therapist with lots of experience from teamgym. The injury protocol revealed four specific mechanisms involved in most injuries in the present thesis. These were joint compression, joint rotation, hyperextension and overuse. These findings all together provide information that most likely could be useful when designing future injury prevention programs in teamgym.

Injury severity

Injury severity can span a spectrum from abrasion to fracture. As a result the athlete can miss a few minutes of a practice session or an entire season due to an injury. Severity of sports injuries can be described on the basis of six criteria according to van Mechelen et al (1992). These are the nature of the sports injury, the duration and nature of treatment, sporting time lost, working time lost, permanent damage, and cost. However, in sports medicine research injury severity is usually based on the length of time loss from athletic participation (Noyes et al, 1988). The National Athletic Injury Registration System (NAIRS) of the United States discriminates between minor (1-7 days), moderately serious (8-21 days) and serious injuries (>21 days).

In gymnastics the time loss definition is most often used, although it is difficult to apply, since gymnasts often practice despite injuries (Sands et al, 1993; Kolt & Kirkby, 1999; Harringe et al, 2004). Bak et al (1994) classified injuries in Danish gymnasts using a five grade scale, where grade 1 was training with pain, possible or minor restrictions in activity, grade 2 was absence from training, grade 3 competing with pain or restrictions in exercise, grade 4 absence from training and competition, and grade 5 was injury requiring hospital admission. This scale has previously been used in sports medicine research (Jörgensen, 1984) but we did not find this scale appropriate in our teamgym gymnasts. They do not practice every day and there are only a few competitions during one season. Furthermore, grade 2 'an injury causing absence from training' could be more severe than 'competing with restrictions', grade 3 in this scale. Subsequently, grade 2 and 3 can not be evaluated as an increased severity.

Due to the design of study I, the type of injury and its severity could not be evaluated. The injury definition in study II was wide enough to cover all degrees of severity according to the NAIRS classification system. However, the injuries in study II and at the National Championships were also evaluated with respect to tissue damage and a diagnosis. Some injuries were evaluated with radiological examination, magnetic resonance imaging and arthroscopy and four injuries in study II required surgery. The diagnosis as well as the diagnostic tools might provide the reader with some information regarding the severity of the injuries.

Injury risk factors

In order to detect injury risk factors in sports, 20-50 injury cases are needed for moderate to strong associations and 200 for small to moderate associations (Bahr & Holme, 2005). In study I, the sample size was large enough to identify injury risk factors. Correlations were studied with a logistic regression modelling and potential injury risk factors were screened. A prospective design such as in study II may reduce the risk for recall bias and be a better design for studying injury risk factors. However, an injury risk factor analysis was not conducted since it was not the primary aim of study II and the sample size was too small.

Injury prevention

An injury prevention program should be based on measures that are likely to reduce the number of injuries and their severity within the actual sport. Thereafter, the effect of the prevention strategies should be evaluated (van Mechelen et al, 1992; Myklebust et al, 2003). In this thesis study III was designed to prevent or reduce low back pain in young female gymnasts. The result from the study indicates a good effect from the intervention, but has only been verified in a short time perspective. Furthermore, the study included a limited number of gymnasts. Therefore study III may be regarded as a pilot study, indicating directions for future investigations including a larger population.

Questionnaires

Injury survey

Questionnaires or injury forms have been used in all studies included in the present thesis. Study I was based on a questionnaire regarding symptoms from injuries at the day of competition (Appendix A). A test-retest of this questionnaire revealed excellent correlation for the questions about anthropometrics and training data as well as for symptoms from injury at the day of competition. The questions regarding event and skill in which the injury had occurred, how long they had practiced the skill and the re-injury rate showed lower correlation between the two test occasions. This is a disadvantage with retrospective questions. The recall time will influence how well the questions will be answered (Kolt & Kirkby, 1999; Junge & Dvorak, 2000). In a study by Kolt & Kirkby

(1999), comparing retrospective and prospective findings in the same sample of gymnasts, no differences were found in terms of anatomical location or type of injury. However, a significantly higher number of injuries were recorded prospectively compared to retrospectively (Kolt & Kirkby, 1999). The questions asked at the start of study II and study IV in the present thesis were similar to the questionnaire used in study I. However, the answers to the questions were discussed with each one of the participating gymnasts. This may have cleared possible confusion and misinterpretation (Sundblad, 2006). In study II and at the National Championships an evaluation of each injury at the time of injury was performed by medical personnel and all questions were asked close to the injury incident. Specific injury forms were used (Appendix C, D). The injury forms included questions regarding state of mood and how well the gymnasts knew the skill in which they were injured. These questions were included after agreement with the Swedish Gymnastics Federation in order to find out whether gymnasts sometimes perform skills that they are not fully prepared for. This may be a possibility in teamgym, since the team score is partly depending on each gymnast's level of skill. The more advanced skill the higher the score.

Pain rating

Every day, the gymnasts in study III reported intensity of low back pain with Borg's CR10® scale (figure 3) (Borg et al 1991; Borg 1998) and a pain map. They also answered two questions regarding what caused pain and what caused pain relief (Appendix F). Borg's pain scale is widely used in assessing musculoskeletal pain (e.g. Harms-Ringdahl, 1986; Borg, 1998), although not in such a young population. To our knowledge, there is no low back pain disability score for an adolescent athletic population. Watson et al (2002) developed a disability questionnaire for evaluation of back pain related disability in school children, aged between 11 and 14 years. It consisted of two parts, firstly a pain map and a question regarding low back pain during the last month, and secondly of questions concerning low back pain during daily living (Watson et al, 2002). This design of the questionnaire was similar to the one used in our study. The questionnaire presented by Watson et al (2002) showed a good reliability and validity in the studied population. The Oswestry low back pain disability questionnaire (Fairbank et al, 1980) has previously been used in male gymnasts aged 19-29 years (Swärd et al, 1991) but was not considered sensitive enough for that population. In the disability rating index (DRI) (Salén et al, 1994) the visual analogue scale (VAS) is used to evaluate disability in correlation to low back pain. A modified DRI in combination with Borg's CR 10® and a pain map might be useful in young gymnasts.

Selection bias

The answering rate of the questionnaires in study I was 63%. The questions were asked at a day of competition. It is understandable that there are gymnasts who rather focus on the competition than answer questions about injuries or symptoms from injuries. Who did and who did not answer the questionnaire? The only information available about the gymnasts who did not answer the questionnaire was gender and age. Therefore, it was not possible to perform a drop-out analysis. However, gender and age did not differ between drop-outs and those that answered the questionnaire. If the majority of the drop-outs were injured then our figures are underestimated and contrary, if the drop-outs were non-injured our numbers of injuries are overestimated. However, the proportions of injuries to different body parts were similar in study I and study II as well as when compared to the study by Bak et al (1994). In study I and at the National Championships top level teamgym gymnasts from all of Sweden were represented. In study II, III and IV gymnasts from top level gymnastics teams in Stockholm were included. The gymnasts compete at national level, but the training conditions as well as apparatus and training facilities between different areas in Sweden could probably vary. However, when comparing the injuries registered at the National Championships (unpublished data) with those recorded in study II, the diagnosis and mechanisms were similar. In study III the initial decision to participate was made by the team coaches and thereafter the gymnasts were asked to participate. Three out of five teams participated. Furthermore, to avoid a cross over effect between gymnasts in one team, the teams could only be included in either the intervention or control group. The two first teams that agreed to participate were included in the intervention group and the third team formed the control group. This procedure may have caused selection bias. However, the medical status of the included gymnasts in each team was not known at time for inclusion, which may have reduced this risk.

