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Jyrki Kettunen

Physical Loading and Later Lower-Limb Function and Findings

A Study Among Male Former Elite Athletes

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JYVÄSKYLÄ 2000

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ABSTRACT

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The effects of different lifetime loading patterns on lower-limb osteoarthritis (OA), OA-related findings and function, particularly on consequent disability were investigated. The subjects were Finnish male former elite athletes, who had represented Finland on the international level between 1920 and 1965, and their matched controls. A subgroup, the "clinical study sample", of former elite long-distance runners (N=28), soccer players (N=31), weight lifters (N=29), and shooters (N=29) participated in a one-day investigation consisting of structured interview, clinical examination and measurements, hip magnetic resonance imaging (MRI) and knee X-ray examination. In 1995, a questionnaire was mailed to the cohort of all surviving former athletes (N=1321) and their controls (N=814). This cohort formed the "questionnaire study cohort". No statistically significant group differences in MRI-diagnosed hip OA were found among ex-athletes in the clinical study sample. Moreover, compared to controls, the former elite male athletes in the questionnaire study cohort, had similar prevalences of physician-diagnosed hip OA. Compared to shooters, soccer players and weight lifters in the clinical study sample were at increased risk of developing radiographic premature knee OA (P=0.016 between the groups). In the questionnaire study cohort, the age-adjusted odds for having physician-diagnosed knee OA was increased among team sport athletes (odds ratio 1.50, 95% confidence interval 1.05 to 2.13). Among soccer players in the clinical study sample the increased risk seems to be largely due to previous joint injuries. In weight lifters it was not possible to separate the effects of loading and high body mass. In repetitive nontraumatic loading, such as running, the risk of premature OA of the tibiofemoral joints seems to be low. No association was found between long-term physical loading and passive hip rotation, but knee injuries, hyperextension of the knee and physical activities involving squatting and kneeling seem to increase knee laxity. The present results also show that, despite lower-limb OA, the former elite athletes had good lower-limb muscle function. In the questionnaire study cohort, endurance, track and field and all athletes combined reported less hip disability than their controls. In the clinical study sample, soccer players and weight lifters reported more knee disability than shooters and in the questionnaire study cohort, team sport athletes reported slightly more knee disability than controls. In conclusion, the role of leisure-time physical activity as a risk factor for lower-limb OA has been reported, but former elite male endurance and track and field athletes and all athletes combined reported less hip disability than their controls. The role of vigorous sport-related activity for the function of knee joints is more controversial, because sports involve risk of knee injuries, and such injuries may predict disability. If prescribed for the promotion of health, especially long-term aerobic activities, which have many health benefits and low injury-risk can be recommended to maintain health and disability-free life in old age.

Keywords: hip, knee, osteoarthritis, disability, sports, laxity, range of motion, strength

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Helsinki, April 2000

Jyrki Kettunen

ABBREVIATIONS

OA	Osteoarthritis
MRI	Magnetic resonance imaging
ADL	Activities of daily living
ROM	Range of motion
AAOS	American Academy of Orthopaedic Surgeons
ACL	Anterior cruciate ligament
BMI	Body mass index
SLR	Straight leg raising
OR(s)	Odds ratio(s)
CI	Confidence interval

LIST OF ORIGINAL ARTICLES

This study is based on the following studies referred to as I-V in the text:

I. Kujala UM, Kettunen J, Paananen H, Aalto T, Battié MC, Impivaara O, Videman T, and Sarna S. 1995. Knee osteoarthritis in former runners, soccer players, weight lifters, and shooters. Arthritis Rheum 38, 539-546.

II. Kettunen JA, Kujala UM, Räty H, Videman T, Sarna S, Impivaara O, and Koskinen S. 2000. Factors associated with hip joint rotation in former elite athletes. Br J Sports Med 34, 44-48.

III. Kettunen JA, Kujala UM, Räty H, Videman T, Sarna S, and Impivaara O. 1997. Determinants of sagittal knee laxity in former elite athletes. Sports Exercise and Injury 3, 164-167.

IV Kettunen JA, Kujala UM, Räty H, and Sarna S. 1999. Jumping height in former elite athletes. Eur J Appl Physiol 79, 197-201.

V Kettunen JA, Kujala UM, Kaprio J, Koskenvuo M, and Sarna S. Lower-limb function among former elite athletes. Submitted.

In addition, some unpublished data are presented.

CONTENTS

1 GENERAL INTRODUCTION

The role of life-long vigorous physical activity in lower-limb function is controversial. On the one hand, occupational and exercise-related physical loading are suspected risk factors for lower-limb osteoarthritis (OA) and on the other hand, physical activity maintains lower-limb function, in particular, in old age.

OA of the lower-limb joints is a disorder characterised by pain and disability. The prevalence and severity of OA increase with age (Van Saase et al. 1989). Increased risk of hip OA has been reported among subjects with strenuous occupational physical loading (Vingård et al. 1991a), and sport participation has been shown to increase the risk of lower-limb OA (Kujala et al. 1994a). Unlike sports with high injury risk, running does not seem to be a strong risk factor for lower-limb OA (Lane et al. 1986).

Lower-limb function is an important factor for independent living in old age. Advanced lower-limb muscle strength may cause problems in performing activities of daily living (ADL). Quadriceps muscle strength decreases with age (Young et al. 1984, 1985), and physical inactivity may explain a part of this strength reduction. Physical activity has favourable effects on the muscoloskeletal system, and good lower-extremity function among active subjects has been reported (Fries et al. 1994). Overall, it seems that among healthy subjects from the general population, physically active old subjects usually have higher strength-levels than their inactive controls, and good lower-limb muscle strength has a favourable effect on their mobility.

Exercise-related physical loading may increase the risk of lower-limb OA, but the same sport which predisposes to OA may have favourable effects on functional ability and health. While physical activity has many health benefits and increases life-expectancy (Sarna et al. 1993, Kujala et al. 1998), it can be expected that this longer life expectancy also offers in more years without lower-limb pain and disability.

Radiographs are commonly used to diagnose OA. Some patients with radiographic OA chances are symptomless. Our understanding as to which aspects of OA cause disability is poor (Sharma & Felson 1998). Furthermore, our knowledge about both the benefits of exercise and the adverse effect of hip or knee OA on lower-limb muscle function among former elite athletes is limited.

Therefore, in addition to radiographic OA diagnosis it also would be appropriate to consider function, when studying the effects of long-term leisure-time physical activity.

This study investigates the OA-related findings and disability of hip and knee joints in former athletes to find out what in sum are the effects of different types of sports history on lower-limb function in old age.

2 REVIEW OF THE LITERATURE

2.1 Lower-limb OA

Lower-limb OA is a common disorder characterised by reduced range of motion, pain and disability. The prevalence of OA increases with age (Lawrence et al. 1966, Acheson & Collart 1975) and is more common among women that men (Davis et al. 1989, Felson et al. 1997). OA is uncommon before the age of 40 years but thereafter its prevalence increases with age. In the Mini-Finland Health Survey, 7.6% of men and 16.1% of women aged 45-54 years, 17.4% of men and 33.4% of women aged 55-64 years, 23.9% of men and 43.3% of women aged 65-74 years, and 29.6% of men and 50.5% of women in the age 75 years or more had OA (Heliövaara et al. 1993a). Suspected risk factors for OA include genetic predisposition (Kellgren & Lawrence 1963, Palotie et al. 1989, Felson et al. 1998), obesity (Anderson & Felson 1988, Davis et al. 1989, Felson et al. 1997), previous knee injury (Jackson 1968, Davis et al. 1989), congenital and developmental factors (Gower & Johnston 1971, Wedge 1978, Ordeberg et al. 1984), and various physical loading conditions (Kellgren & Lawrence 1952, Chantraine 1985, Lindberg & Montgomery 1987, Anderson & Felson 1988, Kujala et al. 1994a). The long-term effects of exercise-related physical loading on the lower-limb joints are relevant not only in sports medicine but also for preventive interventions. Also, the relationship between loading patterns and the pathogenesis of OA is of substantial general interest.

2.1.1 Hip OA

Physical activity and hip OA

The effects of long-term repetitive leisure-time physical loading to the hips are incompletely understood. OA of the hip joints was more common among former soccer players than controls (Klünder et al. 1980, Lindberg et al. 1993). In contrast, Solonen (1966) found no association between soccer playing and hip OA among active amateur players aged 18 to 37 years (mean age 26 years). Some cross-sectional studies have not found any association between running and hip OA (Puranen et al. 1975, Panush et al. 1986, Konradsen et al. 1990). In their eight-year follow-up study among 17 male runners Panush and colleagues (1995) found that both runners and controls had some radiographic progression in hip OA, but there was no difference in the progression of OA between the groups. On the other hand, Vingård and colleagues (1993) found increased risk for severe hip OA among men who practised lots of sports of any kind. Kujala and co-workers (1994a) concluded that athletes from all types of competitive sports are at slightly increased risk of the need to hospital care because of severe lower-limb OA (hip, knee or ankle).

Other risk factors and hip OA

Strenuous occupational physical loading is associated with hip OA (Vingård et al. 1991a, Croft et al. 1992, Forsberg & Nilsson 1992). The association between weight and the prevalence of hip OA has been reported in some (Vingård 1991b, Heliövaara et al. 1993b) but not in all (Saville & Dickson 1968) studies. Congenital and developmental diseases increase the risk of hip OA in later life (Gower & Johnston 1971, Wedge 1978, Ordeberg et al. 1984). Ligament tears and high impact forces on the hip joint are rare or difficult to document, but major lower-limb trauma, such as bone fracture, may cause secondary osteoarthritis of the hip.

2.1.2 Knee OA

Physical activity and knee OA

The type, intensity, and frequency of participation in sports may influence the risk of developing knee OA (Chantraine 1985, Kujala et al. 1994a). The incidence of meniscal and ligamentous injuries to the knees is high in soccer players (Solonen 1966, Chantraine 1985) and both types of injuries predispose to knee OA (Fairbank 1948, Jackson 1968, Jacobsen 1977, Chantraine 1985, Roos et al. 1998). The risk of premature knee OA in athletes participating in power sports, such as weightlifting and wrestling, may also be increased (Kujala et al. 1994a).

Sohn and Micheli (1985) found no association between running and knee OA among former college varsity athletes in their retrospective study. Lane and colleagues (1986) investigated the association between athletic activity and knee OA among male and female long-distance runners and matched controls. They found, in their cross-sectional study, no association between running and knee OA. Thereafter, Lane and co-workers (1993) investigated the effect of running and ageing on the development of knee OA in a five-year longitudinal study. Both runners and controls with a mean age of 63 years had significant knee OA progression, but the runners did not have an accelerated development of radiographic or clinical OA compared to controls. Finally, in their (Lane et al. 1998) nine-year follow-up study among a small subgroup of runners and controls from previous studies, the investigators concluded that the progression of radiographic knee OA was similar between the groups. Likewise, Panush and colleagues (1986) and Konradsen and colleagues (1990) found no association between running and knee OA. Overall, runners seem to have a low risk of developing knee OA.

Other risk factors and knee OA

Obesity (Andersson & Felson 1988, Felson et al. 1997), genetic predisposition (Spector et al. 1996) and female sex (Heliövaara et al. 1993a, Felson et al. 1995) have been associated with osteoarthritis of the knee. Strenuous occupational loading has been associated with an increased incidence of knee OA (Kellgren & Lawrence 1952, Lindberg & Montgomery 1987, Anderson & Felson 1988).

2.2 Range of motion (ROM) of the hip

OA may limit ROM of the joints, and restricted rotation and flexion are considered established clinical indicators of hip OA (Hoppenfeld 1976). Restricted ROM of the hip means problems in daily activities such as putting one's shoes on, squatting and walking. However, there are other factors than OA, which may also change the ROM of joints.

Physical activity and ROM of the hip

There are only limited data on the possible effect of long-term physical activity on the ROM of the hip. In their study of running and OA, Panush and co-workers (1986) found no differences in ROM of the hip between male runners (mean age 56 years) and controls (mean age 60 years). On the other hand, restricted hip adduction and inward rotation among classical ballet dancers has been reported, the greatest restriction being found among older and more experienced dancers (Reid et al. 1987). Also, cultural differences in the ADL (Hoaglund et al. 1973, Ahlberg et al. 1988) may change the ROM of the hip.

Other factors and ROM of the hip

Boone and Azen (1979) reported small differences among male subjects in active hip and knee ROM between younger (1 to 19 years old) and older (20 to 54 years old) age groups. Roach and Miles (1991) concluded that at least up to 74 years of age any substantial loss of joint mobility should be considered abnormal. However, both studies are cross-sectional, which limits the conclusion that can be drawn about the effect of age on ROM.

Svenningsen and co-workers (1989) reported greater motion of the hips among female than male subjects, whereas two other studies (Allander et al. 1974, Fairbank et al. 1984) have shown no differences in hip rotation between the sexes. The role played by anthropometric factors in the ROM of the hip is unknown.

Techniques of measurement

Various methods have been used to measure active or passive joints ROM (Boone & Azen 1979, Ekstrand et al. 1982, Roaas & Andersson 1982, Bergström et al. 1985, Ahlberg et al. 1988) and differences in methods and study populations make comparison of ROM results between studies rather difficult (AAOS 1965, Roaas & Andersson 1982, Pandya et al. 1985, Croft et al. 1996). Widely used measurement technique is the recommendation of American Academy of Orthopaedic Surgeons (AAOS 1965).

The ROM of right and left extremities has been claimed to be rather similar, and therefore the ROM of subject's "healthy" limb can be used as a control, when analysing the clinical status of the affected side in the presence of disease or lesion (Boone & Azen 1979). When measuring ROM with a goniometer, better intra-tester than inter-tester reliability has been reported (Boone et al. 1978, Ekstrand et al. 1982).

2.3 Laxity and instability

General hypermobility

Among subjects with general hypermobility most of the joints are unduly lax and the ROM of joints are in excess of the generally accepted. An association between general hypermobility and joint problems was proposed by Carter and Wilkinson (1964) who devised a scoring system for hypermobility to measure the mobility of a group of joints. This method was modified by Beighton and colleagues (1973). According to these classifications the prevalence of hypermobility in the general population has been found to range between 3% and 7% (Carter & Wilkinson 1964, Carr et al. 1993). The relationship between hypermobility and various diseases has been investigated (Beighton & Horan 1969, Biro et al. 1983).

In measurements of hypermobility, the joints are moved in their normal plane of motion, which means that these tests are really tests of flexibility (Steiner 1987). Laxity of the joints means normal variation in joint looseness without traumatic alteration. Steiner (1987) has tried to explain the difference between flexibility and laxity; he maintained that joint flexibility is chiefly a function of muscle and tendon tightness and joint laxity is chiefly a function of ligament tightness. When studying the laxity of a single joint, Nicholas (1970) found an association between increased risk of knee ligament injuries among professional football players with increased knee laxity. In particular, severe knee ligament injury predicts chronic knee instability (Kannus & Järvinen 1987), but little is known about the other factors which may change the laxity of the knee.

Physical activity and knee laxity

Joint laxity decreases with age, especially in men (Marshall et al. 1980, Dubs &

Gschwend 1988). Laxity of the joints may be altered by athletic training as well. When measuring joint laxity before and after exercise, small increases in knee joint laxity after exercise have been demonstrated (Weisman et al. 1980, Skinner et al. 1986, Steiner et al. 1986). Power lifters did not demonstrate a significant change in laxity after doing squats (Steiner et al. 1986). The drawer test with the knee at 90° flexion among carpet and floor layers with kneeling work postures showed more knee laxity than among painters, but similar increased knee laxity was not seen in arthrometer measurements with the knee at 20° flexion (Kivimäki et al. 1994). Overall, our knowledge about the effect of lifetime physical activity history on knee laxity measurements is limited.

Injuries to anterior cruciate ligament (ACL) are common particularly in team sports, and injury of this ligament may lead to instability. In instability, the stability of the joint is lost in a specific direction because a structure is ruptured. ACL is an important stabiliser of the knee (Butler et al. 1980), and the role of ACL is of special interest in sport medicine. Displacement measurements in non-injured subjects have revealed a wide range of normal laxity and in 88% of cases the right-left difference has been less than 2 mm (Daniel et al. 1985). Therefore the non-injured knee can be used as a control, when testing the stability of the injured knee. However, the reasons for inter-individual differences, which can cause errors in the interpretation of the laxity measurement results, particularly in cases where both knees have been injured, are insufficiently known.

Knee laxity measurements

Measurements of knee stability are usually done manually, using different methods (AMA 1968, Galway et al. 1972, Hughston et al. 1976, Torg et al. 1976, Marshall et al. 1977, Noyes et al. 1983), which all assume clinical experience. Beside manual measurements, it is possible to measure the sagittal laxity of the knee using instrumented devices. Most of the devices nowadays intended for clinical practice measure anterior-posterior laxity at 20°-25° of flexion.

Anterior displacement measurements correlate with ACL disruption (Fukubayashi et al. 1982, Rangger et al. 1993). While non-injured subjects revealed a wide range of normal laxity, the injured vs. non-injured knee laxity difference has more diagnostic accuracy than the measure of absolute displacement, when evaluating ACL disrupted knees (Anderson et al. 1992), even in chronic ACL disruptions (Rangger et al. 1993).

Andersson and co-workers (1992) compared five arthrometers and found that total anterior laxity measurements cannot be generalised from one device to another. They tested anterior tibial displacement using a force of 89 Newtons and with the knee at 30° of flexion. The highest diagnostic accuracy was demonstrated by the KT-1000 knee ligament arthrometer (MEDmetric Corp, San Diego, CA) and Stryker Knee Laxity Tester (Stryker Corp, Kalamazoo, MI), and the manual maximum test improved the accuracy with each device detected ACL ruptures. In the manual maximum test the tester stabilises the leg at patella with one hand and with the other hand applies a strong anterior force directly to the calf. Sommerlath and Gillquist (1991) compared simple and computerised arthrometers and found that the KT-1000 knee ligament arthrometer showed the highest sensitivity (85 %) and specificity (100 %) in detecting ACL ruptures, when evaluating unstable knees.

Reports mostly state good reproducibility in testing knee laxity with the KT-1000 knee ligament arthrometer (Malcom et al. 1985, Steiner et al. 1990). Only Forster and co-workers (1989) found poor intra- and inter-examiner reproducibility among subjects with and without knee injury. However, knee stability is maintained by complex interactions between a large number of factors, such as ligament and other soft-tissue restraints, condylar geometry, active muscular control and tibiofemoral contact forces at the joint interfaces generated during weight-bearing activities (Markolf et al. 1981). Tibial rotation, muscle relaxation, displacement force, flexion angle and other factors related to the measurement system can also contribute to the displacement measurement result.

2.4 Physical activity and lower-limb muscle strength

Isometric (Larsson et al. 1979, Murray et al. 1980, 1985), concentric (Vandervoort et al. 1990, Overend et al. 1992, Poulin et al. 1992, Stanley & Taylor 1993) and eccentric (Vandervoort et al. 1990, Porter et al. 1994) quadriceps muscle group strength decreases with age. From the age of 30 to 70 years, the decrease in maximal muscle strength is on average 30 to 40 percent (Murray et. al 1980). Rantanen and co-workers (1998) measured changes in grip strength over a follow-up period of 27 years among Japanese-American men. The subjects (N=8006) were between 45 to 68 years old at the baseline, and 3741 men (71 to 96 years old) participated to the follow-up examination. The mean reduction in grip strength was one percent per year. Subjects who had a high level of grip strength at the baseline were also likely to retain it 27 years later. The reduction in muscle strength may be small up to the age of 50 years and thereafter the reduction may accelerate (Häkkinen & Häkkinen 1990). One explanation for the reduction in muscle strength is physical inactivity leading to muscle weakness. Muscle strength decreases among physically active subjects as well, but physical activity may slow the effects of ageing. Old, active male subjects have higher isometric knee-extension forces than their population-sample controls (Sipilä et al. 1991), and those subjects with greater maximal isometric strength have better maximal walking speed than those with lower strength-levels (Rantanen et al. 1994). In old age, members of a runners' club had better lower-extremity function than their community controls (Fries et al. 1994). Difficulties in indoor and outdoor mobility, low muscle strength levels, and slow walking speed among elderly subjects (75 to 84 years old) increased the risk of death in a follow-up period of 48 to 58 months (Laukkanen et al. 1995).

Among healthy subjects from the general population, physically active elderly subjects seem to have higher strength-levels than their inactive controls. Moreover, this good lower-limb muscle strength among these active subjects has a favourable effect on physical ability. Therefore, long-term physical activity with its many health benefits may play an important role in preventing lower-limb related disability among elderly people and giving them more physically active years.

2.5 Disability

The proportion of elderly people in the population is increasing rapidly and the relationship between physical activity and a disability-free life is highly relevant for public health.

Radiographic evidence of OA is common among elderly persons. However, only some patients even with radiographic chances have symptoms and our understanding of which aspects of OA cause disability is poor (Sharma & Felson 1998).

The International Classification of Impairments, Disabilities, and Handicaps (ICIDH) was developed by the World Health Organization (WHO 1980). The ICIDH employs three concepts: impairment, disability and handicap. The scheme proposed by sociologist Nagi (1976, 1991) has four concepts: Active pathology, impairment, functional limitation and disability. In this scheme, functional limitation leads to disability and there is no parallel concept for handicap. In 1994, Verbrugge and Jette published their sociomedical model of disability, called "The Disablement Process". The model is based on Nagi's sheme. Overall, when investigating the pathway from disease to disability, the way disability is defined and measured may influence the results. In epidemiological studies, several methods have been used to measure disability (Guccione et al. 1990, Davis et al. 1991, McAlindon et al. 1993) among osteoarthritic subjects. However, while there is no golden standard for the measurement of disability, there is also no general agreement on how to measure disability in epidemiological studies.

Odding and co-workers (1998) measured the association of radiological hip and knee OA with locomotor disability in the Rotterdam Study. They used questions about six lower-limb functions, and subjects experiencing at least some difficulty with three or more functions were classified as having locomotor disability. Lequesne and Mery (1980) proposed an index of severity for hip disease and, later, the index of severity for knee disease was validated and appraised by the same methods as the hip index (Lequesne et al. 1987). The indices included questions on pain, walking distance and some ADLs. In the present studies hip and knee disability were measured with questions related to impairments in lower-limb functions, which former athletes as well as controls do in their daily life.

Physical activity and disability

Rest from physical loading has traditionally been prescribed as a treatment for different musculoskeletal diseases. On the other hand, lifetime physical activity has been shown to help prevent some chronic diseases, such as coronary heart disease (Kujala et al. 1998) and adult onset diabetes mellitus (Helmrich et al. 1991). Moreover, physical activity may help in maintaining good lower-limb function, which is an important factor for independent living at the old age. Rantanen and co-workers (1994) investigated the association between isometric strength and mobility, such as walking and stair mounting, among 75-year-old men and women. They found that good maximal strength levels had a positive association with mobility. There is evidence to support the hypothesis that, even in old age, running helps to maintain lower-limb function (Fries et al. 1994, Kujala et al. 1999). In contrast, sport-related as well as strenuous occupational loading has been shown to increase the risk for hip and knee OA, and lower-limb injuries, such as knee and ankle sprain in soccer, accelerate the development of OA.

Slemenda and co-workers (1997) have even hypothesised, that quadriceps weakness is a primary risk factor for knee pain, disability and progression of knee OA. Furthermore, aerobic or resistance exercise has been reported to reduce pain and disability (Ettinger et al. 1997) among osteoarthritic subjects. Ries and co-workers (1995) recommended a regular, individualised aerobic exercise program for patients with OA. Thus, different types of life-long exercise-related physical loading may increase the risk of lower-limb OA, the same sport which predisposes to OA may also have a favourable effect on mobility and may delay the onset of lower-limb related disability.

3 AIMS OF THE STUDY

The general goals of this study were to investigate the effects of different lifetime loading patterns on lower-limb OA and OA-related findings and function, particularly on consequent disability.

The specific aims of the study were:

To compare the long-term consequences of participation during adolescence and adulthood in different types of sports with clearly different physical loading patterns on knee and hip OA and disability in later adulthood (I, II, IV, V).

To investigate in detail factors associated with the measurement results of OA-related findings, in particular ROM of the hip, knee laxity, and jumping height (I, II, III, IV, V).

4 MATERIAL AND METHODS

4.1 Subjects

The subjects were Finnish male former elite athletes and their matched controls. The athletes had represented Finland between the years 1920 and 1965 at least once in the Olympic games, World or European championships, or inter-country competitions (athletic contests between two or more countries) (Sarna et al. 1993). Vital statistics were available from Finland's Central Population registry. Controls were Finnish men who had been classified as completely healthy at the age of 20 at the beginning of their military service (Sarna et al. 1993). The first questionnaire study (N=2528) was carried out in 1985 to obtain historical data, mainly for follow-up studies (Sarna et al. 1993). The questionnaire, which elicited information on height and weight at the age of 20, weight in 1985, occupation, physical activity, discontinuation of sporting career, health and life-style was mailed to all surviving athletes and referents. The response rate among the athletes was between 80% and 90% according to sport, and among controls it was 77%. The mean age of those who responded and those who did not was similar (56.6 and 56.4 years respectively). The response rate was lower among unskilled workers and farmers as compared with skilled workers. In 1992 a subgroup, labelled the "clinical study sample", of former elite endurance runners, soccer players, weight lifters, and shooters was investigated with respect to lower-limb findings and function (studies I-IV). In 1995 a second questionnaire including questions on knee and hip OA and disability was mailed to all surviving athletes and controls (study V), who were labelled as the "questionnaire study cohort". The study design is presented in figure 1.

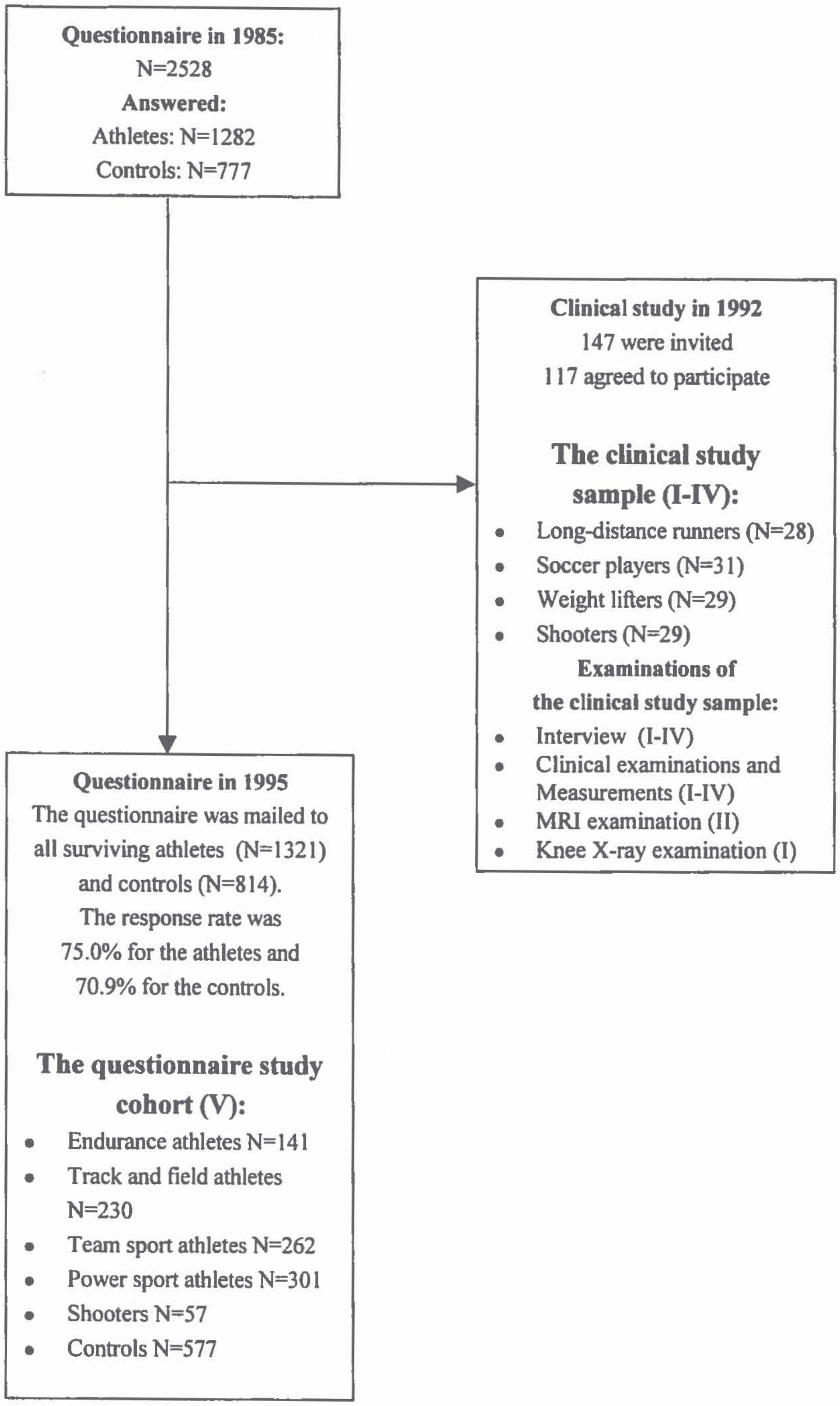

FIGURE 1 The study design

Studies I-IV

The target group for the clinical study sample of the original responders to the 1985 questionnaire included 38 long-distance runners, 89 soccer players, 40 weight lifters and 35 shooters, who in 1992 were alive and 45 to 68 years old. All the shooters (N=35) and runners (N=38), as well as samples of soccer players (N=37) and weight lifters (N=37) comparable in age and occupation with the other groups (a total of 147 subjects), were invited to participate in these studies. Of these, 117 (80%) agreed to participate. Among the participants there were 28 long distance runners, 31 soccer players, 29 weight lifters and 29 shooters. Table 1 shows the basic characteristics of the clinical study subjects. The most important reason for unwillingness to participate was lack of time.

