

Section of Sports Medicine
Department of Surgical Sciences
Karolinska Institutet
Stockholm, Sweden

The elite cross-country skier
clinical and sports related functional tests,
dance training, injuries and self-related health

Marie Alricsson



Stockholm 2003

Covers: Emil Alricsson, the winner of Swedish Kalle Anka Cup, 2000

Photo: Per Hansson

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Om Skidlöpning och Skidtäfling ur medicinsk synpunkt.

Sporten har på senare år tagit ett uppsving i vårt land, som måste glädja hvarje vän af kroppsöfningar. I likhet med många ser jag i sporten, om den idkas med förstånd, en af dessa stora krafter, som kunna omskapa vårt lands bebyggare till lifskraftiga individer och skänka dem en härdad kropp, som genomströmmas af den välgörande känslan af hälsa och vigör. Sporten bereder ock dess utöfvare nöjen, som ej förslappa, men föryngra sinnet och väcka lefnadsmod och lefnadslust. Den är en afgjord fiende till många af vår tids dåliga, men tyvärr allför vanliga nöjen och njutningar, till kaffé- och källarlif, sprit- tobaksbruk samt de faror, som följa alla dessa sämre vanor, hvilka lägga grund till en i förtid försvagad och sjuklig kropp, ekonomisk ruin och däraf följande förtidig ålderdom och lifsleda. Sporten skall ock, tror jag, kunna väsentligen omdana vårt sällskapslif och rena det från mycket osundt och förkonstladt. Den förer samman till närmare beröring olika klasser och bidrager att häfva klassfördomar. Sålunda skall sporten verka välgörande ej blott i fysiskt utan ock i moraliskt och socialt hänseende till en bättre sakernas ordning.

Af

S.E HENSCHEN

Upsala 1898

ABSTRACT

The general aim of this thesis was to study cross-country skiers regarding the effect of dance training on joint mobility and muscle flexibility of the spine, hip and ankle and on speed and agility. Another aim was to perform test-retests of joint mobility and muscle flexibility of the hip and of sports related functional tests. A further aim was to compare high school students with age matched cross-country skiers concerning physical health, activity and location for possible symptoms/injuries. Finally, the aim was to study back pain regarding influence on skiing in high school cross-country skiers.

Athletes aged 11 years (8 boys, 3 girls) completed four different test sessions for two sports related functional tests, emphasising speed and agility, the slalom-test and the hurdle-test. No significant differences were found between testing sessions for either the slalom-test ($p=0.99$) or the hurdle-test ($p=0.96$).

Healthy athletic volunteers (5 males, 5 females) on average 30 ± 16 years performed four joint motion and muscle flexibility tests at three times with one day intervals. The results using intra class correlation coefficients showed the following values 0.99 (knee flexion with hip extended), 0.88 (hip extension with knee extended), 0.93 (hip flexion with knee extended), and 0.53 (a combination of abduction and external rotation of the hip). Subsequently, three out of the four tests showed a good reliability.

A group of young (aged 12-15 years) cross-country skiers ($n=10$) performed dance training during 8 months. Another aged matched group of cross-country skiers ($n=10$) served as a reference group. Before, during and after the intervention period joint mobility and muscle flexibility of the spine, hip and ankle as well as sports related functional tests were performed in all skiers from both groups. The results showed improvements in speed, agility and range of motion of the spine in most of the studied parameters.

A group of elite cross-country skiers (aged 19 ± 3.9 years) either performed additional preseason dance training for 3 months ($n=16$) or served as a reference group ($n=10$). Before and after the intervention period joint mobility and muscle flexibility of the spine, hip and ankle and sports related functional tests were performed in all skiers. Prior to dance training the intervention group showed a slight impairment of range of motion of the spine and the relationship between kyphosis of the thoracic and lordosis of the lumbar spine compared with the reference group. After dance training these parameters were improved and a tendency towards a positive effect on back pain was also found.

Using a questionnaire cross-country skiers from ski high schools ($n=120$) were found to be considerably more physical active in as well other sports as skiing when compared with age matched ordinary high school students ($n=993$). In comparison with controls a higher number of ski high school students described themselves to be physically healthy. Half of the cross-country ski students complained of back problems, mainly low back pain, while skiing and above all during diagonal skiing.

ORIGINAL PAPERS

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

- I Alricsson M, Harms-Ringdahl K, Werner S. Reliability of sports related functional tests with emphasis on speed and agility in young athletes. *Scand J Med Sci Sports* 2001;11:229-232
- II Alricsson M, Werner S. Reliability tests of joint motion and muscle flexibility of the hip in athletes. *Nordisk Fysioterapi* 2002;6:119-124
- III Alricsson M, Harms-Ringdahl K, Eriksson K, Werner S. The effect of dance training on joint mobility, muscle flexibility, speed, and agility in young cross-country skiers. A prospective controlled intervention study. *Scand J Med Sci Sports, In Press*
- IV Alricsson M, Werner S. The effect of preseason dance training on physical parameters and back pain in elite cross-country skiers. A prospective controlled intervention study. *Submitted*
- V Alricsson M, Werner S. Self-reported health, physical activity, and prevalence of complaints in elite cross-country skiers and matched controls. *Submitted*

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INTRODUCTION

Cross-country skiing

Cross-country skiing is a very old sport in Scandinavia and also one of the most popular sports, both for recreation and on a competitive level. It has been traced back to the Stone Age in Sweden and Norway, where skis were first used as transportation in every facet of life—from hunting and fishing to warfare. In Kalvträsk in Västerbotten, Sweden, a ski-tip was found and when examined with the carbon-14 method turned out to be more than 4000 years old. Early nomads used tusks for skis, which later were replaced by boards with toe straps.

During the sixth century Finns and the 14th century Russians fought wars on skis. The first recorded ski competition was by the Norwegian Army in 1767 (Lyon 1980). One of the first races in history, and from a Swedish standpoint the most important one, occurred in 1521 when the rebel Gustav Vasa was trying to escape from the Danes. Two Swedes charged with the task of presenting Vasa with an offer to become the Swedish king pursued him on skis for almost 90 km before overtaking the future monarch. This event was a landmark in Swedish history and gave the idea to the oldest and one of the longest ski races in the world today, the annual Vasa race (“Vasaloppet”), which now covers 90 km. This race has occurred annually since 1923, and attracts 15.000 - 20.000 participants each year (Renström & Johnson 1989).

The Swedish Ski Association founded in 1908 unifies 23 districts with more than 210,000 members from all ski disciplines, of more than 17,000 are licensed cross-country skiers (Annual Report, Swedish Ski Association 2000-2001).

Physical Therapy

The history of physical therapy is characterised by attempts to establish and consolidate its position within the health care system, which initially involved seeking sponsorship from the medical profession. More recently, physical therapy has strived for an equal footing with other health care professions by improving educational standards, broadening the scope of practice, increasing administrative control, and developing a scientific core of knowledge specific to physical therapy. The practice of physical therapy is today based on a body of knowledge that incorporates relevant information from other sciences and disciplines (Cott et al. 1995).