Postural control measurements

Postural control is maintained through the interaction of the somatosensory, visual and vestibular systems together with the central nervous system (Maisson, 1992; Horak & McPherson, 1996). Dysfunction in any part of the system may result in impaired postural control. There are a number of different reasons for evaluating postural control. In sports medicine postural control measurements are often used in order to identify athletes at risk for sports-related injuries (Willems, 2005; McGuine, 2000; Tropp 1985) or to evaluate the outcome of rehabilitation programs (Tropp, 1985; Verhagen 2005). In order to evaluate postural control in upright standing, different types of force platforms can be used. In study IV an AMTI force platform (model OR6-7-1000, Advanced Mechanical Technology, Inc., Watertown, MA, USA) was used for this purpose. Quiet standing was measured during 120 seconds and four different tests were performed in order to challenge the systems for postural control. There seems to be a need to challenge the postural control system in order to obtain useful information from force platform measurements. The most challenging test and also the test that revealed differences between the subgroups was upright standing with eyes closed standing on foam surface. This test requires a well functioning proprioceptive and to some extent vestibular system as the vision is manipulated. The vision is important in gymnastics and maybe tests with eyes open were not challenging enough for this study group. Visual input is considered important in maintaining postural equilibrium (Gantchev, 1972) and even in difficult skills, rotating around the vertical as well as the horizontal axes, gymnasts are taught to use their vision for orientation. Some authors mean that the vision is more important than the proprioceptive input (Lee & Lishman, 1975).

Ethical aspects

Gymnasts, as well as other athletes, complain of pain now and then and when participating in gymnastics they are always at risk for sustaining an injury. Swärd et al (1991) found that athletes with severe back pain had a higher amount of radiological changes to the spine than those with no back pain. It would be highly valuable, but indeed difficult to provide the gymnasts with guidelines for “pain limits” and a maximal border for how much pain that should be allowed during practice and competition. In study III, some gymnasts, at a few occasions, rated their low back pain to be10 on Borg's pain scale, equivalent to maximal intensity of pain. These gymnasts continued with the ordinary training and did not stay out of practice. It may be argued that the gymnasts with high intensity of pain should have been encouraged to stay out of practice. However, due to the study design, the information regarding estimated intensity of pain was not revealed until the end of the study period. All gymnasts/guardians had signed a written consent to participate in the study and knew that they were free to leave the investigation whenever they chose to without giving any explanation.

Statistical methods

Test-retest

In the present thesis two test-retest procedures were performed, one on the questionnaire in study I and one on the COP measurements in study IV. In study I the Spearman rank correlation coefficient (Spearman *R*) was used. This method can be thought of as the regular Pearson product-moment correlation coefficient (Pearson *r*), except that Spearman *R* is computed from ranks. The weighted kappa coefficient (Cohen, 1968) may be a better way of evaluating the reliability of a questionnaire. The weighted kappa and the intraclass correlation coefficient (ICC) are related (Armitage & Berry, 1994). In study IV the ICC was used together with the coefficient of variance (CV). ICC is based on analysis of variance (ANOVA) and considers both the variability between individuals and between test-retest occasions. The CV shows consistency between the test-retest, and is calculated with the standard error of measurement (SEM), equivalent to % SEM (Weir, 2005). Whether using the Pearson *r* or the ICC is a subject of debate in the statistical literature (Weir, 2005). Some authors mean that the Pearson *r* is not suitable in a test-retest setting, while others argue the opposite (Weir, 2005). In a homogenous group, with a small variability between individuals, the ICC could show a false low value. That is if the variability between individuals is smaller than the variability between tests (Weir, 2005). Subsequently, a false high value could occur when the opposite is evident. The CV, providing us with the consistency of the test may be the best measure for evaluating the reliability of the COP measurements. In study IV, the ICC values varied between poor to excellent. If the COP measurements are being used as outcome in rehabilitation it is important to calculate the normal variability for each value. Only differences outside these ranges could be considered as a result of rehabilitation.

Power analysis

There is always a risk for a Type I or Type II error in the statistical analysis. In study II, no correlations between injury mechanisms and diagnoses were detected. Either there are no correlations or this could be a Type II error. Meuwisse (1991) has pointed out the necessity of a large number of homogenous subjects in order to detect correlations. Furthermore, Bahr and Holme (2003) have reported that in order to detect moderate-to-strong associations 20-50 injury cases are needed and to detect small-to-moderate associations about 200 cases are needed. One way of minimizing the risk of a Type I or Type II error is to perform a power analysis prior to investigation. In order to calculate power the primary outcome variable has to be determined. In experimental studies, testing different treatment strategies, the possible effect of the treatment should be known or estimated. Study III may be regarded as a pilot investigation, since the possible effect of the intervention in this specific population was difficult to estimate. A power analysis performed retrospectively suggests that, provided the design stays the same, around 40 subjects in each group should be included to reach 80% power. Despite this, the study provided statistical significances, and with a larger sample size these differences may prove to be larger. Prior to study IV a power analysis was carried out showing that the subgroups should include 15 gymnasts, at a level of 80% power.

Study strengths and limitations

Sources of bias and limitations must be recognized and referred to. Below, the main strengths and limitations of each study are presented.

Study I, which was carried out during an important national competition, had a high drop-out rate. A general weakness and disadvantage of questionnaires is drop-out of individuals, and thereby answers of the whole questionnaire, and drop-out of single answers within the questionnaire. Investigating whether gymnasts compete in spite of symptoms from injuries had not been performed prior to study I, and the high drop-out rate may be a result of the complexity of the competition situation. Since there is no data on the drop-outs, except for gender and age, it can not be concluded whether there is selection bias in this material. There is also the risk of memory biases, since incidents sometimes are forgotten, exaggerated or diminished (van Mechelen, 1997). The main limitations of study I are the high drop-out rate and the questions regarding injury occasion and re-injury rate. The main strength is that study I provide new information, never investigated before, important for future injury prevention studies. Furthermore, the site and injury occasions were in all comparable to the results of study II as well as the unpublished data in this thesis.

Study II included two top level teams, all in all 42 gymnasts. Since, there are a limited number of top level teamgym gymnasts the main purpose of this study was to describe injury mechanisms and injury diagnosis. In order to detect injury risk factors a larger sample size is needed (Bahr & Holme, 2005). The main strength with study II is that each injured gymnast was examined by the same physiotherapist with experience of teamgym. Injuries that needed further evaluation were referred to, and examined by, a sports orthopaedic surgeon. If necessary a radiological examination, magnetic resonance imaging or an arthroscopy was performed. The main limitation of study II is lack of injury severity classification.

In study III a specific training program was evaluated. The aim was to prevent or reduce low back pain in young female gymnasts, competing at national level. The small sample size, due to a limited number of teams at this level of teamgym, made the randomization procedure difficult. Three teams out of five accepted to participate, which led to different sizes of the intervention and the control group. Due to the risk of a cross-over effect between gymnasts within a team, the team could only be included in either of the groups, intervention or control. However, the medical status of the included gymnasts in each team was unknown to the investigators at the time of inclusion. This may be seen as a form of randomization. The control group differed with regard to group size, age, weight, BMI and training hours per week compared to the intervention group. Differences in anthropometrics at inclusion were possibly due to the large age span at this level (11-16 years). Moreover, the variation in number of training hours per week may be due to different coaches and their approach to training. A larger sample size would have evened out the differences at inclusion. During baseline a larger proportion of gymnasts in the intervention group complained of low back pain compared to gymnasts in the control group. However, at the end of the study period a larger proportion of the gymnasts in the control group complained of low back pain compared to gymnasts in the intervention group. The main strength with study III is that gymnasts in the intervention group were improved. The main limitation of study III is the small sample size.

In study IV the influence of low back pain and lower extremity injury on postural control was evaluated in top level female teamgym gymnasts. Earlier studies have shown that patients with low back pain produce a different center of pressure trajectory compared to healthy controls (Nies & Sinnott, 1991; Alexander & LaPier, 1998; Mientjes & Frank, 1999; della Volpe, 2006). However, none of the studies are performed on an active adolescent population. The main strength of study IV is that it provides new information regarding center of pressure measurements in a young active population. The main limitation of study IV is that two out of the four studied subgroups included eleven gymnasts, and the power analysis performed prior to this investigation revealed a need for fifteen gymnasts in each group.

CONCLUSIONS

Study I: Teamgym gymnasts compete in spite of symptoms from an injury. The foot/ ankle (34%) and the back (22) are the most common sites for these symptoms.

Study II: The injury incidence in top level teamgym is 2.2 / 1000 gymnastics hours for both male and female gymnasts. The injuries occur mostly during the landing phase of the gymnastics skill with joint compression and joint rotation as the primary injury mechanisms. Most injuries occur at the end of the gymnastics session and when the gymnasts are in a negative state of mood expressing feelings such as fear, stress or out of focus. The ankle joint and the lower back represent the most common sites for injury, with ligament and muscle damage as the primary diagnoses.