TABLE I Characteristics of participants in the clinical study sample (I-IV) and lifetime regular years* of participation in different types of athletic training (endurance, team, power) at least once a week, and during the past 12 months (hours each week) spent in different types of training

	Long-distance runners N=28	Soccer players N=31	Weight lifters N=29	Shooters N=29
Age in 1992				
Years; Mean (SD)	59.7 (4.7)	56.5 (5.7)	59.3 (5.3)	61.0 (4.3)
Range	51 - 67	45 - 67	46 - 66	50 - 68
Height				
cm; Mean (SD)	173.0 (4.8)	176.9 (5.4)	167.0 (6.6)	175.2 (6.6.)
Range	162.0 - 183.0	165.0 - 187.0	154.0 - 183.0	164.0 - 188.0
Weight				
kg; Mean (SD)	75.7 (9.7)	84.2 (12.1)	80.7 (13.8)	81.9 (8.4)
Range	60.0 - 108.0	68.0 - 123.0	57.0 - 111.0	71.0 - 99.0
BMI at the age of 20				
kg/m2; Mean (SD)	21.7 (2.0)	22.9 (1.4)	24.1 (2.1)	22.4 (2.3)
Range	17.4 - 26.2	20.7 - 26.1	18.5 - 28.7	18.2 - 28.4
BMI in 1992				
kg / m2; Mean (SD)	25.3 (2.8)	26.9 (3.4)	28.8 (3.6)	26.7 (2.5)
Range	20.9 - 34.9	22.0 - 38.8	22.5 - 38.4	22.9 - 30.8
Straight leg raising				
Degrees; Mean (SD)	85.5 (14.0)	84.7 (10.5)	88.7 (10.3)	80.4 (9.6)
Range	63.5 - 119.0	60.0 - 110.0	71.0 - 114.0	56.0 - 92.5
Hypermobility index				
Mean; (SD)	0.7 (0.9)	1.0 (1.3)	0.8 (0.8)	0.9 (1.2)
Range	0.0 - 5.0	0.0 - 5.0	0.0 - 2.0	0.0 - 4.0
Years in heavy work				
Mean; (SD)	12.3 (15.4)	1.7 (7.2)	9.7 (12.6)	3.2 (8.3)
Range	0.0 - 47.0	0.0 - 40.0	0.0 - 43.0	0.0 - 38.0
Years in kneeling or squatting work**				
Mean; (SD)	0.8 (2.9)	1.5 (4.6)	5.4 (9.3)	0.6 (3.2)
Range	0.0 - 15	0.0 - 23.0	0.0 - 32.0	0.0 - 17.0
Endurance training				
Years; Mean (SD)	31.7 (16.6)	17.1 (12.7)	15.8 (17.3)	20.6 (13.7)
Range	4.6 - 68.8	0.0 - 41.0	0.0 - 69.0	0.0 - 46.3
Hours; Mean (SD)	9408 (4213)	2607 (2850)	2269 (2462)	2845 (2219)
Range	1300 - 18752	0 - 9936	0 - 8483	0 - 8536
Hours; Median	8980	1530	1520	2480
Team sport training				
Years; Mean (SD)	3.8 (9.4)	37.0 (18.2)	9.8 (16.0)	5.3 (8.1)
Range	0.0 - 36.5	15.0 - 78.9	0.0 - 80.0	0.0 - 30.0
Hours; Mean (SD)	356 (731)	9043 (3961)	1147 (1435)	807 (1421)
Range	0 - 3072	3864 - 18514	0 - 4888	0 - 5500
Hours; Median	0	8240	1150	140
Power training				
Years; Mean (SD)	0.8 (2.1)	2.1 (3.6)	21.5 (11.2)	0.9 (2.1)
Range	0.0 - 7.5	0.0 - 12.8	3.0 - 44.0	0.0 - 8.3
Hours; Mean (SD)	84 (263)	295 (500)	8118 (4651)	89 (236)
Range	0 - 1280	0 - 1600	284 - 16752	0 - 1092
Hours; Median	0	0	9460	0

(continues)

(TABLE I continues)

Past 12 months endurance training				
Hours/week; Mean	2.2	0.62	0.81	0.55
Range	0.0 - 7.4	0.0 - 5.2	0.0 - 5.8	0.0 - 2.2
Past 12 months team sport training				
Hours/week; Mean	0.00	1.57	0.22	0.10
Range	0.0 - 0.0	0.0 - 8.3	0.0 - 3.0	0.0 - 2.5
Past 12 months power sport training				
Hours/week; Mean	0.12	0.10	0.92	0.00
Range	0.0 - 2.0	0.0 - 1.5	0.0 - 6.0	0.0 - 0.0
Past 12 months shooting				
Hours/week; Mean	0.00	0.00	0.13	0.21
Range	0.0 - 0.0	0.0 - 0.0	0.0 - 2.4	0.0 - 6.2
Past 12 months gymnastics				
Hours/week; Mean	0.07	0.06	0.02	0.06
Range	0.0 - 1.0	0.0 - 1.0	0.0 - 0.5	0.0 - 1.2
Sum of all forms of training Hours/week;				
Mean (SD)	3.19 (2.41)	3.03 (2.36)	2.99 (2.64)	3.70 (2.76)
Range	0.0 - 8.7	0.0 - 7.2	0.0 - 8.8	0.0 - 9.9

*Participation years are also summed in case the subject participated regularly in more than one event at the same time, also in case he participated in two team events at the same time.
**Years in work involving kneeling or squatting more than 10 minutes per working-hour.

Study V

In 1995, a second questionnaire was mailed to the whole cohort of all the surviving former male athletes and controls (N=2135). The response rate was 75.0% (991/1321) for the athletes and 70.9% (577/814) for the controls. In earlier studies (Sarna et al. 1993, Kujala et al. 1994b, Kujala et al. 1996), to investigate different effects on health of different types of sports participation, the athletes were grouped according to the type of training needed to achieve maximal results, i.e. principally aerobic training or mixed training. In the present study the same classification was followed, but athletes with mixed training were classified into two subgroups according to risk of injury to the lower-limb joints. Thus, endurance athletes (long-distance running, cross-country skiing) are those whose training requires a high amount of repetitive loading of the weight-bearing joints. Team sports (soccer, ice hockey, basketball) include those with a greater risk of high impact loads and sprains of the joints. Track and field sports (jumping, sprinting, hurdling, middle distance running, decathlon) include those with a greater risk of high impact loads but a smaller risk of sprains of the joints. Power sports (boxing, wrestling, weightlifting, throwing) include sports with less repetitions but higher forces when loading the joints, and shooting include athletes who take light to moderate general exercise involving some kneeling and squatting. Because, among the power sports group, in particular there is variation in loading patters, some stratified data is also given for each sport event.

The 1995 questionnaire was mailed to the cohort of all the surviving former athletes and controls of whom 25.0% of the athletes and 29.1% of the control subjects tailed to respond. The mean age between those who responded and those who did not was similar (63.5 and 64.3 years, respectively). As seen in the 1985 questionnaire, the response rate was lower among unskilled workers and farmers as compared with skilled workers.

4.2 Methods

The interview and the clinical examinations as well as the magnetic resonance imaging (MRI) and radiographic readings were carried out independently by investigators who were blind to the results obtained by others (I-IV).

4.2.1 Examinations of the clinical study sample

Interview (I-IV)

The subjects were interviewed by the same physician (HR) about their lifetime history (since the age of 12 years) with special emphasis on sports, exercise, and leisure time, as well as occupational hip and knee loading and injuries to the knee. The recall process was guided by linking the course of events to special occasions, such as schooling, marriage, and participation in Olympic games. Among the four groups, the mean length of regular competitive involvement in an athlete's own event (minimum training 3 times per week) ranged from 9.8 years to 14.5 years (individual range 2-36 years), with relatively little participation in other sports. A detailed interview was conducted for each different training regimen and type of training that occurred during the subject's lifetime. Questions addressed the number of years during which the participant trained at least once a week, the sum of training hours during these training periods, and the amount of time during the past 12 months (hours per week) spent in different types of training (Table 1).

Years spent in kneeling or squatting work (years in work involving kneeling or squatting more than 10 minutes per working hour) was calculated (Table 1). Each athlete's occupational loading was also analysed and classified into the following categories:

1 = mainly sedentary
2 = mainly walking or standing
3 = a variety of tasks, including some bending and twisting, but seldom lifting anything heavier than 35 kg
4 = a variety of tasks with bending, twisting and daily lifting more than 35 kg
5 = very heavy jobs, including maximal lifts in bent and twisted positions.

Years spent in occupations in categories 4 or 5 were designated as years at heavy work (Table 1).

An acute knee injury requiring hospital treatment before the age of 40 was considered a previous knee injury. Only the first knee injury in each subject was taken into account.

The occurrence of hip and knee pain during the previous year was investigated separately for each hip and knee. Those who reported hip or knee pain in either hip or knee at least monthly were classified as having monthly hip or knee pain, respectively. Hip and knee disability was scored depending on whether the subjects reported pain or disability (yes=1, no=0) during:

1 nocturnal bed-rest
2 more than five minutes in the morning after getting out of bed
3 sitting for 30 minutes
4 full support by the legs
5 walking more than 1 km
6 going up or down stairs
7 squatting or bending forward.

The sum of positive responses (0-7) was calculated and subjects scoring at least three points for either hip or knee were considered to have hip or knee disability (yes), respectively.

Clinical examination and measurements (I-IV)

The clinical examinations and quantitative measurements were performed by JK. Subjects' weight (kg) and height (cm) was measured and body mass index (BMI) calculated (Table 1). Subjects were placed in the supine position for the measurement of passive flexion and inward and outward rotation of the hip joint and passive extension and flexion of the knee joint. Hip flexion was measured knee flexed using a two-armed standard goniometer. Because the standard goniometer is difficult to adapt for the purpose of measuring hip rotation, hip rotation was measured knee flexed with a Myrin inclinometer (Follo A/S, Oslo, Norway), which is based on a compass method. The total (inward and outward combined) rotation was used to avoid the misclassification of inward and outward rotation. A correlation between radiological changes of the spine and inclinometer ROM measurement results has been reported (Viitanen et al. 1995). Moreover, Viitanen and co-workers (1995) concluded that the reliability of ROM measurements as conducted in this study was good. Hip extension was measured with the subject lying prone with the knee extended, using a standard goniometer.

Knee flexion was measured hip flexed using a two-armed standard goniometer. For measurements of passive hyperextension, with the subjects lying supine, the examiner raised the leg in order to fully hyperextend the knee. The range of motion was measured using a two-armed standard goniometer and recorded to the nearest degree. All hip and knee ROM measurements were made according to the recommendations of the handbook of the American Academy of Orthopaedic Surgeons (AAOS 1965).

Hamstring tightness was measured using passive straight leg raising (SLR) with the inclinometer placed just above the patella of the leg to be tested. The examiner put his leg on the other leg to stabilise it, and raised the leg to be tested slowly and evenly, avoiding abduction and rotation and keeping the knee fully extended until tightness or pain restricted the movement. The mean of the readings from the two legs was used in the calculations.

General hypermobility (hypermobility index) was examined using the Carter and Wilkinson (1964) score as modified by Beighton and colleagues (1973). The test included: passive dorsiflexion of the little fingers beyond 90°, passive apposition of the thumbs to the flexor aspect of the forearm, hyperextension of elbows beyond 10°, hyperextension of the knees beyond 10°, and flexion of the trunk with the knees in extension so that the palms of the hands rested on the floor.

Vertical jumping-height was determined from the flight time of three jumps (Bosco 1980). The subjects performed the jumps with no counter-movement from a static position with a knee angle of 90° and kept their hands on their hips during the entire jump. Flight time was used to calculate the height of the rise of the body's centre of gravity. Recovery time between attempts was 15 s. The coefficient of variation between repeated measurements was 3.9%, with the highest of the three values used for statistical calculations. A total of 110 subjects participated in the jumping test, three were excluded because of knee pain, and the other four were excluded because of low-back pain, hip pain, hip endoprothesis or coronary heart disease (one for each reason).

Medial or lateral instabilities of the knee were evaluated clinically with the knee at 0° and 30° flexion. Instrumented measurements of sagittal knee laxity were taken on both legs with a KT-1000 knee ligament arthrometer (MEDmetric Corporation, San Diego, CA, USA) according to the recommended guidelines. The manual maximum was recorded in three consecutive successful measurements of anterior translation. The coefficient of variation between repeated measurements for the right and left knees was between 2.1% and 2.5%. The mean of the second and third trials was used for statistical calculations.

MRI examination (II)

MRI was performed using a 1.5 Tesla device (Magnetom, Siemens AG, Erlangen, Germany) with a body coil. The subjects were lying supine during the MRI examinations. Since the patients had a subsequent MRI examination of the lumbar spine (Videman et al. 1995), a 3D FISP (Fast Imaging with Steady Precession) sequence, which gives a good visualisation of the articular cartilage in a relatively short time was chosen. Axial slices of both hips were produced. The imaging parameters were as follows: TR 30 ms / TE 10 ms / Flip angle 40°, 256x256 matrix, Field-of-view 36 cm, 2 mm slice thickness with no interslice gap, total imaging time 8 minutes 14 seconds.

The MR images were analysed for narrowing of joint space, cysts and deformation of femoral head. Joint space narrowing (cartilage signal) was graded from 6 slices representing the weight bearing area as follows: *0 = normal, 1 = decrease in 1 - 3 of the studied slices, 2 = decrease in 4 - 6 of the studied slices, 3 = clearly obliterated at least in one slice (no cartilage signal) or 9 = cannot be evaluated.* Cysts and deformation of femoral head were graded as *0 = no, 1 = yes and 9 = can not be evaluated.*

An athlete was considered to have hip OA, if he had obliterated hip joint space (grade 3) or osteoarthritic deformation of femoral head or cyst formation in femoral head. In addition, one subject had undergone total hip replacement due to OA and was therefore classified as osteoarthritic.

To evaluate the intra-observer variation in the MRI readings, the MR images were grouped by grade of joint space narrowing and then picked randomly, some from each group, up to a total of 55 hips, enriching the MR images with OA changes. A radiologist reread these films six months later with no knowledge of the previous readings. The generalised kappa statistics for the re-evaluations of joint space narrowing was 0.58. The reliability of the other readings was not tested because of the small numbers.

A total of 94 subjects were examined (25 long-distance runners, 25 soccer players, 19 weight lifters and 25 shooters). Fourteen subjects were excluded due to foreign bodies or metallic implants, seven for technical difficulties, one because of claustrophobia and one due to problems fitting in the scanner.

Knee X-ray examination (I)

Standard anteroposterior standing (weight-bearing) knee radiographs were obtained with a focus-film-distance of 2 metres: intensifying screens were used. Lateral weight-bearing knee radiographs with a focus-film-distance of 1.2 metres were obtained separately for each knee, with the knee flexed at 30° and the subject supporting his weight on the knee.

Overall osteoarhritic changes were graded from 0 to 4 for tibiofemoral and patellofemoral joints separately, according to the criteria by Kellgren and Lawrence (1957). Subjects having at least grade 2 osteoarthritis changes in the tibiofemoral joint of the more affected knee were deemed to have radiographic tibiofemoral OA. Radiographic patellofemoral OA was determined in a similar way. If the subject had either tibiofemoral or patellofemoral OA, he was considered to have radiographic knee OA.

Detailed evaluation of knee radiographs included analysis of osteophytes, subchondral cysts, joint space narrowing, valgus angle, and patellar height. Joint margin osteophyte formation was recorded according to the method described by Hernborg and Nilsson (1973). Osteophyte size was defined as the largest perpendicular distance from the edge of the cortex to the outer margin of the osteophyte. Osteophyte formation in the tibiofemoral joints was measured at six sites (medial femoral condyle, medial tibial condyle, lateral femoral condyle, lateral tibial condyle, medial tibial eminence, and lateral tibial eminence) on anteroposterior radiographs, and osteophyte formation in the patellofemoral joints was measured at two sites (upper and lower poles of the patella). Each osteophyte was graded according to size on a scale of 0-3, where *0=no osteophyte formation, 1=small osteophytes (1-3 mm), 2=moderate (4-6 mm), and 3=large (>6 mm).* Subjects having at least one grade 2 osteophyte in the more affected tibiofemoral joint were classified as having tibiofemoral osteophytes; patellofemoral osteophytes were recorded in the same way. If the subject had either tibiofemoral or patellofemoral osteophytes, he was considered to have knee osteophytes.

The subject's knee joints were examined for the presence of visible cyst formation. Narrowing of the tibiofemoral joint space was measured in millimetres, from lateral radiographs obtained with full weight-bearing on each knee separately, with the knee flexed at 30°. The means of the lateral and medial joint spaces of each knee were used in statistical calculations. In the anteroposterior radiographs the knee valgus angle was measured in degrees between the long axis of the tibia and the femur, which were the lines passing the center of the diaphysis-metaphysis at 15 cm and 8 cm from the joint line.

To evaluate the reliability (within-observer variation) of the radiographic readings, radiographs were grouped by tibiofemoral OA grade and then randomly chosen, some from each group, up to total of 30, enriching the radiographic examples with osteoarthritic changes. A radiologist reread these films with no knowledge of the previous readings (six months had elapsed since the first reading). Generalised kappa statistics for the re-evaluations were 0.61 (95% confidence interval 0.40 to 0.81) for tibiofemoral OA, 0.61 (0.40 to 0.82) for patellofemoral OA, 0.62 (0.37 to 0.86) for osteophytes, 0.51 (0.25 to 0.76) for height of the joint space, and 0.75 (0.55 to 0.95) for tibiofemoral angulation.

4.2.2 Examinations of the questionnaire study cohort

Questionnaire (V)

The questionnaire in 1995 included items on physician-diagnosed hip and knee OA (yes/no) separately for onset before and after the age of 45 years. Information was also elicited on physician-diagnosed knee ligament injuries, knee meniscal injuries and the need of hospital admission for knee injury. Table 2 shows the characteristics of the study subjects. BMI (Table 2) was calculated based on the basis of self-reported weight and height.

Occupational groups (Sarna et al. 1993) were classified into the following categories: executives, clerical workers, skilled workers, unskilled workers, and farmers. Each person was classified into the group in which he had been occupationally active the longest (Table 2). The category "executives" was used as a reference group when analysing the association between occupational group and disability.

TABLE 2 Characteristics of the study subjects in the questionnaire study cohort (V)

	Endurance athletes	Track and field athletes	Team sport athletes	Power sport athletes	Shooters	Controls
	N=141	N=230	N=262	N=301	N=57	N=577
Age in 1995						
Years; Mean (SD)	68.8 (9.4)	64.4 (9.3)	61.8 (8.3)	64.5 (8.3)	70.7 (10.8)	62.4 (8.1)
Range	50.0 - 92.0	49.0 - 88.0	48.0 - 95.0	48.0 - 90.0	47.0 - 99.0	49.0 - 91.0
BMI in 1995						
kg/cm2; Mean (SD)	24.6 (2.8)	25.3 (2.9)	26.4 (3.0)	28.0 (4.1)	25.7 (3.3)	26.8 (3.7)
Range	19.1 - 33.8	16.1 - 42.6	18.6 - 39.8	19.1 - 46.3	19.5 - 35.5	16.2 -42.6
Occupational group N (%)						
Executives	7 (5.6)	93 (44.9)	84 (36.4)	39 (14.7)	20 (39.2)	64 (12.8)
Clerical workers	62 (49.2)	77 (37.2)	99 (42.9)	96 (36.2)	21 (41.2)	142 (28.3)
Skilled Workers	35 (27.8)	30 (14.5)	47 (20.3)	113 (42.3)	6 (11.8)	213 (42.5)
Unskilled workers	7 (5.6)	1 (0.5)	1 (0.4)	7 (2.6)	0 (0.0)	19 (3.8)
Farmers	15 (11.9)	6 (2.9)	0 (0.0)	10 (3.8)	4 (7.8)	63 (12.6)

Endurance athletes = Long-distance runners, Cross-country skiers, Track and field athletes = Jumpers, Sprinters, Hurdlers, Middle-distance runners, and Decathlon athletes, Team sport athletes = Soccer players, Ice-hockey players, Basketball players, Power sport athletes = Boxers, Wrestlers, Weight lifters, Throwers

Occurrence of hip and knee pain and disability was determined separately for the hips and knees using the same methods as in studies I-IV, except that in the hip and knee disability score question number five "walking more than 1 km" was changed to "walking more than 100 m".

4.2.3 Statistical analysis

The statistical analyses were carried out using BMDP Statistical software. When using regression analysis each sport group variable was converted to a dichotomous (0/1) variable and for entry in these models.

Study I

Fisher's exact test and the generalised Fisher's exact test were used in the cross-tabulations of the different categorical variables. The Student's *t* -test or the Mann-Whitney U -test was used to compare continuous variables for subjects with and without knee OA.

Logistic regression analysis models were used to analyse the associations between different covariates and knee OA.

Study II

One-way analysis of variance (ANOVA) and the mean hip inward or outward rotation, extension and flexion ROM value of the right and left leg was used to compare group means.

ANOVA was used to compare hip rotation right-left differences among subjects with unilateral hip OA and those without this finding. The mean total (inward+outward combined) rotation value of osteoarthritic hip joints and the mean value of right and left total hip rotation among subjects without OA was calculated to compare rotation differences among those two groups.

Multiple linear regression analysis was used for dependent associations between passive hip rotation and with following independent factors: BMI, years in heavy work, lifetime participation hours in different types of athletic training, age, hypermobility index, athlete group, hip OA, monthly hip pain, hip disability and SLR. The mean value of right and left hip rotation (inward and outward combined) was used in these analyses.

Study III

ANOVA was used for to compare group means. For multiple comparisons, Student-Newman-Keuls (SNK) -test was used.

Multiple linear regression analysis was used to study the factors explaining right-left difference in sagittal knee laxity and inter-individual variation in mean knee laxity of right and left knees. Athlete group, BMI, hypermobility index, height, degrees of hyperextension of the knees, extent of tibiofemoral osteoarthritis on the basis of the radiographic examination, hamstring tightness, previous knee injury, years in heavy work, and years in kneeling or squatting work were entered into a step-wise multiple regression analysis as independent factors.

When studying the factors explaining inter-individual variation in knee laxity, subjects (N=9) having a difference of more than 4 mm between the knees in anterior tibial displacement were excluded. Their right or left mean laxity is not likely to represent normal subject-specific knee laxity, because injuries or other abnormalities may explain the side difference. Multiple linear regression analysis was used to study the determinants of variation in inter-individual knee laxity. Athlete group, degrees of hyperextension of the knees, and hamstring tightness value were entered into the final model.

Study IV

ANOVA and analysis of covariance (ANCOVA) was used to compare age-adjusted sport group means in jumping-height among all subjects and among subjects without hip or knee OA, and also to compare age- and sport group adjusted means between subjects with or without hip or knee OA.

Multiple regression analysis was used in evaluating associations between jumping-height and the different explanatory variables. Athlete group, BMI, SLR, age, years in heavy work, lifetime participation (hours) in various types of athletic training, types of physical activity during the past 12 months, hip or knee OA, hip or knee pain and disability were entered into a step-wise multiple regression analysis as independent factors.

Study V

Stepwise logistic regression models were used to analyse the association between different covariates and hip and knee OA, pain and disability.

5 RESULTS

5.1 Physical activity and OA

Hip OA (II, V)

In the clinical study group there were no statistically significant group differences in MRI-diagnosed hip OA (P=0.60). Only 94 subjects participated in the MRI examination; owing to the low number of osteoartritic subjects, it was not possible to carry out further analyses on the association between the various physical loading patterns and hip OA.

In the questionnaire study cohort the age, BMI and occupational group adjusted odds ratios (ORs) of hip OA before the age of 45 years among athletes were similar when compared to controls (Table 3). Moreover, the ORs of any (before or after age of 45 years) hip OA among athletes compared to controls were similar after adjustment for age, BMI and occupational group (Table 4).

TABLE 3 Adjusted ORs for hip and knee OA before the age of 45 years in the questionnaire study cohort (V)

	HIP OA		KNEE OA	
Sports group	Adjusted for age	Adjusted for age, BMI and occupational group	Adjusted for age	Adjusted for age, BMI and occupational group
Endurance athletes				
OR	1.22	1.88	1.28	1.26
95% CI	0.33 to 4.54	0.47 to 7.54	0.45 to 3.61	0.39 to 4.04
P value	0.767	0.355	0.646	0.703
Team sports athletes				
OR	0.93	1.73	2.92	3.38
95% CI	0.32 to 2.68	0.47 to 6.31	1.49 to 5.73	1.55 to 7.37
P value	0.895	0.391	0.002	0.002
Track and field athletes				
OR	0.19	0.44	1.71	2.15
95% CI	0.02 to 1.46	0.05 to 3.76	0.79 to 3.67	0.91 to 5.11
P value	0.113	0.441	0.171	0.083

(continues)

(TABLE 3 continues)

Power sport athletes				
OR	0.86	0.69	2.13	1.98
95% CI	0.30 to 2.48	0.18 to 2.72	1.06 to 4.29	0.91 to 4.33
P value	0.776	0.584	0.034	0.086
Shooters				
OR	0.89	1.73	1.17	0.77
95% CI	0.11 to 7.32	0.20 to 15.3	0.25 to 5.38	0.10 to 6.23
P value	0.913	0.609	0.841	0.805
All athletes				
OR	0.75	1.10	1.94	1.98
95% CI	0.34 to 1.63	0.43 to 2.80	1.12 to 3.38	1.06 to 3.69
P value	0.467	0.844	0.018	0.032
Controls				
OR	1.00	1.00	1.00	1.00

TABLE 4 Number of subjects (No), who answered the specific questions, prevalence rates No(%) of hip and knee OA and pain in the questionnaire study cohort, and adjusted ORs for hip and knee OA and pain among athletes compared with controls

	No	No(%)	95% CI of %	Adjusted for age			Adjusted for age, occupational group and body mass index		
				OR	95 % CI	P value	OR	95 % CI	P value
Hip OA									
Endurance	116	31 (26.7)	18.7 to 34.8	1.16	0.70 to 1.92	0.570	1.40	0.80 to 2.45	0.231
Track and field	203	21 (10.3)	6.2 to 14.5	0.43	0.25 to 0.74	0.002	0.66	0.36 to 1.20	0.165
Team sport	209	28 (13.4)	8.8 to 18.0	0.77	0.48 to 1.24	0.271	1.13	0.66 to 1.92	0.659
Power sport	248	50 (20.2)	15.2 to 25.2	1.02	0.68 to 1.53	0.934	1.06	0.68 to 1.67	0.784
Shooting	54	13 (24.1)	13.5 to 37.6	0.80	0.39 to 1.67	0.552	1.10	0.49 to 2.46	0.824
All sport	830	143 (17.2)	14.7 to 19.8	0.80	0.58 to 1.09	0.153	1.03	0.72 to 1.48	0.863
Controls	481	81 (16.8)	13.5 to 20.2	1.00			1.00		
Knee OA									
Endurance	122	31 (25.4)	17.7 to 33.1	0.84	0.53 to 1.36	0.482	1.11	0.66 to 1.85	0.701
Track and field	212	49 (23.1)	17.4 to 28.8	0.89	0.61 to 1.31	0.564	1.32	0.85 to 2.06	0.215
Team sport	228	70 (30.7)	24.7 to 36.7	1.50	1.05 to 2.13	0.025	2.04	1.35 to 3.07	<0.001
Power sport	253	69 (27.3)	21.8 to 32.8	1.08	0.76 to 1.54	0.673	1.04	0.70 to 1.55	0.828
Shooting	52	11 (21.2)	11.1 to 34.7	0.61	0.30 to 1.27	0.185	0.83	0.37 to 1.86	0.648
All sport	867	230 (26.5)	23.6 to 29.5	1.05	0.81 to 1.36	0.698	1.28	0.95 to 1.73	0.099
Controls	508	120 (23.6)	19.9 to 27.3	1.00			1.00		
Hip pain									
Endurance	125	16 (12.8)	6.9 to 18.7	0.34	0.19 to 0.60	<0.001	0.32	0.17 to 0.61	<0.001
Track and field	224	35 (15.6)	10.9 to 20.4	0.50	0.33 to 0.76	0.001	0.69	0.43 to 1.12	0.133
Team sport	246	39 (15.9)	11.3 to 20.4	0.59	0.39 to 0.88	0.009	0.68	0.43 to 1.09	0.109
Power sport	266	64 (24.1)	18.8 to 29.0	0.87	0.61 to 1.24	0.453	0.84	0.57 to 1.24	0.390
Shooting	54	9 (16.7)	7.9 to 29.3	0.42	0.20 to 0.92	0.029	0.32	0.12 to 0.87	0.028
All sport	915	163 (17.9)	15.3 to 20.3	0.61	0.47 to 0.80	<0.001	0.66	0.50 to 0.88	0.005
Controls	527	128 (24.3)	20.7 to 28.0	1.00			1.00		
Knee pain									
Endurance	133	29 (21.8)	14.8 to 28.8	0.61	0.38 to 0.96	0.035	0.77	0.46 to 1.28	0.309
Track and field	220	52 (23.6)	18.0 to 29.3	0.76	0.52 to 1.09	0.139	1.09	0.71 to 1.66	0.698
Team sport	251	81 (32.3)	26.5 to 38.1	1.29	0.93 to 1.79	0.129	1.56	1.07 to 2.28	0.021
Power sport	272	81 (29.8)	24.2 to 35.0	1.05	0.76 to 1.45	0.783	0.94	0.66 to 1.36	0.759
Shooting	57	12 (21.1)	11.4 to 33.9	0.54	0.27 to 1.08	0.081	0.71	0.33 to 1.51	0.375
All sport	933	255 (27.3)	24.5 to 30.2	1.02	0.81 to 1.30	0.849	1.05	0.82 to 1.36	0.687
Controls	532	146 (27.5)	23.7 to 31.2	1.00			1.00		

Knee OA (I, V)

In the clinical study sample there were statistically significant between-group differences in the prevalences of radiographic knee OA (P= 0.016) and knee osteophytes (P=0.009) (Table 5). In comparison with shooters, both soccer players and weight lifters had a higher prevalence of osteoarthritic knee findings. Soccer players had predominantly tibiofemoral OA and weight lifters patellofemoral OA

(Table 5). Of the subjects with tibiofemoral OA, two soccer players and one weight lifter were affected bilaterally; of those with patellofemoral OA, one soccer player, three weight lifters, and one shooter were affected bilaterally.