Theoretical framework underlying the present thesis

Theory is a set of abstract ideas. By using theory you can create a model, which is a simplified version of reality. Basically, the movement continuum theory of physical therapy has been used here to explain different ideas and concepts. The International Classification of Functioning, Disability and Health (ICF 2002) is today a classification tool designed to serve various disciplines in rehabilitation and to provide a common framework for understanding and communicating of different dimensions of disablement and health. ICF consists of two parts. Part 1 is; Functioning and Disability with a) body functions and structures and, b) activities and participation. Part 2 is; contextual factors meaning c) environmental factors and, d) personal factors. The overall aim of the ICF classification is to provide a unified and standard language to serve as a frame of reference for the consequences of health conditions. In this thesis the framework of ICF was used with a quantitative approach to measure and describe body functions, activities and participation.

Sports Medicine

In the literature there are a number of more or less similar definitions of sports medicine, one being “sports medicine is the field of medicine that uses a holistic, comprehensive, and multidisciplinary approach to health care for those engaged in a sporting or recreational activity” (Stedman’s Medical Dictionary 25th edition 1990). A branch of medicine concerned with the welfare of athletes deals with the science and medical treatment of those involved in sports and physical activities. The object of sports medicine includes prevention, diagnosis, treatment and rehabilitation of injured athletes, and preparation of an individual for physical activity in its full range of intensity. Sports medicine also includes evaluations of the effects of different physical parameters on exercises, training and sport competition in as well healthy as injured athletes. The purpose of this is to produce information useful in prevention, therapy and rehabilitation in order to optimise performance in sports. (Oxford Dictionary of Sports Science and Medicine 2nd edition 1998).

Within sports medicine a sport injury in team sports can be defined as “time lost from play”. However, in cross-country skiing it will be “time lost from performance or competition” (Bronner & Brownstein 1997).

Science of cross-country skiing

The first scientific study of cross-country skiing was reported by Henschen in 1898. He showed, by using percussion, that cross-country skiers had large hearts. The skiers who had heart hypertrophy also won the first prizes in the distance competitions and had the capacity to work hard a very long time (Henschen 1898).

Aerobic capacity

It is well established that cross-country skiers are the most fit of all endurance athletes. Aerobic fitness is the ability to absorb, transport, and use oxygen (Sharkey & Heidel 1981). Race times in cross-country ski competitions generally range from several minutes for sprint events (1,5 km) to several hours for ski marathons. The duration of these events suggests that aerobic processes account for 85-100 % of the total energy metabolism in cross-country ski racing. Therefore, it is not surprising that successful cross-country skiers have some of the highest maximal oxygen uptake values of all athletes (Sharkley et al. 1981, Bergh 1987, Åstrand et al. 1986, Hanson 1973, Rusko et al. 1978). Maximal aerobic power has been identified as one of the main factors predicting success in cross-country ski racing at elite level (Bergh 1987, Niinimaa et al. 1978, Ingjer 1991, 1992). Because of the high aerobic demands of cross-country skiing, muscles of elite competitors usually are characterized by high oxidative enzyme activity (Bergh 1982, Rusko 1978). In addition, the nature of the sport is that cross-country skiing requires maximum or near maximum efforts on uphill and relative rests on downhill sections (Bergh 1982, Rusko et al. 1987, Mogroni et al. 2001). Competitive cross-country skiers have also generally been characterized by a muscle fibre composition of at least 60 % slow-twitch fibres (Bergh 1982, Komi et al. 1977, Rusko et al. 1978). The skating technique requires generation of greater propulsive forces from the upper body than the diagonal stride technique. This has resulted in a greater emphasis on aerobic training and testing of the upper body (Sharkey 1984, Gaskill et al. 1999, 1999, Ng et al. 1999, Im et al. 2001, Mahood et al. 2001). Hoof et al. (1999, 2002) showed that maximal strength training with emphasis on neural adaptations improves strength, particularly rate of force development, and improves aerobic endurance performance by improved work economy. Endurance athletes commonly use altitude training in an attempt to improve their sea-level performance (Ashenden et al. 1999). Blood doping studies have demonstrated that both maximum oxygen uptake and endurance performance are enhanced by increasing total haemoglobin mass (Jones & Tunstall Pedoe 1989). Ashenden et al. (1999) found that red cell

production is not stimulated in male endurance athletes, who spend 23 nights at a simulated altitude of 3000 meters, however.

Muscular strength

For cross-country skiing muscular strength and endurance of all muscle groups are important, especially those of the arm, shoulder, back and abdomen. After the skating technique was introduced the importance of the muscles of the upper body and gluteal muscles have increased (Rusko et al. 2003). Cross-country skiing requires dynamic muscular contractions generally during only a fraction of maximal strength. Bergh (1982) has indicated that skiers seldom use more than 10-20 % of their maximal strength in any single contraction during classical skiing. Furthermore, due to the greater poling forces with skating compared with the diagonal stride technique the muscle strength of the upper body may be more important with the skating technique. While the importance of muscular strength in competitive cross-country skiing is recognised, relatively little emphasis has previously been placed on the evaluation or training of muscular strength in cross-country skiers (Hoffman et al. 1991). Haymes et al. (1980) found that cross-country skiers had lower isometric strength of the quadriceps than alpine skiers even after the strength measures were adjusted for body mass. Komi et al. (1977) also found that cross-country skiers had lower relative isometric quadriceps strength than alpine skiers, but that the cross-country skiers were stronger than 800 meters runners and speed skaters. Cross-country skiers have predominantly slow twitch fibres of their leg and arm muscles. The variability is high, but elite skiers with high maximum oxygen uptake seem to have slightly higher percentage of slow twitch fibres than less successful skiers. Skiing extensively for one to two months increases the intermediate fibres (Rusko et al. 1978).

Since cross-country skiing requires the transport of body mass, it would stand to reason that the best competitors should be lean. Indeed, elite cross-country skiers have low percent of body fat, and the best skiers tend to have the lowest body fat (Hoffman et al. 1991). There is a variety of body fat ranging from about 5-12 % for elite males and 16-22 % for elite females (Orvanová 1987). Among ski racers, the percentage of body fat has been found to be one of the main predictive factors of 5 to 15 km ski race performance (Niinimaa et al. 1978). This analysis suggests that the larger, heavier skier has advantage on downhills, flats and low-grade up-hills, whereas the lighter skier has an advantage on steep uphills.

Ski technique

Cross-country skiing is a typical sport requiring both explosive muscle strength and endurance performance characteristics. Thousands of repetitions take place during competitive skiing and the race time can last from 15 minutes to 2 hours. Force levels produced during diagonal skiing are relatively low, about 2.5 x body mass, but on the other hand the force is used quite rapidly, in about 0.10-0.20 seconds (Paavolainen et al. 1991). Recently, sprint skiing races with up to four repetitions of distance 1000-1700 meters have been included in the programme of international ski competitions. The two different racing techniques, classical and free style and the new short-distance sprint races have resulted in increased velocities and emphasised the importance of both neuromuscular factors and skiing technique as determinants of high level skiing performance (Rusko et al. 2003).

Cross-country skiing techniques can be divided into three categories: diagonal stride, double poling, and skating. The diagonal stride is by far the most widely used Nordic technique for flat and uphill terrain. The rhythmic movements of the upper and lower extremities used in this technique are similar to those of running. The biggest difference between these two activities is the push and glide generated by poling. Double poling without a kick is used for flat or downhill terrain when skiing speed is fairly high. This technique consists of symmetric movements of the arms. When the poles are initially planted, the upper body is fairly erect over the extended poles. The elbows are slightly flexed, as in diagonal stride poling. Initially, as the skier moves toward the poles, a pulling force is initiated on the arms. When the skier begins to move past the pole plant, the upper body literally falls on the poling arms to generate force (Parks 1986).