Study III: Low back pain is common among young female gymnasts and 24 out of 51 gymnasts reported low back pain during a one-month period. Á specific muscle training program of the local lumbar muscles may be of value in reducing low back pain in this population. Whether the training has a preventive effect can not be concluded from this study. However, one gymnast (out of 15) sustained low back pain in the intervention group compared to three (out of 8) in the control group, which may indicate a preventive effect, although not statistically proven.

Study IV: Postural control measured as center of pressure excursion varies with injury location in young female gymnasts. Standing on foam surface with eyes closed during 120 seconds was the most challenging test to the postural control. Gymnasts with low back pain perform a larger area in this test compared to gymnasts with lower extremity injury. The intraclass correlation coefficient and the coefficient of variance vary with injury location and test intervals. The reliability of the measurements for the non-injured group is overall acceptable in the 120 seconds tests.

CONCLUDING REMARKS & FUTURE PERSPECTIVES

Gymnastics is a demanding sport both physically and mentally. Gymnastics performance is depending on a well functioning motor control. Even a minor mistake in a difficult skill may lead to an injury. Therefore, it is important to carefully plan the gymnastics training with regards to the individual level of each gymnast and the demands of the sport.

To our knowledge the present PhD thesis is the first one discussing injuries in teamgym. It provides information about injury incidence, injury mechanisms, injury site and diagnoses in teamgym. An attempt to prevent or reduce low back pain and the influence of low back pain and lower extremity injuries on postural control in teamgym gymnasts has also been conducted. This thesis is an initial step towards describing injuries in teamgym. To prevent these injuries, prospective, randomized, intervention studies evaluating injury preventive strategies should be carried out. The specific demands of tumbling, trampette and floor programme should be determined and injury risk factors identified. Since there is a lack of sensitive tools to evaluate low back pain in adolescent gymnasts, it would be of value to develop a low back pain disability score for this population. Additional fields for future research may be to study group dynamics in teamgym. It is a team sport and the score depends on the performance of every team member.

Based on the present thesis the following recommendations are suggested:

- Maintain a high level of concentration during both practice and competition.
- Divide the training sessions into short periods of training.
- Focus on the technique, especially on the landing phase of the skill.
- Do not perform a skill in competition before being prepared accordingly.
- Avoid full training and competition until the rehabilitation after an injury is regarded completed.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to *Karolinska Institutet, the Swedish School of Sport and Health Sciences and the Swedish National Centre for Research in Sports*, for financial support during my work with this thesis.

I would especially like to thank the following persons without whom this thesis never would have been written;

Docent Suzanne Werner, min entusiastiska handledare. Det var du som sa: ”nu eller aldrig” och som med din övertygelse lockade mig att börja forska. Du är helt enkelt unik och en otroligt underbar människa. Tack för all din hjälp och din support under mina år som doktorand på KI.

Prof. Per Renström, alltid mycket på gång, alltid ett leende och ett “kom in, kom in, för dig har jag alltid tid”. Per, du är en varm person och jag är glad att jag fått äran att lära känna dig och din familj. Du brinner för idrotten och besitter så mycket kunskap. Tack för att du introducerat mig i forskningens underbara värld.

Docent Tönu Saartok, vad vore forskningen utan en rejäl portion kreativ gotlänning? Du är den sanna glädjespridaren. Alltid positiv, redo att spåna fram ny ”världsforskning”. Tack för att jag fått dela dessa år med dig.

Docent Inga Arvidssson, min medförfattare. Jag är glad för att jag har fått lära känna dig, inte bara som lärare och ”proffs” inom OMT, utan också som medförfattare och privatperson. Det har varit ett stort nöje och jag hoppas att vi får anledning att fortsätta vårt samarbete i framtiden.

Kjartan Halvorsen, min medförfattare och den räddande ”norrmannen”! Tusen tack, du är kompetent, innovativ och trevlig. Du är helt enkelt ”great”!

Prof. Eijnar Eriksson Tack för all support och hjälp under mina år som doktorand.

Prof. Bob Johnsson Thank you for reading my first manuscript and providing me with valuable feedback, not only of value for the manuscript, but for my future research.

Lennart Helleday, ditt luftslott och din snabba support har verkligen varit guld värd under de senaste årens lite ”lätta” panik .... Tack!

Jan Kowalski, Gunnar Edman, Magnus Backheden, Elisabeth Berg. Tack för värdefull statistikhjälp under åren som gått. Med er professionella guidning har jag fått lära mig att det till syvende och sist är hur man väljer att tolka resultaten som räknas.

Linda Swirtun, min allra bästa forskarvän. När allt känts hopplöst och jag varit beredd att kasta in handduken, så har du funnits där och lyssnat. Du har inte dementerat, snarare bekräftat, och fått mig att förstå att så här kommer det alltid att vara för en kritisk person i en kritisk bransch. Utan dig hade nog inte forskningen varit lika spännande.

Alla kära kollegor; *Anna, Anna, Cecilia, Anette, Gunilla, Ingrid, Christina, Nina, Paul, Daniel och Johan,* många glädjens och sorgens stunder har vi delat under alla dessa år. Jag ser fram emot nya spännande projekt med er alla.

Tommy E, Sven J och Calle A Det har varit ett sant nöje att lära känna Er. Ni har alla egenskaper som inspirerar och gör en på gott humör. Är det så man blir av friidrott? Jag hoppas att våra vägar fortsätter att korsa varandras. Ett särskilt tack till dig Tommy för sponsring med en Airex balansmatta till Studie IV.

Daniel Benoit and Dan Ramsey the two biomechanics from "over there"… I will always remember us carrying weights all over the Karolinska Hospital to get the force platform calibrated. Thank you for being such wonderful co-workers and friends and for supporting me in a field filled with forces and equations.

Alla underbara glädjespridande gymnaster, cirkusstudenter och ledare som varit inspirationen och drivkraften bakom denna avhandling. Ett extra stort tack vill jag rikta till de gymnaster och ledare som deltagit som försökspersoner i de olika delarbetena.

Hela min underbara familj! Tack för att ni har stått ut med mig och mina humörsvängningar. Jag kan nog inte lova att jag helt kommer att kunna tygla dem, men jag lovar att jag skall göra mitt bästa för att topparna blir fler än dalarna i framtiden.

Mats, min älskade framlidne man, jag vet att du har det bra där du är. Vi, din familj, saknar dig ofantligt. Du har lärt mig så mycket om livets väsentligheter. Om kärlek och uppskattning. Vi ses i ett annat liv!

August, Vilgot och Ludvig, mina underbara barn. Utan Er vore ingenting värt. Ni är det som betyder mest. Jag älskar Er, glöm aldrig det!

Mamma Världens underbaraste och förstående mamma. Vad hade jag gjort utan dig? Du kan konsten att vara en god lyssnare, en fantastisk mamma, mormor och en underbar vän. Det finns inte ord för hur mycket du betyder för mig.

Inger, min moster, och ”ständiga supporter”. Utan dig hade jag nog aldrig ens tänkt tanken akademisk karriär. Du tog mig på min första resa till London, du uppmuntrade mig att resa till USA för ett år på High School och du har alltid berättat för mig hur duktig jag är och uppmuntrat mig att studera vidare. Kram, till min bästa moster.

Stefan, min älskade lillebror! Tack för all snabb bildsupport genom åren.Vi har alltid varit goda vänner. Du är en god lyssnare och en klok person. Jag hoppas att vi nu, när jag inte alltid måste jobba, skall ha tid att lyssna på bra musik och dricka gott vin lite oftare.

Cinna, Moa och Alva – tjejerna i familjen. Våra familjesammankomster har givit mig perspektiv på tillvaron och synnerligen varit sköna avbrott i avhandlingsarbetets hets. Nu, tjejer, kanske även jag kommer att ha tid att träffa Nobel Dancer och Athena.

Min nya, fantastiska storfamilj! Rikard, du kom in i mitt liv, och gav mig så otroligt mycket kärlek, support och uppskattning när jag som mest behövde det. Jag är så glad för att du finns vid min sida!