TABLE 5 Prevalence of radiographic osteoarthritic knee findings in the clinical study sample*

	Long-distance runners N=28	Soccer players N=31	Weight lifters N=29	Shooters N=29	P value†
Knee OA	4 (14)	9 (29)	9 (31)	1 (3)	0.016
95% CI	4 - 33	14 - 48‡	15 - 51‡	0 - 18	
Tibiofemoral OA	1 (4)	8 (26)	5 (17)	0 (0)	0.003
95% CI	0 - 18	12 - 45‡	6 - 36	0 - 12	
Patellofemoral OA	3 (11)	5 (16)	8 (28)	1 (3)	0.064
95% CI	2 - 28	5 - 34	13 - 47	0 - 18	
Knee osteophytes	4 (14)	9 (29)	10(34)	1 (3)	0.009
95% CI	4 - 33	14 - 48‡	18 - 54‡	0 - 18	
Tibiofemoral osteophytes	1 (4)	6 (19)	4 (14)	0 (0)	0.028
95% CI	0 - 18	7 - 37	4 - 32	0 - 12	
Patellofemoral osteophytes	4 (14)	8 (26)	9 (31)	1 (3)	0.028
95% CI	4 - 33	12 - 45	15 - 51‡	0 - 18	
Cysts	1 (4)	7 (23)	2 (7)	1 (3)	0.053
95% CI	0 - 18	10 - 41	1 - 23	0 - 18	
Knee extension deficiency	2 (7)	12 (39)	10 (34)	1 (3)	<0.001
95% CI	1 - 24	22 - 58§	18 - 54	0 - 18	
Monthly knee pain	6 (21)	14 (45)	8 (28)	5 (17)	0.095
95% CI	8 - 41	27 - 64	13 - 47	6 - 36	
Knee disability	3 (11)	11 (35)	7 (24)	2 (7)	0.022
95% CI	2 - 28	19 - 55‡	10 - 44	1 - 23	

* Values are the number (%), 95% CIs of the percentage. See subjects and methods (study I) for detailed definitions.
†By generalized Fisher's exact test for comparison between the osteoarthritic findings in the four athlete groups.
‡ P < 0.05 compared with shooters, by Fisher's exact test for comparisons of osteoarthritic findings (exact two-sided P value has been corrected for multiple comparisons using the Bonferroni method).
§ P < 0.01 compared with shooters, by Fischer's exact test for comparisons of osteoarthritic findings (exact two-sided P value has been corrected for multiple comparisons using Bonferroni method).

The tibiofemoral joint space was narrow with tibiofemoral OA compared to subjects without tibiofemoral OA (mean 4.0 mm, SD 1.7 mm vs. mean 5.6 mm, SD 0.6 mm; P<0.001). Subjects with tibiofemoral OA had a tendency to varus deformity compared to subjects without tibiofemoral OA (mean valgus angle 2.4°, SD 4.7° vs. mean 4.0°, SD 2.6°; P=0.070), but one subject with tibiofemoral OA had a valgus deformity of 13°.

The subjects with radiographic knee OA had higher BMI at the age of 20 than did subjects without knee OA (mean 24.2, SD 2.3 vs. mean 22.4, SD 1.9; P=0.001). When subjects were placed into quartiles based on BMI at 20 years of age, 11% (3/28) of those in the lowest BMI quartile (BMI < 21.35) had knee OA, as compared to 50% (13/26) in the highest quartile (BMI > 23.89) (P=0.003). BMI at the age of 20 correlated with the BMI in 1985 (Spearman rank sum correlation r=0.52) and with BMI in 1992 (r=0.44).

Injuries among the clinical study sample were recorded in three runners, 12 soccer players, six weight lifters, and one shooter. The reported 22 injuries included 17 meniscal and ligamentous injuries, one contusion, one fracture, and three undefined injuries. Fifteen of the 22 primary injuries had occurred during sports activity. Ten of the 12 injuries in soccer players had occurred during soccer, one during ice hockey, and one in non-sports activity. Sports-related injuries can be viewed as a common aspect of soccer participation, whereas in other athletic groups, injuries in the athletes' own events were uncommon, occurring only in one runner and one weight lifter. Fifty percent (11/22) of the subjects with previous knee injuries had knee OA, as compared to 13% (12/95) in those without such reports (P<0.001). The mean years spent in heavy work was 13.7 (SD 17.0) for those with knee OA and 4.9 (SD 9.7) for those without (P=0.054). The mean years in kneeling or squatting work was 4.9 (SD 8.4) for subjects with knee OA and 1.4 (SD 4.9) for those without (P=0.047). Knee extension deficiency (≥4°) was more common among soccer players and weight lifters than shooters (39% and 34% vs. 3%; P<0.001 between groups; Table 5). Moreover, knee extension deficiency was seen in 11 subjects (79%) with tibiofemoral OA and in 10 subjects (10%) without tibiofemoral OA (P<0.001).

Compared with shooters, the age-adjusted risk of having radiographic knee OA was significantly higher in soccer players (OR 12.3, 95% CI 1.35 to 111) and in weight lifters (12.9, 1.47 to 113). The relative risk of knee OA was substantially elevated in runners as well (OR 4.8), but the numbers of shooters and runners with knee OA were too small to rule out either protective or harmful effects (95% CI 0.48 to 47). The age-adjusted risk of having knee OA increased significantly with the number of lifetime hours spent in team sport training (OR 1.14/1000 training hours; 95% CI 1.03 to 1.27) and power training (1.12, 1.00 to 1.25), but there was no significant increase in the risk of having knee OA with hours spent in endurance training (1.06, 0.94 to 1.20). The age-adjusted risk of having knee OA also increased significantly with the number of lifetime years spent in heavy work (OR 1.06/work year, 95% CI 1.02 to 1.09) and years spent in kneeling or squatting work (1.08/work year, 1.01 to 1.16).

Among the questionnaire study cohort the age-adjusted ORs of reported physician-diagnosed knee OA before the age of 45 years were higher among team sport athletes, power sport athletes, and all athletes combined compared to controls (Table 3). After adjustment for age, BMI and occupational group the ORs of knee OA were still higher among team sport athletes and all athletes combined. The age-adjusted ORs of any knee OA with onset (before or after the age of 45 years) either among athletes and controls were similar except among team sport athletes, who had increased OR (Table 4).

Athlete group, age, BMI at the age of 20, years in heavy work, years in kneeling or squatting work, and previous knee injuries, were entered into a stepwise logistic regression analysis to identify predictors of knee OA among the clinical study sample. According to the final multivariate model, the risk of having knee OA was increased in subjects with previous knee injuries (OR 4.73, 95% CI 1.32 to 17.0), higher BMI at the age of 20 (1.76/one unit increase, 1.26 to 2.45), more years in heavy work (1.08/working year, 1.02 to 1.13) and work involving kneeling or squatting (1.10, 1.02 to 1.20), and participation in soccer (5.21, 1.14 to 23.8).

Separate multivariate analyses were conducted to identify specific predictors of patellofemoral and tibiofemoral OA in the clinical study sample. The possible predictor variables considered in the stepwise logistic regression analyses were: previous knee injuries, BMI at the age of 20, and lifetime participation hours in endurance, team, and power sports, and lifetime participation years in heavy work and in kneeling or squatting work. In the final models, previous knee injuries (OR 5.96, 95% CI 1.28 to 27.8), high BMI at the age of 20 (1.54/one unit increase, 1.04 to 2.29), and hours of participation in team sports (1.20, 1.03 to 2.29) were associated with increased risk of tibiofemoral OA. Correspondingly, previous knee injuries (OR 4.87, 95% CI 1.38 to 17.2), high BMI at the age of 20 (1.45/one unit increase, 1.07 to 1.95), years spent in heavy work (1.04/working year, 1.00 to 1.08), and work involving kneeling or squatting (1.08, 1.00 to 1.16) entered into the predictive model for patellofemoral OA.

5.2 ROM of the hip (II)

Table 6 shows the mean values and ranges of the ROM in passive hip (outward and inward rotation, flexion, extension) movements in the clinical study sample. There were no differences in the passive hip joint ROM between the four groups of athletes with divergent long-term patterns of loading, nor between the right and left lower extremities. The mean (SD) right-left difference in rotation (inward+outward combined) was 6.9° (10.2°) in those with unilateral hip OA (N=14) and 4.2° (4.6°) in those without this finding (N=78) (P=0.10).

TABLE 6 Passive ROM of the hip joint in the clinical study sample (II)

	Long-distance runners	Soccer players	Weight lifters	Shooters	P value
	N=28	N=31	N=29	N=29	
Extension					
Degrees; Mean (SD)	18.0 (5.5)	17.1 (6.0)	15.8 (6.5)	19.0 (5.0)	0.17
Range	0.0 - 25.0	0.0 - 28.5	0.0 - 24.0	12.0 - 30.5	
Flexion					
Degrees; Mean (SD)	139.7 (14.1)	140.6 (10.3)	139.4 (11.0)	140.4 (5.7)	0.97
Range	72.0 - 150.0	95.0 - 152.5	95.0 - 154.0	126.5 - 150.0	
Outward rotation					
Degrees; Mean (SD)	35.6 (8.4)	36.9 (7.2)	36.6 (5.1)	37.8 (4.9)	0.66
Range	2.5 - 50.0	20.0 - 47.5	25.0 - 45.0	25.0 - 47.5	
Inward rotation					
Degrees; Mean (SD)	18.9 (5.9)	19.4 (4.7)	20.3 (4.5)	19.3 (7.4)	0.83
Range	0.0 - 29.5	8.5 - 29.0	12.0 - 30.0	9.0 - 40.0	

Nevertheless, in four severe cases of femoral head deformity the right-left rotation difference exceeded 10°. The mean (SD) combined hip rotation was 54.9° (12.8°) in hip joints with hip OA and 56.8° (9.1°) in those without (P=0.51).

The average hip rotation was significantly smaller (P<0.001) in subjects with monthly hip pain (43.3°,SD 15.3°,N=14) than in those who had not experienced this (58.4°,SD 7.9°,N=81). Similarly, those with hip disability had significantly smaller (P<0.001) mean rotations (37.9°,SD 25.3°,N=4) than those without (57.0°,SD 9.1°,N=91).

The associations between hip rotation and different covariates were studied among those who had undergone MR imaging (N=94, the subject with bilateral endoprothesis excluded). The calculations were based on the mean combined rotation of measurements made on the right and left hips. BMI, years in heavy work, lifetime participation hours in different types of athletic training, age, hypermobility index, athletic group, hip OA, monthly hip pain, hip disability and SLR were entered into the model.

The only factors that were significantly associated with hip rotation were BMI (20%) and monthly hip pain (9%), explaining together about 29% of its variation. Mean hip rotation was 61.1° in those with a BMI of 24 or less (N=20), 55.5° in those with BMI between 24.1 and 28 (N=52) and 53.3° if BMI was 28.1 or more (N=22) (P=0.049). When the subjects with hip OA or those with monthly hip pain or hip disability were excluded from the multiple linear regression analysis the only factor that was associated with hip rotation among subjects with "healthy hips" was BMI, which explained about 21% of its variation.

5.3 Knee laxity (III) and instability (I)

The arthrometer measurements showed statistically significant differences in knee laxity between the athlete groups (P<0.001, ANOVA). Laxity was greater (P<0.05; SNK -test) in shooters (mean 9.0 mm) and weight lifters (mean 8.4 mm) than in runners (mean 7.3 mm) and soccer players (mean 7.1 mm) (Table 7).

TABLE 7 Mean values (SD) and ranges of anterior tibial displacement in all athletes and in those with right-left difference of 4 mm or less in clinical study sample (III)

	Long-distance runners N=28	Soccer players N=31	Weight lifters N=29	Shooters N=29	P value
All athletes					
mm; Mean (SD)	7.3 (1.8)	7.1 (2.1)	8.4 (2.0)	9.0 (1.8)	<0.001
Range	4.3 - 11.0	4.0 - 13.9	5.5 - 13.3	4.6 - 12.1	
	N=26	N=28	N=27	N=27	
Athletes with right-left difference 4 mm or less					
mm; Mean (SD)	7.2 (1.8)	6.7 (1.7)	8.3 (1.8)	9.1 (1.7)	<0.001
Range	4.3 - 11.0	4.0 - 11.6	5.5 - 12.6	4.6 - 12.2	

When the knee was examined clinically at 30 degrees flexion, clear medial instability was found in 11 (10.6 %) of the subjects (1 runner, 8 soccer players, 2 shooters). Lateral instability was found in one soccer player. Medio-lateral knee instability was found in six subjects (43%) with tibiofemoral OA and in 10 subjects (10%) without tibiofemoral OA (P=0.004). There was no statistically significant difference in anterior knee laxity between the athletes with and those without clear medio-lateral knee instability (p=0.24).

Among all athletes the mean right-left difference in anterior knee laxity was 1.5 mm (SD 1.6, range 0.0-8.5 mm). A difference of more than 2 mm was documented in three soccer players (10%), five runners (18%), seven weight lifters (24%) and 10 shooters (35%). A difference exceeding 4 mm was found in nine (8%) of the athletes (2 runners, 3 soccer players, 2 weight lifters and 2 shooters).

To establish the factors associated with the right-left difference, athlete group, BMI, hypermobility index, height, degree of hyperextension of the knees, extent of tibiofemoral OA based on the radiographic examination, hamstring tightness, previous knee injury, years with heavy work and years in kneeling or squatting work were entered into a stepwise multiple regression analysis. The only factor that was significantly associated with the right-left difference was previous knee injury explaining about 9% of the variation. The mean difference was 2.3 mm in those injured and 1.3 mm in those without previous injury (P<0.001).

After excluding the nine athletes with a right-left difference of more than 4 mm, differences still remained in anterior knee laxity between the athlete groups (P<0.001) (Table 7). When the determinants of knee laxity were analysed among these subjects (N=108), the following factors entered the final multiple regression model: athlete group, hamstring tightness value and degree of hyperextension of the knees. Together, these three factors explained 29% (Table 8) of the inter-individual variation in knee laxity. The mean anterior laxity was 8.5 mm in those with knee hyperextension of 5° or more (N=42), 7.7 mm in those with hyperextension between 1° and 4° (N=44) and 6.9 mm in those with no hyperextension at all (N=22) (P<0.008). When hyperextension was left out of the regression model, athlete group and hamstring tightness explained 26 % of the inter-individual variation in knee laxity.

TABLE 8 Multiple linear regression analysis of factors explaining inter-individual variation in knee laxity (III)

Factors that entered final model	Cumulative explanation rate* (r^2)	Regression coefficient†	Standard error of regression coefficient†	P value‡
Soccer players	0.0918	- 1.6568	0.4045	0.01
Runners	0.1958	- 1.5199	0.4098	0.01
Hamstring tightness	0.2569	- 0.0313	0.0138	0.03
Knee hyperextension	0.2921	0.1363	0.0627	0.03

* From stepwise model
† From fixed model
‡ From fixed model by Wald's test

Similarly, the mean anterior laxity was 8.5 mm in those with a hamstring tightness value of less than 75° (N=28), 7.9 mm in those with values between 75° and 90° (N=59) and 6.9 mm when the value exceeded 90° (N=21) (P<0.02).

5.4 Lower-limb muscle strength (IV)

No statistically significant (N=110) age-adjusted sport group differences appeared for jumping-height (Table 9) in the clinical study group, but statistically significant age-adjusted sport group differences did occur among subgroup (N=65) of athletes without hip or knee OA (P=0.025 between all groups), weight lifters having the highest (mean 29.4 cm) and shooters (mean 24.2 cm) the lowest jumping-height result (Table 9). After adjustment for age and sport group among all subjects, jumping-height was less in those with hip or knee OA (N=33) (mean 22.4 cm) than in those without (N=65) (mean 25.7 cm) (P=0.002).

TABLE 9 Jumping-height in the clinical study sample (IV)

	Long-distance runners	Soccer players	Weight lifters	Shooters	P value
	N=26	N=30	N=25	N=29	
Jumping-height: All athletes (N=110) cm; Mean (SE) Range	23.3 (0.01) 15.2 - 35.4	24.9 (0.01) 12.2 - 37.5	26.9 (0.01) 14.1 - 38.2	24.2 (0.01) 15.7- 36.6	0.098
	N=18	N=16	N=12	N=19	
Jumping-height: Athletes without hip or knee OA (N=65) cm; Mean (SE) Range	24.7 (0.01) 20.0 - 35.4	26.2 (0.02) 16.1 - 37.5	29.4 (0.02) 19.3 - 37.6	24.2 (0.01) 15.7 - 36.6	0.025
	N=6	N=11	N=9	N=7	
Jumping-height: Athletes with hip or/and knee OA (N=33) cm; Mean (SE) Range	20.1 (0.04) 16.3 - 26.7	23.2 (0.02) 12.2 - 31.0	21.9 (0.03) 14.1 - 35.4	23.4 (0.04) 18.7 - 27.7	0.578

To establish the factors associated with jumping-height (N=89), athlete group, BMI, SLR, age, years in heavy work, lifetime participation (hours) in various types of athletic training, types of physical activity during the past 12 months, hip or knee OA, hip or knee pain and disability were entered into a multiple linear regression analysis. The factors significantly associated with jumping-height were: age (11%, P<0.001), participation in team sports during the past 12 months (7%, P<0.001), reported knee (9%, P<0.001) and hip (7%, P=0.003) disability, lifetime participation in power sport (5%, P=0.004) and monthly knee pain (2%, P=0.042), which together explained 41% of the variation. The younger subjects jumped higher than the older ones; the mean difference in jumping-height was about 12% in a decade.

Among those without hip and knee OA, the factors that associated with jumping-height in the regression analysis were hours spent in team sport training during the previous 12 months (13%, P<0.01), age (9%,P<0.01) and weightlifting (11%, P<0.01), explaining together 33% of the variation.

5.5 Disability

In the whole cohort sample the ORs for both hip and knee disability were higher among older than younger subjects, and subjects with high BMI had higher ORs for hip and knee disability than subjects with low BMI (Table 10). Moreover, occupational group associated with both hip and knee disability (Table 10).

TABLE 10 ORs for hip and knee disability among subjects who completed 1995 questionnaire in study V. BMI and occupational ORs are adjusted for age (V)

	Hip disability OR	95% CI	P value	Knee disability OR	95% CI	P value
Age						
< 50	1.00			1.00		
50 to 59	3.16	0.96 to 10.4	0.057	1.46	0.73 to 2.93	0.289
60 to 69	5.23	1.62 to 16.4	0.006	1.93	0.98 to 3.82	0.058
70 >	7.59	2.31 to 24.9	<0.001	2.34	1.15 to 4.76	0.019
BMI						
< 25	1.00			1.00		
25 to 28	2.65	1.73 to 4.07	<0.001	1.91	1.34 to 2.74	<0.001
28 >	4.07	2.63 to 6.30	<0.001	3.23	2.24 to 4.65	<0.001
Occupational group						
executives	1.00			1.00		
clerical workers	1.52	0.98 to 2.37	0.063	1.22	0.84 to 1.77	0.308
skilled workers	2.34	1.53 to 3.59	<0.001	1.91	1.33 to 2.74	<0.001
unskilled workers	1.26	0.29 to 5.49	0.756	0.71	0.17 to 3.08	0.653
farmers	4.33	2.32 to 8.07	<0.001	1.49	0.75 to 2.96	0.262

Hip disability (II, V)

Among the clinical study sample (II) there were no statistically significant differences in hip disability (P=0.86 between groups) or pain (P=0.45 between groups). Hip disability was reported by two (7%) of the long-distance runners, one (3%) of the soccer players, one (3%) of the weight lifters, and one (3%) of the shooters. Hip disability was reported by 13% (2/16) of the subjects with hip OA and by 3% (2/79) of those without (P=0.07). Twenty-five percent (4/16) of the subjects with hip OA had monthly hip pain, whereas this was reported by 13% (10/79) of those without hip OA (P=0.20).

Table 11 shows the number of subjects, who answered the questions about hip disability and the prevalence rates of hip disability among the questionnaire study cohort (V). Table 12 shows the adjusted ORs of hip disability.

TABLE 11 Number of subjects, who answered the questions about hip and knee disability and the prevalence rates of hip and knee disability among those subjects in study V

Sports	HIP DISABILITY Number of subjects	N(%)	95% CI of %	KNEE DISABILITY Number of subjects	N(%)	95% CI of %
Endurance athletes:	116	9 (7.8)	3.6 to 14.2	109	9 (8.3)	3.9 to 15.1
Long-distance runners	77	6 (7.8)	2.9 to 16.2	71	5 (7.0)	2.3 to 15.7
Cross-country skiers	39	3 (7.7)	1.6 to 20.9	38	4 (10.5)	3.0 to 24.8
Team sports athletes:	236	16 (6.8)	3.9 to 10.8	211	36 (17.1)	12.0 to 22.1
Soccer players	107	7 (6.5)	2.7 to 13.0	90	15 (16.7)	9.6 to 25.3
Ice-hockey players	80	8 (10.0)	4.4 to 18.8	77	15 (19.5)	11.3 to 30.1
Basketball players	49	1 (2.0)	0.0 to 10.9	44	6 (13.6)	5.2 to 27.3
Track and field athletes:	182	5 (2.7)	0.9 to 6.3	175	15 (8.6)	4.9 to 13.7
Power sport athletes:	284	35 (12.3)	8.5 to 16.1	271	43 (15.9)	11.5 to 20.2
Boxers	74	7 (9.5)	3.9 to 18.5	67	6 (9.0)	3.4 to 18.5
Wrestlers	82	13 (15.9)	8.7 to 25.6	83	21 (25.3)	16.4 to 36.0
Weight lifters	44	5 (11.4)	3.8 to 24.6	40	4 (10.0)	2.8 to 23.7
Throwers	84	10 (11.9)	5.9 to 20.8	81	15 (18.5)	10.7 to 28.7
Shooters:	51	4 (7.8)	2.2 to 18.9	50	6 (12.0)	4.5 to 24.3
All athletes:	869	69 (7.9)	6.2 to 9.9	816	109 (13.4)	11.0 to 15.7
Controls:	489	68 (13.9)	10.8 to 17.0	460	59 (12.8)	9.8 to 15.9

TABLE 12 Adjusted ORs for hip (N=1358) and knee (N=1276) disability in subjects who completed 1995 questionnaire (V)

	HIP				KNEE			
		Adjusted for age and:				Adjusted for age and:		
Sports	Adjusted for age	occupational group	BMI	occupational group and BMI	Adjusted for age	occupational group	BMI	occupational group and BMI
Endurance athletes:								
OR	0.37	0.31	0.43	0.35	0.53	0.56	0.70	0.71
95% CI	0.17 to 0.80	0.13 to 0.75	0.19 to 0.94	0.14 to 0.85	0.25 to 1.11	0.25 to 1.24	0.33 to 1.49	0.32 to 1.60
P value	0.011	0.009	0.033	0.019	0.092	0.153	0.357	0.416
Team sports athletes:								
OR	0.45	0.53	0.47	0.56	1.41	1.59	1.61	1.76
95% CI	0.25 to 0.79	0.27 to 1.04	0.27 to 0.83	0.28 to 1.10	0.90 to 2.22	0.94 to 2.68	1.01 to 2.56	1.03 to 3.02
P value	0.006	0.061	0.010	0.088	0.139	0.087	0.046	0.038
Track and field athletes:								
OR	0.20	0.27	0.22	0.30	0.63	0.82	0.77	0.97
95% CI	0.10 to 0.45	0.11 to 0.66	0.10 to 0.50	0.12 to 0.73	0.36 to 1.11	0.44 to 1.54	0.43 to 1.37	0.51 to 1.84
P value	<0.001	0.004	0.001	0.007	0.113	0.542	0.378	0.933
Power sports athletes:								
OR	0.82	0.94	0.72	0.84	1.31	1.48	1.10	1.25
95% CI	0.52 to 1.29	0.58 to 1.54	0.46 to 1.15	0.51 to 1.39	0.85 to 2.03	0.92 to 2.37	0.70 to 1.72	0.77 to 2.03
P value	0.179	0.811	0.168	0.492	0.222	0.104	0.690	0.378
Shooters:								
OR	0.38	0.27	0.41	0.30	0.71	0.70	0.84	0.84
95% CI	0.13 to 1.12	0.06 to 1.21	0.14 to 1.21	0.07 to 1.32	0.28 to 1.79	0.23 to 2.11	0.33 to 2.13	0.27 to 2.55
P value	0.351	0.083	0.106	0.108	0.469	0.526	0.720	0.755
All sports:								
OR	0.47	0.53	0.48	0.54	1.03	1.16	1.10	1.21
95% CI	0.33 to 0.68	0.35 to 0.80	0.33 to 0.69	0.36 to 0.82	0.73 to 1.46	0.79 to 1.71	0.77 to 1.56	0.82 to 1.79
P value	<0.001	0.003	<0.001	0.003	0.856	0.440	0.609	0.345
Controls:								
(OR)	1.00				1.00			

On the basis of the questionnaire, the age-adjusted ORs of having hip disability were lower among the endurance, team sport and track and field athletes, and also among all athletes combined when compared to controls (Table 12). Also the age-adjusted ORs of at least monthly hip pain were lower among the endurance, track and field and team sport athletes, shooters and all athletes combined when compared to controls (Table 4). Compared to controls, the ORs of hip disability among the endurance, track and field and all athletes combined (Table 12), and hip pain among the endurance athletes, shooters and all athletes combined (Table 4) were still lower after adjustment for age, occupational group, and BMI.

Knee disability (I, V)

Among the clinical study sample (I) knee disability was most common in soccer players and weight lifters (P=0.022 between groups) (Table 5). Soccer players and weight lifters also most commonly reported knee pain, but the difference between these groups was not statistically significant (P=0.095 between groups) (Table 5). Subjects with radiographic knee OA had knee disability more commonly (N = 11, 48%) than those without knee OA (N=12, 13%, P<0.001). Subjects with radiographic knee OA reported monthly knee pain (N=13, 57%) more commonly than those without knee OA (N=20, 21%, P=0.001).

Table 11 shows the number of subjects who answered the questions about knee disability and the prevalence rates of knee disability among the questionnaire study cohort (V). Table 12 shows the adjusted ORs of knee disability. The adjusted ORs of having knee pain (Table 4) and disability (Table 12) among athletes and controls were similar, except for team sport athletes, who had slightly increased ORs. Figure 2 shows the age-adjusted ORs of having hip and knee disability by the various sport events.

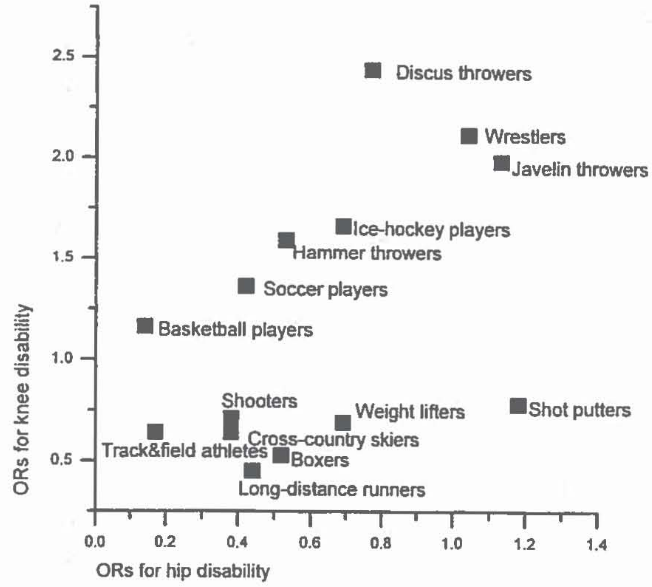

FIGURE 2 The age-adjusted ORs of hip and knee disability among various sport events

In the questionnaire study cohort physician-diagnosed knee ligament injuries were rare among the long-distance runners (7%, 5/73), shooters (9%, 4/47) and controls (11%, 51/473) and most common among the soccer players (41%, 38/92) (P<0.001, between all groups). Fifteen percent of the shooters (7/48) and controls (76/492) reported physician-diagnosed knee meniscal injuries compared to 45% of the soccer players (48/107) (P<0.001). Moreover, 50% of the soccer players reported that they had needed hospital treatment for knee injuries. Subjects with knee ligament or meniscal injury reported more knee disability (29.5%, 95% CI 24.5% to 34.6%) than subjects without (7.7%, 6.0% to 9.6%) such injury (P<0.001).

5.6 Summary of the effects of physical activity on lower-limb findings and function

Compared to shooters long-term physical activity did not increase the risk of hip OA (II). Among the whole cohort the prevalences of physician-diagnosed hip OA were similar among athletes and controls (V).