Skating technique was introduced into cross-country ski racing in 1980. One side skating with double poling for each skate kick was performed in the Worldloppet long distance marathon races. It was given the popular name of "Marathon skating" (Svensson 1994). Today, the most popular poling method to be used with V skating is the double pole every other stride. This is used typically on moderate to steep hills when the skier is achieving slow to moderate speeds. The skating cadence will be relatively fast and the glide distance per skate will be relatively short. Double poling every other stride mandates a rhythmic kick and glide asymmetry of the skis unlike double poling every stride or skating without poles. The pole plant takes place just before the predominantly kicking ski is placed on the snow (Parks 1986). The demands for good skiing technique, economical skiing and fast sprint skiing

emphasise the importance of the neuromuscular system in cross-country skiing. The functional ability of the neuromuscular system should be maintained during ski-races of different duration's when both oxygen uptake and blood lactate concentration is high (Rusko et al. 2003).

Whatever technique used, great demands are placed on the thrusting muscles. Hip extensors, knee flexors, and ankle plantar flexors are all susceptible to overuse injuries (Johnson & Incavo 1990). The hip extensors, mainly the gluteus maximus and the hamstring muscles, are important in controlling tuck angles on downhill slopes. They also initiate the forward thrust during the kick phase of a diagonal stride. The hip flexors, mainly rectus femoris and iliopsoas, are also used in the forward thrust. When performing the fish-bone or skating, the external rotators, the abductors and the extensors of the hip are important (Renström & Johnson 1989). Considerable compressive and shearing forces acting on the lumbar disks can occur during cross-country skiing. Furthermore, back extensors and abdominal muscles are subjected to high demands (Johnson & Incavo 1990).

Incidence of injury

Cross-country skiing has traditionally been considered a low-risk sport. Most research hitherto has been focused on parameters such as maximal oxygen uptake, heart rate, level of hemoglobin, infections and overuse injuries (Berg 1987, Sharkley et al. 1981, Åstrand et al. 1986, Sue-Chu et al. 1996, 1999, Hedelin et al. 2000, Doyon et al. 2001, Videman et al. 2000, Karjalainen et al. 2000, Tan & Spector 2002, Eriksson et al. 1996, Ashenden et al. 1999). However, there are some severe injuries reported (Boyle et al. 1985, Eriksson & Danielsson, 1977, Westlin 1976). Also, skiers especially those at the top level, who train several hours daily are at risk for overuse injuries (Johnson & Incavo 1990).

The new skating techniques developed during the last decades have resulted in higher velocities. Top-level skiers today use strong and ultra light skis of fibreglass and the preparation of the ski course has improved with the development of special track machines. This allows top-level skiers to reach 60 to 80 km/hours on downhill slopes, which has resulted in an increased risk of injury (Renström & Johnson 1989). Since cross-country skiing takes place wherever snow is available, it is difficult to establish accurate injury rates in comparison to alpine skiing, which is performed on specific ski areas. Studies estimate the cross-country ski injury rate in Sweden to be around 0.2 and 0.5 per thousand skier days

(Eriksson & Danielsson, 1978, Westlin 1976). A prospective study of cross-country ski injuries conducted in Vermont, USA, revealed an injury rate of 0.72 per thousand skier days (Boyle et al. 1985). Ekeland & Holm (1985) reported an injury rate of 1.4 injured skiers per 1000 participating racers in all types of alpine competitions arranged in Norway during one season. The race competition in alpine disciplines in the 1994 Olympic Winter Games was 64 % in all disciplines together, but twice as high in the downhill as in slalom. The injury rate was 1.9 per 1000 runs (Ekeland et al. 1996). In the Alpine World Junior Championship of 1995 the overall injury rate was 4 per 1000 runs and in downhill 8.3 injury rate per 1000 runs was recorded (Bergström et al 2001).

During 1983 and 1984 75 % of the injuries of the Swedish National cross-country ski team were due to overuse while 25 % resulted from trauma. The most common overuse injuries included medial-tibial stress syndrome, achilles tendon problems and low back pain (Hemmingsson & Ohlsen 1987). Cross-country skiers, 16 to 21 years of age, complained more frequently of mild low back pain than similarly aged non-skiers. This may result from repetitive hyperextension motions during the kick phase and the recurring spinal flexion and extension during the double poling phase (Frymoyer et al. 1982). Cryon et al. (1976) reported that these repetitive movements produced in the spine result in increased shearing at the pars interarticularis occasionally producing a fatigue fracture.

Central concepts of the thesis

Elite cross-country skiing

Dance training

The interest in sport has increased during the last decades. In order to reach elite level, many sports require training with high intensity and high loads, often starting already at a young age. In some sports the athletes are subjected to considerable forces, due to rapid and forceful movements or external weights, which might lead to an asymmetric load on the body. There are great demands on the vertebral column concerning strength and mobility in some of the above situations, with risk for overload and subsequent injury of the spine. The vulnerability of the spine is high in the growing individual, especially in the growth spurt at puberty (Hellström et al. 1990). A high frequency of radiographic abnormalities of the spine has been shown in athletes participating in sports that put great demands on the back (Lundin et al. 1998, Swärd et al. 1990). Lately, dance training has become a subject of interest in different

sporting activities. Dance training is aimed to give a more all-round type of body exercise in order to "balance" the sport specific training that characterises sports at elite level.

Functional tests

To our knowledge there is a lack of functional tests, with a known reliability, for determining physical performance, especially concerning speed and agility. However, there are investigations dealing with functional tests with emphasis on lower extremity performance, in particular regarding the knee joint. These are for instance the one leg hop test, triple jump test and stairs hopple test (Risberg et al. 1994, 1995). Furthermore, there are authors who have studied the possible correlation between a functional test such as the one leg hop test and knee extensor torque (Greenberger & Paterno 1995, Öberg 1984). A number of tests for measuring parameters such as muscle strength, muscle flexibility and balance are, however, usually performed in a laboratory environment. These laboratory measurements are less accessible and often too expensive for the majority of young athletes. Furthermore, these tests are aimed at measuring one specific parameter, such as muscle strength, for instance. However, what the result of these tests mean for physical performance is still not clear. On the other hand sports related functional tests could be used as guidelines for different physiological parameters such as muscle strength, muscle flexibility and balance, although the main purpose is to evaluate athletic performance. These tests are often inexpensive, easy to perform and usually require only a few test leaders (Bolgla & Keskula 1997).

Easily accessible sport related functional tests that can be conducted close to the training locations are needed for further development of any sport. Furthermore, it is necessary to develop reliable sports related functional tests in order to check whether physical training leads to improvement in physical performance.

Tests of joint motion and muscle flexibility of the hip

During cross-country skiing almost all of the major muscle groups of the body are activated (Rusko 1992). Mahlamäki (1987) found that elite cross-country skier having back problems often showed muscle tightness of their hip flexors and tensions of the erector spinae musculature. Several authors have found a decrease in the mobility of the spine and hip joints to be correlated with back pain in general populations (Swärd et al. 1990, Fairbank et al. 1984, Mellin 1988, Pope et al. 1985). Both the frequencies of the movement in each cross-country skier and the angular movements of the hip, knee and ankle joints are important for

speed development (Rawald et al. 1993). Furthermore, a good flexibility of the hip is of special importance in as well skiing using skate technique as to prevent injuries (Svensson 1994). A good flexibility is important for success in a given sport, and sport performance at top-level is impossible without above average levels of flexibility (Corbin 1984). Therefore, a good joint mobility and muscle flexibility are of great importance for cross-country skiers. In sport and physical therapy there are different exercises designed to improve joint and muscle flexibility. However, to our knowledge there are lack of reliable sports related flexibility tests of the hip joint.