Last but not least, *all my wonderful friends* who make life worth living. Without you nothing is really important. I hope that we now will have time to meet more often!

REFERENCES

Alexander, KM, LaPier TL. Differences in static balance and weight distribution between normal subjects and subjects with chronic unilateral low back pain. J Orthop Sports Phys Ther, 1998;28:378-383.

Andersson EA, Oddsson LI, Grundström H, Nilsson J, Thorstensson A EMG activities of the quadratus lumborum and erector spinae muscles during flexion-relaxation and other motor tasks. Clin Biomech 1996;11:392-400.

Arokoski JP, Kankaanpää M, Valta T, Juvonen I, Partanen J, Taimela S, Lindgren KA, Airaksinen O. Back and hip extensor muscle function during therapeutic exercises. Arch Phys Med Rehabil 1999;80: 842-850

Armitage P, Berry G. Statistical methods in medical research. 3rd Ed, Blackwell Science Ltd, University Press, Cambridge, United Kingdom, 1994.

Arnason A, Gudmundsson A, Dahl HA, Johannsson E. Soccer injuries in Iceland. Scand J Med Sci Sports 1996;6:40-45.

Arvidsson I, Eriksson E, Knutsson E, Arner S. Reduction of pain inhibition on voluntary muscle activation by epidural analgesia. Orthopedics 1986; 9:1415-1419.

Bahr R, Holme I. Risk factors for sports injuries – a methodological approach. Br J Sports Med 2003;37:384-392.

Bahr R, Krosshaug T. Understanding injury mechanisms: a key component of preventing injuries in sport. Br J Sports Med 2005;39:324-329.

Bak K, Kalms SB, Olesen S, Jørgensen U. Epidemiology of injuries in gymnastics. Scand J Med Sci Sports 1994;4:148-154.

Baranto A, Ekström L, Hellström M, Lundin O, Holm S, Swärd L Fracture patterns of adolescent porcine spine: an experimental loading study in bending-compression. Spine 2004;30:75-82.

Bartko JJ. The intraclass correlation coefficient as a measure of reliability. Psychol Rep 1966;19:3-11.

Beckerman H, Roebroeck ME, Lankhorst GJ, Becher JG, Bezemer PD, Verbeek ALM. Smallest real difference, a link between reproducibility and responsiveness. Qual Life Res 2001;10:571-578.

Beith ID, Synnott RE, Newman SA. Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone position. Man Ther 2001;6:82-87.

Bennett DL, Nassar L, DeLano MC. Lumbar spine MRI in the elite-level female gymnast with low back pain. Skeletal Radiol 2006;35:503-509.

Bergmark A. Stability of the lumbar spine: A study in mechanical engineering. Acta Orthop Scand Suppl 1989;230:1-54.

Biering Sörensen F. A prospective study of low back pain in a general population. I. Occurrence, recurrence and aetiology. Scand J Rehabil Med 1983;15:71-79.

Biderman HJ, Shanks GL, Forrest WJ, Inglis J. Power spectrum analyses of electromyographic activity: discriminators in the differential assessment of patients with chronic low-back pain. Spine 1991;16:1179-1184.

Borg G, Holmgren A, Lindblad I. Quantitative evaluation of chest pain. Acta Med Scand Suppl 1981;644:43-45.

Borg G. Borg's perceived exertion and pain scales. Human Kinetics, United States of America, 1998;44-52.

Bono CM. Low-back pain in athletes. Current concepts review. J Bone Joint Surg 2004;86A:382-396.

Bowling A. Injuries to dancers: Prevalence, treatment, and perceptions of causes. BMJ 1989;298:731-734.

Burton AK, Clarke RD, McClune TD, Tillotson KM. The natural history of low back pain in adolescents. Spine 1996;21:2323-2328.

Caine D, Cochrane B, Caine C, Zemper E. An epidemiologic investigation of injuries affecting young competitive female gymnasts. Am J Sports Med 1989;17:811-820.

Carlsson AM. Assessment of chronic pain. I. Aspects of the reliability and validity of the visual analogue scale. Pain 1983;16:87-101.

Cohen J. Weighted kappa: nominal scale agreement with provision for scale disagreement or partial credit. Psychol Bull 1968;70:213-220.

Cresswell AG, Grundström H, Thorstensson A. Observations on intra-abdominal pressure and patterns of abdominal intra-muscular activity in man. Acta Physiol Scand 1992;144:409-418.

Cresswell AG, Oddsson L, Thorstensson A. The influence of sudden perturbations on trunk muscle activity and intra-abdominal pressure with standing. Exp Brain Res 1994;98:336-341.

Dick R, Agel J, Marshall SW. National collegiate athletic association injury surveillance system. Commentaries: Introduction and Methods. J Athletic Training 2007;42:173-182.

de Vet HC, Terwee CB, Ostelo RW, Beckerman H, Knol DL, Bouter LM. Minimal changes in health status questionnaires: distinction between minimally detectable change and minimally important change. Health Qual Life Outcomes 2006;4:54.

della Volpe R, Popa T, Ginanneschi F, Spidalieri R, Mazzocchio R, Rossi A. Changes in coordination of postural control during dynamic stance in chronic low back pain patients. Gait Posture 2006;24:349-355.

Deyo RA. Diagnostic evaluation of LBP. Reaching a specific diagnosis is often impossible. Arch Intern Med 2002;162:1444-1447.

Dietz V. Human neuronal control of automatic functional movements: interaction between central programs and afferent input. Physiol Rev 1992;72:33-69.

Dixon M, Fricker P. Injuries to elite gymnasts over 10 yr. Med Sci Sports Exerc 1993:25:1322-1329.

Ekstrand J, Gillquist J. Soccer injuries and their mechanisms: a prospective study. Med Sci Sports Exerc 1983;15:297-270.

Emery CA. Injury prevention and future research. Med Sport Sci 2005;49:170-191.

Evans T, Hertel J, Sebastianelli W. Bilateral deficits in postural control following lateral ankle sprain. Foot Ankle Int, 2004;25:833-839.

Fairbank JC, Couper J, Davies JB, O'Brien JP. The Oswestry low back pain disability questionnaire. Physiotherapy 1980;66:271-273.

Folksam Idrottsskador (Sports Injuries) 1986-1990. A report from Folksam Insurance Company, Stockholm, Sweden, 1994.

Fu AS, Hui-Chan CW. Ankle joint proprioception and postural control in basketball players with bilateral ankle sprains. Am J Sports Med 2005;33:1174-1182.

Fuller CW, Ekstrand J, Junge A, Andersen TE, Bahr R, Dvorak J, Hägglund M, McCrory P, Meeuwisse WH. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. [Consensus statement] Clin J Sports Med 2006;16:97-102.

Galley PM, Forster AL. Human Movement: an introductory text for physiotherapy students. 2nd Ed. Churchill Livingstone, Australia, 1987;102-110.

Gantchev GN, Draganova N, Dunev S. The role of visual information and ocular movements for the maintenance of body equilibrium. Agressologie 1972;13:SupplB:55-56.

Garrick J. The frequency of injury, mechanism of injury, and epidemiology of ankle sprains. Am J Sports Med 1977;5:241-242.

Garrick J, Requa R. The epidemiology of foot and ankle injuries in sports. Clin Podiatr Medi Surg 1989;6:629-637.

Geurts AC, Nienhuis B, Mulder TW. Intrasubject variability of selected force-platform parameters in the quantification of postural control. Arch Phys Med Rehabil 1993;74:1144-1150.

Goldie PA, Bach TM, Evans OM. Force platform measures for evaluating postural control: reliability and validity. Arch Phys Med Rehabil 1989;70:510-517.

Hagins M, Adler K, Cash M, Daugherty J, Mitrani G. Effects of practice on the ability to perform lumbar stabilization exercises. J Orthop Sports Phys Ther 1999;29:546-555.

Harms-Ringdahl K, Carlsson AM, Ekholm J, Raustorp A, Svensson T, Toresson HG. Pain assessment with different intensity scales in response to loading of joint structures. Pain 1986;27:401-411.