Compared to shooters, soccer players and weight lifters were at increased risk of developing radiographic premature knee OA (I). Team sports athletes had a higher prevalence of physician-diagnosed knee OA compared to control subjects (V). The increased risk of knee OA seems to be largely due to previous knee injuries, particularly in soccer players (I). In weight lifters it was not possible to separate the effects of loading and high BMI, respectively, on OA risk (I).

Long-term physical activity does not seem to change the ROM of the hip (II).

Shooters and weight lifters had greater knee laxity than long-distance runners and soccer players (III). The only factor that associated with the right-left knee laxity difference was previous knee injury (III). Subjects with hyperextension of the knee or hamstring tightness had great knee laxity, and lifetime sport-related knee loading contributes to knee laxity (III).

The age-adjusted jumping-height results between the various sport groups were similar (IV) among all subjects in the clinical study sample but among the subjects without hip or knee OA weight lifters had the highest and shooters the lowest jumping-height result (IV). The ability to jump even with hip or knee OA would suggest that former elite athletes posses advanced lower-limb muscle function.

The prevalences of hip disability were similar in the clinical study sample (II); compared to controls the adjusted ORs of reported hip disability were lower among endurance athletes, track and field athletes, and all athletes combined (V).

Among the clinical study sample knee disability was most common in soccer players and weight lifters (I). The adjusted ORs of knee disability among athletes and controls were similar except among team sport athletes, who had increased ORs (V). Subjects with knee ligament or meniscal injury reported more knee disability than subjects without such injury (V).

6 DISCUSSION

The effects of long-term leisure-time physical loading on lower-limb hip and knee joint findings and function were investigated. Ankle joint was excluded from this study, as ankle OA is rare and more commonly observed as secondary to trauma (Demetriades et al. 1998).

Studies recording lifetime physical activity and joint loading generally encounter difficulties that can be reduced by studying former athletes at the international level. The loading patterns of athletes are rather specific and their exercise histories are more reliable than are those taken from an ordinary person. Athletes typically follow well-planned and defined training routines. Athletic loading in these studies does not necessarily apply specifically to the training regimens of today's athletes, as the training programme of today's elite athletes have become increasingly demanding.

Elite athletes, such as those in the original cohort, can be regarded as a selected group in many respects. First, various selective factors, such as muscle fibre composition, play a role enabling some individual to reach top-level results in competitions. Second, the athletes were presumably free from hip or knee OA during the time they were participating in top-level sports, where good lower limb function is an essential prerequisite. Thus, subjects with sports-related injuries during early athletic career are likely to be dropouts. In this respect the results may underestimate the harmful effects of athletic loading on lower-limbs. The first questionnaire was conducted in 1985. Of the subjects who were still competing in 1985, only nine percent reported knee disability and four percent reported hip disability in 1995. Among the subjects who reported that they had never engaged in competitive sport, the reported rate of knee disability was 13.0% and hip disability 13.8% in 1995. The most important reasons ending a sporting career were age (31.4%), lack of interest (22.9%), and injury/injuries (20.0%).

It was difficult to determine which of the recorded factors were determinants, i.e., belong to the sports event, and which should be classified as confounders. In accordance with earlier studies, high BMI, occupational loading and injuries associated with knee OA.

Among the clinical study sample high BMI was associated with knee OA. BMI was also associated with weightlifting, and therefore it was difficult to separate the effects of BMI and physical loading.

Lifetime years of work-related high loading of the knees were associated with development of knee OA. Some of the weight lifters reported that they lifted heavy burdens at work as part of their training and this make it difficult to separate work- and sport-related physical loading.

Previous injuries were strong predictors of future knee osteoarthritis and subjects reporting injuries had more knee disability than subjects who did not. Moreover, injuries were also associated with team sports, particularly with soccer.

6.1 Physical activity and OA

An athlete's hip or knee, even if clinically free from OA, can show small osteophytes and other radiographic changes that usually are considered signs of OA (Alexander 1990). Hannan and colleagues (1993), for example, reported significantly elevated rates of symptomless osteophytes of the knees among physically active men. Moreover, possible mild OA is diagnosed more sensitively in athletes due to their loading history. Small osteophytes and other mild osteoarthritic changes were ignored to minimise the risk of false positive radiographic findings of hip and knee OA. However, many cases of radiographic OA are symptomless. Radiographic methods are insensitive in detecting early cartilage loss (Brandt et al. 1991). To study the validity of the X-ray grading of OA in the present sample, other radiographic and functional methods were used independent of the grading. The subjects classified as having knee OA more commonly had pain symptoms, functional limitations, joint space narrowing, and angular deformities than did the rest of the subjects.

Hip OA

There were no statistically significant differences in hip OA between the sport groups in the clinical study sample (II). Moreover, the age-adjusted ORs of physician-diagnosed hip OA among athletes and controls were similar in the questionnaire study cohort (V).

In the questionnaire study cohort the OA diagnosis (hip or knee OA) (V) was made using the question: "Has your physician told you that you have OA disease. If so, were you a) under 45 years of age or b) over 45 years of age". Haapanen and co-workers (1997) reported that the agreement between questionnaire data and medical records of hip and knee OA disease was moderate (Kappa value 0.48). They also suggested, that diseases with non-established diagnostic criteria and a fluctuating course may reduce the amount of agreement. Subjects may misunderstand the reported diagnosis, they may forget it, or may be unwilling to report it. Therefore, aside from physician-diagnosed hip or knee OA, hip or knee pain and disability were also recorded.

Marti and co-workers (1989) concluded in their retrospective study of a cohort of elite athletes and controls that long-term, high intensity, high mileage running should not be dismissed as a potential risk factor for premature hip OA. However, in their study the control subjects (mean age 35 years) were younger than the athletes (mean age 42 years). Vingård and co-workers (1993) also found a similar association between sports and severe hip OA. In contrast, in the present studies no association between athletic activity and hip OA was found.

Since traumatic damage to the ligaments and cartilage of the hip may be rare, Felson (1988) concluded that the role of trauma as a risk factor for hip OA would be small. Heliövaara and co-workers (1993b) found, in their study of a population sample, an association between reported previous lower-limb trauma (yes/no) and unilateral hip OA. Moreover, an association between severe lower-limb trauma and hip OA has been found (Typpö 1985). An increased risk for hip OA has been reported among soccer players (Klünder et al. 1980, Lindberg et al. 1993). Lower-limb injuries were common among soccer players in the present studies, but no association between soccer playing and hip OA was found. The limited number of cases of severe lower-limb trauma, such as fracture, did not have sufficient statistical power to allow investigation of the possible association between severe trauma and hip OA.

In the clinical study sample (II) 94 subjects participated in the MRI examination. As only seventeen percent of these subjects had hip OA further analysis of the association between physical loading and hip OA was not statistically possible. Overall, these results agree with the view hold earlier (Puranen et al. 1975, Panush et al. 1986, Konradsen et al. 1990) that sport-related long-term loading is not a strong risk factor for hip OA.

Knee OA

In the clinical study sample soccer players and weight lifters had higher prevalences of knee OA than did shooters (I). Compared to controls, team sport, power sport, and all athletes combined had higher age-adjusted odds for physician-diagnosed knee OA before the age of 45 (V) and team sport athletes higher age-adjusted prevalence of knee OA before or after the age of 45 years (V).

Because people tend to forget mild injuries only injuries that had led to hospital treatments were included (I). Injuries that had occurred after the age of 40 were excluded from the study, because some originally degenerative changes may be misclassified as originating from injury (I). This age limit also was considered necessary because it usually takes several years after injury for osteoarthritic changes to appear (Jackson, 1968).

Kujala and co-workers (1994a) concluded, that mixed-sport and power-sport athletes needed more hospital care than their controls because of premature OA of the hip, knee or ankle. The same cohort was analysed in study V later, and the team sport and power sport athletes had higher age-adjusted odds for knee OA before the age of 45 than their controls. Soccer is characterised by sprinting, stopping, cutting and pivoting situations, and can easily lead to knee injuries (Ekstrand & Nigg 1989) and previous knee injuries are risk factors for knee OA (Solonen 1966, Kannus & Järvinen 1987). The number of previous meniscal and ligamentous knee injuries was high in soccer players (I,V), suggesting that injuries play a role in the etiology of knee OA. One limitation of study V is the diagnosis of OA. In using physician-diagnosed OA without radiographic confirmation, it is possible that some subjects with knee injury and knee pain were falsely classified as having OA on the basis of clinical pain.

Heavy weight training and high BMI among power sport athletes may predispose them to knee OA. In study I high BMI at the age of 20 explained a part of the increased knee OA risk among weight lifters, and power sport athletes had higher odds of knee OA before the age of 45 than their controls (V). It also seems evident that heavy weight training associated with a high body mass causes excessive loading of the patellofemoral joints during lifting, and weight lifters with high BMI commonly had OA, particularly in the patellofemoral joints. Because of the limited number of subjects (I) the analyses could not comprehensively differentiate the effects of weightlifting and high BMI as predictors of knee OA. In the multivariate models years spent in heavy work and work involving kneeling and squatting were also associated with patellofemoral OA.

No evidence was found that long-distance running and cross-country skiing in study V and long-distance running in study I would lead to premature knee OA in these male athletes, who usually had low BMI and had started their engagement in sport at a young age. Moreover, lifetime hours of participation in endurance sports did not explain the osteoarthritic findings. These results agree with the earlier view, that runners seem to have little risk of knee OA (Sohn & Micheli 1985, Lane et al. 1986, 1993, 1998, Panush et al. 1986, 1995).

Low BMI in runners may explain why they seldom had OA at the age studied (Kujala et al. 1994a). The high levels of activity and high life expectancy of endurance athletes may lead to an increased need for hospitalisation because of OA in very old age (Kujala et al. 1994a). Most of the athletes had trained ever since they were young. Joint cartilage adapts to progressive loading, but rapidly increasing amounts of physical loading in previously sedentary adults or after an period of immobilisation may cause cartilage breakdown. Also, animal experiments show conflicting results as to whether running can induce OA (Arokoski et al. 1993, Videman et al. 1979). Further, due to differences in the knee biomechanics between humans and all animals, it is not possible to generalise widely from animal experiments.

Stepwise logistic regression analysis showed that high body mass and previous injuries were strong predictors of future knee OA. These findings confirm earlier reports (Davis et al. 1989, Anderson & Felson 1988, Kellgren & Lawrence 1952). Knee injuries seem to be etiologically related to knee OA, particularly in soccer players.

6.2 Physical activity and the ROM of the hip

There were no differences in the passive hip joint ROM between the four groups of athletes with divergent long-term patterns of loading (II). In accordance with previous studies (Bergström et al. 1985, Ekstrand et al. 1982) no difference was found in the ROM between the right and left hip on average, although some subjects with severe unilateral hip OA showed clear right-left differences. Lifetime physical activity or years spent in heavy work were not associated with hip rotation.

A low range of passive hip adduction and internal rotation among female classical ballet dancers has been reported (Reid et al. 1987). This unbalanced flexibility was attributed to warm-up exercises and dancing activities and the inbalance was worse among older and more experienced dancers. Sarna and colleagues (1993) found that more than 60% of male former elite athletes had been engaged in leisure-time physical activity or competitive sports throughout their entire adult life. However, the hip extension, flexion and rotation ROM among the athletes were similar. Burton and co-workers (1996) investigated the factors associated with lumbar flexibility among male identical twins. They found no relationship between working in flexed or extended position, or sports participation during previous year and lumbar flexibility; it is possible that lumbar flexibility is explained in part by inherent mechanical properties. Moreover, Panush and co-workers (1986) found no differences in ROM of the hip between male runners (mean age 56 years) and controls (mean age 60 years). Overall, the results seem to agree with the earlier view that ROM is determined by a more or less stable anthropometric trait (Van Mechelen et al. 1992).

While the distributions of the variables of lifetime hours spend in different types of training (Table 1) used in the regression analysis were somewhat skewed, these variables were also distributed in quartiles and the analysis was re-run. The main result of the analysis remained similar. High BMI was associated with low hip rotation among all who had undergone MR imaging, and in the subgroup without hip OA, pain or disability. There was an association between high BMI and weightlifting. Heavy weight training strengthens muscles and ligaments and may lead to restricted motion of hip joints. Nevertheless, the hip rotation values of the weight lifters proved similar to those in the other athlete groups; hence the association between hip rotation ROM and BMI remains unclear.

The right-left difference in rotation between subjects with and subjects without MRI-diagnosed hip OA was small. Similarly Croft and co-workers (1996) found no right-left differences in the ROM of the hips among patients with unilateral symptomatic hip OA. However, only six patients participated in their study. MRI is a modern method for detecting hip OA. Yet, the possibility remains that even this method may have missclassified mild hip OA, and consequently failed to show a true association between hip OA and ROM. Reported hip pain and disability seem to have an even more harmful effect on hip rotation than radiographic OA. In the multiple linear regression analysis hip pain was associated with restricted hip rotation. Hughes and colleagues (1994) reported that symptomatic arthritis predicts future disability. Therefore, the effective treatment of hip pain and restricted ROM is important in preventing disability.

6.3 Physical activity and knee laxity and instability

Former shooters and weight lifters had higher sagittal knee laxity than soccer players and runners (III). Besides athlete group, hamstring tightness and hyperextension of the knee proved explanatory for the variation in knee laxity. The only factor that was found to explain the right-left difference was previous knee injury, although most of the variability remained unexplained. Previous meniscal and ligamentous knee injuries as well as medio-lateral instability were common among soccer players (I).

An increase in antero-posterior (Skinner et al. 1986) and medio-lateral (Weisman et al. 1980) knee laxity during exercise among healthy volunteers has been reported. Laxity returns to normal within an hour after cessation of the activity (Stoller et al. 1983). The present study found no evidence that long-term participation in soccer with sprinting, kicking and stopping increase sagittal knee laxity. In only three soccer players was the right-left difference in laxity more than 4 mm; in all the other soccer players the difference was 2 mm or less. One explanation is that exercise strengthens ligaments, a finding which has been reported among dogs (Tipton et al. 1970). However, medio-lateral instabilities were common among soccer players. Because medio-lateral knee stability was measured manually, it was not possible to investigate the association between different knee loading patterns and medio-lateral knee laxity. The possibility that soccer playing would increase medio-lateral laxity remains unclear.

Previous meniscal and ligamentous knee injuries lead to instability, so that subjects with previous trauma and post-traumatic injury are at increased risk for future OA (Kannus & Järvinen 1987). In the study by Brage and co-workers (1994) subjects with severe knee OA had less sagittal knee laxity than subjects with normal knees. They also suggested that among subjects with mild knee OA laxity may be increased and this "pseudolaxity" may be due to loss of cartilage. In the present study, athletes with knee OA had more medio-lateral instability than those without such finding, but in the regression analysis tibiofemoral OA did not associate with sagittal knee laxity. Because of the limited number of osteoarthritic subjects, it was not possible to compare laxity in different grades of knee OA.

The results agree with earlier observations in that physical activities involving kneeling may increase knee laxity. Exercise has been reported to acutely increase knee joint laxity and a more sustained increase in sagittal knee laxity has been reported among miners (Sharrard 1964). The high mean laxity value among weight lifters may be explained by training which includes deep squats. Moreover, none of the weight lifters had medio-lateral instability. Anterior knee laxity was highest in shooters and lowest in soccer players. In the absence of adequate age-specific reference values it is impossible to say whether it is the laxity level of shooters and weight lifters or that of runners and soccer players that represents knee laxity in the general population of corresponding age.

In studying the association between different factors and laxity among the clinical study group, hyperextension of the knee explained some of laxity in the regression analysis. Subjects with more hyperextension of the knee had greater knee laxity than those with less hyperextension of the knee. One explanation is that beside anterior tibial displacement, ACL also controls the hyperextension of the knee. Therefore the regression analysis was re-run without the variable hyperextension of the knee. Overall, the explanation rate of this variable was small. Moreover, weight lifters had a higher mean anterior laxity value than soccer players and long-distance runners, but on average they also had a knee extension deficiency. However, knee laxity was associated with hyperextension, but a similar association was not observed in the case of general hypermobility.

Only few athletes were classified as hypermobile at the age studied and, possibly owing to the low number of hypermobile subjects, the analysis failed to show the true association between general hypermobility and knee laxity.

Increased knee laxity was associated with increased hamstring tightness. This was an unexpected finding. One explanation could be that subjects who have increased knee laxity have hamstring tightness provoked by knee pain.

6.4 Physical activity and lower-limb muscle strength

No differences appeared in jumping-height by sport group, but those male former elite athletes without lower-limb OA had better vertical jumping-height results than their counterparts with lower-limb OA. In the subgroup without OA, weight lifters had the highest and shooters the lowest vertical jump results. However, even shooters were more physically active than the general population and jumped higher than healthy sedentary male subjects in a population sample (Kujala et al. 1994c). In the multiple linear regression analysis, participation in team sports during the past 12 months and lifetime participation in power sports were associated with a good vertical jump result, and age, reported hip or knee disability, and knee pain decreased vertical jumping-height.

Because the distributions of some of the variables (Table 1) were somewhat skewed, the regression analyses were also run using quartiles or dichotomious scales among those variables. The main results remained similar. However, in analysing the associations between jumping-height and different variables among all subjects, instead of participation in team sports during past 12 months and lifetime participation in power sports, lifetime participation in team sports was associated with vertical jumping-height. One explanation is that in multiple regression analysis non-linear variables are unstable.

The present findings agree with earlier observations that muscle strength decreases with age (Overrend et al. 1992, Lindle et al. 1997, Porter et al. 1994). Lexell and colleagues (1988) reported that loss of fibres and a reduction in the size of fibres reduces the vastus lateralis muscle area with increasing age, with approximately 10% of the muscle area lost by the age of 50. Muscle morphology was not imaged in the present study. Among those with no hip or knee OA, the mean decrease in vertical jump was about 12% per decade in this study. In any case, a cross-sectional study design gives only limited information about the effect of ageing on muscle strength.

It is possible that the good vertical jump, especially among the weight lifters is due to an 'a priori' selection or to their training-type. Among subjects without hip and knee OA, weightlifting was associated with jumping height, and participation in team sports during the past 12 months was a sport-related determinant of vertical jump performance. In an earlier study, Sarna and colleagues (1993) found that more than 60% of the male former elite athletes used in this study had been engaged in leisure-time physical activity or competitive sports throughout their entire adult life compared to 17% among the age- and sex-matched control population. The role played by different training and leisure-time physical activities in muscle strength has been reported. Male veteran sprinters and jumpers (aged 70-81 years) were able to jump higher than strength-trained or endurance-trained athletes and controls (Sipilä et al. 1991). Era and colleagues (1992) studied isometric muscle strength in men (31 to 35, 51 to 55 and 71 to 75 years); among the two younger groups good self-rated health and intensity of leisure-time physical exercise was associated with isometric muscle strength. In the oldest group, the most important variable was home gymnastics. Among a Finnish urban population sample as well, everyday physical activity was related to vertical jumping-height (Kujala et al. 1994c). It seems that the effect of present physical activity and type of training are important to explosive strength also in old age.

Hip and knee OA and pain may reduce physical activity and thus reduce muscle function. Radiographic-diagnosed hip or knee OA had harmful effect on the vertical jump, but in the multiple linear regression analysis, reported hip or knee disability and knee pain were associated with jumping-height. One explanation is, that subjects with painful joints produced only a sub-optimal effort in strength measurement. Nevertheless, the study participants were elite athletes and well motivated. Moreover, McAlindon and co-workers (1993) reported that quadriceps strength, knee pain and age were more important determinants of functional impairment among elderly subjects than the severity of radiographic knee OA. After adjusting the jumping-height results of the runners, soccer players and weight lifters to age 55 and comparing these athletes to a population sample of healthy 55-year-old men (Kujala et al. 1994c), it was found that even the athletes with hip or knee OA were able to jump higher than the healthy sedentary men (mean 23.9 cm vs. 19.4 cm) and as high as the healthy active men (mean 23.9 cm vs. 24.5 cm). Because the present study used a squat jump from a static position, compared to the counter-movement jump previously used by Kujala and colleagues (1994c), the difference in favour of the athletes is even higher, since counter-movement jump produces a higher jump than the squat jump (Bobbert et al. 1996). The vertical jump measures concentric explosive strength, and its performance assumes good lower-limb function. It thus seems that, despite hip or knee OA, the athletes have good lower-limb muscle function.

6.5 Disability

Several methods have been published to assess the severity of hip and knee disease. Andersson (1972) compared nine different methods concerning hip-related disability and found contradictory results. Lequesne (1997) concluded that an advantage of their indices of severity for OA of the hip and knee (Lequesne et al. 1987) is that the indices are structured separately for hip and knee OA. In the present studies hip and knee disability was measured separately using the same questions related to hip and knee functions. Subjects scoring at least three points out of seven for either the hip or knee disability questions were classified as having hip or knee disability, respectively. Various cut-off points from one to seven and disability as a continuous variable were used to classify a subject had hip or knee disability, but the results of these calculations were similar. The cut-off point used was also selected to avoid the misclassification of mild cases as disabled. On the other hand, the distribution of the disability variable was skewed, and therefore the limited number of subjects with a disability score of more than three out of seven points did not permit further calculations. Moreover, the hip and knee disability score was associated with radiographic knee OA in study I, with hip rotation in study II and with jumping height in study IV.

Strenuous occupational loading predisposes to lower-limb OA. Therefore the years the subjects had spent in various work-related physical loading were calculated. Only 6.5% of the executives compared to 68.9% of the unskilled workers had spent at least 10 years in heavy work (V). Because the occurrence of OA-related disability may effect the ability to continue doing heavy work, and since an association between work-related loading and occupational group was found, occupational group was used as a covariate in analysing the association between sport and hip and knee disability.

Because age, BMI and occupational group were associated with hip and knee disability in study V, those variables were used as covariates in analysing the risk of hip and knee disability among former elite athletes.

Physical activity and hip disability

The prevalences of hip disability among the four athlete groups were similar (II), and compared to controls, the athletes did not report more hip disability (V). Compared to controls, the covariate-adjusted ORs of hip disability were lower among the endurance, track and field and all athletes combined (V).

A relationship between running and radiographic hip OA has been reported (Marti et al. 1989), but former athletes' joints may show radiographic osteoarthritic changes without loss of function (Alexander 1990). Konradsen and co-workers (1990) found that among male orienteers 22 % of the subjects reported pain in the hip joints associated with running, although there was no difference in radiographic joint degeneration between athletes who had joint pain and those who had not. The ORs of hip pain and disability were low among endurance athletes in the questionnaire study cohort. Low development of disability in an eight-year prospective longitudinal study among older runners who have been engaged in running and other aerobic activities has been reported. This association is probably due to increased aerobic capacity, strength, fitness, and increased organ reserve rather than to the effects of postponed OA development (Fries et al. 1994). Also, a lower BMI in endurance athletes may prevent them from getting hip problems, especially in walking and going up or down stairs. Lysholm and Wiklander (1987) reported hip problems among active long-distance runners, but the present studies show, that in the old age this does not mean more years with hip pain and disability.

Hip OA is usually classified radiographically, and the symptoms are related to the findings (Lawrence et al. 1966). In the Mini-Finland Health Survey, hip OA proved to be a prevalent and strong determinant of disability (Mäkelä et al. 1993). Athletes with MRI-diagnosed hip OA tend to report monthly hip pain and disability more commonly than those without this finding (II). However, some subjects with radiological diagnosis of hip OA are asymptotic. In the present study (II) 75% of the athletes with radiographic hip OA reported no hip pain, reported disability was rare and, also, their lower-limb muscle strength was good

(IV). The limited number of MRI-diagnosed osteoarthritic subjects did not permit analysis of the association between subjects with different grades of hip OA and disability.

Videman and co-workers (1995) investigated the same cohort for spinal findings and function. In the whole cohort, the ORs for back pain were lower among athletes than among controls, and there was no statistically significant difference in the ORs for back-related hospitalisations among athletes and control subjects. In the same subgroup (the clinical study sample), weight lifters and soccer players had greater MRI-diagnosed lumbar spine degeneration than long-distance runners and shooters. Videman and colleagues found, that former elite athletes, even with increased degenerative spinal findings, reported a lower incidence of back pain than controls. These results on back problems are in accordance with the present findings on hips and knees.

Overall, the low number of hip disability among all the athletes (V) suggests that lifetime physical activity helps in maintaining good hip joint function.

Physical activity and knee disability

Among the clinical study sample in study I soccer players and weight lifters reported more knee disability than shooters. Moreover, in the questionnaire study cohort, team sport athletes had slightly higher odds for knee disability than controls (V).

Knee injuries were rare among the endurance athletes, and injury was not a significant confounder, when the association between repetitive loading and knee joint findings and function among endurance athletes was studied. Moreover, the ORs of knee disability and pain among endurance athletes and controls were similar (V). There is some evidence to support the hypothesis that running even in old age maintains lower-limb function (Fries et al. 1994, Kujala et al. 1999). Overall, these studies found no evidence that long-term repetitive loading with low injury risk had harmful effects on knee joint function.

Knee injuries were common among the team sport athletes. Nevertheless, participation in mixed training has a favourable effect on lower-limb muscle function (Kujala et al. 1994c) and team sport training was associated with jumping height (IV). McAlindon and co-workers concluded (1993) that quadriceps strength is a more important determinant of functional impairment in elderly subjects than the severity of knee OA as assessed radiographically. However, knee injuries seem to be etiologically related to knee OA, and team sport athletes also reported knee disability. Some cases of knee OA with pain and disability might be prevented with preservative treatment of meniscal injuries and reconstructive treatment of knee ligament instabilities (Johnson et al. 1984, DeHaven 1985), and, possibly, by effective exercise programmes. Such modern treatment methods were not available at the time when the subjects studied were injured.

Heavy weight training and high BMI among power sport athletes may predispose them to knee OA, and high BMI was also a risk factor for knee disability. In study I high BMI at the age of 20 explained a part of the increased knee OA risk among former elite weight lifters, and as a group, the power sport athletes had high age-adjusted odds for knee OA before age 45 (V). Thus, the low risk of knee disability, and also of hip disability, among the weight lifters was an unexpected finding. Possibly lower-limb joint loading in the physiological flexion-extension direction is less harmful to joint function than other types of knee loading such as in team-games, throwing and wrestling. Moreover, good muscle strength (IV) may protect weight lifters against knee disability. The tendency to increased risk of hip and knee disability among javelin throwers and wrestlers may be explained by non-physiological rotational or medio-lateral forces and by injuries among these athletes.

A relationship between long-term vigorous physical activity and radiographic lower-limb OA has been reported, but little is known about the effects of life-long physical activity on disability. Low aerobic work capacity and lower-limb muscle weakness are associated with disability, and an aerobic or resistance exercise programme has been recommended to reduce self-reported disability and pain among subjects with knee OA (Ettinger et al. 1997). Ettinger and colleagues also found, that moderate exercise did not worsen the disease and that of possible greater importance, than the type of training is the long-term compliance of exercise. Ries and colleagues (1995) also found, that inactivity secondary to severe arthritis symptoms may worsen cardiovascular fitness. The results, therefore, are consistent with the recommendation that leisure physical activity, especially long-term aerobic training with low injury-risk, has favourable effects on mobility and health.

7 MAIN FINDINGS AND CONCLUSION

* The prevalences of physician-diagnosed hip OA among former elite male athletes and controls were similar. On the other hand, former team sport athletes reported a higher prevalence of physician-diagnosed knee OA than their controls. Moreover, compared to shooters, soccer players and weight lifters were at increased risk of developing radiographic premature knee OA.

* In soccer players, the increased risk of OA seems to be largely due to previous joint injuries. In weight lifters it was not possible to separate the effects of loading and high body mass. In repetitive nontraumatic loading, such as running, the risk of premature OA of the tibiofemoral joints seems to be low.

* Long-term loading did not associate with passive hip rotation. Subjects with high BMI had lower hip rotation value than those with low BMI. A clear right-left difference in hip rotation appears to be confined only to subjects with severe hip OA.

* Knee injuries, hyperextension of the knee and physical activities involving squatting and kneeling seem to increase knee laxity. Nevertheless, our understanding of the factors responsible for the inter-individual variation in knee laxity remains limited.

* Lifetime power-training and time spent in training for team sports during the previous 12 months were associated with good vertical jumping-height; however, age, reported hip or knee disability and knee pain decreased the jumping-height. The good jumping-height result also found among athletes with hip or knee OA suggests that despite lower-limb OA, former elite athletes have good lower-limb muscle function.

* Compared to controls, the endurance, track and field and all athletes combined reported less hip disability. Soccer players and weight lifters reported slightly more knee disability than shooters. Moreover, in the questionnaire study cohort, team sport athletes were at slightly increased risk of knee disability when compared to controls.

In conclusion, the role of leisure-time physical activity as a risk factor for lower-limb OA has been reported, but the former elite male endurance and track and field athletes and all athletes combined in the present study reported less hip disability than their controls. The role of vigorous sport-related activity in the function of knee joints is more controversial, because sports involve risk of knee injuries and such injuries may predict disability. Therefore, especially long-term aerobic activities, which have many health benefits and a low injury-risk can be recommended to maintain health and a disability-free life in old age. However, the beneficial and harmful consequences of ball games, need to be re-evaluated.