Prevalence of symptoms and/or injuries with emphasis on back pain

It has been determined that more than 80 % of all cross-country ski injuries occurred in downhill terrain. Most likely, this means that a fall to the ground or a collision with a tree, a rock or another person is the preceding incident to the injury. In most cases of mild to moderate overuse injuries related to recreational cross-country skiing, the injuries are not diagnosed and treated by health care professionals. Thus, reliable information about these types of injury and their frequency is hard to find (Rusko et al. 2003). Skiers at top level, who train several hours daily are at risk for overuse injuries (Johnson & Incavo 1990). Within the last two decades, there have been reports of increased low back pain in young cross country skiers compared to age-matched non-skiers (Rusko et al. 2003). Mahlamäki et al. (1988) reported a higher percentage of back problems among young Finnish cross-country skiers in comparison with age matched controls. Eriksson et al (1996) reported a prevalence of 64 % of back problems in young Swedish elite cross-country skiers, mostly occurring when skiing classical style. Pettersson et al. (1977) showed that the erector spinae musculature is working dynamically during both diagonal and double poling. Cross-country skiing is a monotonous sport often leading to muscle tightness, which might result in injuries or impaired sport performance (Svensson 1994). In 1984 Biering-Sörensen reported a low isometric muscle endurance to be a risk factor for developing low back pain (Biering-Sörensen 1984).

AIMS

The general aim of these investigations was to study cross-country skiers with regards to the effect of dance training on joint mobility and muscle flexibility of the spine, hip and ankle and on speed and agility. Another aim was to perform test-retests of joint mobility and muscle flexibility of the hip and of sports related functional tests. A further aim was to compare high school students with cross-country skiers of the same age concerning physical health, physical activity and location of possible symptoms/injuries. Finally, the aim was to study back pain with regards to influence on skiing and how it relates to different skiing styles and amount of ski training in high school elite cross-country skiers.

The specific aims were:

- to assess the reliability of two sports related functional tests, a speed test (slalom-test) and an agility test (hurdle-test) (Paper I)
- to test the reliability of four joint motion and muscle flexibility tests of the hip (Paper II)
- to study a short (three months) and a long (eight months) term effect of dance training on joint mobility and muscle flexibility of the spine, hip and ankle and also on speed and agility in young elite cross-country skiers (Paper III)
- to evaluate the effect of additional preseason dance training on joint mobility and muscle flexibility of the spine, hip and ankle and on speed and agility in elite cross-country skiers (Paper IV)
- to find out whether preseason dance training could reduce the number of skiers with ski related back pain among elite cross-country skiers (Paper IV)
- to study physical health, physical activity including level of physical effort, and the location of possible symptoms/injuries in elite high school cross-country skiers and regular high school students of the same age (Paper V)
- to study the prevalence of back pain and its influence on skiing, its relation to different styles of skiing and amount of ski training in elite cross-country skiers (Paper V)

SUBJECTS AND METHODS

Ethical considerations

All investigations were approved either by the Swedish National Ethics Committee or the Ethics Committee at the Karolinska Institutet, Stockholm, Sweden.

Subjects

Eight main groups were included in this thesis. Five groups consisted of young cross-country skiers and high school elite cross-country skiers (Paper III-V). One group consisted of healthy children (Paper I), another one of healthy athletic volunteers (Paper II) and a third group comprised a reference group with regular high school students (Paper V). The different groups of subjects are presented in figure 1. Possible gender differences with regards to joint motion and muscle flexibility were checked.

Paper I-II

The first group comprising eleven healthy children aged 11 years (eight boys, three girls), participated voluntarily in the study. All children attended a sports academy during after-school hours. Each child was involved in at least one of the following sports: soccer, basketball, team handball, gymnastics, dance, ice hockey and skiing (Paper I).

The second group comprised ten healthy athletic volunteers, five males and five females. Their mean age was 30 ± 16 years, mean body weight 60 ± 11 kg, and mean height 1.68 ± 0.8 m (Paper II).

Paper III-IV

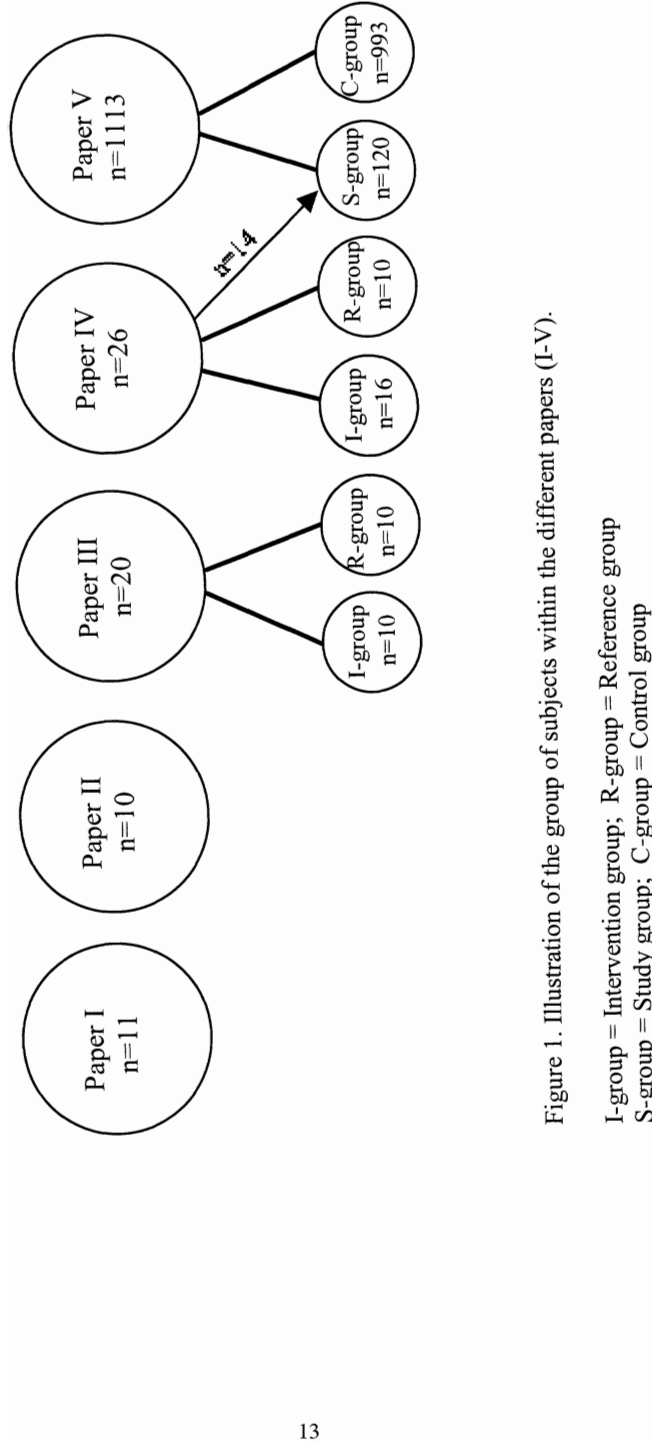
Paper III and IV were designed as intervention studies.