Harreby M, Nygaard B, Jessen T, Larsen E, Storr-Paulsen A, Lindahl A, Fisker I, Laegaard E. Risk factors for low back pain in a cohort of 1389 Danish school children: an epidemiologic study. Eur Spine J 1999;8:444-450.

Hides JA, Stokes MJ, Saide M, Jull GA, Cooper DH. Evidence of lumbar multifidus muscle waisting ipsilateral to symptoms in patients with acute/ subacute low back pain. Spine 1994;19:165-172.

Hides JA, Richardson CA, Jull GA. Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. Spine 1996;21:2763-2769.

Hides JA, Jull GA, Richardson CA. Long-term effects of specific stabilizing exercises for first-episode low back pain. Spine 2001;26:E243-E248.

Hides J, Wilson S, Stanton W, Mcmahon S, Keto H, McMahon K, Bryant M, Richardson C. An MRI investigation into the function of the transversus abdominis muscle during “drawing-in” of the abdominal wall. Spine 2006;6:E175-E178.

Hodges PW, Butler JE, McKenzie DK, Gandevia SC. Contraction of the human diaphragm during rapid postural adjustments. J Physiol 1997;505:539-548.

Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine 1996;21:2640-2650.

Hodges PW, Richardson CA. Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. Exp Brain Res 1997b;114:362-370.

Hodges PW, Richardson CA. Delayed postural contraction of transversus abdominis in low back pain associated with movement of the lower limb. J Spinal Disord 1998;11:46-56.

Hodges PW. Changes in motor planning of feedforward postural responses of the trunk muscles in low back pain. Exp Brain Res 2001;141:261-266.

Hodges PW. Neuromechanical control of the spine. Thesis, Biomechanics and Motor Control Laboratory, Div of Neurophysiology, Dep of Neuroscience, Karolinska Institutet, Stockholm, Sweden, 2003.

Hodges PW, Moseley GL, Gabrielsson A, Gandevia SC. Experimental muscle pain changes feedforward postural responses of the trunk muscles. Exp Brain Res 2003;151:262-271.

Horak FB, McPherson JM. Handbook of Physiology-section 12; Postural orientation and equilibrium. American Physiological Society by Oxford University Press. Inc.: New York Oxford. 1996; 255-257.

Homer S, Mackintosh S. Injuries in Young Female Elite Gymnasts. Physiotherapy 1992;78:804-808.

Hutchinson MR. Low back pain in elite rhythmic gymnasts. Med Sci Sports Exerc 1999;31:1686-1688.

Hägglund M, Waldén M, Bahr R, Ekstrand J. Methods for epidemiological study of injuries to professional football players: developing the UEFA model. Br J Sports Med 2005;39;340-346.

Hägglund M, Waldén M, Ekstrand J. Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. Br J Sports Med 2006;40:767-772.

Indahl A, Kaigle AM, Reikeras O, Holm S. Electromyographic response of the porcine multifidus musculature after nerve stimulation. Spine 1995;20:2652-2658.

Indahl A, Kaigle AM, Reikeras O, Holm SH Interaction between the porcine lumbar intervertebral disc, zygapophysial joints, and paraspinal muscles. Spine 1997;22:2834-2840.

Jarvik JG, Deyo RA. Diagnostic evaluation of low back pain with emphasis on Imaging. Am Intern Med 2002;137:586-597.

Johansson H, Sjölander P, Djupsjöbacka M, Bergenheim M, Pedersen J. Pathophysiological mechanisms behind work-related muscle pain syndromes. Am J Ind Med [Suppl] 1999;1:104-106.

Johnson NL, Welch BL. Applications of the non-central t-distribution. Biometrika 1939;31;362-389.

Jørgensen U. Epidemiology of injuries in typical Scandinavian team sports. Br J Sports Med 1984;18:261-264.

Junge A, Dvorak J. Influence of definition and data collection on the incidence of injuries in football. Am J Sports Med 2000;28:S40-S46.

Jull G, Richardson C, Toppenberg R, Comerford M, Bui B. Towards a measurement of active muscle control for lumbar stabilisation. Australian Physiother 1993;39:187-193.

Kaigle AM, Holm SH, Hansson TH. Experimental instability in the lumbar spine. Spine 1995;20:421-430.

Karlsson L, Lundin O, Ekström L, Hansson T, Swärd L. Injuries in adolescent spine exposed to compressive loads: an experimental cadaveric study. J Spinal Disord 1998;11:501-507.

Katz DA, Scerpella TA. Anterior and middle column thoracolumbar spine injuries in young female gymnasts. Report of seven cases and review of the literature. Am J Sports Med 2003;31:611-616.

Kolt GS, Kirkby RJ. Epidemiology of injury in elite and subelite female gymnasts: a comparison of retrospective and prospective findings. Br J Sports Med 1999:33:312-318.

Kujala UM, Taimela S,Aanttipoika I, Orava S, Tuominen R, Myllynen P. Acute injuries in soccer, ice hockey, volleyball, basketball, judo, and karate: analysis of national registry data. BMJ 1995:311:1465-1468.

Kujala UM, Taimela S, Erkintalo M, Salminen JJ, Kaprio J. Low-back pain in adolescent athletes. Med Sci Sports Exerc 1996;28:165-170.

Kuukkanen TM, Malkia EA. An experimental controlled study on postural sway and therapeutic exercise in subjects with low back pain. Clin Rehabil 2000;14:192-202.

Lee DN, Lishman JR. Visual proprioceptive control of stance. J Hum Movement Stud 1975;1:87-95.

Lundin O, Ekström L, Hellström M, Holm S, Swärd L Exposure of the porcine spine to mechanical compression: differences in injury pattern between adolescents and adults. Eur Spin J 2000;9:466-471.

Lindner KJ, Caine DJ. Injury patterns of female competitive club gymnasts. Can J Sports Sci 1990:15:254-261.

Maisson J. Movement, posture and equilibrium: interaction and coordination. Neurobiology 1992;38:35-56.

McGill SM. Kinetic potential of the lumbar trunk musculature about three orthogonal orthopaedic axes in extreme postures. Spine 1991;16:809-815.

McGuine TA, Greene JJ, Best T, Leverson G. Balance as a predictor of ankle injuries in high school basketball players. Clin J Sport Med 2000;10:239-244.

Meeuwisse WH. Predictability of Sports Injuries What is the Epidemiological Evidence? Sports Med 1991:12:8-15.

Merskey H. Logic, truth and language in concepts of pain. Qual Life Research 1994;3:S69-76.

Merskey H. (Ed.) Classification of chronic pain: description of chronic pain syndromes and pain terms. Pain [Suppl] 1986;3:S217.

Mientjes, MI, Frank JS. Balance in chronic low back pain patients compared to healthy people under various conditions in upright standing. Clin Biomech 1999;14:710-716.

Moseley, GL, Hodges PW. Are the changes in postural control associated with low back pain caused by pain interference? Clin J Pain 2005;21:323-329.

Myklebust G, Engebretsen L, Hoff Brækken I, Skjølberg A, Olsen O-E, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. Clin J Sport Med 2003;13:71-78.

Nies N, Sinnott PL. Variations in balance and body sway in middle-aged adults. Subjects with healthy backs compared with subjects with low-back dysfunction.
Spine 1991;16:325-330.

Noyes FR, Lindenfeld TN, Marshall MT. What determines an athletic injury (definition)? Who determines an injury (occurrence)? In: Sports Injury Research. Am J Sports Med [Suppl] 1988;16:S65-S68.

Omey ML, Micheli LJ. Foot and ankle problems in the young athlete. Med Sci Sports Exerc 1999;3:S470-S486.

O'Sullivan PB, Twomey LT, Allison GT. Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. Spine 1997;22:2959-2967.

Panjabi MM. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. J Spinal Disord 1992;5:383-389.

Papageorgiou AC, Croft PR, Ferry S, Jayson MI, Silman AJ. Estimating the prevalence of low back pain in the general population. Evidence from the south Manchester back pain survey. Spine 1995;20:1889-94.

Parkkari J, Kujala UM, Kannus P. Is it possible to prevent sports injuries? Review of controlled clinical trials and recommendations. Sports Med 2001:31:985-995.