8 YHTEENVETO

Tutkimuksen tarkoituksena oli selvittää pitkäaikaisen liikunnan vaikutuksia alaraajatoimintoihin, -oireisiin ja -löydöksiin entisillä huippu-urheilijamiehillä. Alkuperäinen tutkimuskohortti muodostettiin huippu-urheilijoista, jotka olivat edustaneet Suomea vuosina 1920-1965, sekä heidän verrokeistaan. Verrokit valittiin terveiksi (palveluskelpoisuusluokka A1 tai vastaava) luokitelluista miehistä samoista armeijan palvelukseenastumiseristä kuin urheilijat. Ensimmäinen kyselytutkimus (N=2528) postitettiin vuonna 1985 kaikille elossa olleille entisille huippu-urheilijoille ja heidän verrokeilleen. Urheilijoista kyselyyn vastasi 84% (1282/1518) ja verrokeista 77% (777/1010). Tuon kyselyn yhtenä tarkoituksena oli kerätä perustietoja tulevia tutkimuksia varten. Vuoden 1985 kyselyyn vastanneista urheilijoista, jotka olivat iältään 45-68 vuotiaita, oli elossa vuonna 1992 38 kestävyysjuoksijaa, 89 jalkapalloilijaa, 40 painonnostajaa ja 35 ampujaa. Kaikki kestävyysjuoksijat ja ampujat, sekä iän ja sosiaaliluokan mukaan valittu otos jalkapalloilijoista (N=37) ja painonnostajista (N=37) kutsuttiin yhden päivän kestäneeseen tutkimukseen (yhteensä 147 urheilijaa). Kutsutuista urheilijoista 117 (80%) osallistui Kansaneläkelaitoksen tutkimus- ja kehittämisyksikössä Turussa toteutettuun tutkimukseen ja nämä urheilijat muodostivat "kliinisesti tutkitut" –ryhmän. Aluksi lääkäri haastatteli urheilijat. Strukturoidulla haastattelulla kartoitettiin urheilijan elämänhistoriaa 12 ikävuodesta lähtien. Haastattelu sisälsi kysymyksiä urheilu- ja vapaa-ajan liikuntakuormituksesta, liikuntavammoista ja työkuormituksesta. Lonkka- ja polvinivelkivut selvitettiin tutkimusta edeltäneeltä ajalta, ja lisäksi tutkittavat arvioivat itse lonkka- tai polvinivelistä aiheutuvaa haittaa päivittäisissä toiminnoissaan. Kliinisen tutkimuksen teki fysioterapeutti. Tutkittavilta mitattiin pituus, paino, lonkka- ja polvinivelten liikkuvuudet ja alaraajojen voimantuotto. Polvinivelten sivusuuntainen stabiilius arvioitiin manuaalisesti ja anteriorinen laksiteetti laksiteettimittarilla. Lisäksi tutkittavat osallistuivat lonkan MRI- ja polven röntgen-tutkimukseen.

Vuonna 1995 kaikille (N=2135) elossa olleille urheilijoille ja heidän verrokeilleen lähettiin toinen postikysely. Kyselyyn vastasi 75% (991/1321) urheilijoista ja 70.1% (577/814) verrokeista ja heidät nimettiin "kyselyyn vastanneet" -ryhmäksi. Taustatietojen keruun lisäksi tutkimuksella selvitettiin lääkärin toteama polven tai lonkan nivelrikko ennen tai jälkeen 45 ikävuoden. Tietoa kerättiin myös lääkärin toteamista polven nivelside- ja nivelkierukkavammoista, sekä erikseen tiedusteltiin sairaalahoitoa vaatineet polvivammat. Lisäksi tutkittavat arvioivat lonkka- ja polviniveltensä tilaa samalla menetelmällä kuin vuoden 1992 kliinisessä tutkimuksessa.

Verrattuna ampujiin pitkäaikainen fyysinen aktiivisuus ei lisännyt MRI-diagnostisoitua lonkan nivelrikkoriskiä entisillä huippu-urheilijamiehillä kliinisesti tutkitut -ryhmässä (I). Myöskään kyselyyn vastanneilla urheilijoilla ja verrokeilla ei havaittu eroja lääkärin toteamassa lonkan nivelrikon esiintyvyydessä (V). Jalkapalloilijoilla ja painonnostajilla havaittiin ampujiin verrattuna kohonnut polven nivelrikkoriski (I). Samansuuntainen tulos saatiin kyselyyn vastanneilla; tässä ryhmässä joukkueurheilijoilla oli verrokkeja enemmän polven nivelrikkoa (V). Polven kohonnut nivelrikkoriski oli voimakkaasti yhteydessä polvivammoihin erityisesti jalkapalloilijoilla (I). Painonnostajien polven nivelrikkoriski liittyi sekä kuormitukseen että suureen kehon massaan, eikä näiden kahden nivelrikkoa selittävien tekijöiden osuuksia voitu erottaa toisistaan (I). Pitkäaikaisen fyysisen aktiivisuuden ei havaittu muuttavan lonkkanivelen liikkuvuutta (II). Liikuntakuormitus oli kuitenkin yhteydessä polven laksiteettiin. Ainoa tekijä, joka selitti yksilön oikean ja vasemman polven välistä laksiteettierotusta, oli aiempi polvivamma. Ikä-vakioidussa hyppykorkeustuloksessa ei ollut eroja urheilijaryhmien välillä kaikilla hyppytestiin osallistuneilla (IV). Mutta niistä urheilijoista, joilla ei ollut lonkan eikä polven nivelrikkoa, korkeimmalle hyppäsivät painonnostajat ja matalin keskimääräinen hyppytulos mitattiin ampujilla (IV). Entisten huippu-urheilijoiden hyppytulosta verrattiin myös terveillä suomalaismiehillä tehdyn tutkimuksen tuloksiin. Jopa niiden huippu-urheilijoiden, joilla oli lonkan tai polven nivelrikko, hyppytulos oli yhtä hyvä kuin väestöotoksen terveiden miesten tulos. Kestävyysurheilijat, muut yleisurheilijat ja kaikki urheilijat joukkona ilmoittivat verrokkeja vähemmän lonkkanivelistä johtuvaa haittaa päivittäisissä toiminnoissaan (V). Sitä vastoin kliinisesti tutkitut –ryhmässä polvinivelestä johtuvaa haittaa oli eniten jalkapalloilijoilla ja painonnostajilla ja kyselyyn vastanneiden ryhmässä joukkueurheilijat ilmoittivat verrokkeja enemmän polvesta johtuvaa haittaa. Samoin ne urheilijat, joilla oli lääkärin toteama polven nivelside- tai kierukkavamma, ilmoittivat enemmän polvesta johtuvaa haittaa kuin ne urheilijat, joilla ei ollut raportoituja polvivammoja.

Yhteenvetona voidaan todeta, että pitkäaikainen liikunta-aktiivisuus ei ollut yhteydessä lonkan nivelrikkoon entisillä huippu-urheilijamiehillä. Lisäksi entiset kestävyysurheilijat, muut yleisurheilijat ja kaikki urheilijat joukkona ilmoittivat verrokkeja vähemmän lonkkanivelestä johtuvaa haittaa. Sitä vastoin huippu-urheiluun liittyvä polvivammariski, erityisesti joukkuelajeissa, ilmeni kohonneena polven nivelrikkoriskinä ja koettuna haittana. Aiemmissa tutkimuksissa on pitkäaikaisella liikunta-aktiivisuudella todettu olevan suotuisia terveysvaikutuksia. Tämän tutkimuksen tulosten perusteella, erityisesti aerobista liikuntaa, jossa vammariski on pieni, voidaan suositella ylläpitämään hyvää terveyttä ja toimintakykyä.

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I

Knee osteoarthritis in former runners, soccer players, weight lifters, and shoters

by

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KNEE OSTEOARTHRITIS IN FORMER RUNNERS, SOCCER PLAYERS, WEIGHT LIFTERS, AND SHOOTERS

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Objective. **To determine the relationship between different physical loading conditions and findings of knee osteoarthritis (OA).**

Methods. **We selected 117 male former top-level athletes (age range 45–68 years) who had participated in sports activities with distinctly different loading conditions: 28 had been long-distance runners, 31 soccer players, 29 weight lifters, and 29 shooters. Histories of lifetime occupational and athletic knee loading, knee injuries, and knee symptoms were obtained, and subjects were examined clinically and radiographically for knee findings of OA.**

Results. **The prevalence of tibiofemoral or patellofemoral OA based on radiographic examination was 3% in shooters, 29% in soccer players, 31% in weight lifters, and 14% in runners ($P = 0.016$ between groups). Soccer players had the highest prevalence of tibiofemoral OA (26%), and weight lifters had the highest prevalence of patellofemoral OA (28%). Subjects with radiographically documented knee OA had more symptoms, clinical findings, and functional limitations than did subjects without knee OA. By stepwise logistic regression analysis, the risk for having knee OA was increased in subjects with previous knee injuries (odds ratio [OR] 4.73), high body mass index at the age of 20 (OR 1.76/unit of increasing body mass index), previous participation in heavy work (OR 1.08/work-year), kneeling or squatting work (OR 1.10/work-year), and in subjects participating in soccer (OR 5.21).**

Conclusion. **Soccer players and weight lifters are at increased risk of developing premature knee OA. The increased risk is explained in part by knee injuries in soccer players and by high body mass in weight lifters.**

Suspected risk factors for knee osteoarthritis (OA) include female sex (1), genetic predisposition (2,3), obesity (1,4), previous injury (1,5), and various physical loading conditions (4,6–9). Some types of work-related loading, such as handling of heavy materials and work involving kneeling, have been associated with an increased incidence of knee OA (4,6,7). The long-term effects of exercise-related physical loading on the knee joint are relevant in sports medicine in particular, but the relationship between loading patterns and the pathogenesis of OA is also of substantial general interest. The type, intensity, and frequency of participation in sports may influence the risk for development of knee OA (8,9). The incidence of meniscal and ligamentous injuries to the knees is notoriously high in soccer players (8,10). Both types of injuries predispose to knee OA (8,11–13). The risk for premature knee OA in athletes participating in power sports, such as weight lifting and wrestling, also may be increased (9), whereas runners seem to have little risk (9,14,15). Nevertheless, the role of various types of physical loading in the development of knee OA is still incompletely understood.

The present study was undertaken to investigate the long-term effects of participation during adolescence and adulthood in different types of sports with clearly different physical loading patterns, and the relationships to findings of knee osteoarthritis in later adulthood. We selected former top-level athletes in sports for which the different long-term loading patterns can be clearly determined and distinguished.

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Table 1. Lifetime regular participation-years in different types of athletic training (endurance, team, power) at least once a week, and the sum of training hours during these training periods, in the 4 athlete groups*

	Long-distance runners (n = 28)	Soccer players (n = 31)	Weight lifters (n = 29)	Shooters (n = 29)
Endurance training				
Years, mean ± SD	31.7 ± 16.6	17.1 ± 12.7	15.8 ± 17.3	20.6 ± 13.7
(range)	(4.6–68.8)	(0.0–41.0)	(0.0–69.0)	(0.0–46.3)
Hours, mean ± SD	9,408 ± 4,213	2,607 ± 2,850	2,269 ± 2,462	2,845 ± 2,219
(range)	(1,300–18,752)	(0–9,936)	(0–8,483)	(0–8,536)
Team sport training				
Years, mean ± SD	3.8 ± 9.4	37.0 ± 18.2	9.8 ± 16.0	5.3 ± 8.1
(range)	(0.0–36.5)	(15.0–78.9)	(0.0–80.0)	(0.0–30.0)
Hours, mean ± SD	356 ± 731	9,043 ± 3,961	1,147 ± 1,435	807 ± 1,421
(range)	(0–3,072)	(3,864–18,514)	(0–4,888)	(0–5,500)
Power training				
Years, mean ± SD	0.8 ± 2.1	2.1 ± 3.6	21.5 ± 11.2	0.9 ± 2.1
(range)	(0.0–7.5)	(0.0–12.8)	(3.0–44.0)	(0.0–8.3)
Hours, mean ± SD	84 ± 263	295 ± 500	8,118 ± 4,651	89 ± 236
(range)	(0–1,280)	(0–1,600)	(284–16,752)	(0–1,092)

* Participation-years are summed to account for the possibility of a subject's participating regularly in more than one event during the same period.

They included long-distance runners (long-term repetitive loading), soccer players (high risk for impact loads and sprains), and weight lifters (high peak loads). Former top-level shooters were also studied. This latter sport involves varying, light-to-moderate general physical exercise without any clear harmful exposures except some short-term static postural loading; however, in terms of life-style and social status, elite shooters are similar to other top-level athletes (16).

SUBJECTS AND METHODS

Subjects. We identified male athletes who, between the years 1920 and 1965, represented Finland at least once in the Olympic games, in world or European championships, or in intercountry competitions (athletic contests between 2 or 3 countries) (16). Vital statistics were available from Finland's Central Population Registry. In 1985 we mailed a questionnaire to the surviving former athletes (response rate 84%), eliciting information on height and weight at the age of 20, weight in 1985, occupation, physical activity, and discontinuation of sporting career. On the basis of the questionnaire responses, we calculated body mass index (BMI; kg/m^2) at the age of 20.

The responders to the 1985 questionnaire included 38 long-distance runners, 89 soccer players, 40 weight lifters, and 35 shooters who were alive in 1992. They ranged in age from 45 to 68 years. All of the shooters and runners were invited to participate in the present study, as were subsamples of the soccer players (n = 37) and weight lifters (n = 37), who were selected based on age and occupational physical loading characteristics similar to those of the shooters and runners. Of the 147 subjects invited, 117 (80%) agreed to participate. Among the participants were 28 long-distance runners, 31 soccer players, 29 weight lifters, and 29 shooters (Table 1). The interview and the clinical examinations, as well as the radiologic readings, were carried out independently, and investigators were blinded to results obtained by the other methods. The study was accepted by the Ethical Committee of the Research Centre of the Social Insurance Institution (Turku, Finland).

Interview. Examinations included a 2-hour structured interview by one of the authors (HP) about lifetime history (since the age of 12 years) with special emphasis on sports, exercise, and leisure time, as well as occupational knee loading and injuries to the knee. The recall process was guided by linking the course of events to special occasions, such as schooling, marriage, and participation in Olympic games. Among the 4 groups, the mean length of regular competitive involvement in an athlete's own event (minimum training 3 times per week) ranged from 9.8 years to 14.5 years (individual range 2–36 years), with relatively little participation in other sports. We conducted a detailed interview for each different training regimen and type of training that occurred during the subject's lifetime. Questions addressed the number of years during which the participant trained at least once a week, and the frequency, intensity, and duration of training sessions (Table 1). We found the expected clear differences in the different types of lifetime athletic loading indices between different athletic groups. However, soccer players, weight lifters, and shooters, in addition to long-distance runners, commonly engaged in regular endurance exercise (Table 1).

Similarly, we analyzed each leisure time activity and the athlete's job. The job type was classified into 1 of 5 categories: 1 = mainly sitting; 2 = mainly walking or standing; 3 = a variety of tasks including some bending and twisting, but seldom lifting burdens heavier than 35 kg; 4 = a variety of tasks with bending, twisting, and daily lifting more than 35 kg; and 5 = very heavy jobs including maximal lifts in bent and twisted positions. The groups showed no differences in years worked in jobs in categories 1–3, but

Table 2. Distributions of potential confounding factors in the 4 athlete groups

Potential confounding factor	Long-distance runners (n = 28)	Soccer players (n = 31)	Weight lifters (n = 29)	Shooters (n = 29)
Age, years, in 1992, mean ± SD (range)	59.7 ± 4.7 (51–67)	56.5 ± 5.7 (45–67)	59.3 ± 5.3 (46–66)	61.0 ± 4.3 (50–68)
Body mass index, kg/m² at age 20, mean ± SD (range)	21.7 ± 2.0 (17.4–26.2)	22.9 ± 1.4 (20.7–26.1)	24.1 ± 2.1 (18.5–28.7)	22.4 ± 2.3 (18.2–28.4)
Years in heavy work, mean ± SD (range)	12.3 ± 15.4 (0.0–47.0)	1.7 ± 7.2 (0.0–40.0)	9.7 ± 12.6 (0.0–43.0)	3.2 ± 8.3 (0.0–38.0)
Years in kneeling or squatting work, mean ± SD (range)*	0.8 ± 2.9 (0.0–15)	1.5 ± 4.6 (0.0–23.0)	5.4 ± 9.3 (0.0–32.0)	0.6 ± 3.2 (0.0–17.0)

* Years in work involving kneeling or squatting more than 10 minutes per working-hour.

there were group differences in work-years in categories 4 and 5. Years spent in jobs in categories 4 or 5 were designated as years in heavy work (Table 2). Detailed interviews were conducted to determine working postures, using figures to illustrate examples of different postures. Years spent in kneeling or squatting work were included in calculations if the work involved kneeling or squatting at least 10 minutes per hour (Table 2).

An acute knee injury requiring hospital treatment before the age of 40 was considered previous knee injury. Only the first knee injury in each subject was taken into account. Injuries were recorded in 3 runners, 12 soccer players, 6 weight lifters, and 1 shooter. The reported 22 injuries included 17 meniscal and ligamentous injuries, 1 contusion, 1 fracture, and 3 undefined injuries. Fifteen of the 22 primary injuries had occurred during sports activity. Ten of the 12 injuries in soccer players had occurred during soccer, 1 during ice hockey, and 1 in non-sports activities. Of the knee injuries in soccer players, 11 were meniscal or ligamentous injuries and 1 was a fracture; all were treated surgically. Sports-related injuries can be viewed as a common aspect of soccer participation, whereas in other athletic groups, injuries in the athletes' own events were uncommon, occurring only in 1 runner and 1 weight lifter.

Occurrence of knee pain during the last year was investigated separately for each knee. Those who reported having pain in either knee at least once per month were classified as having monthly knee pain. Disability was scored for each knee on a scale of 0–7 depending on whether the subject reported pain or disability during 1) nocturnal bedrest, 2) more than 5 minutes in the morning after getting up, 3) sitting for 30 minutes, 4) full support, 5) walking more than 1 km, 6) going up or down stairs, or 7) squatting or bending forward. The sum of positive responses was calculated and subjects scoring at least 3 points for either knee were considered to have knee disability.

Clinical examination and quantitative functional measurements. A physiotherapist (JK) performed the clinical examination and quantitative measurements. First, height and weight were measured. The clinical examination included the measurement of knee extension deficiency, using a goniometer. Subjects with a deficiency of >3° (from 0° extension) for the more affected knee were classified as having knee extension deficiency. Medial knee instability and lateral knee instability were analyzed manually. Measurements of sagittal instability were obtained on both legs with a KT-1000 arthrometer (MEDmetric Corporation, San Diego, CA), according to recommended guidelines. Manual maximum was recorded in 3 consecutive successful measurements of anterior translation. The coefficient of variation between repeated measurements on the right and left knees was between 2.1% and 2.5%. The mean of the second and third trials was used for calculations. Subjects having either clear mediolateral instability or a difference of more than 4 mm between the knees in the sagittal knee instability measurement by arthrometer were classified as having knee instability, which was found in 3 runners, 8 soccer players, 2 weight lifters, and 3 shooters.

Radiographic methods. Standard anteroposterior standing (weight-bearing) knee radiographs were obtained with a focus-film-distance of 2 meters; intensifying screens were used. Lateral weight-bearing knee radiographs with a focus-film-distance of 1.2 meters were obtained separately for each knee, with the knee flexed 30° and the subject supporting his weight on the knee.

Overall osteoarthritic changes were graded from 0 to 4 for tibiofemoral and patellofemoral joints separately, according to the criteria used by Kellgren and Lawrence (17). Subjects having at least grade 2 osteoarthritic changes in the tibiofemoral joint of the more affected knee were determined to have radiographic tibiofemoral OA; radiographic patellofemoral OA was determined in a similar way. If the subject had either tibiofemoral or patellofemoral OA, he was considered to have radiographic knee OA.

Detailed evaluation of knee radiographs included analysis of osteophytes, subchondral cysts, joint space narrowing, valgus angle, and patellar height. Joint margin osteophyte formation was recorded according to the method described by Hernborg and Nilsson (18). Osteophyte size was defined as the largest perpendicular distance from the edge of the cortex to the outer margin of the osteophyte. Osteophyte formation in the tibiofemoral joints was measured at 6 sites (medial femoral condyle, medial tibial condyle, lateral femoral condyle, lateral tibial condyle, medial tibial eminence, and lateral tibial eminence) on anteroposterior radiographs, and osteophyte formation in the patellofemoral joints was measured at 2 sites (upper and lower poles of the patella). Each osteophyte was graded according to size on a scale of 0–3, where 0 = no osteophyte formation, 1 = small osteophytes (1–3 mm), 2 = moderate (4–6 mm), and 3 = large (>6 mm). Subjects having at least one grade 2 osteophyte in the more affected tibiofemoral joint were classified as having tibiofemoral osteophytes; patellofemoral osteophytes were recorded in the same way. If the subject had either tibiofemoral or patellofemoral osteophytes, he was considered to have knee osteophytes.

The subject's knee joints were examined for the presence of visible cyst formation. Narrowing of the tibiofemoral joint space was measured in millimeters, from lateral radiographs obtained with full weight-bearing on each knee separately, with the knee flexed 30°. The means of the lateral and medial joint spaces of each knee were used in statistical calculations. In anteroposterior radiographs the knee, valgus angle was measured in degrees between the long axis of the tibia and the femur, which were the lines passing the center of the diaphysis–metaphysis at 15 cm and 8 cm from the joint line. Patellar height was assessed, using the method of Insall and Salvati (19), as the ratio of the length of the patellar tendon to the length of the patella, measured from the lateral radiographs.

To evaluate the reliability (within-observer variation) of radiographic readings, we grouped radiographs by tibiofemoral OA grade and then randomly chose some from each group up to a total of 30, enriching the radiographic examples with osteoarthritic changes. The radiologist (TA) reread these films without information on previous readings (6 months had elapsed since the first reading). Generalized kappa statistics for reevaluations were 0.61 (95% confidence interval [95%CI] 0.40–0.81) for tibiofemoral OA, 0.61 (95% CI 0.40–0.82) for patellofemoral OA, 0.62 (95% CI 0.37–0.86) for osteophytes, 0.51 (95% CI 0.25–0.76) for height of the joint space, 0.75 (95% CI 0.55–0.95) for tibiofemoral angulation, 0.59 (95% CI 0.36–0.81) for length of the patellar tendon, and 0.84 (95% CI 0.66–1.01) for patellar length.

Statistical analysis. Fisher's exact test for 2 × 2 tables and the generalized Fisher's exact test for 2 × k tables were used in cross-tabulations of different categorical variables. The *P* values presented are 2-sided and calculated using the exact procedure (StatExact) (20). Student's *t*-test or Mann-Whitney U test was used to compare continuous variables for subjects with and those without OA.

We used logistic regression models to analyze the associations between different covariates and knee OA. Age, lifetime participation (hours) in different types of sports (endurance, team, power), lifetime years of heavy work or years of kneeling or squatting work, BMI at the age of 20, and previous knee injuries were used as covariates in logistic regression models. The associations were expressed using odds ratios (OR) and their 95% confidence intervals. Analyses were conducted with BMDP statistical software using programs 4F and LR.

RESULTS

Univariate analyses. There were statistically significant between-group differences in the prevalence rates of knee OA ($P = 0.016$) and knee osteophytes ($P = 0.0085$) (Table 3). In comparison with shooters, both soccer players and weight lifters had a higher prevalence of knee osteoarthritis findings. Soccer players had predominantly tibiofemoral OA and weight lifters patellofemoral OA (Table 3). Of the subjects with tibiofemoral OA, 2 soccer players and 1 weight lifter were affected bilaterally; of those with patellofemoral OA, 1 soccer player, 3 weight lifters, and 1 shooter were affected bilaterally.

The tibiofemoral joint space was narrow in subjects with tibiofemoral OA compared with subjects without tibiofemoral OA (mean ± SD 4.0 ± 1.7 mm versus 5.6 ± 0.6 mm; $P < 0.0001$). Subjects with tibiofemoral OA had a tendency to varus deformity compared with subjects without tibiofemoral OA (mean ± SD valgus angle 2.4 ± 4.7° versus 4.0 ± 2.6°; $P = 0.070$), but 1 subject with tibiofemoral OA had a valgus deformity of 13°.

The subjects with radiographic knee OA had higher BMI at the age of 20 than did subjects without knee OA (mean ± SD 24.2 ± 2.3 versus 22.4 ± 1.9; $P = 0.0003$). When subjects were classified into quartiles based on BMI at 20 years of age, 11% (3 of 28) in the lowest BMI quartile (BMI <21.35) had knee OA, as compared with 50% (13 of 26) in the highest quartile (BMI >23.89) ($P = 0.0025$). BMI at the age of 20 correlated with BMI in 1985 (Spearman rank sum correlation [r] = 0.52) and with BMI in 1992 (r = 0.44).

Fifty percent (11 of 22) of the subjects with previous knee injuries had knee OA, as compared with 13% (12 of 95) of those without reports of previous knee injuries ($P = 0.0003$). The mean ± SD number of years spent in heavy work was 13.7 ± 17.0 for those with knee OA and 4.9 ± 9.7 for those without ($P = 0.054$). The number of years in kneeling or squatting work was 4.9 ± 8.4 for subjects with knee OA and 1.4 ± 4.9 for those without ($P = 0.047$).

Patellar height was similar between the groups with and without patellofemoral OA.

Multivariate analyses. Compared with shooters, the age-adjusted risk of having knee OA was significantly higher in soccer players (OR 12.3, 95% CI 1.35–111) and in weight lifters (OR 12.9, 95% CI 1.47–113). The relative risk of knee OA was substantially elevated in runners as well (OR 4.8), but the numbers of shooters and runners with knee OA were too small to rule out

Table 3. Prevalence of findings of knee osteoarthritis in the 4 athlete groups*

	Long-distance runners (n = 28)	Soccer players (n = 31)	Weight lifters (n = 29)	Shooters (n = 29)	P†
Knee osteoarthritis	4 (14), 4–33	9 (29), 14–48‡	9 (31), 15–51‡	1 (3), 0–18	0.016
Tibiofemoral osteoarthritis	1 (4), 0–18	8 (26), 12–45‡	5 (17), 6–36	0 (0), 0–12	0.0032
Patellofemoral osteoarthritis	3 (11), 2–28	5 (16), 5–34	8 (28), 13–47	1 (3), 0–18	0.064
Knee osteophytes	4 (14), 4–33	9 (29), 14–48‡	10 (34), 18–54‡	1 (3), 0–18	0.0085
Tibiofemoral osteophytes	1 (4), 0–18	6 (19), 7–37	4 (14), 4–32	0 (0), 0–12	0.028
Patellofemoral osteophytes	4 (14), 4–33	8 (26), 12–45	9 (31), 15–51‡	1 (3), 0–18	0.028
Cysts	1 (4), 0–18	7 (23), 10–41	2 (7), 1–23	1 (3), 0–18	0.053
Monthly knee pain	6 (21), 8–41	14 (45), 27–64	8 (28), 13–47	5 (17), 6–36	0.095
Knee disability	3 (11), 2–28	11 (35), 19–55‡	7 (24), 10–44	2 (7), 1–23	0.022
Extension deficiency	2 (7), 1–24	12 (39), 22–58§	10 (34), 18–54	1 (3), 0–18	0.0003

* Values are the number (%), 95% confidence interval of the percentage. See Subjects and Methods for detailed definitions.
† By generalized Fisher's exact test for comparison between the findings of osteoarthritis in the 4 athlete groups.
‡ $P < 0.05$ compared with shooters, by Fisher's exact test for comparisons of osteoarthritic findings (exact 2-sided P value has been corrected for multiple comparisons, using the Bonferroni method).
§ $P < 0.01$ compared with shooters, by Fisher's exact test for comparisons of osteoarthritic findings (exact 2-sided P value has been corrected for multiple comparisons, using the Bonferroni method).

either protective or harmful effects (95% CI 0.48–47). The age-adjusted risk of having knee OA increased significantly with the number of lifetime hours spent in team sport training (OR 1.14/1,000 training hours, 95% CI 1.03–1.27) and power training (OR 1.12, 95% CI 1.00–1.25), but there was no significant increase with hours spent in endurance training (OR 1.06, 95% CI 0.94–1.20). The age-adjusted risk of having knee OA also increased significantly with the number of lifetime years spent in heavy work (OR 1.06/work-year, 95% CI 1.02–1.09) and years spent in kneeling or squatting work (OR 1.08/work-year, 95% CI 1.01–1.16).

Athlete group, age, BMI at the age of 20, years in heavy work, years in kneeling or squatting work, and previous knee injuries were entered into a stepwise logistic regression analysis to identify predictors of knee OA. According to the final multivariate model, the risk of having knee OA was increased in subjects with previous knee injuries (OR 4.73, 95% CI 1.32–17.0), higher BMI at the age of 20 (OR 1.76/unit increase, 95% CI 1.26–2.45), more years in heavy work (OR 1.08/work-year, 95% CI 1.02–1.13) and in work involving kneeling or squatting (OR 1.10, 95% CI 1.02–1.20), and participation in soccer (OR 5.21, 95% CI 1.14–23.8).

Separate multivariate analyses were conducted to identify specific predictors of patellofemoral and tibiofemoral OA. The possible predictor variables considered in the stepwise logistic regression analyses were previous injuries, BMI at the age of 20, lifetime participation-hours in endurance, team, and power sports, and lifetime participation-years in heavy work and in kneeling or squatting work. In the final models, previous knee injuries (OR 5.96, 95% CI 1.28–27.8), high BMI at the age of 20 (OR 1.54/unit increase, 95% CI 1.04–2.29), and hours of participation in team sports (OR 1.20, 95% CI 1.03–2.29) were associated with increased risk of tibiofemoral OA. Correspondingly, previous knee injuries (OR 4.87, 95% CI 1.38–17.2), high BMI at the age of 20 (OR 1.45/unit increase, 95% CI 1.07–1.95), years spent in heavy work (OR 1.04/work year, 95% CI 1.00–1.08), and work involving kneeling or squatting (OR 1.08, 95% CI 1.00–1.16) entered into the predictive model for patellofemoral OA.