Paper III included 20 cross-country skiers, divided into an intervention group (five males, five females) and a reference group (five males, five females), aged 12-15 (13.6 ± 1.0) years. The two groups were comparable according to gender, age and skill of cross-country skiing. They came from the same ski area and were at the same level of skiing. Only skiers without any injury were included. Paper IV included 26 elite cross-country skiers, mean age 19 ± 3.9

years, from the cross-country ski high school in Järpen and cross-country university in Östersund, Sweden. The subjects were divided into an intervention group (six males, ten females) and a reference group (six males, four females). All skiers were well-trained young individuals at top international and national level of their age groups.

Paper V

Paper V was designed as a questionnaire survey, involving 120 out of 131 (92%) ski students from all five cross-country ski high schools in Sweden (study group) and 993 out of 1307 (68%) regular high school students from three nearby school districts/ski area in Sweden (control group).



Methods

Sports related functional tests (Paper I, III, IV)

Prior to the start of the studies, three months later and eight months later (Paper III) all subjects performed two sports related functional tests, the slalom-test and the hurdle-test. Both tests, that emphasise speed and agility, have been tested for reliability (Paper I).

Range of motion measurements (Paper II, III, IV)

Prior to the start of the studies, three months later (Paper III, IV) and eight months later (Paper III) each subject performed different range of motion measurements of the spine, hip and ankle joints (Paper III, IV). Range of motion of the hip has been tested for reliability (Paper II).

Thoracic and lumbar spine (Paper III, IV)

Maximal active flexion and extension of the thoracic and lumbar spine and also the difference between the thoracic kyphosis and lumbar lordosis were measured using Debrunner's kyphometer (Protek AG, Bern, Switzerland). This was performed once in each direction (flexion, extension) with the subject in a standing position (Lundon et al. 1998, Öhlén et al. 1989, 1989). Maximal active rotation of the thoracic spine in both directions was measured with a goniometer with the subject in a sitting position on a stool (Ekstrand et al. 1982, Mellin 1986). Maximal active lateral flexion of the spine was measured using a ruler. One trial in each direction was performed with the subject in a standing position (Kujala et al. 1994).

Hip measurements

The following four flexibility tests were performed; knee flexion with the hip extended, hip extension with the knee extended, hip flexion with the knee extended, and a combination of abduction and external rotation (Ekstrand et al. 1982, Möller 1984, Fredriksen et al. 1997). A dynamometer (Salter 235 PIAB, Täby, Sweden) was used to measure the force (in Newton) applied by the examiner during the different range of motion measurements. At the first test occasion (start of the study) a force for the different range of motion measurements was chosen for each subject, meaning that each subject was tested with an individual force. The same individual force was then used during all test occasions. One trial of each leg was performed in all the four range of motion measurements of the hip.

Ankle dorsiflexion

Maximal ankle dorsiflexion was measured using a goniometer. This was carried out with the subject in a standing position keeping one leg in front of the other. The goniometer was applied at the apex of the patella of the posterior leg, the testing leg (Ekstrand et al. 1982).

Questionnaires

A questionnaire, a modified version of the one published by Eriksson et al. (1996) (Paper IV, V) combined with a few questions similar to those published by Brattberg (1989) (Paper V) was used. Both groups answered questions aimed to define self-related physical health, level of physical effort, physical activity and possible locations for symptoms/injuries during the last three months (Paper V). Furthermore, we specifically asked the skiers about the location of possible back pain (lumbar, thoracic or cervical), when it occurs (during skating and/or classical technique), and how it affects their skiing ability (negligibly, somewhat or very much) (Paper IV, V). The entire questionnaire has been tested for reliability (Paper V).

Intervention

Dance training

Besides cross-country skiing, roller skiing and running the intervention groups (Paper III, IV) received dance training on average six hours a week at two different occasions during a period of three months (Paper IV) and eight months (Paper III), respectively. None of the skiers had any previous experience of dance training. The dance training was taught by an independent professional instructor and carried out to music and mainly performed single. The dance exercises included different types of dancing such as ballet, modern dance, jazz dance and character dance in order to improve balance, co-ordination, muscle flexibility and agility. The test leaders did not influence the different dance exercises that were included in the programme.

Statistical methods

Descriptive statistics were mainly obtained by using Microsoft Excel (Microsoft Inc.,USA) and for further analysis SPSS and minitab (SPSS, minitab Inc.,USA) for personal computer was used. In all papers the statistical significant level was set at 5 percent ($p \leq 0.05$). The statistical methods used in the different papers are presented in Table 1.

Table 1. Statistical methods used in Paper I - V

Statistical method	Paper I	Paper II	Paper III	Paper IV	Paper V
<i>Descriptive statistics</i>	X	X	X	X	X
<i>Between groups differences</i>					
- <i>t</i> -test			X	X	X
- Anova	X	X	X		
- Chi-square					X
<i>Within groups differences</i>					
- ICC	X	X			
- Wilcoxon	X				X
<i>Correlations</i>					
- Spearman	X				X
<i>Regression analysis</i>					
- Linear, multivariate			X		

Paper I-II

ANOVA (analysis of variance) was used for repeated measures, and a possible learning effect of the subjects from one session to another was studied. A method based on “relative” reliability was calculated on the basis of intra class correlation coefficients (ICC) with 95 % confidence interval (CI). Standard error of measurement (SEM) and coefficient of variation (CV) were used to describe “absolute” reliability (Shrout & Fleiss 1979, Denegar & Ball 1993, Atkinson & Nevill 1998). ICC was determined by use of the formula $ICC = [BMS-EMS]/[BMS+(k-1)EMS]$, where BMS is the between-targets mean square and EMS is the residual mean square from a two-way ANOVA. SEM was determined as follows: $SEM = SD \sqrt{1-ICC}$.

Paper III-IV

Descriptive statistics (mean, standard deviation, range) was used. Student’s *t*-test for independent variables was used when comparing the subjects of the intervention and reference groups with regards to age, height, body weight and gender differences. The differences between test results before, during (three months) and after (eight months) dance

training were analysed with ANOVA. Possible group differences concerning range of motion measurements of the spine, hip and ankle and the two sports related functional tests were analysed at the second test occasion using *t*-test for independent variables. Possible differences in the same parameters within the intervention group before and after dance training were analysed using *t*-test and ANOVA for dependent variables. Multiple regression models were estimated for the test results with age, gender, height and/or body weight as independent variables together with a dummy variable for case/control, in order to estimate the direct effect of the intervention.

Paper V

Frequency tables were used for data analysis. Differences between groups were tested using Students *t*-test for two-sample assuming equal variances and Chi-square test for qualitative variables. Spearman ranks correlation test and Wilcoxon signed ranks test were used for evaluating the reliability of the questionnaire.

RESULTS

Methods

Reliability (Paper I, II, V)

Sports related functional tests (Paper I)

There were no significant differences between testing occasions for either the slalom-test ($p=0.99$) or the hurdle-test ($p=0.96$), showing no systematic variation between testing times. The intra class correlation coefficients (ICC) were 0.96 and 0.90 respectively, indicating a good reliability. Standard error of measurement (SEM) and a possible difference between manual and electrical timing was estimated, slalom-test SEM = 0.15 seconds, hurdle-test SEM = 0.39 seconds, respectively. The result of manual timing and electrical timing (measured on track and field competition with pistol start) showed that manual timing was constant -0.3 seconds estimated with Spearman ranks correlation test ($r=0.99$) and Wilcoxon signed ranks test ($p=0.001$).