Platzer W. Color atlas and textbook of human anatomy. Vol 1: Locomotor System, Georg Thieme Verlag, Stuttgart, Germany 1986;74,86.

Price DD, Mcgrath PA, Rafii A, Buckingham B. The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. Pain 1983;17:45-56.

Quint U, Wilke H-J, Shirazi-Adl A, Parnianpour M, Loer F, Claes LE. Importance of the intersegmental trunk muscles for the stability of the lumbar spine. Spine 1998;23:1937-1945.

Rantanen J, Hurme M, Falck B, Alaranta H, Nykvist F, Lehto M, Einola S, Kalimo H. The lumbar multifidus muscle five years after surgery for a lumbar disc herniation. Spine 1993;18:568-574.

Richardson CA, Jull GA. Muscle control – pain control. What exercises would you prescribe? Man Ther 1995;1:2-10.

Roland M, Morris R. A study of the natural history of low back pain. Part 1. Development of a reliable and sensitive measure of disability in low-back pain. Spine 1983;8:141-144.

Salén BA, Spangfort EV, Nygren ÅL, Nordemar R. The disability rating index: An instrument for assessment of disability in clinical settings. J Clin Epidemiol 1994;47:1423-1434.

Sands W, Shultz B, Newman AP. Women's gymnastics injuries. A 5-year study. Am J Sports Med 1993:21:271-276.

Sands WA. Injury prevention in women's gymnastics. Sports Med 2000;30:359-373.

Sjolie AN. Associations between activities and low back pain in adolescents. Scand J Med Sci Sports 2004;14:352-359.

Smith, M. Coppieters MW, Hodges PW. Effect of experimentally induced low back pain on postural sway with breathing. Exp Brain Res 2005;166:109-117.

Stevens, VK, Bouche KG, Mahieu NN, Cambier DC, Vanderstraeten GG, Danneels LA. Reliability of a functional clinical test battery evaluating postural control, proprioception and trunk muscle activity. Am J Phys Med Rehabil 2006;85:727-736.

Storheim K, Bø K, Pederstad O, Jahnsen R. Intra-tester reproducibility of pressure biofeedback in measurement of transversus abdominis function. Physiother Research Int 2002;7:239-249.

Sundblad G. Perceived health in Swedish school students. A longitudinal prevalence study. Thesis, Department of Molecular Medicine and Surgery, Section of Orthopaedics and Sports Medicine, Karolinska Institutet, Stockholm, Sweden, 2006.

Swärd L, Hellström M, Jacobsson B, Peterson L. Back pain and radiologic changes in the thoraco-lumbar spine of athletes. Spine 1990;15:124-129.

Swärd L, Hellström M, Jacobsson B, Nyman R, Peterson L. Disc degeneration and associated abnormalities of the spine in elite gymnasts. A magnetic resonance imaging study. Spine 1991:16:437-443.

Tertti M, Paajanen H, Kujala UM, Alanen A, Salmi TT, Kormano M. Disc degeneration in young gymnasts. A magnetic resonance imaging study. Am J Sports Med 1990;18:206-208.

Thornbury JR, Fryback DG, Turski PA, Javid MJ, McDonald JV, Beinlich BR, Gentry LR, Sackett JF, Dasbach EJ, Martin PA. Disk-caused nerve compression in patients with acute low-back pain: diagnosis with MR, CT myelography, and plain CT. Radiology 1993;186:731-738.

Tropp, H, Odenrick P, Gillquist J. Stabilometry recordings in functional and mechanical instability of the ankle joint. Int J Sports Med 1985;6:180-182.

Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. Am J Sports Med 1985; 3:259-262.

Van Mechelen W, Hlobil H, Kemper CG. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. Sports Med 1992;14:82-99.

Van Mechelen W. Sports injurie surveillance system. ‘One size fits all?’ Sports Med 1997;24:164-168.

Vera-Garcia FJ, Elvira JLL, Brown SHM, McGill SM. Effects of abdominal stabilization maneuvers on the control of spine motion and stability against sudden trunk perturbations. J Electromyogr Kinesiol 2007;17:556-567.

Verhagen E, Bobbert M, Inklaar M, van Kalken M, van der Beek A, Bouter L, van Mechelen W. The effect of a balance training programme on centre of pressure excursion in one-leg stance. Clin Biomech 2005;20:1094-1100.

Wadley GH, Albright, JP. Women's intercollegiate gymnastics. Injury patterns and "permanent" medical disability. Am J Sports Med 1993:21:314-320.

Watson KD, Papageorgiou AC, Jones GT, Taylor S, Symmons DPM, Silman AJ, Macfarlane GJ. Low back pain in schoolchildren: occurrence and characteristics. Pain 2002;97:87-92.

Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. J Strength Cond Res 2005;19:231-240.

Welch PD. "The use of fast fourier transform for the estimation of power spectra: a method based on time averaging over short, modified periodograms," IEEE Trans. Audio Electroacoustics 1967;15:70-73.

Wilke H-J, Wolf S, Claes LE, Arand M, Wiesend A. Stability increase of the lumbar spine with different muscle groups. Spine 1995;20:192-198.

Willems TM, Witvrouw E, Delbaere K, Philippaerts R, De Bourdeaudhuij I, De Clercq D. Intrinsic risk factors for inversion ankle sprains in females--a prospective study. Scand J Med Sci Sports 2005;15:336-345.

Winter D. Biomechanics and motor control of human movement. 3rd Ed, John Wiley & Sons, Inc., Hoboken, New Jersey, United States of America, 2005;106-108.

Appendix A [1/5]

Allmän del:

☐ Man ☐ Kvinna Födelseår _____ Längd: _____ cm Vikt: _____ kg

☐ Jag deltog i Juniorcupen 16-17 mars 1996 ☐ Jag svarade på enkäten under Juniorcupen

Var vänlig fyll i enkäten även om du fyllde i den under Juniorcupen. TACK !

1. Hur länge har du hållit på med gymnastik ? (Avrunda till närmaste hela år)

☐ 1-3 år ☐ 4-6 år ☐ 7-9 år ☐ 10-12 år ☐ 13 år el mer

2. Hur många gånger i veckan (i snitt) tränar du gymnastik ?

☐ 1 gång ☐ 2 gånger ☐ 3 gånger ☐ 4 gånger ☐ 5 ggr el mer

3. Hur många timmar per vecka (i snitt) tränar du gymnastik ?

☐ 1-3 tim ☐ 4-6 tim ☐ 7-9 tim ☐ 10-12 tim ☐ 13 tim el mer

4. Hur många tillfällen per vecka tränar du respektive redskap ?
(Om du ej deltar i något redskap, ange orsak)

Matta	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5 el mer
Hopp	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5 el mer
Fristående	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5 el mer
Styrketräning	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5 el mer

Jag tränar ej ________ pga ____

____

5. Hur länge värmer du upp i samband med träning ?

☐ 5 min ☐ 10 min ☐ 15 min ☐ 20 min el mer

6. Hur ofta stretchar du ?

☐ Aldrig ☐ Före varje träning ☐ Efter varje träning

☐ Annat alternativ: ____

7. Hur länge stretchar du ?

☐ 5 min ☐ 10 min ☐ 15 min el mer

Appendix A [2/5]

Specifik del:

1.1 Har du, just nu, problem med någon skada/besvär som uppkommit i samband med träning, tävling, uppvisning eller vid annat tillfälle då du utövat gymnastik ?

☐ Ja ☐ Nej (fortsätt till fråga 2.1)

1.2 Vad för slags skada/besvär har du problem med ? (kryssa för aktuell kroppsdel och ge en kortfattad beskrivning, diagnos el dyl)

☐ Ansikte, huvud	☐ Nacke	☐ Höft, buk
☐ Tänder	☐ Rygg	☐ Knä
☐ Axel	☐ Arm	☐ Fot
☐ Bröst, revben	☐ Hand	☐ Annan kroppsdel: ________

Kortfattad beskrivning: ____________________

____

1.3 När ådrog du dig skadan/besväret ?

☐ på tävling ☐ på träning ☐ på uppvisning

☐ Vid annat tillfälle. Vilket ? ____________________

1.4 I vilket redskap och övning ådrog du dig skadan/besväret ? (kryssa för aktuellt redskap. Ange övningen på efterföljande rad samt markera hur länge du har tränat övningen.)