Clinical findings. Knee extension deficiency (>4°) was more common among soccer players and weight lifters than among shooters (39% and 34% versus 3%; $P = 0.0003$ between groups) (Table 3), and knee disability was also most common in soccer players and weight lifters ($P = 0.022$ between groups). Soccer players and weight lifters also reported the most knee pain, but the difference between groups was not statistically significant ($P = 0.095$ between groups).

Associations between clinical and radiographic findings. The subjects with knee OA reported monthly knee pain (13 of 23; 57%) more commonly than did those without knee OA (20 of 94; 21%) ($P = 0.0014$). The subjects with knee OA had knee disability more commonly (11 of 23; 48% than did those without knee OA (12 of 94; 13%) ($P = 0.0004$). Knee extension deficiency was seen in 11 subjects (79%) with tibiofemoral OA and in 10 subjects (10%) without tibiofemoral OA ($P < 0.0001$). Knee instability was found in 6 subjects (43%) with tibiofemoral OA and in 10 subjects (10%) without tibiofemoral OA ($P = 0.0038$).

DISCUSSION

In our study, soccer players and weight lifters had higher prevalence rates of OA than did shooters. Soccer is characterized by sprinting, stopping, cutting, and pivoting situations, and can easily lead to knee injuries (21). The number of previous meniscal and ligamentous knee injuries was high in soccer players, suggesting that injuries play a role in the etiology of knee OA. Weight lifters with high BMI commonly had OA, particularly in the patellofemoral joints. In the multivariate models, work-related loading also was associated with patellofemoral OA. We found no evidence that long-distance running would lead to premature knee OA in male runners, who usually had low BMI and had started running at a young age.

Investigations attempting to record lifetime physical activity and joint loading generally encounter difficulties that can be reduced by studying subjects who are former athletes at the international level. The loading patterns of athletes are rather specific, and their exercise histories are more reliable than are those obtained from an individual who has exercised recreationally only. Athletes typically follow well-planned and defined training routines. Since we also recorded work-related knee loading, our data on loading of the knee can be considered comprehensive. Athletic loading in our study does not necessarily apply specifically to the training regimens of today's athletes, but instead may be more relevant for persons actively involved in regular exercise or recreational athletics. The training programs of today's elite athletes have become increasingly demanding.

The athletes in our study presumably were free from knee OA at the time they participated in top-level sports, in which good lower limb function is an essential prerequisite. In children, sports-related knee injuries can occur during the growth phase, and are likely to prevent the person from becoming a top-level athlete as an adult. In this respect our study underestimates the harmful effects of athletic loading on the knee. Because people tend to forget mild injuries, we included only injuries that had led to hospital treatment. Injuries that had occurred after the age of 40 were excluded from our study because some originally degenerative changes could be misclassified as originating from injury. This age limit also was considered necessary because it usually takes several years after injury before osteoarthritic changes will appear (11).

The athlete's knee, even if clinically free from OA, can show small osteophytes and other radiographic changes that usually are considered signs of OA (22). We ignored small osteophytes and other mild osteoarthritic changes to minimize the risk of false-positive radiographic findings of knee OA. Radiographic methods are, however, insensitive for detecting early cartilage loss (23). To study the validity of our radiographic grading of OA we used other radiographic and functional methods independent of the grading. The subjects who were classified as having knee OA more commonly had pain symptoms, functional limitations, joint space narrowing, and angular deformities compared with the rest of the subjects. We used a new method to measure joint line narrowing. This method is based on the assumption that the contacting weight-bearing area can be better assessed from lateral radiographs than from anteroposterior radiographs, provided the knees are flexed 30° and the joint surfaces compressed against each other with full weight.

The limited number of subjects in our study did not allow sufficient statistical power for detailed comparisons. Only 1 runner had tibiofemoral OA, and 2 of the 4 runners with knee OA reported a previous injury that probably had led to OA. Moreover, lifetime hours of participation in endurance sports did not explain osteoarthritic findings. Low BMI in runners may have an effect, in that they seldom had OA at the age at which our subjects were studied (9). The high levels of activity and high life expectancy of endurance athletes may lead to an increased need for OA-related hospitalization at a very old age (9). Most of the runners in our study had trained ever since they were young. Joint cartilage adapts to progressive loading, but rapidly increasing amounts of running in previously sedentary adults or after a period of immobilization may cause cartilage breakdown. Also, animal experiments show conflicting results as to whether running can induce OA (24–26). Further, due to differences in the knee biomechanics between humans and all animals, we cannot generalize widely from animal experiments.

It is difficult to determine which of the recorded factors are determinants, i.e., associated with the sports event, and which should be classified as confounders. All of the studied factors are associated with both physical loading and athletic group. Injuries are associated with soccer, and high BMI is associated with weight lifting. Some of the weight lifters reported that they lifted heavy burdens at work as part of their training. Stepwise logistic regression analysis showed that high body mass and previous injuries were strong predictors of future knee OA. Lifetime years of work-related heavy loading of the knees also was associated with development of knee OA. These findings confirm earlier reports (1,4–7). Knee injuries seem to be etiologically related to knee OA, particularly in soccer players. It also seems evident that heavy weight training associated with a high body mass causes excessive loading of the patellofemoral joints during lifting. Because of the limited number of subjects, we could not comprehensively differentiate the effects of weight lifting and high BMI as predictors of knee OA. High-lying patella is known to predispose to patellofemoral OA (27). This was not a significant confounder in our study, because there was no difference in the patellar height index between the subjects with and those without patellofemoral OA. However, there may be biomechanical factors associated with the selection of top athletes that we were unable to control for in our study.

Various team sports as well as power sports enjoy great popularity around the world. Sports, in particular endurance sports, yield many health benefits (16), and participation in various sports has been advised to maintain or promote health. Soccer alone has more than 60 million registered players in 150 countries associated with the International Federation of Football Associations (21). Several other popular team sports cause stresses to the knee similar to those encountered in soccer and may involve a risk for knee OA (9). Many types of power sports are increasing in popularity. Approximately 8% of the US population participates yearly in running or jogging and approximately 6% in weight training (28). Approximately 60% of these persons participate in their activity at least 100 times per year (28). If prescribed for the promotion of health, running seems to be devoid of adverse effects leading to knee degeneration, compared with sports in which injuries frequently occur. Weight training with light or moderate weights is not likely to cause excessive high-impact loads to the joints. In our study, heavy weight lifters who had trained with maximal weights had a high prevalence of knee OA.

Some cases of knee OA might be prevented with preservative treatment of meniscal injuries and reconstructive treatment of knee ligament instabilities (29,30). Such modern treatment methods to preserve the meniscus and reconstruct the ligaments of unstable knees should be tested for their potential to prevent knee OA following knee injuries. These methods were not available at the time our study subjects were injured.

In conclusion, soccer players and weight lifters are at increased risk of developing premature knee OA. In soccer players the increased risk seems to be largely due to previous joint injuries. In weight lifters the effects of loading and high body mass could not be separated. In activities that involve repetitive nontraumatic loading, such as running, the risk of premature OA of the tibiofemoral joints seems to be small. These findings constitute the basis for exercise counseling and ergonomic planning aimed at the prevention of knee OA that can result from participation in sports or from excessive work-related loading.

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II

Factors associated with hip joint rotation in former elite athletes

by

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Factors associated with hip joint rotation in former elite athletes

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Abstract

***Objectives*—To study factors associated with passive hip rotation range of motion (ROM) in former elite male athletes.**

***Methods*—Athletes were interviewed about hip pain, disability, lifetime occupational loading, and athletic training. The passive hip rotation was measured with a Myrin inclinometer in 117 former elite male long distance runners, soccer players, weight lifters, and shooters aged 45–68 years. Magnetic resonance imaging was used to detect hip osteoarthritis.**

***Results*—There were no differences in passive hip rotation ROM between the four athlete groups nor between diverging lifetime loading patterns associated with occupational or athletic activities. Among the subjects without hip osteoarthritis, hip pain, and hip disability according to a stepwise linear regression analysis, the only factor that was associated with the passive hip rotation ROM was body mass index (BMI), explaining about 21% of its variation. Subjects with high BMI had lower passive hip rotation ROM than those with low BMI. There was no right-left difference in the mean passive hip rotation ROM in subjects either with or without hip osteoarthritis as determined by magnetic resonance imaging. Nevertheless, hip rotation ROM was clearly reduced in a few hips with severe caput deformity.**

***Conclusions*—Long term loading appears to have no association with passive hip rotation ROM. On the other hand, the hip rotation value was lower in subjects with high BMI than in those with low BMI. A clear right-left difference in hip rotation was found only in those subjects who, according to our magnetic resonance imaging criteria, had severe hip osteoarthritis. These findings should be taken into account when hip rotation ROM is used in the clinical assessment of hip joints.**
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Keywords: hip joint rotation; range of motion; osteoarthritis; athletic training; body mass index

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Osteoarthritis is a common disorder characterised by pain and reduced range of motion (ROM) of the joints. Its prevalence and severity increase with age.[1] Restricted rotation and flexion are established clinical indicators of hip osteoarthritis.[2]

Hip inward and outward rotation ROM is larger in children and adolescents than adults.[3] Roach and Miles[4] concluded that, at least up to 74 years of age, any substantial loss of ROM should be considered abnormal. However, differences in methods and study populations make comparisons of results for ROM of the hip between studies rather difficult.[5-8]

In addition to age, ROM of the hip may be affected by a number of other factors including physical loading,[9] activities of daily life,[10] and anthropometric factors, such as body mass index (BMI).

Mechanical stress in farmers is known to increase their risk of developing osteoarthritis,[11 12] Sporting activity has been shown to increase the risk of developing hip osteoarthritis.[13 14] This increase is clear for sports involving traumatic loading such as soccer[15 16] but not so clear for sports such as running.[17]

Hip rotation measurement is a clinical manoeuvre performed when diagnosing hip osteoarthritis, but there are few data on factors other than osteoarthritis that change hip rotation ROM. The main aim of this study was to investigate the association between sports involving different ranges of hip rotation and loading and hip rotation ROM. A further aim was to study the associations between hip rotation ROM and other factors, such as age, hip osteoarthritis, reported hip pain or hip disability, work related physical activity, muscle tightness, and anthropometry, which, like athletic activity, may change the ROM of the hip.

We enrolled in this study former top level athletes consisting of long distance runners (medium range flexion-extension and long term repetitive loading), soccer players (wider range of hip motion, including rotation, and high risk of impact loads on hip joint), weight lifters (extreme range of flexion and high peak loads on hip joint), and shooters. Shooters represent athletes who generally take only light to moderate physical exercise.

Methods

In our study former male long distance runners, soccer players, weight lifters, and shooters participated in a structured two hour interview, clinical examinations, functional measurements, and a hip magnetic resonance imaging (MRI) examination.

SUBJECTS

We identified male athletes who had represented Finland between the years 1920 and 1965 at least once in the Olympic games, World or European championships, or international competitions (athletic contests be-

Table 1 Characteristics of participants

	Long distance runners (n=28)	*Soccer players (n=31)*	*Weight lifters (n=29)*	*Shooters (n=29)*
Age (years)				
Mean (SD)	59.7 (4.7)	56.5 (5.7)	59.3 (5.3)	61.0 (4.3)
Range	51–67	45–67	46–66	50–68
Height (cm)				
Mean (SD)	173.0 (4.8)	176.9 (5.4)	167.0 (6.6)	175.2 (6.6)
Range	162.0–183.0	165.0–187.0	154.0–183.0	164.0–188.0
Weight (kg)				
Mean (SD)	75.7 (9.7)	84.2 (12.1)	80.7 (13.8)	81.9 (8.4)
Range	60.0–108.0	68.0–123.0	57.0–111.0	71.0–99.0
Body mass index (kg/m^2)				
Mean (SD)	25.3 (2.8)	26.9 (3.4)	28.8 (3.6)	26.7 (2.5)
Range	20.9–34.9	22.0–38.8	22.5–38.4	22.9–30.8
Hip osteoarthritis*				
No (%)	3 (12)	3 (12)	4 (20)	6 (24)
Hip pain				
No (%)	6 (21)	4 (13)	2 (7)	5 (17)
Hip disability				
No (%)	2 (7)	1 (3)	1 (3)	1 (3)
Lifetime endurance training (hours)				
Median	8980	1530	1520	2480
Range	1300–18752	0–9936	0–8483	0–8536
Lifetime team sport training (hours)				
Median	0	8240	1150	140
Range	0–3072	3864–18514	0–4888	0–5500
Lifetime power training (hours)				
Median	0	0	9460	0
Range	0–1280	0–1600	284–16752	0–1092
Years in heavy work				
Mean (SD)	12.3 (15.4)	1.7 (7.2)	9.7 (12.6)	3.2 (8.3)
Range	0.0–47.0	0.0–40.0	0.0–43.0	0.0–38.0
Hypermobility index				
Mean (SD)	0.7 (0.9)	1.0 (1.3)	0.8 (0.8)	0.9 (1.2)
Range	0.0–5.0	0.0–5.0	0.0–2.0	0.0–4.0
Straight leg raising				
Mean (SD)	85.5 (14.0)	84.7 (10.5)	88.7 (10.3)	80.4 (9.6)
Range	63.5–119.0	60.0–110.0	71.0–114.0	56.0–92.5

*Long distance runners, n = 25; soccer players, n = 25; weight lifters, n = 20 (19 cases documented by magnetic resonance imaging and one hip prosthesis); shooters, n = 25.

tween two or more countries).[18] In 1985, a questionnaire eliciting information on health and lifestyle was mailed to all surviving athletes. The responders included 38 long distance runners, 89 soccer players, 40 weight lifters, and 35 shooters, who in 1992 were alive and 45–68 years old. All the shooters (n = 35) and runners (n = 38), as well as a sample of soccer players (n = 37) and weight lifters (n = 37) comparable in age and occupation with the other groups (a total of 147 subjects), were invited to take part. Of these, 117 (80%) agreed to participate: 28 long distance runners, 31 soccer players, 29 weight lifters, and 29 shooters. A postal questionnaire was mailed to those who declined to participate, and 19 (63%) of them responded. The most common reason for non-participation was lack of time.

The interview, clinical examinations, and MRI readings were carried out independently by different investigators who were blinded to the results obtained by the others.

The study was reviewed and approved by the ethics committee of the research centre of the Social Insurance Institution (Turku, Finland).

INTERVIEW

The subjects were interviewed by one of the authors (HR) about hip pain, disability, lifetime occupational loading, and lifetime regular participation hours in different types of athletic training (endurance, team, power). The methods have been described in detail previously.[19 20] Table 1 shows the main characteristics and background factors in the four groups of athletes. Occurrence of hip pain during the past year was investigated separately for each hip. Those who reported hip pain in either hip at least once a month were classified as having monthly hip pain. Disability was scored as yes/no on a scale of 0 to 7 depending on whether the subjects reported pain or disability (*a*) during nocturnal bedrest, (*b*) for more than five minutes in the morning after getting out of bed, (*c*) while sitting for 30 minutes, (*d*) during full support by the legs, (*e*) while walking more than 1 km, (*f*) while going up or down stairs, and (*g*) while squatting or bending forward. The sum of positive responses was calculated, and subjects scoring at least three points for either hip were considered to have a hip disability (yes).

CLINICAL EXAMINATIONS AND FUNCTIONAL MEASUREMENTS

The clinical examinations and quantitative measurements were performed by the first author (JK). Each subject's weight (kg) and height (m) were measured and the BMI calculated. Subjects were placed in the supine position for the measurement of passive flexion and inward and outward rotation of the hip joint. Hip flexion was measured with the knee flexed using a two armed standard goniometer. As a standard goniometer is difficult to adapt for measurement of hip rotation, the latter was measured with the knee flexed with a Myrin inclinometer, which is based on a compass method. The total (inward and outward combined) rotation was used to avoid misclassification of inward and outward rotation. A correlation between radiological changes in the spine and inclinometer ROM measurement results has been reported.[21] Moreover, Viitanen and co-workers[21] concluded that the reliability of ROM measurements as conducted in this study was good. Hip extension was measured, using a standard goniometer, with the subject lying prone with the knee extended. All hip ROM measurements were made following the recommendations of the handbook of the American Academy of Orthopedic Surgeons.[5]

Hamstring tightness was measured using passive straight leg raising, with the inclinometer placed just above the patella of the leg to be tested. The examiner placed his leg on the other leg to stabilise it, and raised the leg to be tested slowly and evenly, avoiding abduction and rotation and keeping the knee fully extended until tightness or pain restricted the movement. The mean of readings from the two legs was used in the calculations.

Systemic hypermobility was assessed using the Carter and Wilkinson score[22] modified by Beighton and co-workers.[23] The test included passive dorsiflexion of the little fingers beyond 90°, passive apposition of thumbs to the flexor aspect of the forearm, hyperextension of elbows beyond 10°, hyperextension of the knee beyond 10°, and flexion of the trunk with the knees in extension so that the palms of the hands rested on the floor.

MAGNETIC RESONANCE IMAGING

MRI was performed using a 1.5 T device (Magnetom; Siemens AG, Erlangen, Ger-

Table 2 Passive range of motion (ROM) of the hip joint in the four groups of athletes (calculated from mean values of measurements made on the right and left lower extremity)

	Long distance runners (n=28)	*Soccer players (n=31)*	*Weight lifters (n=29)*	*Shooters (n=29)*	*p Value*
Extension (°)					
Mean (SD)	18.0 (5.5)	17.1 (6.0)	15.8 (6.5)	19.0 (5.0)	0.17
Range	0.0–25.0	0.0–28.5	0.0–24.0	12.0–30.5	
Flexion (°)					
Mean (SD)	139.7 (14.1)	140.6 (10.3)	139.4 (11.0)	140.4 (5.7)	0.97
Range	72.0–150.0	95.0–152.5	95.0–154.0	126.5–150.0	
Outward rotation (°)					
Mean (SD)	35.6 (8.4)	36.9 (7.2)	36.6 (5.1)	37.8 (4.9)	0.66
Range	2.5–50.0	20.0–47.5	25.0–45.0	25.0–47.5	
Inward rotation (°)					
Mean (SD)	18.9 (5.9)	19.4 (4.7)	20.3 (4.5)	19.3 (7.4)	0.83
Range	0.0–29.5	8.5–29.0	12.0–30.0	9.0–40.0	

many) with a body coil. The subjects were supine during the MRI examinations. As they had a subsequent MRI examination of the lumbar spine,[24] a three dimensional FISP (fast imaging with steady precession) sequence, which gives good visualisation of the articular cartilage in a relatively short time, was chosen. Axial slices of both hips were produced. The imaging parameters were as follows: repetition time 30 milliseconds; echo time 10 milliseconds; flip angle 40°; 256 × 256 matrix; field of view 36 cm; 2 mm slice thickness with no interslice gap; total imaging time 8 minutes 14 seconds.

The MR images were analysed for narrowing of joint space, cysts, and deformation of head of femur. Joint space narrowing (cartilage signal) was graded from six slices representing the weight bearing area as follows: 0 = normal; 1 = decrease in one to three of the studied slices; 2 = decrease in four to six of the studied slices; 3 = clearly obliterated at least in one slice (no cartilage signal); 9 = cannot be evaluated. Cysts and deformation of the head of femur were graded as 0 = no, 1 = yes and 9 = cannot be evaluated.

An athlete was considered to have hip osteoarthritis, if he had obliterated hip joint space (grade 3) or osteoarthritic deformation of the head of femur or cyst formation in the head of femur. In addition, one subject had undergone total hip replacement because of osteoarthritis and was therefore classified as osteoarthritic.

A total of 94 subjects were examined (25 long distance runners, 25 soccer players, 19 weight lifters, and 25 shooters). Fourteen were excluded because of foreign bodies or metallic implants, seven because of technical difficulties, one because of claustrophobia, and one because of having excessively broad shoulders.

STATISTICAL ANALYSIS

The statistical analyses were carried out using BMDP statistical software. One way analysis of variance and the mean hip inward or outward rotation, extension and flexion ROM value of right and left leg were used to compare group means. Analysis of variance was used to compare hip rotation right-left differences among subjects with unilateral hip osteoarthritis and those without such a finding. The mean total (inward and outward combined) rotation value of osteoarthritic hip joints and the mean value of the right and left total hip rotation in subjects without osteoarthritis was calculated to compare rotation differences among these two groups.

We used multiple linear regression analysis for associations between the passive hip rotation ROM and different factors. The mean value of the right and left hip rotation (inward and outward combined) was used in these analyses.

Results

Table 2 shows the mean values and ranges of the passive ROM of the hip (rotation, flexion, extension) for the four athlete groups. No statistically significant group differences were found between the groups, nor between the right and left lower extremities in the total material. The mean (SD) right-left difference in rotation was 6.9 (10.2)° in those with unilateral hip osteoarthritis (n = 14) and 4.2 (4.6)° in those (n = 78) without this finding (p = 0.10). Nevertheless, in four severe cases of caput deformity, the right-left rotation difference exceeded 10°. The mean (SD) total hip rotation was 54.9 (12.7)° in those hip joints with osteoarthritis and 56.8 (9.1)° in those without (p = 0.51).

In total, 25% (4/16) of the subjects with hip osteoarthritis had monthly hip pain, whereas monthly hip pain was reported by 13% (10/79) of those without hip osteoarthritis (p = 0.20). Hip disability, on the other hand, was reported by 13% (2/16) of the subjects with hip osteoarthritis and by 3% (2/79) of those without (p = 0.07).

The average hip rotation ROM was significantly (p<0.0001) smaller in subjects with hip pain (43.3 (15.3)°, n = 14) than in those who had not experienced this (58.4 (7.9)°, n = 81). Similarly, those with hip disability had significantly (p = 0.0003) smaller mean rotations (37.9 (25.3)°, n = 4) than those not reporting this (57.0 (9.1)°, n = 91).

MULTIVARIATE ANALYSIS

Associations between hip rotation ROM and different covariates were studied in those who had undergone MRI (n = 94, the subject with bilateral endoprothesis excluded). The calculations were based on the mean combined rotation of measurements made on the right and left hips. BMI, years in heavy work, lifetime participation hours in different types of athletic training, age, hypermobility index, athlete group, hip osteoarthritis, monthly hip pain, hip disability, and straight leg raising were entered into the model.

The only factors that were significantly associated with the hip rotation ROM were BMI (20%) and monthly hip pain (9%), explaining about 29 % of its variation. The mean hip rotation was 61.1° in those with BMI 24 or less (n = 20), 55.5° in those with BMI between 24.1 and 28 (n = 52), and 53.3° if BMI was 28.1 or more (n = 22) (p = 0.049). When the subjects with hip osteoarthritis or those with monthly hip pain or hip disability were excluded from the multiple linear regression analysis, the only factor that was associated with hip rotation among those with "healthy hip joints" was BMI, explaining about 21% of its variation.

Discussion

There were no differences in the passive ROM of the hip between the four groups of athletes with divergent long term patterns of loading. In accordance with previous studies,[25 26] on average no difference was found in the ROM between the right and left hip, although some subjects with severe hip osteoarthritis showed clear right-left rotation differences. In multiple linear regression models, lifetime physical activity or years spent in heavy work was not associated with hip rotation ROM.

Compared with non-ballet dancing controls, a lower range of passive hip adduction and inward rotation among female classical ballet dancers has been reported.[9] This unbalanced flexibility was attributed to warm up exercises and dancing activities, and the imbalance was worse among older and more experienced dancers. Sarna *et al*[18] found that more than 60% of our former male elite athletes had engaged in leisure time physical activity or competitive sports throughout their entire adult life, but their hip extension, flexion, and rotation ROM were similar.

Because the distributions of the variables of lifetime hours spent in different types of athletic activity (table 1) used in regression analysis were somewhat skewed, we also distributed these variables in quartiles and performed the analysis again. The main result of the analysis was similar. However, on reanalysis of the association between hip rotation and different covariates among those without hip osteoarthritis, pain, or disability, soccer playing showed a small explanation rate (5%) in addition to BMI (22%).

High BMI was associated with low hip rotation in all those who had MRI and in the subgroup without hip osteoarthritis, pain, or disability. There was an association between high BMI and weight lifting. Heavy weight training strengthens muscles and ligaments and may lead to restricted motion of hip joints. However, hip rotation ROM values for weight lifters were similar to those for the other athlete groups, and the association between hip rotation ROM and BMI remains unclear.

Hip osteoarthritis is usually classified radiographically, and symptoms are related to the findings.[27] On the other hand, some patients with radiological diagnosis of hip osteoarthritis are asymptomatic. In our study it was not possible to make comparisons between subjects with different grades of hip osteoarthritis because of the limited number of osteoarthritic subjects. MRI is at present probably the best method for detecting hip osteoarthritis. However, the possibility remains that even this method may have missed mild hip osteoarthritis, and consequently failed to show a true association between hip osteoarthritis and ROM.

We found that athletes with hip osteoarthritis tend to report monthly hip pain and disability more often than those without this finding. However, 75% of the athletes with hip osteoarthritis reported no hip pain, and also disability was rare. One explanation for the low rate of symptoms among athletes with hip osteoarthritis diagnosed by MRI may be that our subjects were volunteers and not patients with hip osteoarthritis. Also in *x* ray studies, subjects with mild osteoarthritic changes are often asymptomatic. On the other hand, reported hip pain and disability seem to have harmful effects on the hip rotation ROM, and symptomatic arthritis is known to predict future disability.[28]

CONCLUSIONS

Long term loading seems to have no association with passive hip rotation ROM. Subjects with high BMI have lower hip rotation values than those with low BMI. A clear right-left difference in hip rotation appears to be confined to subjects with severe hip osteoarthritis.

This study was financially supported by the Finnish Ministry of Education and Social Insurance Institution, Finland. Contributors: J K designed the study, participated in data collection, and made the statistical analysis of the data as well as wrote the first draft of the manuscript. U K participated in the design and analysis of the study. H R participated in planning the questionnaire and design and collection of the data. T V participated in planning the questionnaire and designing the study. S S identified the original study cohort, participated in the design, data collection, and statistical analysis of the data. O I participated in planning the study, was involved in interpreting the results, and edited the paper. S K organised MRI studies and analysed MR images. All investigators read and contributed to successive drafts of the paper, before approving the final version. J K and U K are the guarantors of the paper.

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Take home message

We found no association between long term athletic activity and passive hip rotation ROM, but subjects with high BMI had lower ROM than subjects with low BMI. Moreover, only the most severe cases with hip OA had reduced hip rotation.

One doctor's conversion to running

I started running about three years ago, aged 42, deliberately to get fitter. Repeated spells of 1-in-1 had precluded hockey, my preferred sport, and I ate for comfort during stressful times.

Easier time off and reliable mobiles made exercise easier to contemplate. Watching my brother in the Highland Cross Biathlon (far harder than a marathon) inspired me to start running, and my wife (the best cook I've ever met, unfortunately) bought me Cannondale bikes. I looked like a pig in Lycra!

My 1998 Highland Cross time was "...geological...". Quicker this year. I've run three marathons, very slowly. In Los Angeles, a fat runner's vest said "For Mom...and Alice-...and Faith...and ALL women with breast cancer." Runners overtook him, applauding. I run the New York marathon in November for Imperial Cancer Research with the names of three friends with breast cancer on my own vest. Donations accepted.

Why run? Because I enjoy it, I feel better, I'm slimmer and fitter, it relaxes me, I sleep better, and attractive women are impressed. (My daughters, I mean.) Doctors needn't run marathons to be good at their jobs, but being seen to stay fit, while enjoying themselves is surely an important piece of health education.

LINDSAY EASTON
Perth

III

Determinants of sagittal knee laxity in former elite athletes

by

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ORIGINAL ARTICLE

Determinants of sagittal knee laxity in former elite athletes

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SUMMARY. To investigate factors that are associated with knee laxity, anterior knee laxity was measured on 117 former elite male runners, soccer players, weight lifters and shooters (age range 45–68 years) with a KT-1000 knee ligament arthrometer. Knee laxity was greater among shooters (mean 9.0 mm; SD 1.8 mm) and weight lifters (8.4 mm; SD 2.0 mm) as compared to runners (7.6 mm; SD 1.8 mm) and soccer players (7.1 mm; SD 2.1 mm) ($P = 0.0002$ for group differences). According to a multiple linear regression analysis among athletes whose right–left laxity difference was ≤ 4 mm ($n = 108$), athlete group and straight-leg-raising test explained 26% of the inter-individual variation in sagittal knee laxity and hyperextension of the knees explained an additional 3%. The mean right–left laxity difference was 1.5 mm (SD 1.6 mm, range 0.0–8.5 mm). The only factor that was associated with the right–left difference was previous knee injury.

In conclusion, subjects who have increased hyperextension of the knee and hamstring tightness tend to have increased knee laxity. Lifetime sport-related knee loading contributes to knee laxity and should be taken into consideration when knee laxity measurements are interpreted in clinical practice.

INTRODUCTION

Most of the resistance of the tibia to anterior displacement is attributable to the anterior cruciate ligament (ACL).[1] Injuries to this ligament are common and often lead to instability. In the clinical examination of unstable knees, the KT-1000 arthrometer has showed high sensitivity (85%) and specificity (100%) in detecting ACL ruptures.[2] This method is therefore widely used for measurements of sagittal knee laxity.

Knee stability is maintained by complex interactions between a large number of factors including:

- Ligament and other soft-tissue restraints
- Condylar geometry
- Active muscular control
- Tibiofemoral contact forces at the joint interfaces generated during weight-bearing activities.[3]

Moreover, tibial rotation, muscle relaxation, displacement force, flexion angle and similar factors may affect the results of displacement measurements.