Tests of joint motion and muscle flexibility of the hip (Paper II)

Repeated measures analysis of variance showed no significant differences ($p=0.89, 0.55, 0.28,$ and 0.12) between the test occasions that could be explained by a learning effect. SEM for hip extension with the knee flexed and extended ranged from 0.89 cm to 1.58 cm and hip flexion, and a combination of abduction and external rotation of the hip ranged from 2.38 degrees to 2.73 degrees. The three tests, knee flexion with hip extended, hip extension with knee extended and hip flexion with knee extended showed a good reliability with ICC values of 0.99, 0.88 and 0.93, respectively, while the ICC value was 0.53 of the combined abduction and external rotation of the hip.

Questionnaire (Paper V)

The questionnaire showed a very good reliability, $r=1.0$ (Spearman ranks correlation test) and no significant difference between test occasions, $p=1.0$ (Wilcoxon signed ranks test).

Subjects (Paper III, IV)

The subjects from the intervention group increased their height and body weight from October to May (eight months) on average 6.0 cm ($p=0.000$) and 2.2 kg ($p=0.006$), respectively. The subjects from the reference group increased their height and body weight on

average 4.0 cm ($p=0.02$) and 2.1 kg ($p=0.07$), respectively (Paper III). There were no significant differences between the groups with regards to age, height and body weight before and after the study period (Paper III, IV). The only significant differences between males and females concerning joint motion and muscle flexibility were that females had a greater mobility in a) flexion-extension of the lumbar spine (8° , $p=0.01$), and b) knee flexion with hip extended (5.5 cm, $p=0.003$) when the distance between calcaneus and the buttock was measured with a ruler.

Dance training (Paper III, IV)

On average 94% of the subjects that carried out dance training for a period of eight months (Paper III) and on average 79% of the subjects that performed a three month preseason dance training programme (Paper IV) participated in all dance training sessions. Twenty-one percent of the subjects did not attend all dance sessions depending on illnesses and/or preseason travel to snow area.

Sports related functional tests

The subjects from the intervention group (Paper III) increased their speed with 0.3 seconds after as well three months ($p=0.05$) as eight months ($p=0.02$), when measured with the slalom-test. They also improved their speed and agility according to the hurdle-test after three months with 0.8 seconds ($p=0.000$) and eight months with 0.6 seconds ($p=0.01$). No positive effects of dance training on sports functional tests were observed (Paper IV).

Range of motion measurements

Paper III

There was a significant increase in the range of motion with regards to flexion-extension of the thoracic spine with 7.5° after three ($p=0.05$) and with 9.0° after eight ($p=0.03$) months of dance training in the intervention group, while no differences were shown in the reference group. The intervention group also increased flexion-extension of the lumbar spine with 8.8° after three months ($p=0.05$), while no change was shown in the reference group. Lateral flexion of the lumbar spine was increased with 0.04 m after three ($p=0.005$) and 0.03 m after eight ($p=0.02$) months of dance training in the intervention group, while no change was shown in the reference group. Rotation of the thoracic spine did not change in any of the two groups. After 3 and 8 months there was a significant difference between the groups with

regards to lateral flexion of the spine. In the intervention group there was a significant increase in hip flexion with 4.1° after three months ($p=0.03$) of dance training, while there was a significant decrease in the reference group with 6.8° at three ($p=0.006$) and 8.9° at eight months ($p=0.001$). These differences were significant between the groups ($p=0.0006$, $p=0.008$, respectively). The reference group showed a significant decrease between 3 and 8 months with 5.0° ($p=0.000$) and between the start and after 8 months with 4.3° ($p=0.05$) regarding the combined abduction and external rotation of the hip. These differences were significant between the groups ($p=0.0007$, $p=0.01$, respectively). No significant changes were found with regards to the other range of motion variables of the hip and ankle joints.

Paper IV

After dance training the intervention group showed significant improvement of the different parameters of the thoracic and lumbar spine including the relationship between kyphosis of the thoracic and lordosis of the lumbar spine. In comparison with the reference group some of these parameters showed a slight impairment prior to dance training. Those group differences did not exist after the intervention period. In the reference group there were no differences in any of the studied range of motion measurements of the spine at the three month test occasion. The intervention group showed a significant increase in hip flexion with on average 7.1° ($p=0.02$) and in dorsiflexion of the ankle joint with on average 3.5° ($p=0.00007$) after twelve weeks of dance training. The reference group showed a significant decrease with 0.08 m ($p=0.01$) in hip extension at the three month test occasion.

Back pain

Three (out of six) subjects from the intervention group, that reported ski related back pain at the start of the study, did not complain of back pain after the twelve week period of dance training. The other six subjects, three from each group, did not report any changes in back pain. (Paper IV).

Questionnaire (Paper V)

All subjects of the study group were physically active also in other sports than skiing, while only 26 % of the controls participated in any type of sport. In comparison with the controls the skiers performed their sporting activities at considerably higher levels of physical effort. Ninety-two percent of the study group and 76 % of the control group described themselves as

healthy, meaning “very good” or “good” ($p=0.0001$). Fifty-five percent of the study group and 64 % of the control group reported symptoms from some part of the body ($p=0.06$) during the last three months. Fifty-three skiers (47 %) reported previous or present complaints of back pain while skiing. Out of these 50 (94 %) suffered from low back pain. There was no significant gender differences or difference between preseason and ski season for males and females regarding back pain. The majority of skiers with back pain associated their problems with different styles of skiing, where the highest number of skiers (70 %) had problems during diagonal skiing. Forty-seven percent of the skiers with back pain manage to self-cure their problems by changing body position from a flexed position to a more extended one while skiing. Out of the 53 skiers with back problems 41 (77 %) reported their back pain to disappear during rest.

DISCUSSION

Study design

The present thesis comprises different types of study designs for data collection. A test-retest design was used in Paper I and II and data were collected at four (Paper I) and three (Paper II) occasions, respectively. In Paper III and IV a prospective controlled intervention study design was used, where data were collected before, during and after an intervention of dance training. In Paper V cross-country ski high school students answered a questionnaire prospectively, while students from regular high schools answered the same questionnaire retrospectively.

Drop-outs

In Paper I and II there were no drop-outs, which strengthens the test-retest study design. In Paper III we started with 21 elite cross-country skiers. However, after the first test occasion one male skier moved to another ski area far away and was therefore classified as a drop-out. On average 94 % of the subjects in the intervention group (Paper III) participated in all dance training sessions over the period of eight months. This can be regarded as very good, since many studies with an intervention design over a long period of time usually lose many participants by time. This might mean that our cross-country skiers found the dance training programme to be good for their skiing performance, and they also enjoyed this type of physical training. In the preseason intervention study (Paper IV) on average 79 % of the skiers in the intervention group participated in all dance training sessions. Twenty-one percent of the skiers, however, did not perform all dance sessions depending on illness and preseason travelling to snow area for skiing performance.

The study group in Paper V included a total of 92 % (120/131) of the cross-country skiers from all five ski high schools in Sweden and a control group consisting of regular high school students from three nearby school districts in a Swedish ski area, giving a response rate of 92 % among the skiers compared with 68 % (993/1307) among the controls. One reason for the group difference in response rate might be that ski high school teachers are more interested in evaluating possible symptoms and injuries of their ski students, since problems can destroy the career of an elite skier. In contrast, regular high school teachers might feel lack of the same interest.