Matta	☐	________	☐ ny övn.	☐ 1 år	☐ 2 år el mer
Hopp	☐ bräda:	________	☐ ny övn.	☐ 1 år	☐ 2 år el mer
	☐ trampett:	________	☐ ny övn.	☐ 1 år	☐ 2 år el mer
Fristående:	☐	________	☐ ny övn.	☐ 1 år	☐ 2 år el mer
Annat:	☐	________	☐ ny övn.	☐ 1 år	☐ 2 år el mer

1.5 Har du uppsökt professionell hjälp för skadan/besväret ? (Ange till vem du har gått)

☐ Ja
- ☐ Läkare
- ☐ Sjukgymnast
- ☐ Naprapat
- ☐ Chiropraktor
- ☐ Annan yrkeskategori Vilken ? ________

☐ Nej

Appendix A [3/5]

2.1 Har du skadat dig, eller haft besvär de senaste 12 månaderna i samband träning, tävling uppvisning eller vid annat tillfälle då du utövat gymnastik ?

- [ ] Ja (Om det är samma skada som du tidigare har beskrivit, fortsätt till fråga 3.1)
- [ ] Nej (fortsätt till fråga 3.1)

2.2 Vad för slags skada/besvär har du haft problem med ? (kryssa för aktuell kroppsdel och ge en kortfattad beskrivning, diagnos el dyl)

- [ ] Ansikte, huvud
- [ ] Tänder
- [ ] Axel
- [ ] Bröst, revben
- [ ] Nacke
- [ ] Rygg
- [ ] Arm
- [ ] Hand
- [ ] Höft, buk
- [ ] Knä
- [ ] Fot
- [ ] Annan kroppsdel: ______________

Kortfattad beskrivning: ______________________________

____

2.3 När ådrog du dig skadan/besväret ?

- [ ] på tävling
- [ ] på träning
- [ ] på uppvisning
- [ ] Vid annat tillfälle. Vilket ? ______________

2.4 I vilket redskap och övning ådrog du dig skadan/besväret ? (kryssa för aktuellt redskap. Ange övningen på efterföljande rad samt markera hur länge du har tränat övningen.)

Matta	[ ]	______________	[ ] ny övn	[ ] 1 år	[ ] 2 år el mer
Hopp	[ ] bräda:	______________	[ ] ny övn	[ ] 1 år	[ ] 2 år el mer
	[ ] trampett:	______________	[ ] ny övn	[ ] 1 år	[ ] 2 år el mer
Fristående:	[ ]	______________	[ ] ny övn	[ ] 1 år	[ ] 2 år el mer
Annat:	[ ]	______________	[ ] ny övn	[ ] 1 år	[ ] 2 år el mer

2.5 Uppsökte du eller har du uppsökt professionell hjälp för skadan/besväret ? (Ange till vem du har gått)

- [ ] Ja
  - [ ] Läkare
  - [ ] Sjukgymnast
  - [ ] Naprapat
  - [ ] Chiropraktor
  - [ ] Annan yrkeskategori Vilken ? ______________
- [ ] Nej

Appenix A [4/5]

3.1 Har du skadat dig eller haft besvär <u>någon gång</u> i samband med träning, tävling, uppvisning eller vid annat tillfälle då du utövat gymnastik ?

- [ ] Ja (Om det är samma skada som du tidigare har beskrivit, fortsätt till fråga 4.1)
- [ ] Nej (fortsätt till fråga 4.1)

3.2 Vad för slags skada/besvär har du haft problem med ? (kryssa för aktuell kroppsdel och ge en kortfattad beskrivning, diagnos el dyl)

[ ] Ansikte, huvud	[ ] Nacke	[ ] Höft, buk
[ ] Tänder	[ ] Rygg	[ ] Knä
[ ] Axel	[ ] Arm	[ ] Fot
[ ] Bröst, revben	[ ] Hand	[ ] Annan kroppsdel: ____________

Kortfattad beskrivning: ____

____

3.3 När ådrog du dig skadan/besväret ?

[ ] på tävling [ ] på träning [ ] på uppvisning

[ ] Vid annat tillfälle. Vilket ? ____________________________

3.4 I vilket redskap och övning ådrog du dig skadan/besväret ? (kryssa för aktuellt redskap. Ange övningen på efterföljande rad samt markera hur länge du har tränat övningen.)

Matta	[ ]	____________	[ ] ny övn.	[ ] 1 år	[ ] 2 år el mer
Hopp	[ ] bräda:	____________	[ ] ny övn.	[ ] 1 år	[ ] 2 år el mer
	[ ] trampett:	____________	[ ] ny övn.	[ ] 1 år	[ ] 2 år el mer
Fristående:	[ ]	____________	[ ] ny övn.	[ ] 1 år	[ ] 2 år el mer
Annat:	[ ]	____________	[ ] ny övn.	[ ] 1 år	[ ] 2 år el mer

3.5 Uppsökte du eller har du uppsökt professionell hjälp för skadan/besväret ? (Ange till vem du har gått)

[ ] Ja
- [ ] Läkare
- [ ] Sjukgymnast
- [ ] Naprapat
- [ ] Chiropraktor
- [ ] Annan yrkeskategori Vilken ? ____________________

[ ] Nej

Appenix A [5/5]

4.1 Är det någon skada/besvär som du har haft upprepade besvär med ?

☐ Ja ☐ Nej

4.2 Vilken/vilka skador/besvär har du haft upprepade besvär med ?

____

____

TACK FÖR DIN MEDVERKAN !

Appendix B

FYSTEST KS/ GYMNASTER

Delprojekt 2

Namn: ______________________________ Personnr. __________________________

Mensdebut: (ålder) ____________________

Längd: ____________________ cm Vikt: _______________________ kg

TRÄNINGSINFORMATION

När började du med gymnastik? ____________________ (ålder)

Hur många träningspass per vecka tränar du? gymnastik: ___________________

övrigt: _______________________

Hur många timmar per vecka tränar du? gymnastik: ___________________

övrigt: _______________________

Ringa in det/ de alternativ som stämmer in på dig. Uppvärmning = tiden du ägnar åt att preparera kroppen för träning.

Hur länge värmer du upp?	5 min	10 min	15 min	20 min eller mer
När stretchar du?	Aldrig	Före träning		Efter träning
Hur länge stretchar du?`	5 min	10 min	15 min eller mer	

AKTUELLA BESVÄR/ SKADA

Har du någon skada/ några besvär just nu? ja / nej

Vad för skada ? (ange kroppsdel och/eller ev diagnos)____

____

Hur länge har du haft aktuell skada / besvär ? ____

Hur ådrog du dig skadan / besväret ? ____

I vilket redskap/ övning ? ____

Hur länge hade du tränat övningen ? ____

Kunde du övningen väl? ja / nej

Vad gör du för att förebygga/ rehabilitera skadan ?____

____

Använder du någon form av ortos, bandage, tejp el liknande när du tränar? ja / nej

Vad ? ____

När ? (Hela tiden eller endast i vissa övningar/ redskap) ____

____

Appendix C

SKADERAPPORT / Gymnaster
Delstudie 2

Namn: ________________________ Personnr. ______________________

Rapportdatum: ________________

Skadedatum: ________________ Datum för återgång till träning: ________________

1. Skadad kroppsdel: ____
(precisera så gott det går)
____

2. Skadetillfälle: ☐ träning ☐ tävling ☐ uppvisning

3. Tid på träning/ tävling/ uppvisning då skadan inträffade: ______________________________

4. Gren: ____

5. Tid in på aktuell gren: ____

6. Övning: ____

7. Hur gick det till? ____

____

8. Hur säker var övningen ?
☐ mycket säker
☐ säker
☐ ej säker

9. Var övningen att betrakta som ny för dig ? ☐ ja ☐ nej

10. Hur upplevde du skadesituationen ?

Jag var:
☐ koncentrerad ☐ okoncentrerad
☐ pigg ☐ trött
☐ stressad ☐ rädd

annan känsla/ orsak, precisera: _________________________________

____

11. Frånvaro från träning, tävling och uppvisning:

Träningsfrånvaro:	a. antal tillfällen du helt avstått från träning	____________
	b. antal tillfällen du ej kunnat träna ”för fullt”	____________
Tävlingsfrånvaro:	a. antal tillfällen du helt avstått från tävling	____________
	b. antal tillfällen du ej kunnat tävla ”för fullt”	____________
Uppvisning:	a. antal tillfällen du helt avstått från uppvisning	____________