Joint-looseness decreases with age, especially in men.[4,5] The range of motion of a joint may be altered by athletic training as well. Exercise has been shown to slightly increase knee joint laxity[6-8] whereas there was no significant acute change in laxity in the case of power lifters who frequently practise squats.[8]

The main aim of the study described in this paper was to find out whether there are other determinants of sagittal knee laxity other than those related to the method of measurement and previous knee injuries that should be taken into account in the clinical evaluation of an unstable knee joint.

Our specific goal was to measure anterior tibial displacement in former top-level athletes with different long-term patterns of loading the knee. Long-distance runners are susceptible to long-term repetitive loading, soccer players are at a high risk for impact loads, sprains and twisting and weight lifters repeatedly undertake high peak loads. Former top-level shooters represented athletes who take only light to moderate general exercise involving some kneeling and squatting.

MATERIALS AND METHODS

We identified a number of male athletes who had represented Finland at least once in the Olympic games, World or European championships, or intercountry competitions (athletic contests between two or more

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countries) between the years 1920–1965.[9] A questionnaire eliciting information on health and lifestyle was mailed to all surviving athletes in 1985.

The questionnaire responders included 38 long-distance runners, 89 soccer players, 40 weight lifters and 35 shooters, who in 1992 were alive and between 45 and 68 years old. All shooters (n = 35) and runners (n = 38), as well as systematic samples of soccer players (n = 37) and weight lifters (n = 37) of similar age and occupation as the participants from the other groups (a total of 147 subjects), were invited to the present study. Of these, 117 (80%) agreed to participate. Among the participants, there were 28 long-distance runners, 31 soccer players, 29 weight lifters and 29 shooters. The interviews and the clinical examinations as well as the radiographic assessments were carried out independently by different investigators who were blinded to the results obtained by other investigators.

The study was accepted by the Ethical Committee of the Research Centre of the Social Insurance Institution (Turku, Finland).

The subjects were interviewed by one of the authors (HR) about their experience of knee injuries and a lifetime of occupational loading. The number of years of work involving kneeling or squatting (for more than 10 min per working hour) and number of years of work involving heavy lifting was calculated. An acute knee injury requiring hospital treatment was considered as a previous knee injury. A total of 27 injuries were reported including 25 meniscal and/or ligamentous injuries, one contusion and one fracture.

The clinical examinations carried out by one of the authors (JK) included measurements of hyperextension of the knee and hamstring tightness while the subjects lay in a supine position. For measurements of passive hyperextension, the examiner raised the leg in order to fully hyperextend the knee. The range of motion was measured using a two-armed standard goniometer and findings were recorded to the nearest degree.

Hamstring tightness was measured using passive straight-leg-raising (SLR) with a hydrogoniometer placed just above the patella of the leg to be tested. The examiner put his leg on the other leg for stability purposes, and raised the leg to be tested slowly and evenly, avoiding abduction and rotation and keeping the knee fully extended until tightness or pain restricted movement. The mean of readings from the two legs was used for calculations. Subjects with a right–left difference exceeding 15° were excluded from this analysis.

Systemic hypermobility (hypermobility index) was examined using the Carter and Wilkinson Score as modified by Beighton et al.[10] The test included passive dorsiflexion of the little fingers beyond 90°, passive apposition of thumbs to the flexor aspect of the forearm, hyperextension of elbows beyond 10°, hyperextension of the knees beyond 10° and flexion of trunk with the knees in extension so that the palms of the hands rested on the floor.

The vertical jumping height was determined from the flight time of three jumps.[11] The subjects kept their hands on their hips during the entire jump. The flight time of the jumps was used to calculate the height of the rise of the body's centre of gravity. The recovery time between the attempts was 15 seconds. The coefficient of variation between repeated measurements was 3.9%. The highest of the three values was used for calculations.

Knee instability was assessed manually and instrumentally. Clear medial or lateral instabilities resulting from totally ruptured ligaments were evaluated clinically with the knee in 0 and 30° flexion.

Instrumented measurements of sagittal knee laxity were taken on both legs with a KT-1000 arthrometer (MEDmetric Corporation, San Diego, CA, USA) according to the recommended guidelines. Manual maximum was recorded in three consecutive successful measurements of anterior translation. The coefficient of variation between repeated measurements for right and left knees was between 2.1% and 2.5%. The mean of the second and third trials was used for calculations.

Table 1 Characteristics of the participants

	Runners (n = 28)	Soccer† players (n = 31)	Weight lifters (n = 29)	Shooters (n = 29)
Age, years				
Mean (SD)	59.7 (4.7)	56.5 (5.7)	59.3 (5.3)	61.0 (4.3)
Range	51–67	45–67	46–66	50–68
Height (cm)				
Mean (SD)	173.0 (4.8)	176.9 (5.4)	167.0 (6.6)	175.2 (6.6)
Range	162.0–183.0	165.0–187.0	154.0–183.0	164.0–188.0
Weight (kg)				
Mean (SD)	75.7 (9.7)	84.2 (12.1)	80.7 (13.8)	81.9 (8.4)
Range	60.0–108.0	68.0–123.0	57.0–111.0	71.0–99.0
Body-mass index (kg/m^2)				
Mean (SD)	25.3 (2.8)	26.9 (3.4)	28.8 (3.6)	26.7 (2.5)
Range	20.9–34.9	22.0–38.8	22.5–38.4	22.9–30.8

Table 2 Mean values (SD) and ranges of anterior tibial displacement (mm) in all athletes of the four groups and in those with right–left difference of 4 mm or less

	Runners (n = 28)	Soccer players (n = 31)	Weight lifters (n = 29)	Shooters (n = 29)
All athletes				
Mean (SD)	7.3 (1.8)	7.1 (2.1)	8.4 (2.0)	9.0 (1.8)
Range	4.3–11.0	4.0–13.9	5.5–13.3	4.6–12.1
Athletes with right–left difference 4 mm or less	(n = 26)	(n = 28)	(n = 27)	(n = 27)
Mean (SD)	7.2 (1.8)	6.7 (1.7)	8.3 (1.8)	9.1 (1.7)
Range	4.3–11.0	4.0–11.6	5.5–12.6	4.6–12.2

All subjects also underwent a knee X-ray examination and modification of Kellgren and Lawrence criteria was used in the radiographic grading of knee osteoarthrosis.[12] Weight and height were measured and body-mass index (BMI) was calculated (Table 1).

Statistical analyses were carried out using BMDP Statistical software. One-way analysis of variance (ANOVA) was used to compare group means. For multiple comparisons, Student–Newman–Keuls (SNK) test was used.

The authors used multiple linear regression analysis, when analysing the determinants of variation in inter-individual knee laxity (anterior tibial displacement) and used the mean of right and left knees in this analysis. Subjects (n = 9) with a more than 4 mm difference between the knees in anterior tibial displacement were excluded from the analysis.

Multiple linear regression analysis was also used to study the determinants of the right–left difference in knee laxity.

RESULTS

The arthrometer measurements showed statistically significant differences of knee laxity between the athlete groups (P = 0.0002, ANOVA). Laxity was greater (P < 0.05; SNK test) in shooters (mean 9.0 mm) and weight lifters (mean 8.4 mm) than in runners (mean 7.3 mm) and soccer players (mean 7.1 mm) (Table 2). When the knee was examined clinically in 30° flexion, clear medial instability was found in 11 (9.4%) of the subjects (one runner, eight soccer players, two shooters). Lateral instability was found in one soccer player. There was no statistically significant difference in anterior knee laxity between the athletes with or without clear medio-lateral knee instability (P = 0.24).

Among all athletes, the mean right–left difference in anterior knee laxity was 1.5 mm (SD 1.6; range 0.0–8.5 mm). A difference of more than 2 mm was documented in three soccer players (10%), Five runners (18%), seven weight lifters (24%) and 10 shooters (34%). A difference exceeding 4 mm was found in nine (8%) of the athletes (two runners, three soccer players, two weight lifters and two shooters).

To establish the factors associated with the right–left difference, the following factors were entered into a step-wise multiple regression analysis:

- Athelete group
- BMI
- Hypermobility index
- Height
- Degree of hyperextension of the knees
- Extent of tibiofemoral osteoarthrosis based on the radiographic examination
- Hamstring tightness
- Previous knee injury
- Years of heavy occupational lifting
- Years in kneeling or squatting work.

The only factor that was significantly associated with the right–left difference was previous knee injury explaining about 9% of its variation. Previous knee injury was recorded in 14 soccer players, six weight lifters, three runners and three shooters. The mean difference was 2.3 mm in those injured and 1.3 mm in those without previous injury (P < 0.001).

After excluding the nine athletes with a right–left difference of more than 4 mm, there were still differences in anterior knee laxity between the athlete groups (P < 0.001) (Table 2). When the determinants of knee laxity were analysed among these subjects (n = 108) the following factors entered the final multiple regression model:

- Athlete group
- Hamstring tightness value
- Degree of hyperextension of the knees.

Together, these three factors explained 29% (Table 3) of the inter-individual variation in knee laxity. The mean anterior laxity was 8.5 mm in those with knee hyperextension of 5° or more (n = 42), 7.7 mm in those with hyperextension between 1° and 4° (n = 44) 7.7 mm and 6.9 mm in those with no hyperextension at all (n = 22) (P < 0.008). When hyperextension was left out from the regression model, athlete group and hamstring tightness explained 26% of the inter-individual variation in knee laxity.

Table 3 Multiple linear regression analysis of factors explaining inter-individual variation in knee laxity

Factors that entered final model	Cumulative explanation rate* (r^2)	Regresion coefficient†	Standard error of regression coefficient†	P-value‡
Soccer players	0.0918	−1.6568	0.4045	0.01
Runners	0.1958	−1.5199	0.4098	0.01
Hamstring tightness	0.2569	0.0313	0.0138	0.03
Knee hyperextension	0.2921	0.1363	0.0627	0.03

*From stepwise model; †from fixed model; ‡ from fixed model by Wald's test.

Similarly, the mean anterior laxity was 8.5 mm in those with hamstring tightness value less than 75° ($n = 28$), 7.9 mm in those with values between 75° and 90° ($n = 59$) and 6.9 mm when the value exceeded 90° ($n = 21$) ($P < 0.02$).

DISCUSSION

We found that former shooters and weight lifters had higher sagittal knee laxity than soccer players and runners. Previous meniscal and ligamentous knee injuries as well as medio-lateral instability were common among soccer players. However, in only three soccer players, the right–left difference in laxity was more than 4 mm and in all other soccer players, the difference was 2 mm or less. Besides athlete group, hamstring tightness and hyperextension of the knee moved explanatory for the variation in knee laxity. The only factor that was found to explain the right–left difference was previous knee injury, although most of the variability remained unexplained.

Overall, our results agree with earlier observations in that physical activities involving kneeling may increase knee laxity. Exercise has been reported to acutely increase knee joint laxity[8] which returns to normal within 1 hour after cessation of the activity.[13] A more sustained increase in sagittal knee laxity has been reported among miners.[14] Anterior knee laxity was highest in shooters and lowest in soccer players. In lack of adequate age-specific reference values, it is impossible to say weather it is the laxity level of shooters and weight lifters or that of runners and soccer players that represents the knee laxity in the general population of corresponding age.

In our study, laxity was positively associated with hyperextension of the knee. Interestingly, similar association was not observed with general hypermobility. Increased knee laxity was associated with increased hamstring tightness. This was an unexpected finding. One explanation could be that, subjects who have increased knee laxity are probably found to have hamstring tightness provoked by knee pain.

Knee injuries, hyperextension of the knee and physical activities involving squatting and kneeling seem to increase knee laxity. Nevertheless, our understanding of factors responsible for the inter-individual variation in knee laxity is still limited.

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IV

Jumping height in former elite athletes

by

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ORIGINAL ARTICLE

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Jumping height in former elite athletes

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Abstract To evaluate lower-limb explosive strength with respect to lifetime athletic activity, we measured vertical jumping height on a contact mat in former male runners ($n = 28$), soccer players ($n = 31$), weightlifters ($n = 29$) and shooters ($n = 29$) (age range 45–68 years). There were no statistically significant age-adjusted sport-group differences in jumping height, but differences by sport were evident among the subgroup of athletes without hip or knee osteoarthritis ($n = 65$) ($P < 0.05$). Thus, sports that increased jumping height also predisposed to lower-limb osteoarthritis. After adjustment for age and sport, the subjects without osteoarthritis jumped higher than those with osteoarthritis ($n = 33$) ($P < 0.01$). In a multiple linear regression analysis, age, reported hip and knee disability, and knee pain reduced jumping height. Hours spent in team-training during the past 12 months and the hours spent during their lifetime in power training were associated with improved vertical jumping height and together explained 41% of the difference among the subjects. The ability to jump even among athletes with hip or knee osteoarthritis would suggest that former elite athletes possess advanced lower limb muscle function.

Key words Knee · Hip · Sports · Osteoarthritis · Explosive strength

Introduction

The importance of life-long physical activity for lower limb function is controversial. Exercise-related physical loading can predispose to osteoarthritis (OA) of weight-bearing joints. In particular, hip and knee OA have been reported among former team game and power sport athletes (Klünder et al. 1980; Lindberg et al. 1993; Kujala et al. 1994a 1995), but the risk has not been found to be equally elevated in former endurance athletes (Kujala et al. 1994a).

Old active male subjects have been found to develop higher isometric knee-extension forces than do their population sample controls (Sipilä et al. 1991) and those with greater isometric strength also demonstrate a higher maximal walking speed (Rantanen et al. 1994). In old age, members of a runners' club have been shown to have better lower-extremity function than do their community controls (Fries et al. 1994). Among healthy subjects from the general population, physically active old subjects are usually stronger than inactive controls, and lower-limb muscle strength has a favourable effect on their mobility.

Among former elite athletes the benefits on mobility of lower-limb muscle strength versus the adverse effect of hip or knee OA are unknown. The aim of this study was to investigate jumping height among former elite athletes from different sports, taking into account the possible development of hip or knee OA. We selected former top-level athletes in sports which differed in the long-term loading on hip and knee joints and training of the muscles. The four study groups included former long-distance runners, soccer players, weightlifters and shooters.

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Methods

Subjects

We identified male athletes who had participated at least once in the Olympic, World or European championships, or in intercountry competitions between 1920 and 1965 (Sarna et al. 1993). In 1985, a questionnaire on health and life-style was mailed to all such surviving athletes. Respondents who in 1992 were aged 45–68 years including all the shooters ($n = 35$) and runners ($n = 38$), as well as a sample of the soccer players ($n = 37$) and weightlifters ($n = 37$), who were of comparable age and occupation, were invited to participate in the study. Of the total 117 (80%) agreed to participate including 28 runners, 31 soccer players, 29 weightlifters and 29 shooters (Table 1). Interviews, clinical examinations and

Table 1 Characteristics of the participants, lifetime regular participation-hours in various types of athletic training, participation during the past 12 months (hours each week) in physical activity, years of heavy work, reported hip and knee pain and disability and hip or knee osteoarthritis (*OA*) among former elite male athletes in the four groups of athletes. Pain, disability and *OA* values are cases (%)

	Long-distance runners $n = 28$	Soccer players $n = 31$	Weightlifters $n = 29$	Shooters $n = 29$
Age (years)				
Mean	59.7	56.5	59.3	61.0
Range	51–67	45–67	46–66	50–68
Height (cm)				
Mean	173.0	176.9	167.0	175.2
Range	162.0–183.0	165.0–187.0	154.0–183.0	164.0–188.0
Body mass (kg)				
Mean	75.7	84.2	80.7	81.9
Range	60.0–108.0	68.0–123.0	57.0–111.0	71.0–99.0
Body-mass index (kg/m^2)				
Mean	25.3	26.9	28.8	26.7
Range	20.9–34.9	22.0–38.8	22.5–38.4	22.9–30.8
Straight leg-raising (°)				
Mean	85.5	84.7	88.7	80.4
Range	63.5–119.0	60.0–110.0	71.0–114.0	56.0–92.5
Lifetime endurance training				
Hours, median	8980	1530	1520	2480
Range	1300–18752	0–9936	0–8483	0–8536
Lifetime team-sport training				
Hours, median	0	8240	1150	140
Range	0–3072	3864–18514	0–4888	0–5500
Lifetime power training				
Hours, median	0	0	9460	0
Range	0–1280	0–1600	284–16752	0–1092
Past 12 months endurance training				
Hours each week, mean	2.23	0.62	0.81	0.55
Range	0.0–7.4	0.0–5.2	0.0–5.8	0.0–2.2
Past 12 months team-sport training				
Hours each week, mean	0.00	1.57	0.22	0.10
Range	0.0–0.0	0.0–8.3	0.0–3.0	0.0–2.5
Past 12 months power-sport training				
Hours each week, mean	0.12	0.10	0.92	0.00
Range	0.0–2.0	0.0–1.5	0.0–6.0	0.0–0.0
Past 12 months shooting				
Hours each week, mean	0.00	0.00	0.13	0.21
Range	0.0–0.0	0.0–0.0	0.0–2.4	0.0–6.2
Past 12 months gymnastics				
Hours each week, mean	0.07	0.06	0.02	0.06
Range	0.0–1.0	0.0–1.0	0.0–0.5	0.0–1.2
Sum of all forms of training				
Hours each week, mean	3.19	3.03	2.99	3.70
Range	0.0–8.7	0.0–7.2	0.0–8.8	0.0–9.9
Years of heavy work				
Years, mean	12.3	1.7	9.7	3.2
Range	0.0–47.0	0.0–40.0	0.0–43.0	0.0–38.0
Pain				
Monthly knee pain, *n* (%)	6 (21)	14 (45)	8 (28)	5 (17)
Monthly hip pain, *n* (%)	6 (21)	4 (13)	2 (7)	5 (17)

Table 1 (contd.)

	Long-distance runners $n = 28$	Soccer $n = 31$	Weightlifters players $n = 29$	Shooters $n = 29$
Disability				
Reported knee disability, n (%)	3 (11)	11 (35)	7 (24)	2 (7)
Reported hip disability, n (%)	2 (7)	1 (3)	1 (3)	1 (3)
OA				
Knee OA, n (%)	4 (14)	9 (29)	9 (31)	1 (3)
Hip OA[a] n (%)	3 (12)	3 (12)	4 (16)	6 (30)

[a] *Hip OA* runners $n = 25$, soccer players $n = 25$, weightlifters $n = 20$ (19 magnetic resonance imaged documented cases and one hip prothesis), shooters $n = 25$

radiographic assessments were carried out independently by investigators unaware of the results obtained by others. This study was accepted by the Ethics Committee of the Research Centre of the Social Insurance Institution (Turku, Finland).

Interview

The subjects were interviewed by one of the authors (HR) on lifetime regular participation (hours) in various types of athletic training (endurance, team, power) and on hip or knee pain and disability (Table 1). Sports participation during the 12 months prior to the interview (hours each week) and the sum of all forms of training were calculated. We classified the occupation of each athlete into categories: 1 = mainly sedentary; 2 = mainly walking or standing; 3 = with a variety of tasks including some bending and twisting, but seldom lifting anything heavier than 35 kg; 4 = a variety of tasks with bending, twisting and daily lifting more than 35 kg; and 5 = very heavy jobs including maximal lifts in bent and twisted positions. Years spent in occupations in categories 4 or 5 were designated as years of heavy work (Table 1).

During the previous year occurrence of hip pain was noted for each hip when it appeared at least monthly. Disability was scored for each hip on a scale from 0 to 7 depending on whether the subjects reported pain or disability with/during:

1. Nocturnal bedrest
2. More than 5 min in the morning after getting out of bed
3. Sitting for 30 min
4. Fully supported by the legs
5. Walking more than 1 km
6. Going up or down stairs
7. Squatting or bending forward

The sum of positive responses was calculated and scores of at least three *points* for either hip were considered to indicate hip disability. Occurrence of knee pain and disability were investigated by the same criteria as for the hip.

Clinical examinations and quantitive functional measurements

These examinations were performed by JK. The subjects' body mass and height were measured and body-mass index (BMI) calculated (Table 1). Hamstring tightness was measured for passive straight-leg-raising (SLR) with a hydrogoniometer. Vertical jumping height was determined from the flight time of three jumps (Bosco 1980). The subjects performed the jumps with no countermovement from a static position of 90° knee angle while they kept their hands on their hips. Flight time was used to calculate height of the rise of the body's centre of gravity. Recovery time between attempts was 15 s. The coefficient of variation between repeated measurements was 3.9%, with the highest of the three values used for calculations.

A total of 110 subjects participated in the jumping test. Of this number 3 subjects were excluded because of knee pain and 4 subjects because of low back pain, hip pain, hip endoprothesis and coronary heart disease.

Knee x-ray examination

All the subjects underwent a knee x-ray examination. A modification of the Kellgren and Lawrence criteria was used in the grading of knee OA (Kujala et al. 1995).

Hip magnetic resonance imaging

Supine magnetic resonance imaging (MRI) was performed by a 1.5 T device (Magnetom, Siemens AG, Erlangen, Germany) with a body coil. A 3D FISP (fast imaging with steady precession) sequence was chosen because it gives a good image of the articular cartilage. Axial slices of both hips were produced, with imaging parameters as follows: TR 30 ms/TE 10 ms/flip angle 40°, 256 × 256 matrix, field-of-view 36 cm, 2-mm slice thickness with no interslice gap, total imaging time 8 min 14 s. Of the 94 subjects examined, 25 were long-distance runners, 25 soccer players, 19 weightlifters and 25 shooters. Of the 23 subjects not imaged, 14 had foreign bodies or metallic implants, 7 offered technical difficulties, 1 had claustrophobia and 1 had shoulders too wide to be monitored.

An athlete was considered to have hip OA if he had an obliterated hip joint space (grade 3) or osteoarthritic deformation of the caput femoris or cyst formation in the caput femoris. There was 1 subject with hip prothesis due to OA who was included in the OA group, but he did not take part in jumping test.

To evaluate the reliability (intra-observer variation) of the MRI-readings, we grouped MR images by grade of joint-space narrowing, and then randomly added some from each group up to a total of 55 hips, enriching the MR images with OA changes. The radiologist re-read these films without information on previous readings (6 months had elapsed since the first reading). The generalized kappa statistics for re-evaluations for joint-space narrowing was 0.58. Of the other noted changes evaluation of the repeatability was not possible because of their small number.

Statistical analysis

The statistical analysis was carried out using BMDP statistical software. Analysis of covariance was used to compare age-adjusted sport-group means among all the subjects and among subjects without hip or knee OA, and also to compare age- and sport-group-adjusted means between subjects with or without hip or knee OA. Multiple regression analysis was used in evaluating association between jumping height and different explanatory variables.

Results

No statistically significant ($n = 110$) age-adjusted sport-group differences appeared for jumping height (Table 2),

Table 2 Jumping height (cm) in the four athlete groups. *OA* Osteoarthritis

	Long-distance runners (n = 26)	Soccer players (n = 30)	Weightlifters (n = 25)	Shooters (n = 29)	P
Jumping height: all athletes (n = 110)					
Mean (SEM)	23.3 (0.01)	24.9 (0.01)	26.9 (0.01)	24.2 (0.01)	0.098
Range	15.2–35.4	12.2–37.5	14.1–38.2	15.7–36.6	
	(n = 18)	(n = 16)	(n = 12)	(n = 19)	
Jumping height: athletes without hip or knee OA (n = 65)					
Mean (SEM)	24.7 (0.01)	26.2 (0.02)	29.4 (0.02)	24.2 (0.01)	0.025
Range	20.0–35.4	16.1–37.5	19.3–37.6	15.7–36.6	
	(n = 6)	(n = 11)	(n = 9)	(n = 7)	
Jumping height: athletes with hip or/and knee OA (n = 33)					
Mean (SEM)	20.1 (0.04)	23.2 (0.02)	21.9 (0.03)	23.4 (0.04)	0.578
Range	16.3–26.7	12.2–31.0	14.1–35.4	18.7–27.7	

but age-adjusted sport-group differences did occur among subgroups (n = 65) of athletes without hip or knee OA ($P < 0.05$ among all groups): weightlifters having the highest (mean 29.4 cm) and shooters the lowest (mean 24.2 cm) jumping height.

After adjustment for age and sport group, jumping height was less in those with hip or knee OA (n = 33) (mean 22.4 cm) than in those without (n = 65) (mean 25.7 cm) ($P < 0.01$).

To establish the factors associated with jumping height (n = 89), we entered athlete-group, BMI, SLR, age, years in heavy work, lifetime participation (hours) in various types of athletic training, types of physical activity during the past 12 months, hip or knee OA, hip or knee pain and disability into a multiple linear regression analysis. The factors associated with jumping height were: age (11%, $P < 0.01$), participation in team sports during the past 12 months (7%, $P < 0.01$), reported knee (9%, $P < 0.01$) and hip (7%, $P < 0.01$) disability, lifetime participation in power sport (5%, $P = 0.01$) and monthly knee pain (2%, $P = 0.05$) together explaining 41% of its variation. The mean decrease in jumping height was about 12% in a decade.

Among those subjects without hip and knee OA, factors that were associated with jumping height were hours spent in team-sport training during the previous 12 months (13%, $P < 0.01$), age (9%, $P < 0.01$) and weightlifting (11%, $P < 0.01$), explaining altogether 33% of its variation.

Discussion

Among the sport groups investigated, there appeared to be no differences in jumping height by sport group, but those former elite male athletes without lower limb OA did have better vertical jumping height than those with lower limb OA. Among the subgroup without OA, weightlifters had the highest and shooters the lowest vertical jump results. However, the shooters were more physically active than the general population and jumped higher than did healthy sedentary male subjects in a similar population sample (Kujala et al. 1994b). In the multiple linear regression analysis, participation in team-sports during the past 12 months and lifetime participation in power-sports were associated with a high vertical-jump result, and age, reported hip or knee disability, and knee-pain decreased vertical jumping height. Because distributions of some variables (Table 1) were somewhat skew, we also carried out the regression analysis using quartiles and dichotomical scale. The main results were similar. However, when analysing the association between jumping height and different variables among all subjects, rather than participation in team sports during the past 12 months and lifetime participation in power sport, lifetime participation in team sport was associated with the vertical jumping height.

Our findings confirmed the findings that have been obtained by others, that muscle strength decreases with age (Overrend et al. 1992; Porter et al. 1994; Lindle et al. 1997). Lexell et al. (1988) have reported that loss of muscle fibres and a reduction in the size of the fibres reduce the vastus lateralis muscle area with increasing age: approximately 10% of the muscle area is lost by the age of 50. We did not image muscle morphology but among those with no hip or knee OA, the mean decrease in vertical jump was about 12% per decade.

The ability to perform a vertical jump, especially among weight-lifters may be related to selection of *talents* or to type of training. Among the subjects without hip and knee OA, weightlifting was associated with jumping height as was participation in team sports during the past 12 months. Sarna et al. (1993) have found that more than 60% of former male elite athletes engage in leisure-time physical activity or competitive sports throughout their adult life compared to 17% among the age-matched control population. The role played by training and leisure-time physical activity for muscle strength has been reported. Male veteran sprinters and jumpers (aged 70–81 years) were able to jump higher than strength-trained or endurance-trained athletes and controls (Sipilä et al. 1991). Era et al. (1992) have studied isometric muscle strength in men in their thirties, fifties and seventies. Among the two younger groups of subjects, good self-rated health and intensity of leisure-time physical exercise were associated with isometric muscle strength. In the oldest group, the most important variable was home gymnastics. Also among a sample of a Finnish urban population everyday physical activity has been related to vertical jumping height, and subjects participating in mixed training could jump higher than those participating only in typical aerobic training (Kujala et al. 1994b).

Hip and knee OA and pain may lower physical activity and thus reduce muscle-function. Hip or knee OA reduce the vertical jump, but in the multiple linear regression analysis, only reported hip or knee disability and knee pain were associated with jumping height. Moreover, McAlindon et al. (1993) have reported that quadriceps strength, knee-pain and age were more important determinants of functional impairment among elderly subjects than was the severity of radiographic knee OA. After adjusting the jumping-height results of our athletes to age 55 years and comparing our athletes to a population sample of healthy 55-year-old men (Kujala et al. 1994b), even our athletes with hip or knee OA were able to jump higher than healthy sedendary men (mean 23.9 cm vs 19.4 cm) and as high as the healthy active men (mean 23.9 cm vs 24.5 cm). Because we used a squat jump from a static position, compared to the counter-movement jump that has been previously used (Kujala et al. 1994b), the difference in favour of the athletes is even higher. It has been shown that it is possible to jump higher in the countermovement jump than in the squat jump (Bobbert et al. 1996). Thus, despite hip or knee OA, the athletes have good lower-limb muscle function. Shooters were excluded from this analysis, because shooters served as a *control* group for the present study.

Among former elite male athletes, lifetime hours spent in power -training and in team-sport training during the previous 12 months were associated with good vertical jumping height; however age, reported hip or knee disability and knee pain decreased the height of a vertical jump. The jumping-height result among athletes with hip or knee OA would suggest that despite lower-limb OA, the former elite athletes did have good lower-limb muscle function.