Subjects

Many different subjects participated in this thesis. Paper I involved eleven boys and girls aged 11 years in order to have a homogeneous group of young athletes that were old enough to perform sports related functional tests with good physical ability. The reason for choosing this age group was that Peltenburg et al (1982) reported the sense of balance to be not fully developed in younger individuals (gymnasts, 8 year old) and Sanborn & Wyrich (1969) that balance abilities are related to speed, agility and rhythm. Since our two sports related functional tests emphasise both speed and agility, we chose subjects aged 11 years in order to reduce the risk for great variations when performing the test-retest procedure.

In Paper II, ten healthy athletic volunteers, five males and five females, participated in the present study. Their age ranged between 12 and 54 years. This distribution of age correlates well with normal distribution of individuals that are physically active in a variety of sports in Sweden. The test leader examined each subject to ensure that nobody had a previous injury of the lower extremity or any other medical problems that could interfere with the test result. All subjects were familiar with different stretching techniques and were highly motivated to participate.

In the intervention studies it could be argued that the number of subjects is relatively small. However, due to geographical reasons, we had to involve young elite cross-country skiers from the same region to be able to perform the dance training. This means that all cross-country skiers at the highest elite level, who regularly (each week) had the possibility to carry out the dance training programme, were included in the intervention group. Subsequently, the reference group included skiers at the same high elite level, but skiers who reported that they could not regularly participate in the dance training.

In Paper V the study group consisted of well-trained young cross-country skiers at top national level of their age groups. Since the five different schools are boarding schools, the students also came from different parts of the country. The competition to enter the schools is extremely high, with previous results in international and national races as merits. Therefore, the study group included the best Swedish cross-country skiers of their age group and level of skiing and the controls included youths from three school districts in the north part of Sweden. The reason for choosing high school students from three different districts was that we wanted to include youths from as well the town as the countryside (Paper V).

Dance training

The intervention study of dance training for three and eight months showed increase in speed and improvements in agility, hip flexion and flexibility of the spine in young cross-country skiers (Paper III). The preseason dance training performed during three months led to positive effects on joint mobility and muscle flexibility of the spine, including an improved relationship between kyphosis of the thoracic and lordosis of the lumbar spine, in top-level cross-country skiers with slightly impaired range of motion of the spine when compared with the reference group (Paper IV). Dance training as well as dance performance involves both dynamic and static work of large and small muscle groups. Dance training can generally be characterised as intermittent exercise with exercise bouts of brief duration. Fifty percent of the training sessions (range 40-57 %) consisted of active exercise. The single exercises were of different duration in the various dance styles such as modern dance, jazz dance and character dance (Dahlström 1996). Dance training also is generally carried out in order to improve joint mobility and muscle flexibility (Hamilton et al 1992). The dance training performed in the present studies was aimed to improve balance, co-ordination, muscle flexibility and rhythm. We chose to measure joint motion and muscle flexibility, since good evaluation methods exist. It would of course be of value also to measure balance and co-ordination. However, hitherto there are no well established and reliable methods for measuring these parameters at the training locations, where our measurements were carried out, but only in the clinics and/or laboratory.

The self-evident purpose of dance training for cross-country skiers is to optimise their performance at ski competitions. To become and maintain an expert cross-country skier at the highest level it is, however, very important to be free of injury, whatsoever. This was one reason for our evaluations of joint motion and muscle flexibility, which may play a role in preventing injuries. How to evaluate an intervention such as dance training with regards to skiing performance for cross-country skiers seems to be very difficult. Since skiing is performed outdoor and weather conditions vary, preparation of skis and ski tracks vary, and there are many simultaneous competitions available. These different parameters make it difficult for comparisons between skiers with regards to the order of rank in ski competitions.

Sports related functional tests

After dance training the subjects of the intervention group (Paper III) increased their speed and agility when evaluated with the slalom-test and the hurdle-test. It could be argued that the improvements that the intervention group demonstrated in speed and agility were small. The reference group showed a significant decrease in agility according to the hurdle-test, although this is not evident based on the Standard error of measurement (SEM). SEM was estimated to 0.15 seconds for the slalom-test and 0.39 seconds for the hurdle-test. The hurdle-test might put demands on good range of motion and flexibility of the hip joint. Therefore, it may at least to some extent explain their impaired flexion and combined abduction and external rotation of the hip joint at the eight month test occasion (Paper III). Furthermore, Corbin (1984) pointed out the importance of a good flexibility of the hip joint for optimal sport performance. Sanborn et al. (1969) reported balance ability to be related to speed, agility and rhythm. The improvements of the intervention group in speed and agility evaluated with the slalom-test and the hurdle-test might therefore be due to improved balance, co-ordination and rhythm. The reason for these improvements could of course also be due to other factors. However, improved balance, co-ordination and rhythm are likely to be a result of the dance training that the intervention group received (Paper III).

The preseason dance training did not lead to any changes in sports performance according to the sports related functional tests, the slalom-test and the hurdle-test (Paper IV). Both these tests, that include sprint distances, put high demands on the ability of fast acceleration and running. However, these indoors “running” tests might not play a big role for cross-country skiers. To our knowledge there are no sports related functional tests that imitate cross-country skiing. Since skiing is performed outdoors, it is likely that for instance weather conditions and snow conditions differ from time to time, which will hazard the reliability of this type of functional tests. This might also be the reason for the lack of this kind of sports related functional tests. The dance training performed in the present study was aimed to improve balance, co-ordination, muscle flexibility and rhythm, which might to some extent explain why there were no improvements in speed and agility according to the slalom-test and the hurdle-test. To further improve the stability of measurement those tests have been checked between manual timing and electrical timing (measured on track and field competition with pistol start). A constant of – 0.3 seconds was found between electrical and manual timing, which corresponds well with officials that use the same equipment during other sport events such as track and field, for instance.

Range of motion of the hip and ankle joints

Svensson (1994) pointed out the importance of a good range of motion of the hip as well from an injury preventing point of view as from a technical point of view in cross-country skiers.

Range of motion measurements of the hip and ankle joints were performed by three test leaders. These tests were performed in athletes and were also aimed to be useful to measure joint motion and muscle flexibility in the vicinity of sport and training areas (Norrning & Olsson 1995). Here there are no problems whatsoever to get hold on assisting examiners, but there is a lack of physical therapy equipment such as a treatment table, for instance.

After eight months of dance training the subjects from the intervention group maintained their range of motion of the hip joint in as well flexion as in the combined abduction and external rotation, while the subjects from the reference group showed a reduction of these parameters (Paper III). After a preseason dance training for three months the subjects from the intervention group improved their hip flexion, while the subjects from the reference group showed a reduction of their hip extension (Paper IV). The joint mobility and muscle flexibility exercises that the intervention groups carried out by dance training could probably explain this. The decreased mobility in hip movements that the reference group showed might be explained by the fact that major muscles such as the hip flexors are very active in cross-country skiing (Mahlamäki et al. 1987, Rusko 1992) and hard working muscles are likely to get shortened (Möller 1984). The dance training that the intervention groups participated in included flexibility training with stretching exercises, which very likely could explain the differences in hip flexion between the groups. The reason why the reference group, that did not perform any dance training, showed impaired joint mobility and muscle flexibility is probably because cross-country skiing is a very monotonous sport often leading to muscle tightness (Mahlamäki 1987). Elite cross-country skiing during one season is muscle fatiguing, which might lead to muscle shortening. Subsequently, skiers that do not combine their skiing with any type of muscle flexibility training, such as dance training, for instance may therefore be more vulnerable to muscle tightness.