Diagnos: ________________

Läkarens/ Sjukgymnastens anteckningar: ____

____

Appendix D

Ifylles av sjukvårdspersonalen. *Namn:* ____________________

Skaderapport SM - 2001

Datum: __________

Gymnast: ____________________ Födelseår: ____________________

Förening: ____________________ Division/Klass: ____________________

Telefon: ____________________ e-mail: ____________________

Typ av skada: a. ☐ Akut b. ☐ Gammal skada - komplettera med skaderapporten: "gammal skada"

Skadad kroppsdel/ diagnos: ____________________ ☐ vä ☐ hö

☐ skelettskada	☐ spricka	☐ fraktur	
☐ ligamentskada	☐ uttänjning	☐ partiell ruptur	☐ total ruptur
☐ muskelskada	☐ sträckning	☐ partiell ruptur	☐ total ruptur
☐ senskada	☐ uttänjning	☐ partiell ruptur	☐ total ruptur
☐ annan ledskada	☐ brosk	☐ menisk	
☐ kontusion	☐ med hematom	☐ utan hematom	

☐ annan skada/kompletterande information: ____________________

____

____

Undersökningsfynd: ____________________

____

forts på baksidan

Prognos - beräknad återgång till idrott:	☐ < 1 dag	☐ < 1 vecka
	☐ < 1 månad	☐ > 1 månad

Skadetillfälle:	☐ fri förträning	☐ förträning	☐ tävling
Tid in på träning/tävling?	☐ början	☐ mitten	☐ slutet
Gren:	☐ matta	☐ fristående	
	☐ hopp	☐ annat tillfälle	____________
Tid in på aktuell gren:	☐ början	☐ mitten	☐ slutet
Skademekanism:	☐ översträckning	☐ vridvåld	☐ kompression

Övning: ____________________

Beskriv hur det gick till: ____________________

____

Anamnes: (Sjukvårdaren ställer frågorna och ger svarsalternativen till gymnasten.)

Kände du dig säker på övningen ? ☐ mycket säker ☐ säker ☐ ej säker

Hur upplevde du skadesituationen ?

☐ koncentrerad	☐ pigg	☐ stressad	☐ hade ont
☐ okoncentrerad	☐ trött	☐ rädd	☐ annan känsla

annan känsla: ____________________

Appendix E

Veckovis sammanställning av träningsdagbok

Namn: ________________________ Personnr.: ______________________________

Vecka: ______

Ange antal träningstillfällen samt totalt antal träningstimmar du utfört under veckan.

Gymnastik	Matta	antal tillfällen ______	antal timmar _____
	Hopp	antal tillfällen ______	antal timmar _____
	Frist/dans	antal tillfällen ______	antal timmar _____
Styrketräning		antal tillfällen ______	antal timmar _____
Stretch		antal tillfällen ______	antal timmar _____
Aerobics/ gympa		antal tillfällen ______	antal timmar _____
Löpträning		antal tillfällen ______	antal timmar _____
Övrigt ____________		antal tillfällen ______	antal timmar _____
__________________		antal tillfällen ______	antal timmar _____
Tävling:		antal tillfällen ______	antal timmar _____
Uppvisning:		antal tillfällen ______	antal timmar _____

Vecka: ______

Ange antal träningstillfällen samt totalt antal träningstimmar du utfört under veckan.

Gymnastik	Matta	antal tillfällen ______	antal timmar _____
	Hopp	antal tillfällen ______	antal timmar _____
	Frist/dans	antal tillfällen ______	antal timmar _____
Styrketräning		antal tillfällen ______	antal timmar _____
Stretch		antal tillfällen ______	antal timmar _____
Aerobics/ gympa		antal tillfällen ______	antal timmar _____
Löpträning		antal tillfällen ______	antal timmar _____
Övrigt ____________		antal tillfällen ______	antal timmar _____
__________________		antal tillfällen ______	antal timmar _____
Tävling:		antal tillfällen ______	antal timmar _____
Uppvisning:		antal tillfällen ______	antal timmar _____

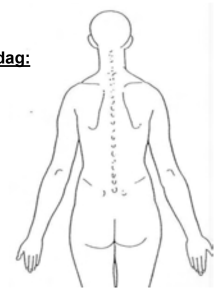
Appendix F

Så här fyller du i din dagbok:

Menstruation (M): Sätt ett kryss (x) vid första dagen av menstruationen.

1. Har du haft ont i ryggen idag?
Här kryssar du i Nej om du inte haft ont
Om du haft ont kryssar du i Ja och fortsätter med resten av frågorna. Ja □ Nej □

Markera med ett kryss (x) på figuren var någonstans du har eller har haft ont i ryggen idag:



Hur intensiv har besvären/smärtan varit idag? (Borg's CR10 skala)

0.	Inget alls	"Ingen P"
0.3		
0.5	Extremt svag	Just märkbar
1.	Mycket svag	
1.5		
2.	Svag	Lätt
2.5		
3.	Måttlig	
4.		
5.	Stark	Tung
6.		
7.	Mycket stark	
8.		
9.		
10.	**Extremt stark**	**"Max P"**
11.		
¤	Absolut maximum	Högsta möjliga

Vad förvärrar besvären/smärtan?

1. Inget bestämt
2. Gång
3. Sittande
4. Liggande
5. Beröring
6. Gymnastikträning; fristående
7. Matta; framåtstäm hand
8. Matta; framåtstäm fot
9. Matta; bakåtstäm hand
10. Matta; bakåtstäm fot
11. Matta; landning
12. Hopp; inhopp
13. Hopp; frånskjut
14. Hopp; landning
15. Annat; vad?________________________________

Vad lindrar besvären/ smärtan?

1. Inget bestämt
2. Mediciner
3. Vila
4. Värma
5. Kyla
6. Annat; vad?________________________________

Appendix G

Formulas for the force platform measurements

Let *x*(*t*) be the position of the centre of pressure (CoP) in med-lat direction, and *y*(*t*) be the position in ant-post direction. The force plate outputs six signals. These are the three components of the ground reaction force (GRF) and the three components of the moment of the GRF with respect to the origin of the force plate. The signals are sampled at discrete times, indexed from 1 to *N* for a single trial. From the force and moment signals, the COP is calculated according to

$$COP_x = \frac{-M_y - d_z F_x}{F_z}$$
$$COP_y = \frac{M_x - d_z F_y}{F_z}$$

where F_x, F_y and F_z are the components of the GRF, and M_x and M_y are components of the moment vector. The factor d_z is the depth of the force plate, i.e. the distance from the surface of the plate to the center of the force transducers.

The 95% confidence ellipse area of the COP excursion was calculated as

$$area = 6\pi\sqrt{\mathrm{var}(x)\mathrm{var}(y) - \mathrm{cov}(x,y)^2}$$

where var(*x*) is the variance of the time series *x*(*t*), and cov(*x,y*) is the covariance of the two time series. The path length was calculated as

$$pathlength = \sum_{t=2}^{t=N} \sqrt{\left(x(t) - x(t-1)\right)^2 + \left(y(t) - y(t-1)\right)^2}$$

The Root Mean Square (RMS) of the velocity was calculated using the backward difference, for the med-lat direction and likewise for the ant-post direction.

$$RMSvel_x = \sqrt{\frac{1}{N-1}\sum_{t=2}^{t=N} v_x(t)^2}, \quad \text{where}$$
$$v_x(t) = \frac{1}{dt}\left(x(t) - x(t-1)\right)$$

The RMS of the total velocity was calculated as

$$RMSvel_{total} = \sqrt{\frac{1}{N-1}\sum_{t=2}^{t=N} \left(v_x(t)^2 + v_y(t)^2\right)}$$

The frequency content (power spectral density) of the time series *x*(*t*) and *y*(*t*) was calculated using Welch method (Welch, 1967) from which the mean frequency was calculated.