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V

Lower-limb function among former elite athletes

by

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Manuscript

LOWER-LIMB FUNCTION AMONG FORMER ELITE MALE ATHLETES

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ABSTRACT

To determine the relationship between previous lower-limb loading and current self-reported hip and knee disability we sent a questionnaire to former elite male athletes (N=1321), who had represented Finland between 1920 and 1965 in international competition and controls (N=814), who had been classified healthy at the age of 20. After adjustment for age, BMI and occupational group the odds ratios of hip disability compared with controls were 0.35 in endurance athletes (95% confidence interval 0.14 to 0.85, P=0.02), 0.56 in team sport athletes (0.28 to 1.10, P=0.09), 0.30 in track and field athletes (0.12 to 0.73, P<0.01), 0.84 in power sport athletes (0.51 to 1.39, P=0.49), 0.30 in shooters (0.07 to 1.32, P=0.11) and 0.54 (0.36 to 0.82, P<0.01) in all athletes combined. Compared to controls, only team sport athletes had higher odds ratio of knee disability (1.76, 1.03 to 3.02, P=0.04). Even though athletes have been reported to be at increased risk for lower-limb OA, our data show that former elite male endurance and track and field athletes and all athletes combined reported less hip disability than their controls. The effect of vigorous athletic activity on the function of knee joints is more controversial, because sports involve the risk of knee injuries and such injuries may predict disability.

INTRODUCTION

The number of elderly people in the population is increasing rapidly and the relationship between physical activity and a disability-free life is highly relevant for public health. Lifetime of physical activity reduces the risk of several major chronic diseases, such as coronary heart disease and NIDDM. In contrast sport-related loading (Kujala et al. 1994, Lindberg et al. 1993, Vingård et al.1993) and strenuous occupational loading (Vingård et al.1991, Croft et al.1992) have been shown to increase the risk of hip and knee osteoarthritis (OA). Lower-limb injuries, such as knee and ankle sprain in soccer, accelerate the development of osteoarthritis. However, our knowledge of the role of sport-related activity in youth for lower-limb function in old age is limited.

Musculoskeletal disability decreases quality of life. In our previous study, former elite athletes with knee OA were more likely to report knee pain and disability than were athletes without knee OA (Kujala et al. 1995). On the other hand, physical activity helps maintain good lower-limb function, which is an important factor for independent life in old age. Among 75-year-old men and women good maximal strength levels were positively associated with mobility (Rantanen et al. 1994). Slemenda and coworkers (Slemenda 1997) have even hypothesized that quadriceps weakness is a primary risk factor for knee pain, disability and progression of knee OA. Furthermore, aerobic or resistance exercise has been reported to reduce knee pain and disability (Ettinger et al.1997) and good lower-limb muscle function among former elite athletes, even among those with hip or knee OA has been reported (Kettunen et al. 1999). Thus, different types of exercise-related physical loading during adolescence and adulthood may increase the risk for lower-limb OA, but the same activity which predisposes to OA may also have a favorable effect on mobility and may delay onset of physical disability. The purpose of this paper was to investigate the association between participation in different types of sports during adolescence and adulthood and self-reported lower-limb pain and disability in older men. These findings are compared with those for controls, who were reported to be healthy at the age of 20.

MATERIALS AND METHODS

Subjects

We identified male athletes who had participated at least once in the Olympic Games, World or European championships, or international competitions (athletic contests between two or more countries) between 1920 and 1965. Controls were selected among Finnish men who were classified at the age of 20 years completely healthy at the beginning of their military service (Sarna et al. 1993). In earlier investigations of various health effects of different types of athletic activity (Sarna et al. 1993, Kujala et al. 1994, Kujala et al. 1996) the athletes were grouped according to the type of training needed to achieve maximal results, i.e. principally aerobic training, principally anaerobic training, or mixed training. In present study we followed the same classification, but athletes with mixed training were further classified into two subgroups according to the risk of injury to the lower-limb joints. Thus, endurance athletes (long-distance running, cross-country skiing) are those that experience a high amount of repetitive loading of the weight-bearing joints; team sport athletes (soccer, ice hockey, basketball) include those with greater risk of high impact loads and sprains of the joints; track and field athletes (jumping, sprinting, hurdling, middle-distance running, decathlon) are at higher risk of high impact loads but smaller risk of sprains of the joints; power sport athletes (boxing, wrestling, weight lifting, throwing) are exposed to less repetitions but higher forces when loading the joints; and shooters who take light to moderate general exercise involving some kneeling and squatting. Because, among the power sports group in particular there is variation in the loading patterns, some results are given also separately for each sport type.

The 1995 Questionnaire

In 1995 a questionnaire was mailed to the cohort of surviving former athletes and controls (N=2135). The response rate was 75.0% (991/1321) for the athletes and 70.9% (577/814) for the controls. The questionnaire included items on physician-diagnosed hip or knee osteoarthritis (yes/no) separately for onset before and after the age of 45 years. Moreover, items referring specifically to physician-diagnosed knee ligament injuries, knee meniscal injuries and the need of hospital treatment for knee injury were included. Table 1 shows the characteristics of the study subjects. BMI was calculated based on self-reported weight and height.

TABLE 1 Characteristics of the study subjects

	Endurance sport N=141	Track and field sport N=230	Team sport N=262	Power sport N=301	Shooters N=57	Controls N=577
Age in 1995						
Years, mean(SD)	68.8(9.4)	64.4(9.3)	61.8(8.3)	64.5(8.3)	70.7(10.8)	62.4(8.1)
Range	50.0-92.0	49.0-88.0	48.0-95.0	48.0-90.0	47.0-99.0	49.0-91.0
BMI						
Mean(SD)	24.6(2.8)	25.3(2.9)	26.4(3.0)	28.0(4.1)	25.7(3.3)	26.8(3.7)
Range	19.1-33.8	16.1-42.6	8.6-39.8	19.1-46.3	19.5-35.5	16.2-42.6
Occupational group N(%)						
Executives	7(5.6)	93(44.9)	84(36.4)	39(14.7)	20(39.2)	64(12.8)
Clerical workers	62(49.2)	77(37.2)	99(42.9)	96(36.2)	21(41.2)	142(28.3)
Skilled workers	35(27.8)	30(14.5)	47(20.3)	113(42.3)	6(11.8)	213(42.5)
Unskilled workers	7(5.6)	1(0.5)	1(0.4)	7(2.6)	0(0.0)	19(3.8)
Farmers	15(11.9)	6(2.9)	0(0.0)	10(3.8)	4(7.8)	63(12.6)

Endurance sport = Long-distance running, Cross-country skiing, Track and field = Jumping, Sprinting, Hurdling, Middle-distance running, and Decathlon, Team sport = Soccer, Ice hockey, Basketball, Power sport = Boxing, Wrestling, Weight lifting, Throwing

Occupational groups (Sarna et al. 1993) were classified into the following categories: executives, clerical workers, skilled workers, unskilled workers, and farmers. Each person was classified into the group in which he had been occupationally active the longest (Table 1). Executives were used as a reference group when analyzing the association between occupational group and disability.

Occurrence of hip or knee pain during the previous year and the occurrence of hip or knee disability were determined separately for hips and knees. Those who reported having hip or knee pain at least once per month were classified as having monthly hip or knee pain. Hip and knee disability was scored depending on whether the subjects reported pain or disability (yes=1,no=0) during: 1) nocturnal bedrest, 2) more than 5 minutes in the morning after getting out of bed, 3) sitting for 30 minutes, 4) full support by the legs, 5) walking more than 100 m, 6) going up or down stairs, 7) squatting or bending forward. The sum of positive responses (0-7) was calculated, and subjects scoring at least 3 points for either hip or knee were considered to have hip or knee disability (yes), respectively.

Statistical analyses

The statistical analyses were carried out using BMDP Statistical software. We used stepwise logistic regression models (LR) to analyze the association between different covariates and hip and knee OA, pain and disability.

RESULTS

As expected, the odds ratios (Ors) for either hip or knee disability were higher among older than younger subjects (Table 2), and subjects with high BMI

TABLE 2 ORs and 95% confidence intervals (CI) for hip and knee disability among subjects who completed the 1995 questionnaire. The BMI and occupational group odds ratios are adjusted for age.

	Hip disability			Knee disability		
	OR	95% CI	P-value	OR	95% CI	P-value
Age						
< 50	1.00			1.00		
50 to 59	3.16	0.96 to 10.4	0.08	1.46	0.73 to 2.93	0.29
60 to 69	5.23	1.62 to 16.4	<0.01	1.93	0.98 to 3.82	0.06
70 >	7.59	2.31 to 24.9	<0.001	2.34	1.15 to 4.76	0.02
BMI						
< 25	1.00			1.00		
25 to 28	2.65	1.73 to 4.07	<0.001	1.91	1.34 to 2.74	<0.001
28 >	4.07	2.63 to 6.30	<0.001	3.23	2.24 to 4.65	<0.001
Occupational group						
Executives	1.00			1.00		
Clerical workers	1.52	0.98 to 2.37	0.06	1.22	0.84 to 1.77	0.31
Skilled workers	2.34	1.53 to 3.59	<0.001	1.91	1.33 to 2.74	<0.001
Unskilled workers	1.26	0.29 to 5.49	0.76	0.71	0.17 to 3.08	0.65
Farmers	4.33	2.32 to 8.07	<0.001	1.49	0.75 to 2.96	0.26

had higher ORs for both hip and knee disability than subjects with low BMI (Table 2). Moreover, occupational group was associated with the ORs of either hip or knee disability (Table 2).

Subjects with knee ligament or meniscal injury reported more knee disability (29.5%, 95% confidence interval (CI) 24.5% to 34.6%) than subjects without such injury (7.7%, 6.0% to 9.6%) (P<0.0001).

Table 3 shows the number of subjects who answered the questions about hip and knee disability and the prevalence of hip or knee disability among those subjects.

TABLE 3 Number of subjects who answered the questions about hip and knee disability and the prevalence of hip and knee disability among those subjects.

Sports	HIP DISABILITY Number of subjects	%(N)	95% CI	KNEE DISABILITY Number of subjects	%(N)	95% CI
Endurance sports:	116	7.8 (9)	3.6 to 14.2	109	8.3 (9)	3.9 to 15.1
Long-distance running	77	7.8 (6)	2.9 to 16.2	71	7.0 (5)	2.3 to 15.7
Cross-country skiing	39	7.7 (3)	1.6 to 20.9	38	10.5 (4)	3.0 to 24.8
Team sports:	236	6.8(16)	3.9 to 10.8	211	17.1 (36)	12.0 to 22.1
Soccer	107	6.5 (7)	2.7 to 13.0	90	16.7 (15)	9.6 to 26.0
Hockey	80	10.0 (8)	4.4 to 18.8	77	19.5 (15)	11.3 to 30.1
Basketball	49	2.0 (1)	0.0 to 10.9	44	13.6 (6)	5.2 to 27.3
Track and field:	182	2.7 (5)	0.9 to 6.3	175	8.6 (15)	4.9 to 13.7
Power sports:	284	12.3(35)	8.5 to 16.1	271	15.9 (43)	11.5 to 20.2
Boxing	74	9.5 (7)	3.9 to 18.5	67	9.0 (6)	3.4 to 18.5
Wrestling	82	15.9(13)	8.7 to 25.6	83	25.3 (21)	16.4 to 36.0
Weight lifting	44	11.4 (5)	3.8 to 24.6	40	10.0 (4)	2.8 to 23.7
Throwing	84	11.9(10)	5.9 to 20.8	81	18.5 (15)	10.7 to 28.7
Shooters:	51	7.8 (4)	2.2 to 18.9	50	12.0 (6)	4.5 to 24.3
All Sports:	869	7.9(69)	6.2 to 9.9	816	13.4(109)	11.0 to 15.7
Controls:	489	13.9(68)	10.8 to 17.0	460	12.8 (59)	9.8 to 15.9

N = Number of subjects with disability

Based on the questionnaire, the age-adjusted OR of hip disability was lower among endurance, team sport and track and field athletes, and also among all athletes combined (Table 4) when compared to controls. Additionally the age-adjusted OR of at least monthly hip pain was lower among endurance, team sport, track and field athletes, shooters and all athletes when compared to controls (Table 5). Compared to controls, the OR of hip disability among endurance, track and field and all athletes combined (Table 4), and hip pain among endurance athletes, shooters and all athletes combined (Table 5) were still lower after adjustment for age, occupational group, and BMI. The ORs of knee disability (Table 4) and pain (Table 5) among athletes and controls were similar, except among team sport athletes, who had increased ORs. The ORs of any hip OA either among athletes and controls were similar after adjustment for age, BMI and occupational group (Table 5). Team-sport athletes had higher OR for knee OA after adjustment for age, BMI and occupational group (Table 5). Moreover, compared with controls, the age-adjusted OR for physician-diagnosed knee OA (N=73) before age of 45 was significantly higher among team sport (OR 2.92, 95% CI 1.49 to 5.73, p<0.01) and power sport athletes (2.13, 1.06 to 4.29, p=0.03). The covariate-adjusted OR of knee OA before age of 45 was still higher among team sport athletes (3.38, 1.55 to 7.37 P<0.01). When the sport groups were combined, all athletes had higher age-adjusted OR for physician-diagnosed knee OA (1.98, 1.06 to 3.69, P=0.03) before the age of 45 when compared to controls. The ORs of hip OA (N=27) before age of 45 among athletes and controls were similar.

TABLE 4 Adjusted ORs for hip (N=1358) and knee (N=1276) disability in subjects who completed 1995 questionnaire

Sports	HIP				KNEE			
		Adjusted for age and:				Adjusted for age and:		
	Adjusted for age	occupational group	BMI	occupational group and BMI	Adjusted for age	occupational group	BMI	occupational group and BMI
Endurance athletes:								
OR	0.37	0.31	0.43	0.35	0.53	0.56	0.70	0.71
95% CI	0.17 to 0.80	0.13 to 0.75	0.19 to 0.94	0.14 to 0.85	0.25 to 1.11	0.25 to 1.24	0.33 to 1.49	0.32 to 1.60
P value	0.011	0.009	0.033	0.019	0.092	0.153	0.357	0.416
Team sports athletes:								
OR	0.45	0.53	0.47	0.56	1.41	1.59	1.61	1.76
95% CI	0.25 to 0.79	0.27 to 1.04	0.27 to 0.83	0.28 to 1.10	0.90 to 2.22	0.94 to 2.68	1.01 to 2.56	1.03 to 3.02
P value	0.006	0.061	0.010	0.088	0.139	0.087	0.046	0.038
Track and field athletes:								
OR	0.20	0.27	0.22	0.30	0.63	0.82	0.77	0.97
95% CI	0.10 to 0.45	0.11 to 0.66	0.10 to 0.50	0.12 to 0.73	0.36 to 1.11	0.44 to 1.54	0.43 to 1.37	0.51 to 1.84
P value	<0.001	0.004	0.001	0.007	0.113	0.542	0.378	0.933
Power sports athletes:								
OR	0.82	0.94	0.72	0.84	1.31	1.48	1.10	1.25
95% CI	0.52 to 1.29	0.58 to 1.54	0.46 to 1.15	0.51 to 1.39	0.85 to 2.03	0.92 to 2.37	0.70 to 1.72	0.77 to 2.03
P value	0.179	0.811	0.168	0.492	0.222	0.104	0.690	0.378
Shooters:								
OR	0.38	0.27	0.41	0.30	0.71	0.70	0.84	0.84
95% CI	0.13 to 1.12	0.06 to 1.21	0.14 to 1.21	0.07 to 1.32	0.28 to 1.79	0.23 to 2.11	0.33 to 2.13	0.27 to 2.55
P value	0.351	0.083	0.106	0.108	0.469	0.526	0.720	0.755
All sports:								
OR	0.47	0.53	0.48	0.54	1.03	1.16	1.10	1.21
95% CI	0.33 to 0.68	0.35 to 0.80	0.33 to 0.69	0.36 to 0.82	0.73 to 1.46	0.79 to 1.71	0.77 to 1.56	0.82 to 1.79
P value	<0.001	0.003	<0.001	0.003	0.856	0.440	0.609	0.345
Controls:								
(OR)	1.00				1.00			

TABLE 5 Number (N) of subjects, who answered the specific questions, prevalence rates N(%) of hip and knee OA and pain among athletes and controls, and adjusted ORs and 95% CIs for hip and knee OA and pain among athletes compared with controls

	N	N(%)	95% CI	Adjusted for age			Adjusted for age, occupational group and body mass index		
				OR	95 % CI	P-value	OR	95 % CI	P-value
HIP OA									
Endurance	116	31(26.7)	18.7 to 34.8	1.16	0.70 to 1.92	0.57	1.40	0.80 to 2.45	0.23
Track and field	203	21(10.3)	6.2 to 14.5	0.43	0.25 to 0.74	<0.01	0.66	0.36 to 1.20	0.17
Team-sport	209	28(13.4)	8.8 to 18.0	0.77	0.48 to 1.24	0.27	1.13	0.66 to 1.92	0.66
Power-sport	248	50(20.2)	15.2 to 25.2	1.02	0.68 to 1.53	0.93	1.06	0.68 to 1.67	0.78
Shooting	54	13(24.1)	13.5 to 37.6	0.80	0.39 to 1.67	0.55	1.10	0.49 to 2.46	0.82
All sport	830	143(17.2)	14.7 to 19.8	0.80	0.58 to 1.09	0.15	1.03	0.72 to 1.48	0.86
Controls	481	81(16.8)	13.5 to 20.2	1.00		1.00			
KNEE OA									
Endurance	122	31(25.4)	17.7 to 33.1	0.84	0.53 to 1.36	0.48	1.11	0.66 to 1.85	0.70
Track and field	212	49(23.1)	17.4 to 28.8	0.89	0.61 to 1.31	0.56	1.32	0.85 to 2.06	0.22
Team-sport	228	70(30.7)	24.7 to 36.7	1.50	1.05 to 2.13	0.03	2.04	1.35 to 3.07	<0.01
Power-sport	253	69(27.3)	21.8 to 32.8	1.08	0.76 to 1.54	0.67	1.04	0.70 to 1.55	0.83
Shooting	52	11(21.2)	11.1 to 34.7	0.61	0.30 to 1.27	0.19	0.83	0.37 to 1.86	0.65
All sport	867	230(26.5)	23.6 to 29.5	1.05	0.81 to 1.36	0.70	1.28	0.95 to 1.73	0.10
Controls	508	120(23.6)	19.9 to 27.3	1.00			1.00		
HIP PAIN									
Endurance	125	16(12.8)	6.9 to 18.7	0.34	0.19 to 0.60	<0.01	0.32	0.17 to 0.61	<0.01
Track and field	224	35(15.6)	10.9 to 20.4	0.50	0.33 to 0.76	<0.01	0.69	0.43 to 1.12	0.13
Team-sport	246	39(15.9)	11.3 to 20.4	0.59	0.39 to 0.88	0.01	0.68	0.43 to1.09	0.11
Power-sport	266	64(24.1)	18.8 to 29.0	0.87	0.61 to 1.24	0.45	0.84	0.57 to 1.24	0.39
Shooting	54	9(16.7)	7.9 to 29.3	0.42	0.20 to 0.92	0.03	0.32	0.12 to 0.87	0.03
All sport	915	163(17.8)	15.3 to 20.3	0.61	0.47 to 0.80	<0.01	0.66	0.50 to 0.88	0.01
Controls	128	(24.3)	20.7 to 28.0	1.00			1.00		
KNEE PAIN									
Endurance	133	29(21.8)	14.8 to 28.8	0.61	0.38 to 0.96	0.04	0.77	0.46 to 1.28	0.31
Track and field	220	52(23.6)	18.0 to 29.3	0.76	0.52 to 1.09	0.14	1.09	0.71 to 1.66	0.70
Team-sport	251	81(32.3)	26.5 to 38.1	1.29	0.93 to 1.79	0.13	1.56	1.07 to 2.28	0.02
Power-sport	272	81(29.8)	24.2 to 35.0	1.05	0.76 to 1.45	0.78	0.94	0.66 to 1.36	0.76
Shooting	57	12(21.1)	11.4 to 33.9	0.54	0.27 to 1.08	0.08	0.71	0.33 to 1.51	0.38
All sport	933	255(27.3)	24.5 to 30.2	1.02	0.81 to 1.30	0.85	1.05	0.82 to 1.36	0.69
Controls	532	146(27.5)	23.7 to 31.2	1.00			1.00		

Figure 1 shows the age-adjusted ORs of hip or knee disability among participants in various athletic activities.

Physician-diagnosed knee ligament injuries were rare among long-distance runners (7%, 5/73), shooters (9%, 4/47) and controls (11%, 51/473) and those injuries were most common among soccer players (41%, 38/92) (P<0.0001, between all groups). Fifteen percent of shooters (7/48) and controls (76/492) reported physician-diagnosed knee meniscal injuries and the proportion of meniscal injuries was highest among soccer players (45%, 48/107) (P<0.0001). Moreover, 52% (61/118) of soccer players reported, that they had needed hospital treatment for knee injuries.

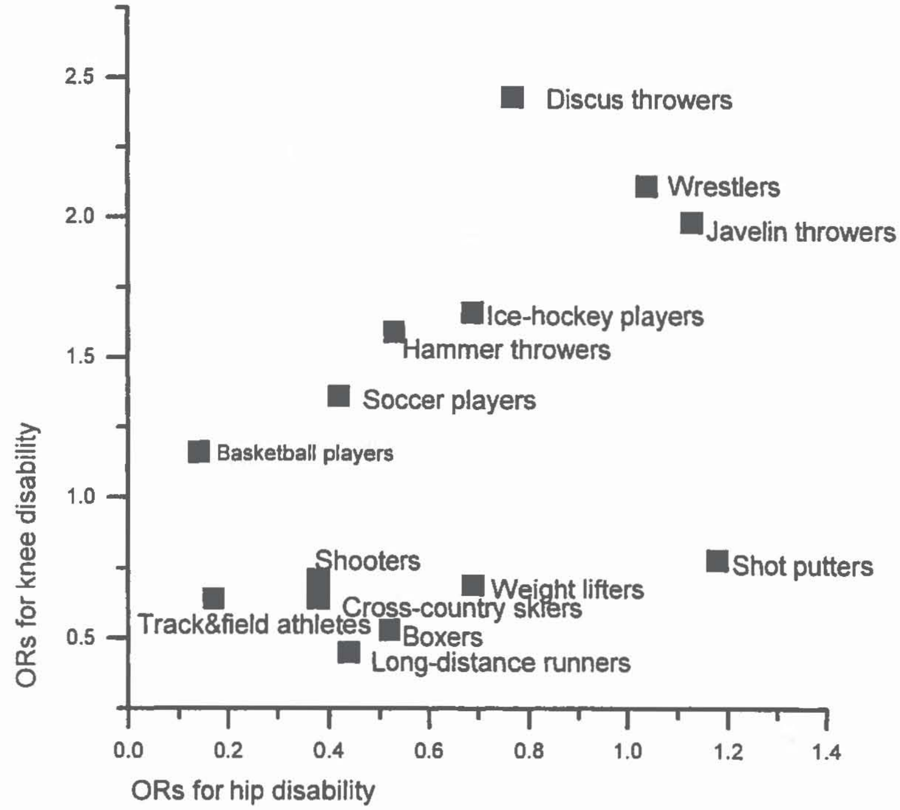

FIGURE 1 The age-adjusted ORs of hip or knee disability among participants in various athletic activities.

DISCUSSION

Because age, BMI and occupational group were associated with hip or knee disability, we used these as covariates when analyzing the risk of hip or knee disability among former elite athletes. Our endurance sport, track and field sport, power sport athletes or shooters did not report more hip or knee disability compared to controls. The covariate-adjusted ORs of hip disability were lower among endurance, track and field and all athletes combined. On the other hand, team sport athletes had slightly higher OR for knee disability when compared to controls.

Investigations to record lifetime physical loading generally encounter difficulties. Those problems can be reduced by studying former elite athletes, because their loading patterns are rather specific, they follow well-planned and defined training routines and their exercise histories are more reliable than are those obtained from an individual who has exercised recreationally only.

Our cohort includes elite athletes, who are a selected group in many ways. First, various selective factors, such as muscle fibers composition, play a role enabling role for some individuals to reach top-level results in competitions. Second, the athletes were presumably free from hip or knee OA at the time they participated in top-level sports in which good lower-limb function is an essential prerequisite. Thus, subjects with sports-related injuries during early athletic career likely to be drop-out. At this respect the results may underestimate the harmful effects of athletic loading on lower-limb.

Our athletes had represented Finland on international level at least once between 1920 and 1965. In 1985, a questionnaire study was carried out to our subjects to obtain historical data mainly for follow-up studies (Sarna et al. 1993). About the subjects, who were still competing in 1985, only nine percent reported to have knee disability in 1995. The reported rate of hip disability among those athletes was four percent. Among the subjects, who reported, that they had never participated to competitive sport, the reported rate for knee disability was 13.0% and 13.8% for hip disability. The most important reasons to end the career were age (31.4%), lack of interest (22.9%), and injuries (20.0%).

In epidemiological studies several methods have been used to measure pain (Kellgren & Lawrence 1952, Lawrence et al. 1966, Davis et al. 1992) and disability (Cuccione et al. 1990, Davis et al. 1991, McAlindon 1993) among osteoarthritic subjects. However, there is no general agreement on how to measure disability in epidemiological studies. We measured hip disability and knee disability with questions on activities which both former athletes and controls do in their daily life. The subjects scoring at least three points of seven for either hip or knee disability questions were classified to have hip or knee disability, respectively. We calculated both hip disability and knee disability using different cut-points, but the results of those calculations were similar. Moreover, a significant association between our disability score and radiographic knee OA (Kujala et al. 1995) and jumping height (Kettunen et al. 1999) has been shown.

Strenuous occupational loading predisposes to lower-limb OA. Therefore we calculated each subject's work years in various work-related physical loading. Only 6.5% of executives compared to 68.9% of unskilled workers had spent at least 10 years in heavy work. Because occurrence of OA-related disability may affect the ability to continue heavy work and because we found associations between work-related loading and occupational group, we used occupational group as a covariate when analyzing the association between athletic activity and hip or knee disability.

Despite the reported relationship between running and radiographic hip OA (Marti et al. 1989) former athletes' joints may show radiographic osteoarthritic changes without loss of function (Alexander 1990). Moreover, the ORs of hip pain and disability were low among our endurance athletes. Low development of disability among older runners who had engaged running and other aerobic activities has been reported and this association was probably related to increased aerobic capacity, strength, fitness, and increased organ reserve rather than to the effects of postponed osteoarthritis development (Fries et al. 1994). Also lower BMI in endurance athletes may prevent the occurrence of hip problems especially in walking and going up or down stairs. Lysholm and Wiklander (1987) reported that active long-distance runners have hip problems, but in old age these problems do not result in more years with hip pain and disability. Nor did we find any evidence that repetitive loading with low injury risk during adolescence and adulthood has harmful effects on knee joint function at older age.

Kujala and coworkers (1994) concluded that mixed sport and power sport athletes need more hospital care than their controls because of premature osteoarthritis of the hip, knee or ankle, however in endurance athletes the admissions are at an older age. They also pointed out that only the most severe cases needed hospital treatment. We used the same subjects in this study and our team sport athletes had high odds ratios for knee. Knee injuries were common especially among soccer players and previous knee injuries are risk factors for knee OA (Solonen 1966, Chantraine 1985, Kannus & Järvinen 1987, Kujala et al. 1995). Thus, it seems, that the increased risk of knee OA among team sport athletes is explained in part by knee injuries. One limitation of our study is the diagnosis of OA. We used physician-diagnosed osteoarthritis and it is possible that some subjects with knee injury and knee pain were falsely classified as having OA based on clinical pain even without radiographic confirmation.

Nevertheless, participation in mixed training has a favorable effect on lower-limb muscle function (Kujala et al. 1994, Kettunen et al. 1999). McAlindon and coworkers concluded McAlindon et al. 1993) that quadriceps strength is a more important determinant of functional impairment in elderly subjects than the severity of knee OA as assessed radiographically. However, knee injuries are probably etiologically related to knee OA, and the odds ratios for knee disability were high among team sport athletes. Therefore knee injury prevention and effective treatment of such injuries are important for the prevention of injury-related knee disability. Furthermore, our study is in concordance with earlier observations (Räty et al. 1997) that lower-limb pain and disability are more commonly attributed to knee rather than hip problems.

Heavy weight training and high BMI among power sport athletes may predispose them to knee OA and subjects with high BMI had higher ORs for hip and knee disability than subjects with low BMI. In our previous study (Kujala et al. 1995) high body mass index at age 20 explained some of the increased knee OA risk among former elite weight lifters and our power sport athletes had high age-adjusted odds ratio for knee OA before age of 45. Thus, the low odds ratio for hip or knee disability among weight lifters was an unexpected finding. Possibly lower-limb joint loading in physiological flexion-extension direction is less harmful for joint function than the type of knee loading encountere in team sports, throwing and wrestling. The tendency to increased odds ratios for hip and knee disability among javelin throwers and wrestlers may be explained by non-physiological rotational or medio-lateral loading and injuries among these athletes.

Despite the reported relationship between long-term vigorous physical activity and radiographic lower-limb OA little is known about the effects of physical activity on lower-limb function. Low aerobic work capacity and lower-limb muscle weakness are associated with disability and aerobic or resistance exercise programs have been recommended to reduce self-reported disability and pain among subjects with knee OA (Ettinger et al. 1997). Ettinger and colleagues have also pointed out that long-term compliance with exercise regimens is possibly more important than the type of therapy or training to reduce pain and disability. Our former athletes are a selected and therefore our results can not be generalized widely. However, our results are consistent with the recommendation that leisure physical activity, especially aerobic training with low risk of injury, has favorable effects on mobility and health.

In conclusion, despite reports of the role of leisure-time physical activity as a risk factor for lower-limb OA former elite male endurance and track and field athletes and all athletes combined reported less hip disability than their controls.

The role of vigorous athletic activity for the function of knee joints is more controversial, because sports involve risk of knee injuries and such injuries may predict for disability. Therefore, our results support the thesis, that especially aerobic activities with many health benefits and with low risk of injury can be recommended to maintain health and a disability-free life in old age.

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