The dance training performed did not affect the range of ankle dorsiflexion (Paper III). One reason for this might be that both groups already at the start of the investigation had a good range of dorsiflexion according to "normal" values (Greene & Heckman 1994). Another reason might of course be that the dance training performed in the present study did not include exercises that were effective enough to improve ankle dorsiflexion. Ankle

dorsiflexion increased after dance training in Paper IV. However, this was a small increase, which most likely has no clinical relevance. Furthermore, Khan et al. (2000) reported that dorsiflexion did not change over time and that this was due to dorsiflexion being limited by bony apposition rather than by soft tissue.

Range of motion of the spine and back pain

The subjects from the intervention groups (Paper III, IV) increased their range of motion of the spine in most of the tested variables, while no differences were found in the reference group. We believe, that this is due to the exercises used in the dance training, which were aimed at improving posture, flexibility and co-ordination. Svensson (1994) reported that a good range of motion is an important factor in order to learn a good technique in cross-country skiing. Mahlamäki (1987) found tightness of the back muscles in cross-country skiers with back problems. In light of these reports we find our results to be of interest, i.e. both for sport performance and for injury prevention. Furthermore, there was an increase in lateral flexion of the spine after dance training. This might improve the technique in diagonal poling by easing the propulsion of the pelvis and hip and the contralateral upper extremity, that characterises diagonal poling in cross-country skiing.

The relationship in degrees between the kyphosis of the thoracic spine and lordosis of the lumbar spine decreased after three months of dance training (Paper IV). Several cross-country skiers of top-level have developed a larger kyphosis relative to their lumbar lordosis. A possible reason for this could be the high duration of ski training, while keeping the spine in a static flexed position, above all when skiing the classic technique. Wojtys et al. (2000) reported that a high exposure of intensive athletic training might increase the risk for developing adolescent hyperkyphosis in certain sports. Our subjects from the intervention group showed a more pronounced difference between kyphosis and lordosis of the thoracic and lumbar spine, respectively at the start of the study. In a clinical screening of the Norwegian national team cross-country skiers in 1993, Scheuermann abnormalities (increased thoracic kyphosis) were found in 66 % of skiers with no difference between males and females being observed (Rusko et al. 2003). A characteristic finding in skiers with Scheuermann's disease was that they had started systematic and specialised training for competitive cross-country skiing in younger ages, 10-13 years, compared to those without this diagnosis, age 13-16 years (Rusko et al. 2003).

Wojtys et al. (2000) reported that there is a known association between hyperkyphosis and adult-onset back pain. This might at least partly explain why there was a higher number of subjects from the intervention group that complained of back pain at the start of the investigation. Three of the six subjects, that reported back pain, from the intervention group, did not complain of this after the period of dance training. Due to the small number of subjects, however, we can not prove that the reduction of the number of subjects with back pain depends on the dance training programme performed. Based on these findings we speculate that since the three subjects from the reference group, that reported back pain, still complained of back problems, dance exercises might play a role in reduction of back pain.

Physical activity, health, levels of effort and back pain

A considerably higher number of cross-country skiers from ski high schools are physically active also in other sports than skiing when compared with regular high school students. Furthermore, the ski students performed their sporting activities on a considerably higher level of physical effort. These findings describe the extremes of participating or not participating in sports in high school students. Ninety-two percent of the skiers and 76 % of the controls described themselves to be physically healthy. Our results are better than those presented earlier by Brattberg (1994), who studied 471 Swedish school children in an age group including younger subjects (8-17 years old) and reported that 65 % of these described themselves as healthy. One reason for this might be due to that Brattberg (1994) studied health from a psychological as well as a physiological perspective and made a combination of both. Furthermore, it should be pointed out that the ski students in the present investigation have been carefully selected to enter the boarding schools and their goal is to become international top skiers, which might to some extent explain why they reported such a high satisfaction concerning their physical health. They also reported the same high health satisfaction during preseason as well as ski season. A higher number of controls than of skiers complained of symptoms from some part of the body during the last three months. This is in line with an earlier epidemiological study on general populations in Sweden, where 66 % reported pain and/or discomfort from different parts of the body (Brattberg et al. 1989). Furthermore, since the ski students to a considerably higher extent participate in sports, this strengthens the importance of being physically active in order to enjoy a good health.

Almost half of the skiers suffered from back problems, mainly low back pain, while skiing and above all during diagonal skiing. Although, most athletes are in good general physical condition, one cannot assume that athletes have spent much time strengthening and stretching their low back and abdominal muscles. Injuries are often due to poor conditioning of the spine, poor biomechanics or the stresses placed on the spine by the nature of the sport (Harvey et al. 1991). After having started ski high school the frequency of the skier's training programme increases dramatically from about two-three training times to almost an every day training schedule. The students are studying four years at this school. Four years with this intensive daily training programme might to some extent explain why a higher number of skiers reported back pain at the final class compared to the first one, four years earlier. The vulnerability of the spine is high in the growing individual, especially in the growth spurt at puberty (Hellström et al. 1990). In the present study the average age of the subjects was 18 years, meaning that some of the students still might be growing. Cross-country skiing is characterised to be performed with the back and hip in a flexed position. This might lead to great demands on the spine concerning strength and mobility with a certain risk for overload and subsequent injury of the spine (Frymoyer et al. 1982). Almost half of the skiers with back pain in the present study self-cure their problems by changing body position from a flexed to a more extended position while skiing. This can explain the discomfort of the prolonged flexed position in cross-country skiers while skiing. Furthermore, the skiers report that their symptoms disappear during rest. This probably means that their back problems are only related to skiing and likely due to overuse. The reasons for overuse symptoms usually are related to some kind of physical weakness such as for instance impaired muscle strength or reduced flexibility. Therefore, we recommend that each skier as well during preseason as during ski season performs an individualised prevention programme, based on his/her physical condition.

CONCLUSIONS

- The sports related functional tests, slalom-test and hurdle-test, showed a good reliability in a group of young athletic individuals (Paper I).
- Three (out of four) joint motion and muscle flexibility measurements, knee flexion with hip extended, hip extension with knee extended, and hip flexion with knee extended showed a good reliability (Paper II).
- Additional dance training (October to May) improved speed, agility as well as range of motion of the spine in most of the studied parameters. Dance training also showed positive effects by maintaining flexion, and a combination of abduction and external rotation of the hip joint in young cross-country skiers throughout the entire ski season. A reduction of these parameters was found in the reference group that did not perform any dance training (Paper III).
- Additional preseason dance training (September to November) improved joint mobility and muscle flexibility of the spine, including a positive effect of the relationship between kyphosis of the thoracic and lordosis of the lumbar spine in elite cross-country skiers with slightly impaired flexibility of the spine. Dance training also led to an improved range of motion in hip flexion with knee extended, while the reference group showed impaired hip extension with knee extended (Paper IV).
- Cross-country skiers from ski high schools are considerably more physical active in as well other sports as skiing when compared with age matched regular high school students. In comparison with controls a higher number of ski high school students described themselves to be physically healthy (Paper V).
- Approximately half of the cross-country ski students suffered from back problems, mainly low back pain, while skiing and above all during diagonal skiing (Paper V).

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